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Compatibility and sharing studies related to the introduction of broadband and narrowband systems in the bands 410-430 MHz and 450-470 MHz

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0 EXECUTIVE SUMMARY

This Report considers the impact that broadband and narrowband systems may have on systems that currently are operated in the 400 MHz band and in adjacent bands. For practical reasons, the broadband system's radio characteristics (such as channel bandwidth, centre frequency, spectrum mask, e.i.r.p.) are derived throughout the report from the LTE standards and typical usage of current and future LTE systems. Although the systems are referred to as LTE systems, the findings in the report are equally valid for any other technology with comparable radio characteristics.

This Report analyses the impact of introducing:

- Long-term Evolution (LTE) technology for professional mobile radio (PMR), public access mobile radio (PAMR), mobile/fixed communication network (MFCN) (with channel bandwidth of 1.4 MHz, 3 MHz and 5 MHz) and machine to machine/internet of things (M2M/IoT) (including MTC/eMTC, NB-IoT) based on 3GPP specifications; and
- For low power wide area network (LPWAN) technology for M2M/IoT, in the bands 410-430 MHz and 450-470 MHz.

It also analyses the impact of the introduction of Broadband (BB) PPDR in the band 410-430 MHz with a view to give protection to radiolocation and radio astronomy services. Compatibility studies between LTE based BB-PPDR systems at 410-430 MHz and 450-470 MHz and other services were carried out in ECC Report 240 [1].

The use of the 400 MHz band is very complex – both in terms of which services already use the bands and on the density of usage by country.

The outcome of the studies performed can be summarised as follows:

0.1 LTE IMPACT ON NARROWBAND PMR

It should be noted that narrowband PMR includes analogue, DMR and TETRA systems.

Simulations of interference from LTE transmitters into narrowband PMR receivers in adjacent frequency spectrum show that the probabilities of interference based on Out-of-Band Emissions (OOBE) and blocking for low to medium Base station (BS) and Mobile station (MS) densities are generally on the average 1% or less, although unwanted emission improvement compared to the 3GPP Spectrum Emission Mask at the BS may be required to keep the interference from the LTE BS into the PMR MS at these low levels. However, the interference probability calculations are performed for downlink limited systems; results may differ for uplink limited systems, which may tolerate a noise rise in MS receivers up to the level of the DL/UL imbalance. Please also note that other techniques needed to protect the LTE400 BS own reception band (such as duplex filtering) help to provide necessary attenuation of Out-of-Band emissions of the LTE BS into the TETRA MS reception band. Furthermore, the interference probability averaged over the coverage area of the narrowband BS decreases, if the LTE cell size increases. The probability of interference is highest closest to the LTE BS. Out of Band Emission improvement may not be needed depending on the acceptable level of degradation over the coverage area.

The interference probabilities for the LTE BS impact on PMR MS are lower in comparison to the interference probabilities simulated in ECC Report 240 for the PPDR-LTE BS impact on the PMR MS. Even lower interference probabilities are expected if the bursty nature of M2M traffic will be included in the calculations.

Another interference effect to be taken into account is the potential impact of Intermodulation Distortion (IMD) in PMR receivers caused by neighbouring broadband signals. This is dependent on the frequency offset of the LTE carrier from the victim PMR receiver, the received power and the intermodulation performance of the victim PMR receiver at that frequency offset. The assessment of outage probability due to intermodulation by simulations appeared to be far from straightforward. No conclusion on the intermodulation effect from broadband interferers into narrow band victims could be reached.

0.2 LPWAN COMPATIBILITY WITH TETRA

The results of the Monte Carlo simulations carried out show that TETRA and Low Power Wide Area Network (LPWAN) systems can cohabitate without any major difficulty in the band 410-430 MHz, if both of the following mitigation techniques are implemented:

- A guard band of 200 kHz between the TETRA base station (BS) and the LPWAN end device (ED). This guard band is needed to minimise the interference from TETRA BS transmitter to LPWAN ED receiver.
- A minimum separation distance of 90 m (64 dB minimum coupling loss) between the TETRA BS and the LPWAN BS. This minimum separation distance is needed to minimise the interference from TETRA BS transmitter to LPWAN BS receiver and can easily be achieved with on site configuration when deploying LPWAN networks.

It should be observed that based on the assumptions of the analysis, the TETRA BS e.i.r.p. is 49 dBm, which is almost 15 dB more than the e.i.r.p. of the LPWAN BS. That could justify why the impact of the TETRA BS into the LPWAN systems is greater than the one in the reverse way. Given that many deployed PMR systems operate with an e.i.r.p. 40 dBm, it could be expected that real life operation of these two systems leads to an even better compatibility than the results presented in this analysis.

In the co-channel situation between TETRA and LPWAN systems, the minimum separation distance between base stations is more than 100 km.

The co-channel operation in the same area is not possible between TETRA and LPWAN systems.

0.3 LPWAN COMPATIBILITY WITH RLOC

With the RLOC frequency set to 430 MHz and the LPWAN system using the uplink frequency of 413.7375 MHz and downlink frequency of 423.7375 MHz with a 125 kHz channel bandwidth, the minimum separation distances needed to ensure the protection of RLOC are presented in Table below.

Table 1: Separation Distance between Radars and LPWAN system (km)

Separation Distance between Radars and LPWAN system (km)		Due to blocking (km)	Due to desensitisation in co-channel (km)	Due to desensitisation in adjacent channel (km)
Airborne Radar	LPWAN ED	0.04	1374	0.015
	LPWAN BS	0.015	522	0.0025
Ground Radar	LPWAN ED	0.14	9730	0.110
	LPWAN BS	0.66	46560	0.232

The results of the compatibility studies carried out show that the compatibility between an LPWAN system and airborne radar is possible in the adjacent channel scenario with a minimum guard band of 0.5 MHz from the edges. The minimum separation distances are then:

- 40 m between the LPWAN End Devices and Airborne;
- 15 m between the LPWAN Base Station and Airborne.

The compatibility between an LPWAN system and Ground radar is possible in the adjacent channel scenario with a minimum guard band of 0.5 MHz from the edges. The minimum separation distance is then:

- 140 m between the LPWAN End Devices and ground radar;
- 660 m between the LPWAN Base Station and ground radar.

For the co-channel cases there is no possibility for compatibility between LPWAN system and airborne radar or LPWAN system and ground radar.

0.4 LPWAN COMPATIBILITY WITH RAS

The compatibility between LPWAN system and the Radio astronomy service concludes that:

- For a frequency separation between the LPWAN base station and the RAS of 13.7375 MHz (edge to edge), the MCL calculation provides a required minimum path loss equal to 97.51 dB; Using the ITU-R propagation model Rec. ITU-R P.452-16, the calculated separation distance is 4.4 km;
- For a frequency separation between the LPWAN end device and the RAS of 3.7375 (edge to edge), the MCL calculation provides a required minimum path loss equal to 101.91 dB. Using the ITU-R propagation model Rec. ITU-R P.452-16, the calculated separation distance is 3.05 km.

0.5 LPWAN COMPATIBILITY WITH LTE

This section summarises the compatibility between LTE and LPWAN systems in the 410-430MHz band.

All the initial configurations of LTE systems are based on figures in the corresponding ETSI standards TS 136 101 and TS 136 104 and the LPWAN system parameters stated in this report. LTE parameters were considered as invariant in the simulations, except when considering LTE BS ACLR in adjacent channel. BS ACLR was based on the measured LTE signal which is 20 dB better than that derived from the transmitter mask in the ETSI standard [13]. It should be noted that the measured ACLR in the first adjacent channel is expected to be lower than the ACLR in adjacent channels further away from the BS centre frequency. According to the ETSI standard for LTE systems [13], there are minimum requirements for the protection of own reception which lead to an ACLR higher than 100 dB/3MHz, that will provide a lower level of unwanted emissions in the LTE BS uplink reception band and its vicinity compared to the level of unwanted emissions resulting from the measured ACLR value used in the analysis.

Amongst the simulated interference scenarios, in three cases it was necessary to improve the ACLR and the Adjacent Channel Selectivity (ACS) of the LPWAN system to ensure compatibility between LTE and LPWAN systems:

- LPWAN BS impact on LTE BS:
  - With the initial LPWAN base station transmitter ACLR and the LTE base station receiver selectivity defined in ETSI standard [13], the LTE bit rate loss is higher than 5%. It is necessary to improve the LPWAN base station transmitter ACLR by 30 dB to reduce the bit rate loss below 5% in the adjacent band scenario. Compatibility is not achieved in the co-channel scenario.
- LTE BS impact on LPWAN BS:
  - With the initial LTE base station transmitter ACLR of 45 dB (which is applicable in the adjacent channel) and the LPWAN base station receiver selectivity as derived from transmitters masks defined in ETSI standard [13], the probability of interference is higher than 10%. Based on the measurements, it can be assumed that the LTE base station ACLR is at least 20 dB better than the value defined in ETSI standards [13], therefore the compatibility is ensured with an improvement of the LPWAN receiver ACS by 30 dB (Probability of Interference < 10 %). Due to the protection of LTE own reception according to the minimum requirements in the ETSI standards, it is expected that the compatibility between the two systems is much better than the results presented in this analysis when the LPWAN operates in the LTE uplink band and probably in the case of operation close to this LTE uplink band. Compatibility is not achieved in co-channel scenario.
- LTE BS impact on LPWAN ED:
  - It may be needed to improve the LTE base station ACLR of 45 dB by several dBs to ensure the compatibility in the adjacent scenario. Based on the measurements, it can be assumed that the LTE base station ACLR is at least 20 dB better than the value defined in ETSI standard [13] so compatibility is expected.

Concerning the LPWAN End Device, compatibility is achieved in adjacent band scenarios. Compatibility is not achieved in co-channel scenario.

The results in this analysis assume an activity factor of 100% of the LPWAN BS and of LTE BS. In practice, the activity factor of LPWAN BS and LTE BS may be lower. That may reduce the potential impact of each system on the other, thus improving the compatibility between the two systems.

0.6 LTE IMPACT ON DTT ABOVE 470 MHZ

The compatibility studies are carried out in this report for LTE based PMR systems in the 400 MHz band with various base station (BS) e.i.r.p. in the range of 48-62 dBm and with DTT receiver ACS of 61 dB. The analyses concluded that an ACLR of 67 dB/8MHz would be required to minimise the interference from LTE BS to DTT reception, irrespective of the bandwidth and the activity factor as long as the LTE BS e.i.r.p. is below 60 dBm. For a BS e.i.r.p. above 60 dBm, the ACLR needs to be improved in such a way that the BS OOBE do not exceed the value of -7 dBm/8MHz., Simulations were conducted with LTE operating within 3GPP Band 31, while in several European countries, 3GPP Band 72 may be used, which offers a higher guard band with regard to DTT systems above 470 MHz.

It should be noted that all BS in the modelled LTE network may not operate at the same time with full buffer packet traffic. Therefore, although the optimal ACLR for LTE BS remains the same, when there is intermediate protection for DTT service, the requirement of LTE BS ACLR could be relaxed (e.g. -4 dBm/8MHz corresponding to an ACLR of 60 dB/8MHz).

These requirements for LTE PMR base stations are summarised in the table below.

Table 2: LTE 400 Base Station e.i.r.p. and OOBE levels for protection of DTT above 470 MHz Frequency range

	Condition on Base station in-block e.i.r.p, P (dBm/cell)	Maximum mean OOBE e.i.r.p (dBm/cell)	Measurement bandwidth
For DTT frequencies above 470 MHz where broadcasting is protected (NOTE 1)	P ≥ 60	-7	8 MHz
	P < 60	(P – 67)	8 MHz
For DTT frequencies where broadcasting is subject to an intermediate level of protection or when mitigation techniques are used (NOTE 2)	P ≥ 56	-4	8 MHz
	P < 56	(P – 60)	8 MHz

NOTE 1: Based on these results, it can be concluded that the limits defined for the base stations of LTE based BB-PPDR in ECC Decision(16)02, should apply to the base stations of LTE based PMR/PAMR as well.
NOTE 2: At a national level based on the type of mobile network deployment the OOBE limits of BS might be relaxed (See ANNEX 9 for a list of possible mitigation techniques/ measures).

At a national level, the out-of-band emissions limit might be relaxed. For example, with a sparse network deployment, using high remote sites, such as those used for DTT, the probability of interference to DTT reception is significantly reduced. Such a deployment has been successfully implemented in Scandinavian countries. Also, the requirement on the ACLR of the LTE PMR BS can be relaxed when the victim DTT receiver is located close to the DTT transmitter so that the received DTT signal is strong enough to mitigate the interferer. Further mitigation measures, as described in Annex 9 may allow solving possible remaining interference, on a case by case basis.

Additionally, based on the results presented in this Report, it can be concluded that LTE eMTC and NB-IoT BS (including in-band, guard band and standalone NB-IoT) provide a better context of compatibility with DTT than typical LTE BS.

Based on the results obtained for the user equipment (UE), it can be concluded that the limits defined for the UE of LTE based BB-PPDR in ECC Decision (16)02 should apply to the UE of LTE based PMR PAMR. This requirement for the LTE PMR UE is summarised in the table below:

Table 3: LTE UE OOBE level for protection of DTT above 470 MHz

Frequency range	User equipment maximum mean OOBE	Measurement bandwidth
For DTT frequencies above 470 MHz where broadcasting is protected	- 42 dBm	8 MHz

0.7 LTE IMPACT ON RADARS

ECC Report 240 demonstrated that LTE based BB-PPDR systems operating in the band 420-430 MHz could cause severe desensitisation of radars in the co-channel case. Calculations lead to large exclusion zones based on free space propagation loss and statistic propagation model (EPM73), therefore further studies were conducted based on additional assumptions.

The new studies focused on the impact of LTE BS (downlink) on radar systems and investigated several propagation models and scenarios for co-channel (420-430 MHz) and adjacent channel (430-440 MHz) operation of the two systems. The effect of the LTE UE (uplink) on the radar system was already addressed in the ECC Report 240 with 37 dBm e.i.r.p. of UE.

To avoid radar desensitisation operated in 430-440 MHz (-114.9 dBm/MHz) based on the present studies, the proposed technical solution for operating LTE in the 410-430 MHz frequency range is to respect both a guard band of 2.5 MHz from the upper edge of LTE BS channel to 430 MHz and 40 dB of OOBE reduction from the standard with LTE BS duplexer filtering. Assuming the above mentioned guard band of minimum 2.5 MHz, a possible LTE channel arrangement could be entirely placed in the tuning range of 410-417.5/420-427.5 MHz applying 100 kHz channel spacing.

The required separation distance depends on the used propagation models (calculating with free space propagation and smooth Earth, or with the Earth curvature, diffraction, reflection or with tuned models using real terrain data).

For ground radars, the required separation distance is around 120 km in the co-channel scenario and less than 40 km in the adjacent channel scenario over smooth Earth (EPM73, Rec. ITU-R P.526-13). Applying digital terrain based propagation models (General 450 and MYRIAD), the minimum required separation distance could be varied from 1.5 to 28 km in the adjacent channel scenario which can be further reduced by using proper mitigation techniques and a well-designed LTE network (calculating with LTE BS antenna downtilting, LTE BS power reduction, additional LTE BS duplexer filtering, etc.).

For airborne radars, the required separation distance remains more than 400 km required in the co-channel scenario if no particular mitigation technique is applied. Co-existence in the adjacent channel scenario for airborne radars can be achieved with the appropriate filtering and frequency separation which however implies that airborne radars are limited to operate above 430 MHz even though the radar tuning range is 420-450 MHz. The coexistence of LTE in the frequency band 410-430 MHz and radars operated on a secondary basis in the frequency band 420-430 MHz cannot be ensured only by technical conditions. It has to be noted that some countries have already concluded multilateral frequency co-ordination agreements for LTE usage without having taken into account the secondary radiolocation service.

0.8 LTE IMPACT ON RADIO ASTRONOMY

Two studies using different statistical calculation methods were used for evaluation of interference from LTE based BB-PPDR systems operating in the band 410-430 MHz into radio astronomy stations in the band 406.1-410 MHz. One study was done by using SEAMCAT and the propagation model described in Recommendations ITU-R P.1546-5 [10] and ITU-R P.452-16 [33] with a different network layout when aggregated effect of BSs and UEs were taken into account; another one - used Matrix Laboratory software (MATLAB) program and the propagation model described in Recommendation ITU-R P.452-16.

Generic compatibility calculations for LTE systems in the band 410-430 MHz and radio astronomy operating in the band 406.1-410 MHz showed that compatibility may be achievable by implementing emission-free zones around RAS stations.

Analysis by using SEAMCAT showed that for an LTE PPDR network completely surrounding a RAS station, the exclusion zone extended up to 241 km with Recommendation ITU-R P.1546-5 and 362 km with Recommendation ITU-R P.452-16 around RAS when no guard band was used. The exclusion zone extended up to 117 km with Recommendation ITU-R P.1546-5 and 261 km with Recommendation ITU-R P.452-16 when 2.5 MHz guard band was used. Separation distances became smaller when the LTE network's layout comprises a part of the ring placed on one side of RAS. They shrank down to 94 km with Recommendation ITU-R P.1546-5 and 246 km with Recommendation ITU-R P.452-16 when no guard band was used between systems. They shrank to 18 km with Recommendation ITU-R P.1546-5 and 127 km with Recommendation ITU-R P.452-16 when 2.5 MHz guard band was used. Such a case could be met when coordination of different systems between two countries occurs.

There is a difference between results for different propagation models Recommendation ITU-R P.1546-5 and Recommendation ITU-R P.452-16. Protection of investigated services could be ensured by applying distances given by using Rec. ITU-R P.1546; for a more precise exclusion zone Rec. ITU-R P.452 might be applied with real terrain data.

Analysis by using MATLAB with Recommendation ITU-R P.452-16 for the outdoor UE, considering a 1 MHz guard band, the separation distances for single emitter and aggregate cases become 78 km and 326 km, respectively. For indoor usage and additional wall attenuation of 11 dB the separation distances for single emitter and aggregate cases are reduced to 34 km and 190 km, respectively. The separation distances decrease with larger guard bands; for example, with a guard band of 5 MHz the separation distances for single emitter and aggregate cases of outdoor UE become 41 km and 261 km, respectively.

0.9 LTE IMPACT ON FIXED SERVICE

According to the worst-case estimation (assuming free space propagation between the stations and both antennas pointing towards each other) in co-channel frequency range, sharing will not be possible between LTE and the FS. In adjacent frequency ranges, the compatibility is limited in the remaining scenarios and would require protection distances of about 30 km.

A more realistic estimation implies the propagation model described in Recommendation ITU-R P.452-16 between the LTE BS and the FS station. Between the LTE UE and the FS station, the extended HATA propagation model is used. If more realistic investigation options are used, in co-channel frequency range, sharing will be possible between LTE BS and the FS if protection distances of about 85 km are kept. In adjacent frequency ranges, compatibility can be expected if protection distances of about 35 km are respected. Operations at smaller distances are possible but require coordination and/or a lower OoBE level for the LTE station within the channel used by fixed service.

LTE UE satisfies sharing requirements for operational distances larger than 4 km to the FS station. If used in an adjacent frequency range, no interference for operational distances larger than 0.5 km is expected.

0.10 LTE IMPACT ON PMR LINKS IN AUDIO-VISUAL PRODUCTION

As a result from ECC Report 240, co-existence, operating within these bands, is possible due to the additional filtering required to fulfil the 3GPP protection of own UL minimum requirement (UE) duplexers to limit the interference at an acceptable level. Indeed such duplexers are needed to ensure both fulfilment of the 3GPP minimum requirements and correct performance of the LTE400 system itself.

Two new scenarios (TDD PMSE and 100 m co-location) based on those considered in ECC Report 240, relating to the impact of the LTE BS on the PMSE BS (receiving in 453-455 MHz), have been studied:

- Considering the general spurious emissions limits given in 3GPP TS 36.104 [14], coexistence is unlikely to be reached due to the large separation distances required. The level given in ECC/DEC/(06)02 [45] (e.i.r.p. limit of -43 dBm/100 kHz) is not sufficient. Coexistence is expected if the BS spurious emissions meet the minimum requirements of -96 dBm/100kHz emissions in the band 450-455 MHz (Annex 2 in 3GPP TS 36.104 [14]) except if the base stations are located within 100 m where the interference become significant.
- Considering scenarios differing from those considered in ECC Report 240, for example, the TDD case or MS transmitting in 455-460 MHz, the achieved separation distances are larger, and the risk of interference is quite

high, in particular when the PMSE BS is located nearby the LTE BS and receiving in the first megahertzs adjacent to the LTE band. A mixture of TDD PMSE and LTE400 should be avoided.

Based on MCL calculations, the separation distance between LTE UE and PMSE MS is of the order of 10 m, leading to a risk of interference if they are operated in the same location.

Similar conclusions apply for the lower band, 410-430 MHz.

0.11 LTE IMPACT ON PAGING

The results of SEAMCAT simulation considering the impact of LTE BS on paging receiver indicate that the level of interference strongly depends on the LTE cell radius. It is also seen that a decrease of the level of unwanted emissions by additional filtering or any other means improves the compatibility. Blocking appears however to be a significant effect. This effect is not specific to LTE; any system with the same in-band transmitter levels will cause the same level of outage due to the poor ACS of the paging receiver.

Outage due to interference of blocking may be reduced by repeating the paging messages, which is a standard mechanism in paging systems. The simulations used the spectrum emission mask according to ETSI standard operating band unwanted emission limits requirement and considered an offset of 970 kHz and 3 MHz. If the offset between the paging frequency and the edge of the LTE system is smaller, then the probability of interference will be higher. The application of the 45dB ACLR from LTE BS ETSI standard would provide additional reduction of the LTE spectrum emission mask contributing to reach the additional reduction for which no interference is expected. Studies show compatibility with an additional reduction of 25 dB to the LTE spectrum emission mask according to ETSI standard operating band unwanted emission limits requirement . However, no sensitivity study has been conducted related to this additional reduction value of 25dB.

Additional simulations may be needed to consider the impact of 5 MHz and 1.4 MHz systems and the impact of the MS.

0.12 LTE IMPACT ON SRD SYSTEMS

Studies show that there are compatibility issues in case of automotive SRD systems and LTE UEs are used in close proximity (< 1 m).

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
ACCP	Adjacent Channel co-polarized
ACIR	Adjacent Channel Interference Ratio
ACLR	Adjacent Channel Leakage Ratio[1]
ACPR	Adjacent Channel Power Ratio
ACS	Adjacent Channel Selectivity
AF	Activity factor
AMSL	Above Mean Sea Level
BB	Broadband
BEM	Block Edge Mask
BP	Break Point
BS	Base station
Bth	Blanking threshold (for radars)
BW	Bandwidth
CCR	Co-channel Rejection
CDMA	Code Division Multiple Access
CEPT	European Conference of Postal and Telecommunications Administrations
CNR	Carrier to Noise Ratio
CPC	Channel Performance Criterion
CSS	Chirp Spread Spectrum
DGNA	Dynamic Group Number Assignment
DL	Downlink
DNO	Distribution Network Operator
dRSS	Desired Received Signal Strength
DT	Decorrelation Time
DTT	Digital Terrestrial Television
DVB	Digital Video Broadcasting
ECC	Electronic Communications Committee

[1] In the present document, ACLR is used as the ratio of the transmitted interfering signal power measured in its assigned channel to the transmitted interfering signal out-of-band emissions power measured in the victim receiver channel. It does not have the same meaning as the term ACLR used in organizations such 3GPP and ETSI in technical specifications or harmonised standards.

Abbreviation	Explanation
ECO	European Communications Office
ECU	Electronic Control Unit
ED	End Device
EFIS	ECO Frequency Information System
e.i.r.p.	equivalent isotropically radiated power
ENG/OB	Electronic News Gathering/Outside Broadcasting
eMTC	enhanced Machine Type Communication
ETSI	European Telecommunications Standards Institute
FER	Frame Error Rate
FM	Frequency Modulation
FS	Fixed Service
FSK	Frequency Shift Keying
GB	Guard band
GDO	Garage Door Openers
ILT	Interfering Link Transmitter (SEAMCAT)
IM	Intermodulation
IM3	Third Order Intermodulation
IMD	Intermodulation Distortion
IMT	International Mobile Telecommunications
INR	Interference-to-Noise Ratio
IoT	Internet of Things
IP	Interference Probability
iRSS	Interfering Received Signal Strength
ITU-R	International Telecommunication Union - Radiocommunication Sector
LPWAN	Low Power Wide Area Network
LTE	Long-Term Evolution
M2M	Machine-to-Machine
MAPL	Maximum Allowable Path Loss
MATLAB	Matrix Laboratory software
MCL	Minimum Coupling Loss
MFCN	Mobile/Fixed Communication Network
MIMO	Multiple Input Multiple Output
MS	Mobile Station
NB	Narrowband
NB-PMP	Narrowband Point-to-Multipoint

Abbreviation	Explanation
NER	Nominal Error Rate
NF	Noise Figure
NFD	Net Filter Discrimination
NJFA	NATO Joint Civil/Military Frequency Agreement
NM	Nautical Mile
NM	Nautical Mile
OFDM	Orthogonal Frequency Division Multiplex
OOB	Out-of-Band
OOBE	Out-of-Band Emissions
PAMR	Public Access Mobile Radio
PMR	Private Mobile Radio
PMSE	Programme Making and Special Events
PPDR	Public Protection and Disaster Relief
PRB	Physical Resource Block
QPSK	Quarterly Phase Shift Keying
RAS	Radio Astronomy Service
RB	Resource Block
RCL	Realised Coupling Loss
RES	Radio Equipment and Systems
RF	Radio Frequency
RKE	Remote Keyless Entry
RLOC	Radiolocation
RR	Radio Regulations
Rx	Receiver
SAP/SAB	Services Ancillaty to Programme Making/Services Ancillary to Broadcasting
SEAMCAT	Spectrum Engineering Advanced Monte Carlo Analysis Tool
SEM	Spectrum Emission Mask
SF	Spreading Factor
SINR	Signal to Interference and Noise Ratio
S/N	Signal to Noise
SNR	Signal-to-Noise Ratio
SRD	Short Range Device
TETRA	Terrestrial Trunked Radio
Tetrapol	TETRA for police
T	Threshold

Abbreviation	Explanation
TPC	Transmit Power Control
TPM	Tyre Pressure Monitoring
TV	Television
TW	Time Window
Tx	Transmitter
UE	User equipment
UHF	Ultra High Frequency
UL	Uplink
WB	Wideband
WRC	World Radiocommunication Conference

1 INTRODUCTION

This Report considers the impact that broadband and narrowband systems may have on systems that currently are operated in the 400 MHz band and in adjacent bands. For practical reasons, the broadband system’s radio characteristics (such as channel bandwidth, centre frequency, spectrum mask, e.i.r.p.) are derived throughout the report from the LTE standards and typical usage of current and future LTE systems. Although the systems are referred to as LTE systems, the findings in the report are equally valid for any other technology with comparable radio characteristics.

This Report analyses the impact of introducing:

- Long-term Evolution (LTE) technology for professional mobile radio (PMR), public access mobile radio (PAMR), mobile/fixed communication network (MFCN) (with channel bandwidth of 1.4 MHz, 3 MHz and 5 MHz) and machine to machine/internet of things (M2M/IoT) (including MTC/eMTC, NB-IoT) based on 3GPP specifications and,
- For low power wide area network (LPWAN) technology for M2M/IoT in the bands 410-430 MHz and 450-470 MHz.

It also analyses the impact of the introduction of Broadband (BB) PPDR in the band 410-430 MHz with a view to give protection to radiolocation and radio astronomy services. Compatibility studies between LTE based BB-PPDR systems at 410-430 MHz and 450-470 MHz and other services were carried out in ECC Report 240[1].

The present Report expands the analysis of the use of LTE based BB-PPDR in 410-430 MHz and LTE/LPWAN introduction considering different usage scenarios for PMR, PAMR, MFCN, and M2M/IoT in 410-430 MHz and 450-470 MHz. Introducing LTE into the band 450-470 MHz for BB-PPDR was considered in ECC Report 240 [1]. This Report expands the analysis of the use of LTE based BB-PPDR in 410-430 MHz and LTE introduction considering different usage scenarios in 410-430 MHz and 450-470 MHz.

1.1 THE BAND 410-430 MHZ

This Report analyses the impact of introducing LTE technology (with a channel bandwidths of 1.4 MHz, 3 MHz and 5 MHz) and cellular M2M/IoT (including LTE MTC/eMTC, NB-IoT) and LPWAN technology for M2M/IoT in the band 410-430 MHz.

Since the band 410-430 MHz is not covered in the ECC Decision (16)02 on “Harmonised technical conditions and frequency bands for the implementation of Broadband Public Protection and Disaster Relief (BB-PPDR) system” [3], this Report also includes compatibility and sharing studies complementary to ECC Report 240 for BB-PPDR systems operating in the band 410-430 MHz.

The studies in ECC Report 240 showed that there could be compatibility difficulties between LTE based BB-PPDR systems and existing systems (radars and radio astronomy) leading to wide exclusions zones. Additional studies were conducted with the aim to determine the technical and operational conditions (including possible mitigating factors) of LTE-based BB-PPDR network in order to provide co-existence with RAS and radars. These studies take into account statistical models and/or different propagation models than in ECC Report 240.

1.2 THE BAND 450-470 MHZ

This Report analyses the impact of introducing LTE technology (with channel bandwidth of 1.4 MHz, 3 MHz and 5 MHz) and cellular M2M/IoT (including LTE MTC/eMTC, NB-IoT) and LPWAN technology for M2M/IoT in the band 450-470 MHz

New studies were performed to complete the analysis for BB-PPDR in ECC Report 240 to take into account some differences in the usage scenarios as well as different user equipment densities and resource block usage (for reference, see Table 3 "LTE400 UE Densities" in ECC Report 240).

Typical new usage scenarios include the introduction of:

- MFCN-like use in a PMR/PAMR environment,
- broadband PMR/PAMR using LTE technology,
- LTE based M2M/IoT used for PMR/PAMR mission critical wide-area networks

ETSI TR 103 401 [2] for smart grid systems and other radio systems suitable for utility operations, and their long-term spectrum requirement, also covering the 400 MHz band was used in these studies. Smart grids/smart metering applications have their terminals dominantly not portable but fixed installations in either local, metropolitan or regional networks with cell ranges of up to 20-35 km.

2 GENERAL CONSIDERATIONS

2.1 ASSUMED ROLL-OUT OF LTE SYSTEMS

This Report is based on an assumed roll-out for Long-term Evolution (LTE) systems using single site, multiple sites and large wide area networks.

The baseline scenario under study is designed to offer coverage from fixed base stations that support the operation of PMR/PAMR services. Both radio parameters and inter-site distance are set to meet a desired level of service availability and protection ratio at the cell edge (see ANNEX 13: link budgets).

It is foreseen that such LTE networks will be deployed primarily for critical M2M/IoT type of services. Typical characteristics of such networks are:

- LTE networks and devices are MTC/eMTC compatible (according to the 3GPP defined Cat-M1) and/or NB-IoT, which implies that they are designed with higher fade margins and, as a consequence, larger radio cells;
- Most devices are indoor and at fixed locations;
- There are a large number of devices each sending or receiving only very small amounts of data at a time;
- Devices transmit powers that are generally lower than those used for common MFCN terminals or PPDR devices (see ANNEX 13:).

In comparison with LTE networks built for PPDR services, these types of networks will have significantly less impact on other systems in the 400 MHz band. The number of active devices is anyway limited due to the capacity of the radio cell. Hence, the conclusions from ECC Report 240[1], which considers the impact of LTE based BB-PPDR networks in the 400 MHz band, may be considered as the worst case in most scenarios.

2.2 SERVICES ALLOCATIONS IN FREQUENCY BANDS 406.1-430MHZ AND 450-470MHZ

ECC Decision (04)06 [5] decides that Wide Band Digital Land Mobile PMR/PAMR systems in the bands 410-430 MHz and/or 450-470 MHz shall be with 10? MHz duplex spacing between the transmit frequencies of mobile stations (410-420 MHz and 450-460 MHz) and the transmit frequencies of base stations (420-430 MHz and 460-470 MHz) as shown in Figure 1.

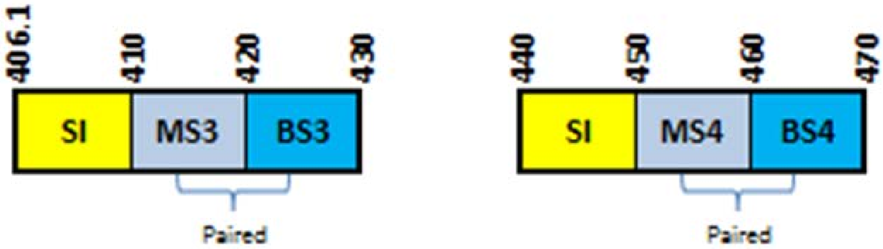


Figure 1: Illustrative mobile service allocations in the 400 MHz range: Simplex (SI) and paired Mobile station (MS) Base station (BS) use

The band 406.1-410 MHz is allocated to fixed, mobile (except aeronautical) and radio astronomy services on a primary basis. According to RR footnote No. 5.149 [3], administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. It should be noted that 14 CEPT countries registered RAS in Europe (see Table 86).

In the band 420-430 MHz, there is a secondary allocation to the radiolocation service for 29 CEPT countries out of 48 and the only exception is the UK where it is allocated on a primary basis based on RR footnote No. 5.269. It should be noted that only the UK and France reported real radar usage in part of the band 420-430 MHz, according to the EFIS (ECO Frequency Information System) database[2].

The allocation of the band 420-430 MHz for the radiolocation service in Europe according to EFIS (in 2016) is in Figure 2.

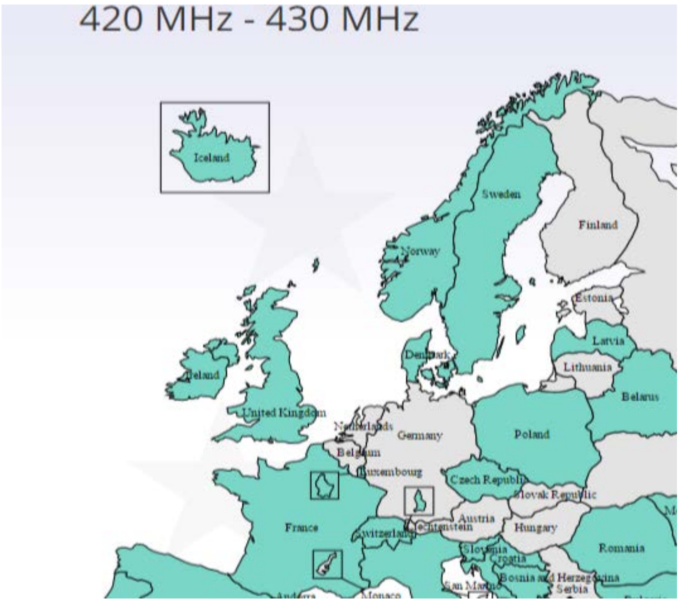
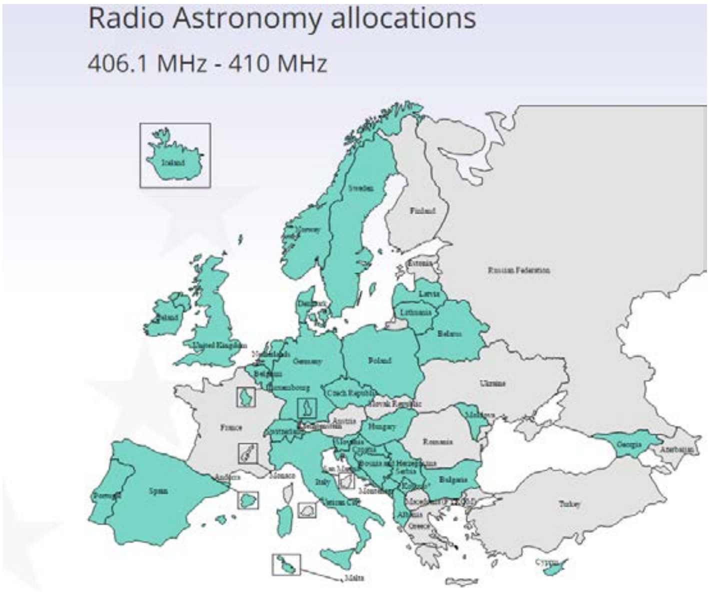


Figure 2: Radiolocation allocations in the band 420-430 MHz according to EFIS in 2016

The allocation of the band 406.1-410 MHz for the radio astronomy service in Europe according to EFIS (in 2016) is in Figure 3[3].



2 http://www.efis.dk/

3 http://www.efis.dk/include2/graphTool.jsp?lowRange=406.1+MHz&highRange=410+MHz&action=search&specifyRange=1&low=406.1&high=410&unit=MHz&user=1&languages=English&searchOption=Allocation&orientation=horizontal

Figure 3: Radio astronomy allocations in the band 406.1-410 MHz according to EFIS in 2016

2.3 CHANNEL ARRANGEMENT OPTIONS

ECC Decision (16)02 [4] addresses the harmonised conditions for the implementation of BB-PPDR radio systems. In this decision, the following harmonised frequency arrangements for BB-PPDR 450-470 MHz are given:

- 450.5-456.0 MHz (uplink) / 460.5-466.0 MHz (downlink);
- 452.0-457.5 MHz (uplink) / 462.0-467.5 MHz (downlink)

A new work item was proposed and approved at the 3GPP plenary meeting in December 2016 to include these frequency arrangements into the 3GPP Release 15 specifications (see work item description for "450MHz E-UTRA FDD Band for LTE PPDR and PMR/PAMR in Europe" in RP-162514).

The contributions on the band plan are covered in R4-1700772 and R4-1701015 and propose the reuse of existing Band 31 and the introduction of a new Band 72 in the range 451-456 MHz / 461-466MHz for BB-PPDR and PMR/PAMR operation. It was highlighted that the implementation of 5.5 MHz wide tuning ranges as recommended by ECC Decision (16)02 is not feasible using a single duplexer due to the small duplex gap between uplink and downlink bands. Furthermore Band 31 has been updated to be aligned with the UE emission requirements from ECC Decision (16)02.

The Technical Report TR 36.748 was created to capture the studies of this work item. The completion date of the work item is in June 2018.

The allocations of Band 31 and Band 72 are illustrated in Figure 4 below.

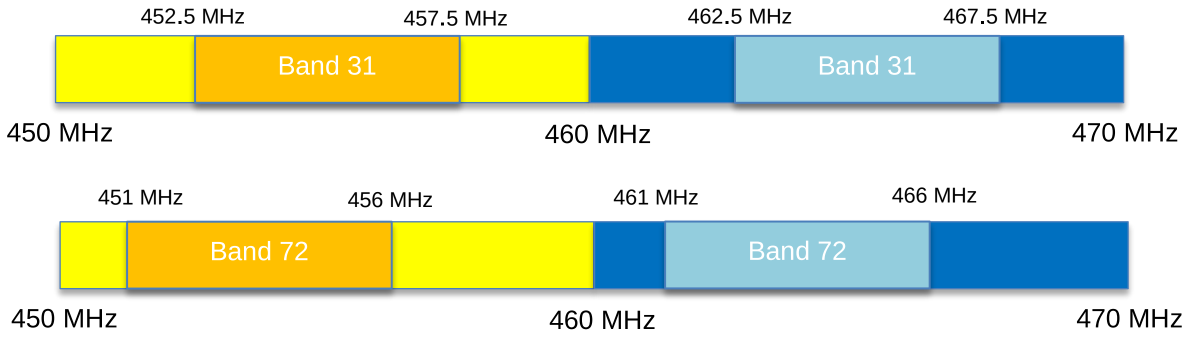


Figure 4: Spectrum arrangement options for the band 450-470 MHz based on 3GPP LTE bands

Standardised channel bandwidths that can be applied in Bands 31 and 72 are 1.4 MHz, 3 MHz and 5 MHz. Combinations of these are also possible, for example channels of 1.4 MHz and 3 MHz.

In addition, Band 31 and Band 72 have been designated in 3GPP TS 36.104 also for use with NB-IoT and LTE-MTC/eMTC carriers.

In addition to these channel options, the following options for the band 410-430 MHz were considered in the studies in this Report, illustrated in Figure 5 below.

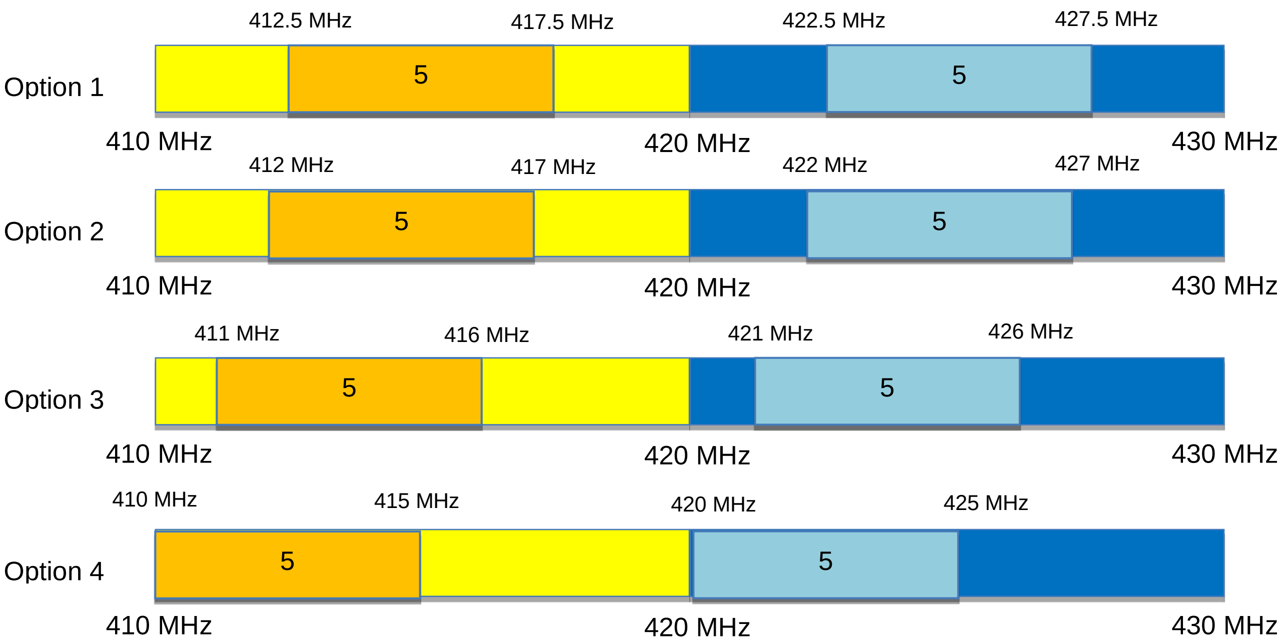


Figure 5: Non-exhaustive spectrum arrangement options for the band 410-430 MHz

2.4 COMPARISON BETWEEN PARAMETERS USED THIS REPORT FOR DIFFERENT TYPE OF LTE SYSTEMS

Scenario specific parameters are applied for compatibility studies in this Report in order to reflect the typical characteristics of LTE networks mentioned above, other than those deployed for PPDR purposes and described in ECC Report 240 [1]. The tables below provide a summary of parameters for BS and UE as applied to eMTC LTE (PMR/PAMR)/ Application. To facilitate a clear comparison, the parameters from ECC Report 240 (LTE based BB-PPDR) are also given. Additional parameters for LTE technology are provided in ANNEX 1:.

Table 4: LTE BS parameters (including those from ECC Report 240 for comparison)

LTE BS parameters	Baseline Value for BS (from ECC Report 240 for comparison)	MTC/eMTC (PMR / PAMR) Value for BS	NB-IoT In-band / Guard band / Standalone
e.i.r.p.	60 dBm	54 dBm (Note 6)	54 dBm
Maximum transmit Power (source: Report ITU-R M.2292 [6])	47 dBm / 3 MHz (Note 1)	41 dBm / 3 MHz (Note 6)	41 dBm / 3 MHz (Standalone 43 dBm / 200 kHz)
Antenna gain (source: Report ITU-R M.2292) (Note 2)	15 dBi	15 dBi	15 dBi
Feeder Loss ECC Report 240 (Note 3)	2 dB	2 dB	2 dB
Centre frequency	468.5 MHz	463.5 MHz (Note 6)	464 MHz (Standalone 467.3 MHz)
Channel bandwidth (Note 6)	3 MHz	3 MHz	3 MHz (Standalone 200 kHz)

LTE BS parameters	Baseline Value for BS (from ECC Report 240 for comparison)	MTC/eMTC (PMR / PAMR) Value for BS	NB-IoT In-band / Guard band / Standalone
Number of Resource Blocks (RBs) in accordance to the channel bandwidth	15 RBs (1 RB = 180 kHz)	6 + 6 RBs, eMTC cat-M1 devices support ≤ 6 RBs. 3 MHz allocation allows two 1.4 MHz Channels, each supporting 6 RBs (1 RB = 180 kHz)	15 RBs (1 RB = 180 kHz) (Standalone 1 RB)
Activity factor (Note 8)	100%	100% (Note 7)	100%
Antenna Height (source: Report ITU-R M.2292) [6]	30 m	30 m	30
Spurious Emissions (Note 4)	-36 dBm (see [13] table 6.6.4.1.2.1-1)	-36 dBm (see [13] table 6.6.4.1.2.1-1)	-36 dBm (see [13] table 6.6.4.1.2.1-1)
Frequency Reuse Factor	1	1	1
Antenna Pattern/ Number of Sectors (Note 2)	Directional / 3	Directional / 3	Directional / 3
Adjacent Channel Leakage Ratio (ACLR)	45 dB (see [13], table 6.6.2.1-1)	45 dB (see [13], table 6.6.2.1-1)	45 dB (see [13], table 6.6.2.1-1) Standalone 40 dB / 50 dB (see [13] Table 6.6.2.1-2b)
Reference Sensitivity Quarterly Phase Shift Keying (QPSK)	-107.77 dBm used in ECC Report 240 (TS 36.104 V12.3.0 states -103 dBm (3 MHz) not -107.7 dBm, see Table 7.2.1-1 in [1])	-135 dBm (see [13]) (3GPP LTE Reference Sensitivity refers to certain throughput; rather not relevant for PMR / PAMR / eMTC. Instead supporting of severe propagation conditions. Therefore use of minimum conditions to maintain relevant PHY channel (DL, UL) under severe propagation conditions)	-127.3 dBm NB-IoT Sub-carrier spacing 15 kHz, -133.3 dBm NB-IoT Sub-carrier spacing 3.75 kHz (see [13] Table 7.2.1-5)
Deployment Density/ Cell Range	0.0091 km^{-2} / (7.5 km cell range) 0.077 km^{-2} / (2.584 km cell range)	0.0018 km^{-2} / (17 km cell range) for Urban Outdoor 0.015 km^{-2} / (5.868 km cell range) for Urban Indoor 0.17 km-2 / (1.74 km cell range) for Urban Indoor.	0.0018 km^{-2} / (17 km cell range) for Urban Outdoor 0.015 km^{-2} / (5.868 km cell range) for Urban Indoor
Duty cycle	100%	100%	100%

Note 1: In general, regulatory demands require the e.i.r.p. in the 400 MHz band to be 53 dBm or lower. Values given for transmit power, gains and losses are given for reference and for uplink link budget calculations. Their actual values should be limited such that they match the e.i.r.p. used in simulations

Note 2: Considering two power amplifiers transmit power is up to 47 dBm. (For one amplifier, the power is 44 dBm.)

Note 3: Antenna gains between 6.5 to 13 dBi are considered in this Report. In ECC Report 240, 13 dBi was used, typical directive antenna (15 dBi) including cable loss (2 dB). Kathrein product datasheet (742 242) was used to create SEAMCAT antenna patterns.

Note 4: Report ITU-R M.2292 defines 3 dB, but in ECC Report 240 value of 2 dB was used, since according to manufacturers it is more realistic for the 400 MHz range

Note 5: -96 dBm/100kHz is the 3GPP requirement for protection of own UL band. BS emissions are expected to be equal or lower than this level at the RAS frequencies due to rejection from the Tx filter.

Note 6: In some studies, the bandwidths of 1.4 and 5 MHz were considered. In particular in the LTE vs DTT compatibility analysis, the BS transmit power assumed is 43 dBm (56 dBm e.i.r.p.) for a system bandwidth of 5 MHz and centre frequency of 465 MHz.
Note 7: In the LTE vs DTT compatibility analysis, the impact of an LTE PMR BS activity factor of 50% is assessed in a sensitivity analysis.
Note 8: The appropriate activity factor value (20…100%) depends on the compatibility study. Information on the proper use of activity factor is provided in ANNEX 2:of this Report.

Table 5: System Parameters for UE (including those for PPDR for comparison)

LTE UE parameters	Baseline Value for UE (from ECC Report 240 for comparison)	eMTC Value for UE (PMR / PAMR Application)	NB-IoT Inband / Guard band / Standalone
Transmit Power (source: Report ITU-R M.2292 [6])	37 dBm	23 dBm (ref. [12], section 6.2.2E) (-40 to 23 dBm with Power Control)	23 dBm (ref. [12], section 6.2.2E) (-40 to 23 dBm with Power Control)
Antenna gain (source: Report ITU-R M.2292)	0 dBi	-3 dBi	-3 dBi
Antenna Pattern	Omni-directional	Omni-directional	Omni-directional
Channel bandwidth	3 MHz	3 MHz	0.180 MHz
Antenna Height (source: Report ITU-R M.2292)	1.5 m	1.5 m	1.5 m
BS Sector-carrier BW / RBs per sector-carrier	3 MHz / 15	1.4 MHz / 6	3 MHz / 15
RBs per UE / UE bandwidth	3, 5 & 15 / 0.2, 1 & 3 MHz	1 / 0.2 MHz	1 / 0.2 MHz
Number of Active UEs / Network Load for 1 RB/UE for a 3 MHz / 1.4 MHz sector-carrier	100%	100%	100%
e.i.r.p.	37 dBm	20 dBm	20 dBm
Centre frequency	458.5 MHz	453.5 MHz	454 MHz
Body Loss (source: Report ITU-R M.2292)	4 dB	0 dB	0 dB
Wall Penetration Loss (source: ECC Report 240)	11 dB	15 dB (urban) 9 dB (rural/suburban)	15 dB (urban) 9 dB (rural/suburban)
Wall Loss Standard Deviation (source: ECC Report 240)	6 dB	6 dB	6 dB
Average Density of Active UE (UE/km^2)	0.027 km^{-2} (3 UE/cell) 0.055 km^{-2} (6 UE/cell) 0.082 km^{-2} (9 UE/cell) 0.137 km^{-2} (15 UE/cell) (7.5 km cell range, ECC	0.011 km^{-2} (6 UE/cell) 0.021 km^{-2} (12 UE/cell) 0.032 km^{-2} (18 UE/cell) 0.053 km^{-2} (30 UE/cell) 0.064 km^{-2} (36 UE/cell)	0.080 km^{-2} (45 UE/cell) (17 km cell range, 15 UE/sector, 1 RB/UE) 0.671 km^{-2} (45 UE/cell)

LTE UE parameters	Baseline Value for UE (from ECC Report 240 for comparison)	eMTC Value for UE (PMR / PAMR Application)	NB-IoT Inband / Guard band / Standalone
	Report 240, table 3)	(17 km cell range for urban outdoor) 0.089 km^{-2} (6 UE/cell) 0.179 km^{-2} (12 UE/cell) 0.268 km^{-2} (18 UE/cell) 0.447 km^{-2} (30 UE/cell) 0.537 km^{-2} (36 UE/cell) (5.868 km cell range for urban indoor)	(5.868 km cell range, 15 UE/sector, 1 RB/UE)
Environment	Urban	Urban	Urban
Distribution of Transmitting UE (% indoors / % outdoors) in Urban Scenario	25% / 75%	100% (indoors)	100% (indoors)
Adjacent Channel Leakage Ratio (ACLR)	30 dB, (see [12], Table 6.6.2.3.1-1)	30 dB, (see [12], Table 6.6.2.3.1-1)	30 dB, (see [12], Table 6.6.2.3.1-1)
Reference Sensitivity Quarterly Phase Shift Keying (QPSK)	-95.7 dBm (see [12], Table 7.3.1-1)	-119.2 dBm, (see [12]) (3GPP LTE reference sensitivity refers to certain throughput; rather than supporting severe propagation conditions as needed for M2M/IoT type of services. Therefore use of minimum conditions to maintain relevant PHY channel (DL, UL) under severe propagation conditions)	-108.2 dBm (see [12] Table 7.3.1F.1-1)
Transmit Power Control	Max allowed Tx power = 37 dBm Min transmit power = -40 dBm Power scaling threshold = 0.9 Balancing factor (0<γ<1) = 1; (see Annex 5 of ECC Report 240)	Max allowed Tx power = 23 dBm Min transmit power = -40 dBm Power scaling threshold=0.9 Balancing factor (0<γ<1) = 1; see Annex 5 of ECC Report 240	Max allowed Tx power = 23 dBm Min transmit power = -40 dBm Power scaling threshold=0.9 Balancing factor (0<γ<1) = 1; see Annex 5 of ECC Report 240

2.5 CELL RANGE AND INTERFERER DENSITY

In order to define the interferer density, cell range calculations at 450 MHz in an urban environment have been performed using the radio parameters of the different system and the extended Hata propagation model as available within SEAMCAT. For DTT considerations, the cell range has been calculated at 474 MHz (central frequency of Channel 21) using the propagation model specified in Recommendation ITU-R P.1546 [10].

For PMR systems, cell ranges have been calculated in order to guarantee a 75% confidence level at the cell fringe. The cell range depends on applications and environments considered.

Table 6 shows UE densities with a 5.868 km cell range associated to a BS (urban and UE indoor).

Table 6: UE densities with 5.868 km cell range (urban indoor)

UE per Sector per 1.4 MHz Carrier	Number of Active UE’s per Sector	Number of Active UE’s per Cell	Density (UE/ km^2)
1	2	6	0.089
2	4	12	0.179
3	6	18	0.268
4	8	24	0.358
5	10	30	0.447
6	12	36	0.537

3 DESCRIPTION OF DIFFERENT SYSTEMS

This Report covers several systems. Their characteristics and special features relevant to these studies are discussed in this section.

3.1 PMR

Private Mobile Radio (PMR) systems are characterised by being privately owned and operated under licensed conditions, offering professional group-communication facilities, tailor-made UE design, with deployment of predominantly portable devices allowing users to have full control over their activities.

PMR services include Group Call Voice Services (commonly called 'all informed net' and 'talk group call'), Pre-Emptive Priority Call (Emergency Call), Call Retention, Priority Calling, Dynamic Group Number Assignment (DGNA), Ambience Listening, Call Authorized by Dispatcher, Area Selection, Late Entry, Direct Mode, Short Data Service, Packet Data service and smooth migration from analogue to digital platforms.

The study in this Report takes into account that BB-PMR deployment will consist of many independent standalone licensed networks that are un-synchronised.

3.2 PAMR

Public Access Mobile Radio (PAMR) networks are intended for those users who need PMR type services but cannot afford to build their own network. Operators of PAMR networks can allocate resources to different closed user groups including security companies, transportation or construction companies etc. Many of the current PAMR networks are based on TETRA technologies. The trunking principle allows mobile stations to choose any available free channel rather than having to wait for a certain channel to become available. Networks can be regional or nationwide.

3.3 M2M/IOT

Many forecasts and studies show that Machine-to-Machine (M2M) communications and Internet of Things (IoT) will play an increasingly important role in Europe in the near future and will be a main contributor to economic development. A significant portion of M2M/IoT applications will be used for critical applications in the private and government related sectors like utilities, city and national infrastructures and other sectors such as production, transport/logistics as well as in healthcare. Critical M2M/IoT applications require telecommunication networks with deep indoor coverage, robust resilience and high service availability.

New deployments of 450 MHz networks focussing on M2M/IoT are using either Code Division Multiple Access (CDMA) or LTE. CDMA technology is widely used worldwide and is already customised for M2M/IoT. LTE is a next generation technology that promises substantial technical benefits for M2M/IoT with regards to coverage, performance, cost and power consumption.

3.3.1 Inband NB-IoT

In an inband deployment, the IoT technology will use some of the resources of an existing wideband carrier. This corresponds to a change of transmission mode on some subcarriers of a wideband carrier. This is very similar to what happens when a specific modulation is selected by the BS to serve a specific terminal.

Embedding an NB-IoT in an LTE carrier does not change the power or the Spectrum Emission Mask (SEM), either on the BS or the UE side. In particular, it is not possible to go closer to block edge than a current LTE UE could go.

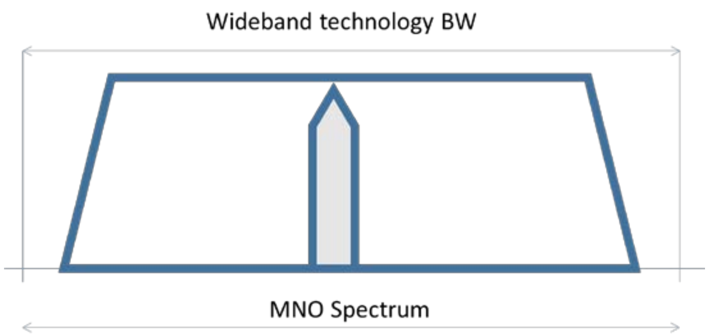


Figure 6: In-band deployment of IoT

3.3.2 Guard band NB-IoT

A guard band NB-IoT deployment corresponds to the case where a narrowband transmission is added on the side of an existing wideband carrier. This is made possible by the fact that wideband transmission technologies typically transmit a signal narrower than the channel bandwidth, i.e. they implement implicit guard bands within their transmission channel. The IoT can leverage these implicit guard bands as operating spectrum.

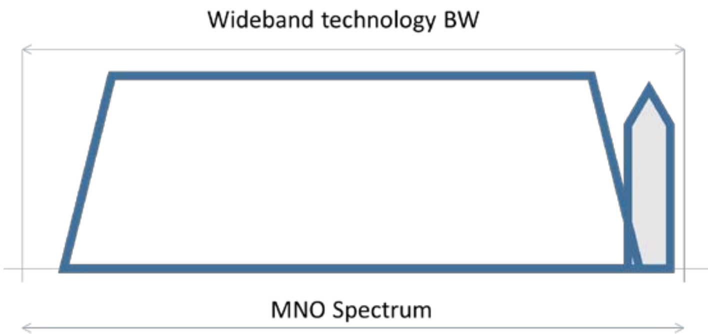


Figure 7: Guard band deployment of IoT

3.3.3 Standalone NB-IoT

In a standalone deployment, the IoT carrier is deployed independently, in its own narrowband spectrum. Typically, the IoT carrier only uses a fraction of the band allocated to an MNO. This is exactly the same deployment mode as GSM.

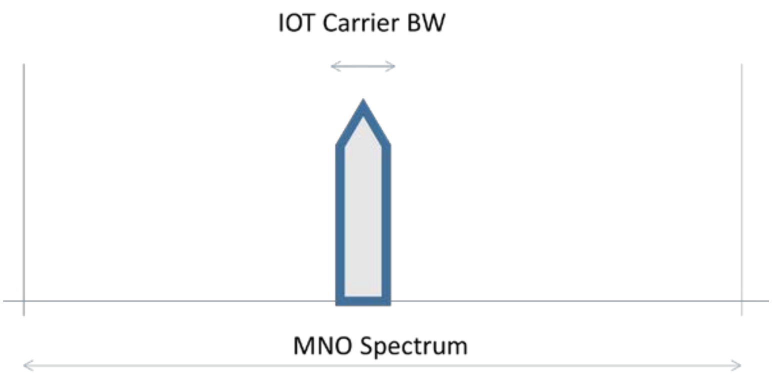


Figure 8: Standalone deployment of IoT

3.4 LPWAN

Low Power Wide Area Network (LPWAN) is a type wide area network (WAN) designed to allow long range communications at a low bit rate among things (connected objects), such as sensors operated on a battery. The low power, low bit rate and intended use distinguish this type of network from a wireless WAN that is designed to connect users or businesses, and carry more data, using more power.

3.5 DTT

Digital terrestrial television (DTT) networks are deployed within Europe in channels above 470 MHz using DVB-T and DVB-T2 to serve both fixed and portable receivers.

To limit interference from services operating in bands adjacent to those used by DTT, unwanted emissions levels from the radio transmitters of these services, both base station and user equipment, will need to be limited. In certain circumstances additional mitigation measures might be required to allow co-existence; e.g. external filtering at the DTT receiver.

3.6 PPDR

Public protection (PP) radiocommunication: Radiocommunications used by agencies and organizations responsible for the maintenance of law and order, protection of life and property and emergency situations. (source: ITU-R Resolution 646 (Rev. WRC-15))

Disaster Relief (DR) radiocommunication: Radiocommunications used by agencies and organisations dealing with a serious disruption of the functioning of society, posing a significant, widespread threat to human life, health, property or the environment, whether caused by accident, natural phenomena or human activity, and whether developing suddenly or as a result of complex long-term processes. (source: ITU-R Resolution 646 (Rev. WRC-15))

PPDR networks are based on cellular type architecture augmented, where necessary, by vehicle mounted relay stations and direct mode operation.

3.7 RLOC

Radiolocation (RLOC) characteristics are defined in Recommendation ITU-R M.1462 [15].

420-450 MHz is the tuning range of airborne and ground radars, as described in Recommendation ITU-R M.1462. This frequency range is harmonised for NATO ground, air and naval military radar systems as described in the NATO Joint Civil/Military Frequency Agreement (NJFA). Spectrum agility in this range is an essential requirement to ensure coordination with other systems using this band and to operate in an Electronic Warfare context. Thus, radiolocation systems cannot be limited to some specific frequencies in particular in the band 420-430 MHz, where radiolocation is a secondary service, and in the band 430-440 MHz, where radiolocation is a primary service.

Airborne radars are used on aeronautical platforms and are operating daily over wide areas that consist of several hundreds of kilometres over land and sea.

Ground radars are transportable systems used to enhance the protection of specific areas. In practice, these radars could be co-located with military forces that are operating communication systems derived from current and future PPDR technology. Military forces are equipped with narrowband (NB) PPDR systems to interoperate with other governmental actors for national missions. These systems are also used for military operation in addition to hardened tactical communication systems.

3.8 RAS

The band 406.1-410 MHz is one of the preferred bands for continuum observations for the radio astronomy service (RAS). The service involves only passive systems, which are very sensitive. Radio astronomers have no control over the power, the frequency or other characteristics of the emissions able to cause harmful interferences. To meet the needs of radio astronomy, there may be a need to limit the unwanted emission levels of the radio transmitters and their use in the vicinity of the radio astronomy observatories.

3.9 FS

The fixed service (FS) in the 400 MHz is dedicated to single narrowband radio links. It is not intended to assemble network structures. In case of not having another option for communication, these links are considered as an alternative. The applications are mainly used by utilities and public service providers for metering and process control purposes.

Even though these applications are not covered by the Harmonised Standard ETSI EN 302 217-2-2 [24] they can be considered as specific in some countries

3.10 PMSE

Within all areas of Programme Making and Special Events (PMSE)[4] productions, there is a need for service links for activities such as communications, control of staff operating cameras and machinery; these are either conventional push-to-talk systems or constant carrier base unit.

Such use can be land-, air-, or sea-based, and some of them are internationally harmonised for aerial use to ease cross-border coordination.

The demands of broadcast productions make the full-duplex operation of wireless intercom systems an absolute necessity for stage managers, lighting and audio technicians or any professional who has to deal with the breakneck speed and complexity of television productions. Wireless intercoms encompass all sorts of systems from the most basic pair of “walkie-talkies” (PMR) to dedicated professional full duplex wireless intercom products. Wireless intercom systems are employed where the limitations of wireless systems, which can include fidelity, interference, lack of range, lack of security (real or perceived) and battery life limitations, are outweighed by the freedom of being cordless. This freedom is essential in many applications.

Wireless intercom systems can be designed, installed, configured and operated in partyline[5] or matrix6 configurations, and may very likely be connected to a hard-wired matrix intercom system at some point. For daily use in event and sport productions, OBVs (Outside Broadcast Van) needs at least 2x duplex (open microphone production/engineers with talkback) and 2x simplex (simplex and interrupted foldback systems). High quality wireless intercoms offer a distinct advantage over traditional, two-way radios in that they offer a more natural full duplex operation. This enables all users on the system to speak and hear other users simultaneously without blocking other users’ transmissions.

PMSE links use both simplex, duplex, and semi-duplex (constant carrier base unit) in both identified bands 410-430 MHz and 450-470 MHz. Frequencies used by airplanes or helicopters are internationally harmonised and coordinated; these include 419.8375 MHz, 419.8625 MHz, 419.9250 MHz, 419.9500 MHz, 419.9750 MHz, 429.8375 MHz, 429.8625 MHz, 429.9250 MHz, 429.9500 MHz, 429.9750 MHz.

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[4] The SAP/SAB applications include both ENG/OB and SNG/OB applications and also the communication links that may be used in the production of programmes, such as talk-back or personal monitoring of telecommand, remote control and similar applications.

[5] Wireless intercom loop system that people can join just by plugging in their unit and select who he wants to talk to.

[6] Point-to-point or point-to-multipoint wireless intercom system.

3.11 PAGING

Currently paging use covers a wide range of applications such as:

- secure smart energy grid operation for Distribution Network Operator (DNO) e.g. remote control of renewable energy production;
- load control for storage heating.

Safety of life critical alerting applications, (e.g. firemen, ambulances, medical staff and service personnel of utility companies) also have to provide reliable indoor reception in case of lack of other communication alternatives or if the availability of service has to be increased.

3.12 SRD

Short Range Device (SRD) systems may operate as non-specific SRDs in accordance with band g1 - g3 (i.e. 433.05-434.79 MHz) of Annex 1 of ERC REC 70-03 [8] and ETSI EN 300 220-1 and -2 [9]. These frequency bands are directly adjacent to the frequency band 410-430 MHz.

The 433 MHz frequency band is of eminent importance for all kinds of non-specific SRD applications since this band is amongst the few bands for these kind of applications that are globally available harmonised and available. For example, many automotive applications like Garage Door Openers (GDO), Block Heater Remote Controls, Remote Keyless Entry (RKE) or Tyre Pressure Monitoring (TPM) systems make use of the band g1 (433.05-434.79 MHz) according to Annex 1 of ERC REC 70-03.

Automotive Remote Keyless Entry Systems (RKE-Systems) combine safety and comfort-related functions. They are designed to prevent unauthorised access to the vehicle and for theft-prevention. The comfort-related aspect of these systems is to remotely and effortlessly lock and unlock the doors of a car.

Such systems consist of an external remote Key (Transceiver) as well as of an antenna module and an Electronic Control Unit (ECU) (Transceiver) built into the vehicle itself.

The particular Radio Frequency (RF) parameters depend on the model and the manufacturer and therefore have a wide variation. For this investigation a contemporary complex ”keyless-Go” system and a legacy “keyless-Entry” system have been chosen to represent this kind of application.

4 LTE IMPACT ON NARROWBAND PMR

4.1 LTE BS IMPACT ON PMR BS IN ADJACENT FREQUENCIES

LTE transmitters may cause interference to PMR receivers in adjacent frequencies. There are multiple interference mechanisms, which are described in the following sections:

- Transmitter out-of-band emissions (OOBE);
- Receiver blocking;
- Spurious responses;
- Receiver intermodulation.

Other than OOBE which is only attributed to the imperfect operation of the interfering transmitter system receiver blocking, receiver spurious response and receiver intermodulation are caused by imperfectness of victim receiver i.e. its non-linearity, limited dynamic range and limited selectivity. Signals from other systems which are received by a victim receiver with sufficient signal strength may cause blocking or produce an intermodulation product in the victim receiver.

4.2 TRANSMITTER OUT-OF-BAND EMISSIONS (OOBE)

No transmitter is able to confine all of its transmitted energy within its defined wanted bandwidth. Therefore out-of-band emissions, which are a combination of spurious emissions and wideband noise, are present in adjacent frequency bands where they can be the cause of undue interference to receivers belonging to other systems. Due to the frequency allocations in 400 MHz, narrowband receivers will be operating in adjacent frequency bands to broadband transmitters, thus the level of spurious and wideband noise emissions from LTE transmitters will be according to that specified in 3GPP specifications.

In the case of undue interference, out-of-band emissions from the LTE transmitter can be mitigated by additional filtering applied to the transmitter. This can reduce the level of emissions that interfere with narrowband receivers until reaching a point where the overload effect in a receiver (through blocking or intermodulation) becomes dominant. Beyond this point, further filtering at LTE transmitter does not add any benefits.

The duplex filter needed by an LTE base station to protect its own receiver is an example of a filter, which can improve the out-of-band emissions performance. This will provide substantial attenuation of OOBE effects at the LTE receiver band, and will also provide variable degrees of attenuation in adjacent bands. The PMR receiver band will receive the same amount of out-of-band emissions if this is overlapping with the LTE receiver band. If PMR is allocated in the duplex band of the LTE band, this will receive less protection.

4.3 PMR BS RECEIVER BLOCKING

Blocking is a measure of the capability of the receiver to receive a wanted (weak) input signal in the presence of a strong input signal on the adjacent channels, without a degradation of the performance of the receiver beyond a specified limit. Receiver blocking of the defined weak wanted signal occurs when the interfering signal strength at the victim receiver is higher than the blocking level specified for the victim receiver.

A blocking effect can be observed when non-linear receiver processes a weak desired signal in the presence of a strong signal (the blocker) with the frequency within the selectivity range of the receiver. The blocking effect depends of the power of the blocking signal but not of the blocking’s signal nature It can be shown that a strong signal will reduce the gain and the low (desired) signal will experience a desensitisation effect. This is illustrated below.

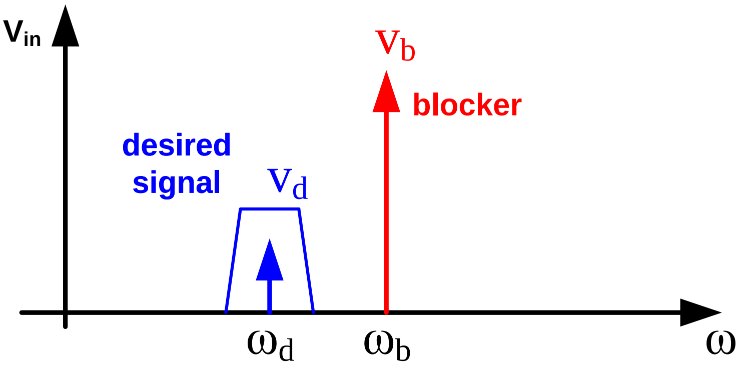

Figure 9: Desired signal and blocking signal

In the respective test procedure the wanted signal level is set 3 dB above the receiver reference sensitivity and the measurement of receiver performance is made up to the defined blocking signal levels. For example for TETRA receivers the wanted signal is set to -109 dBm and the performance must be maintained up to blocking signal strength of -25 dBm at the frequency offset greater than 500 kHz. The performance of the receiver above the blocking threshold is not specified and it is not possible to make generic assumptions about practical receiver performance beyond this level, however it is likely that the receiver will in practice continue to function in some conditions if the wanted signal level is higher than that used for the measurement threshold. Blocking performance can be improved by selectivity in the front end stages of the receiver that attenuates the blocking signal. However, there are very, very few locations in a practical situation where the received level of the interfering signal will exceed -25 dBm, and so the impact on simulations of receiver performance with an interfering signal in excess of -25 dBm can be ignored.

The effect of blocking is confined to locations close to the LTE transmitter. Generally other effects such as spurious response, transmitter Out-of-Band Emissions (OOBE) and receiver intermodulation distortion may also be present at such locations.

4.4 SPURIOUS RESPONSE REJECTION

Spurious responses arise due to the unwanted signal mixing with other frequency sources within the receiver, or unwanted products from the mixer. Examples of such unwanted frequency sources can include spurious outputs from the receiver synthesizer, power supply harmonics, digital clock frequencies etc. With good receiver design practice, typically a careful planning of all frequencies in analogue and digital part of receiver is done so that all considered frequencies are carefully coordinated. However due to many contradicting demands the resulting frequency plan is a compromise so that not all spurious responses can be avoided. A spurious response rejection test will require that there are a maximum of 5% responses at frequency offsets where the blocking test has not been successfully passed. Receiver performance can be improved by selectivity in the receiver before the mixer that provides attenuation at the frequency of a spurious response.

4.5 RECEIVER INTERMODULATION

Intermodulation distortion in receivers is caused by non-linearity and limited selectivity, which are inherent to any real receiver implementation. Multiple strong signals at different frequencies or a broadband signal (LTE, CDMA, DTT etc.) appearing at a non-linear receiver input generate intermodulation products at frequencies related to these unwanted signals.

The Third order intermodulation products are of particular interest with regard to the receiver performance testing because they are stronger than higher odd order interference products which may fall into the receiver band when the receiver band is adjacent to the transmitter frequency. Since it is not feasible to implement a perfectly linear receiver frontend, technical standards define minimum performance requirements based on Third order intermodulation products. As a consequence of these minimum requirements, receivers of certified (standardised) equipment may experience some intermodulation distortion caused by operation of a radio system in neighbouring bands.

A weak signal accompanied by two nearby (strong) interfering signals experiences Third order non-linearity, then one of the occurring intermodulation products may fall in the desired band of the narrowband receiver.

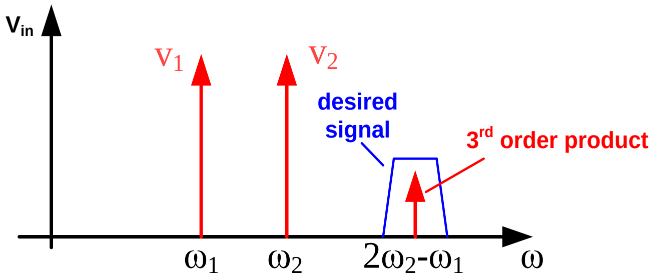

Figure 10: Third order intermodulation products falling in the desired band

Intermodulation performance is specified in equipment standards as the level at which the unwanted signals generate a product at the wanted receiver frequency which is at an equal level to the receiver noise floor assumed by the receiver's sensitivity specification. The level of the product increases at a level of 3 dB for every 1 dB of increase of the strength of the combined unwanted signals. This is illustrated as line B in Figure 11 below. Theoretically, the level can increase until it crosses the linear response of the receiver, line A in Figure 11 at a point known as the 3rd order intercept point, but in practice at higher signal levels, the receiver will not be able to process signals in a linear manner and gain compression occurs which limits the maximum level of these products that the receiver can experience. Typically, a receiver reaches the 1 dB compression point of its linear response about 10 dB below the theoretical 3rd order intercept point.

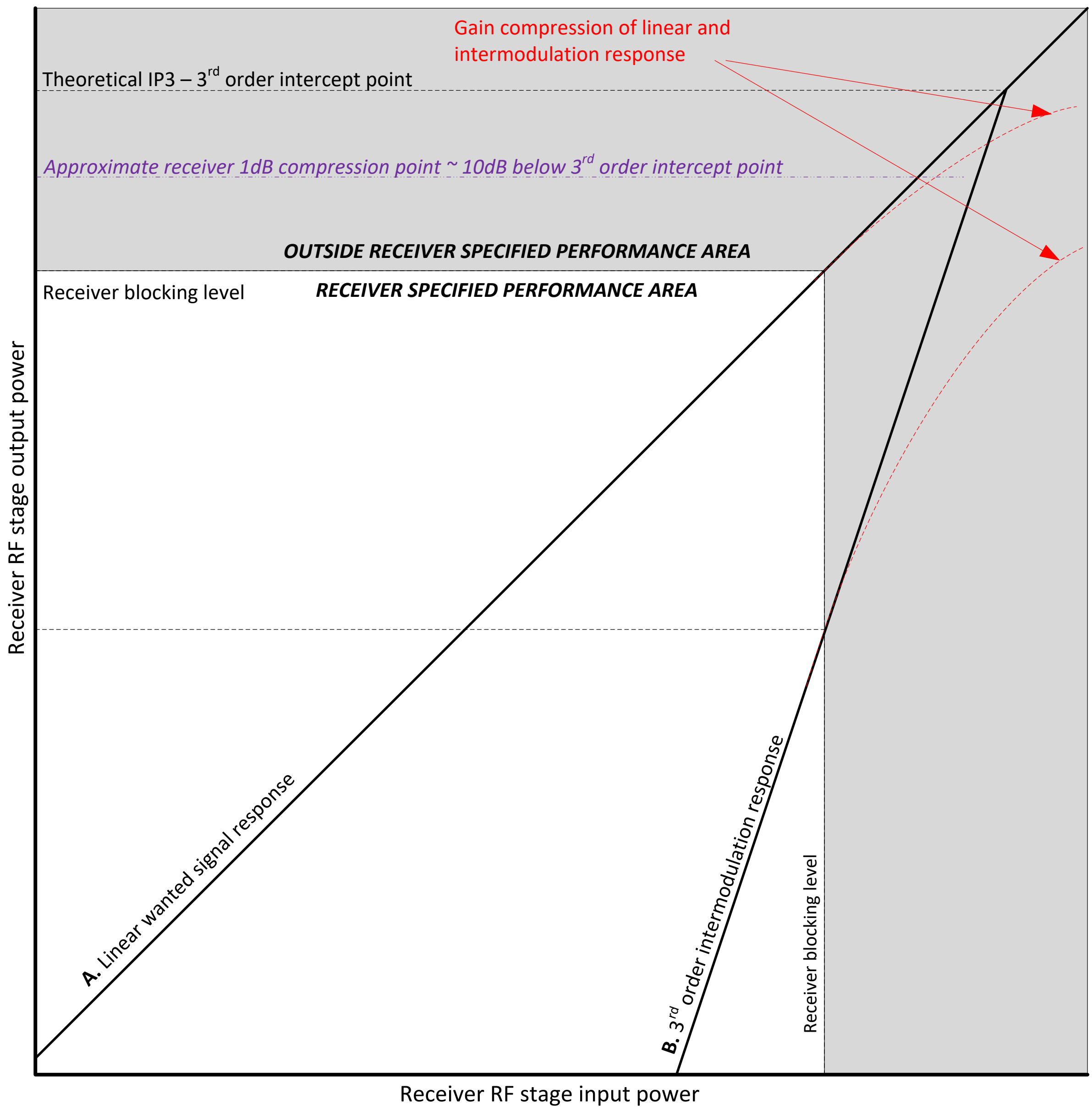

Figure 11: Receiver linear and 3rd order intermodulation response

The validity range of the weak non-linearity approximation that predicts a 3 times steepness for the Intermodulation (IM) products up to -20 dBm, which is higher than the level given in the blocking specification of up to -25 dBm (see ETSI EN 300 392-2 section 6.5.1) could be defined from Figure 11.

Figure 11 shows the raise of IP3 products with increasing input level with a usual two tone test. The approximation of “weak non-linearity” implying threefold steepness of Third Order Intermodulation (IM3) products only holds up to the 1 dB compression point. Above that the model’s errors get very large. The model is too pessimistic for levels above. It predicts too strong IM products which in the following could lead to outage decision in SEAMCAT, although outage is not in place. Therefore using the simple IM equations above 1 dB compression point should not be conducted.

However, as stated in section 4.3 of this Report, the blocking threshold is at a level of -25 dBm for TETRA, or -23 dBm for EN 300 113 [25], and very few locations within a real or simulated coverage area will experience a level of interference greater than this. Thus any non-linearity in the intermodulation response curve can be neglected as being irrelevant for simulations.

4.6 WIDEBAND NON-LINEAR MODEL OF THE RECEIVER

For the study of the intermodulation distortion in narrowband receivers due to wideband signals, a receiver model covering weak non-linear effects for large frequency ranges in the order of the wideband system bandwidths is required.

Narrowband standards provide intermodulation response rejection parameters for small frequency offsets. Figure 12 below shows a comparison between the standard measurement set-up for TETRA and the set-up for the intermodulation distortion due to an LTE signal.

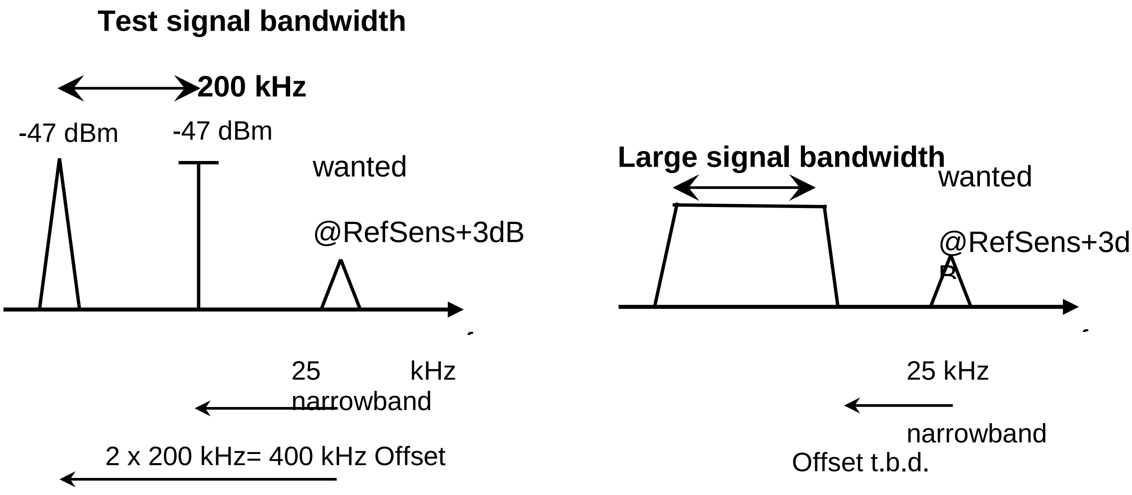

Figure 12: Signal bandwidth with narrowband versus wideband interferers with intermodulation response test

Due to significant differences in the signal bandwidths of the interfering signals and the offsets, the performance figure derived from the narrowband standard may differ from the performance of the wideband signal. This is because the receiver line-up usually contains many frequency dependent non-linear elements (LNA, mixer, etc.) and frequency dependent circuits between the receiver stages.

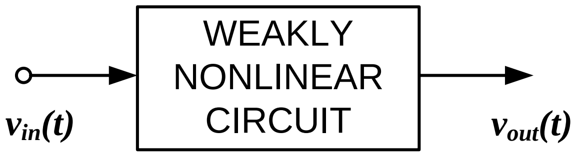

Figure 13: Weakly nonlinear circuit model for Volterra-Series analysis

The theory of weak non-linear systems, such as the Volterra series expansion, provides applicable models for the studies of the behaviour of such systems due to wideband signals. There are also modern circuit simulation tools, which allow for the analysis of known non-linear systems. The analysis of spectral zones is just one example. However, for the purpose of the report neither measurements for extraction of the Volterra series model nor simulations of a large number of typical receivers are available.

Instead, a simplified receiver non-linearity model based on the Taylor series expansion model may be used, provided that memory effects of filters or other components in the receiver are properly accounted for. The Taylor series expansion model consists of a filter (or a matching network) in front of a memoryless weak non-linear system of which the output depends solely on the instant value of the input.

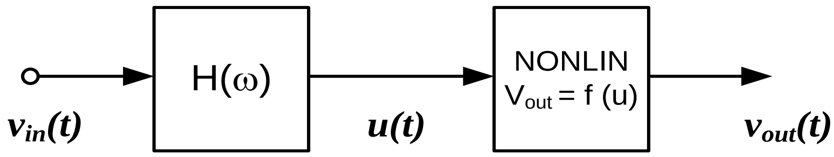

Figure 14: Taylor series model

The weak non-linearity Taylor model can therefore be described by the effective preselector filter H(ω) response and the effective Third order intercept point IIP3. The effective values of this simplified model account for the memory effects mentioned.

The non-linear receiver model must take into account all standard performance specifications of the receiver non-linearity, namely:

- Intermodulation response;
- Spurious response;
- Blocking;
- Nominal Error Rate.

A receiver design has to meet all these four specifications. This may imply using components with higher IIP3 values or including tuneable pre-selectors / tracking filters. In particular a wideband non-linear receiver model cannot be solely extrapolated from the intermodulation response specification of narrowband standards since the intermodulation response by the victim receiver is dependent on the signal bandwidth. The simulations can only provide useful results if the extraction of the effective receiver model parameters is done in a proper way. Indications for extraction of non-linear wideband receiver model are given in Annex 3.

a) Analysis of existing receivers

Suppliers published some circuit layouts and system design parameters of some of the existing narrowband receivers. It was found that high order reactive networks are used with input filter, interstage filter and IF filter. These all contain memory, which in principle compels to use a non-linear transfer function (Volterra series expansion) for the extraction of an accurate non-linear receiver model. However, for the chosen simplified non-linear receiver model these effects have to be ignored.

The simplified memoryless model allows for the cascading of IIP3 values of the deployed elements like LNA and mixers. Some of the analysed receiver circuits use pre-selector filters but not all of them.

b) Further approach

Another method to assess the intermodulation performance in narrowband receivers due to a wideband interferer is to conduct a measurement campaign of existing narrowband receivers. Such campaign could not be accomplished within the timeframe of this Report.

4.7 CONCLUSIONS

Simulations of interference from LTE transmitters into narrowband PMR receivers in adjacent frequency spectrum show that the probabilities of interference based on Out-of-Band Emissions (OOBE) and Blocking for low to medium Base station (BS) and Mobile station (MS) densities are generally on the average 1% or less, although unwanted emission improvement compared to the 3GPP Spectrum Emission Mask at the BS may be required to keep the interference from the LTE BS into the PMR MS to these low levels. However, the interference probability calculations are performed for downlink limited systems; results may differ for uplink limited systems, which may tolerate a noise rise in MS receivers up to level of the DL/UL imbalance. Please also note that other techniques needed to protect the LTE400 BS' own reception band (such as duplex filtering) help to provide necessary attenuation of Out-of-Band emissions of the LTE BS into the TETRA MS reception band. Furthermore, interference probability averaged over the coverage area of narrowband BS decreases, if LTE cell size increases. The probability of interference is highest closest to the LTE BS. Out of Band Emission improvement may not be needed depending on the acceptable level of degradation over the coverage area.

The interference probabilities for the LTE BS impact on PMR MS are lower in comparison to the interference probabilities simulated in ECC Report 240 for PPDR-LTE BS impact on PMR MS. Even lower interference probabilities are expected if the bursty nature of M2M traffic will be included in the calculations.

Another interference effect to be taken into account is the potential impact of Intermodulation Distortion (IMD) in PMR receivers caused by neighbouring broadband signals. This is dependent on frequency offset of the LTE carrier from the victim PMR receiver, the received power and the intermodulation performance of the victim PMR receiver at that frequency offset. The assessment of outage probability due to Intermodulation by simulations appeared to be far from straightforward.

The following requirements must be taken into account:

- The simulations must be reproducible;
- Results must be convergent, meaning that the Intermodulation (IM) levels converge to a stable value when simulations are done with ever decreasing frequency slices;
- For simplicity, simulations will be done in the frequency domain, although non-linearity is best described in the time domain. Outcomes must therefore be crosschecked between frequency and time domain before being accepted;
- Simulations must be done with selected values for IIP3 and Receiver Selectivity, where for IIP3 worst case, typical case and best case values are used and Receiver Selectivity is supposed to be either present or absent.

During the studies, several algorithms were implemented in a SEAMCAT plugin, but no agreement on the algorithm has been achieved. Towards the finalisation of the drafting of this ECC Report, a new analytical model was provided by stakeholders. Nevertheless, there was no sufficient time to agree on it. Therefore, further work is required to agree on this new analytical algorithm, implement it in SEAMCAT and validate its implementation. For that reason and despite all efforts, no conclusion on the intermodulation effect from broadband interferers into narrow band victims could be reached.

5 LPWAN COMPATIBILITY STUDIES

Internet of Things (IoT) communications can be operated by various technologies under the generic designation of Low Power Wide Area Networks (LPWAN) as already provided in unlicensed bands (865-868 MHz). These technologies are envisaged to operate in the 400 MHz. This study analyses the compatibility between LPWAN communications based on narrowband technologies and the Long-term Evolution (LTE) systems envisaged in the 400 MHz band as well as with incumbent services in adjacent band. Systems description, calculation method and assumptions considered for the analysis are presented in the following sections.

5.1 PARAMETERS FOR NARROWBAND LPWAN

The system characteristics presented below are one example of the narrowband technologies envisaged to host LPWAN communications in the bands 410-430 MHz and 450-470 MHz.

5.1.1 LPWAN Network Model

The network configuration is illustrated in Figure 15 below:

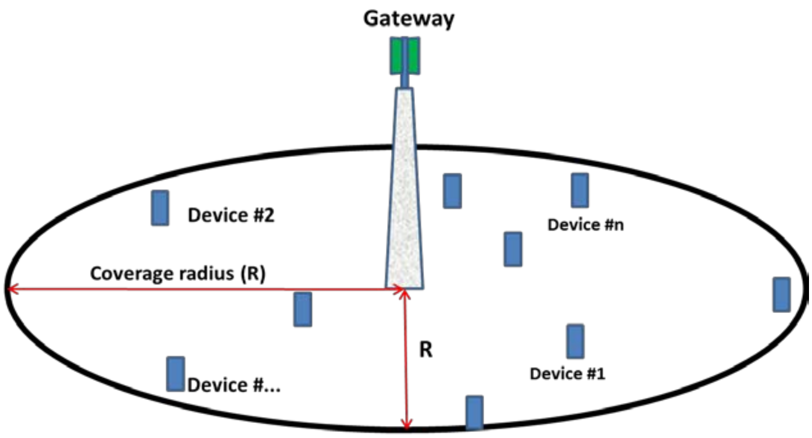

Figure 15: Network configuration of LPWAN

The following parameters are used for LPWAN.

5.1.1.1 *Coverage Radius*

Table 7: Coverage radius

Environment	Typical coverage radius
Urban	100 m to 10 km
Rural	10 to 30 km

The LPWAN coverage radius depends on the environment, the indoor/outdoor case and the configuration of the LPWAN signal (Spreading Factor 7 up to Spreading Factor 12).

5.1.1.2 *Deployment Cases*

Table 8: Deployment scenarios

Equipment	Typical Density	Maximum Density	Activity factor
Device	500 / gateway	10 000 / gateway	Up to 100%
Gateway	2 / km²	4 / km²	Up to 100%

5.1.1.3 *End user and gateway antenna height*

Table 9: Antenna height

Equipment	Minimum antenna height	Average antenna height	Maximum antenna height
Device	-5 m	1.5 m	6 m
Gateway	6 m	30 m	120 m

5.1.2 LPWAN gateway and end user parameters

Table 10: LPWAN system parameters for BS

LPWAN BS parameters	Baseline value for BS
Channel bandwidth	125 kHz
e.i.r.p. (transmit power dBm + antenna gain dBi - feeder loss dB)	33.6
Average Antenna height	30 m
Antenna gain (Note 1)	5.6 dBi
Antenna pattern	Omnidirectional
Activity factor	Up to 100%

Note1: Typical antenna deployed in France in the band 865-868 MHz.

Table 11: LPWAN system parameters for end user device

LPWAN end user parameters	Baseline value for end user
Channel bandwidth	125 kHz
e.i.r.p. (transmit power dBm + antenna gain dBi - feeder loss dB)	23 dBm
Average Antenna height	1.5 m
Antenna gain (Note 1)	-3 dBi
Antenna pattern (Note 1)	omnidirectional
Distribution of transmitting end devices (% indoors / % outdoors) in urban environment	90% / 10%
Activity factor	Up to 100%

Note1: Typical antenna deployed in France in the band 865-868 MHz.

5.1.2.1 *Receiver Sensitivity for different SF and NF, receiver bandwidth*

Table 12 below gives the required in-band Signal to Interference and Noise Ratio (SINR) to achieve demodulation with a 10% Packet error rate with coding rate of 4/5, for 20 bytes payload.

The sensitivity of a LPWAN receiver is calculated as follows:

The thermal noise density is -174 dBm/Hz in a 50 Ohm load.

The equivalent radio noise is therefore -174 dBm + NF

In that case for a given Spreading factor (SF) a LPWAN receiver would have a sensitivity of:

$$sensi_{SF} = -174 + NF + 10 * log10(BW) + SNR_{SF}$$

Where SF refers to Log2 of the spreading factor.

For example, when a LPWAN receiver exhibits a noise factor of 7 dB, for a modulation bandwidth of 125 kHz the sensitivity using SF12 will be:

$$sensi_{SF12} = -174 + 7 + 10 * log10(125.10^3) - 21.9 = -137.9\ dBm$$

A low power end-point chip typically exhibits a noise factor of 5 to 7 dB depending on the external impedance matching components. A gateway front-end typically exhibits a noise factor of 3 dB to 6 dB.

Table 12: Receiver sensitivity for different SF and NF

Spreading factor (SF)	Spreading factor	SNR (dB)	Sensitivity (dBm)@3dB Noise Figure (NF)	Sensitivity (dBm)@7dB NF
7	128	-8.0	-128.0	-124.0
8	256	-10.8	-130.8	-126.8
9	512	-13.6	-133.6	-129.6
10	1024	-16.3	-136.3	-132.3
11	2048	-19.2	-139.2	-135.2
12	4096	-21.9	-142.9	-137.9

5.1.2.2 *Receiver blocking mask*

The base station and end device receiver masks are based on the ETSI SR Doc TR 103 526 [54].

Table 13: Base station and end device receiver selectivity

Offset (MHz)	Mask(dB)
6	73.25
5	68.25
2	63.25
1	58.25
70.5	48.25
0.25	33.25
0.125	8.25
0.0625	-1.74
-0.0625	-1.74
-0.125	8.25
-0.25	33.25
-0.5	48.25
-1	58.25
-2	63.25
-5	68.25
-6	73.25

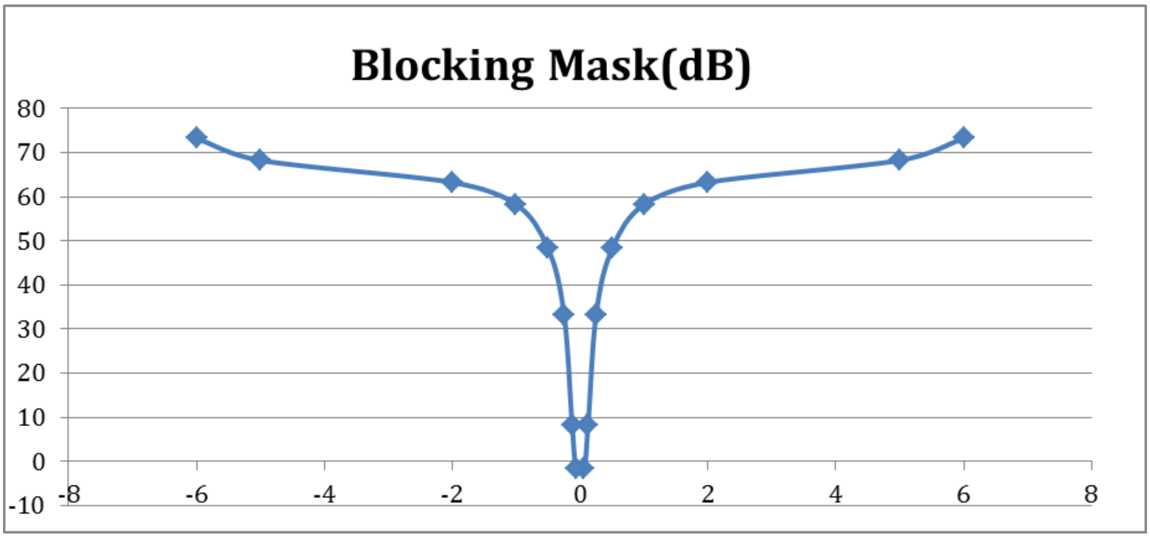

Figure 16: Base station and end device receiver selectivity

5.1.2.3 *Transmitter Out-of-Band Emissions*

The base station and end device transmitter masks are based on the ETSI SR Doc TR 103 526 [54].

Base station:

The mask has been calculated for a 1 kHz reference bandwidth.

Table 14: Base station emission mask

Offset (MHz)	Mask (dB)	Ref. Bandwidth (kHz)
6	-85.97	1
0.5	-85.97	1
0.25	-68.97	1
0.125	-58.97	1
0.0625	-20.94	1
-0.0625	-20.94	1
-0.125	-58.97	1
-0.25	-68.97	1
-0.5	-85.97	1
-6	-85.97	1

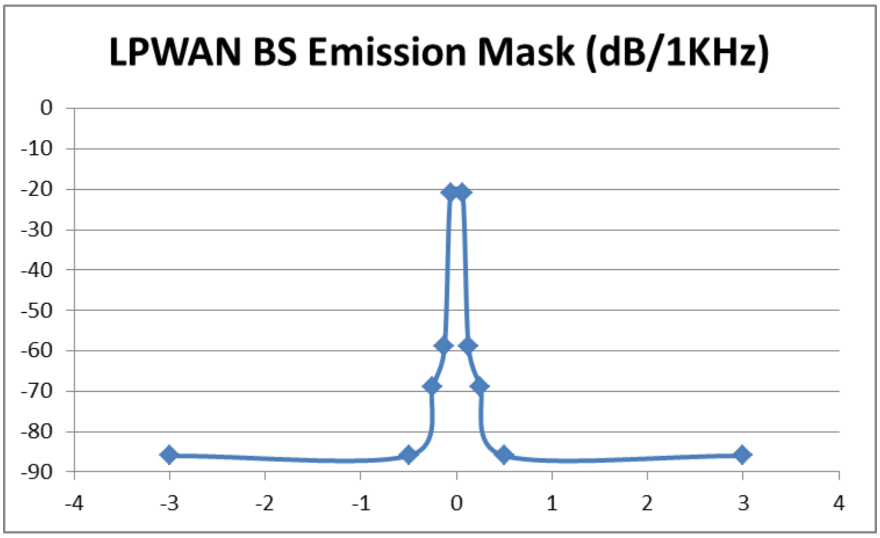

Figure 17: Base station emission mask

End device:

The mask has been calculated for a 1 kHz reference bandwidth.

Table 15: End device emission mask

Offset (MHz)	Mask (dB)	Ref. bandwidth (kHz)
6	-78.97	1
0.5	-78.97	1
0.25	-63.97	1
0.125	-53.97	1
0.0625	-20.97	1
-0.0625	-20.97	1
-0.125	-53.97	1
-0.25	-63.97	1
-0.5	-78.97	1
-6	-78.97	1

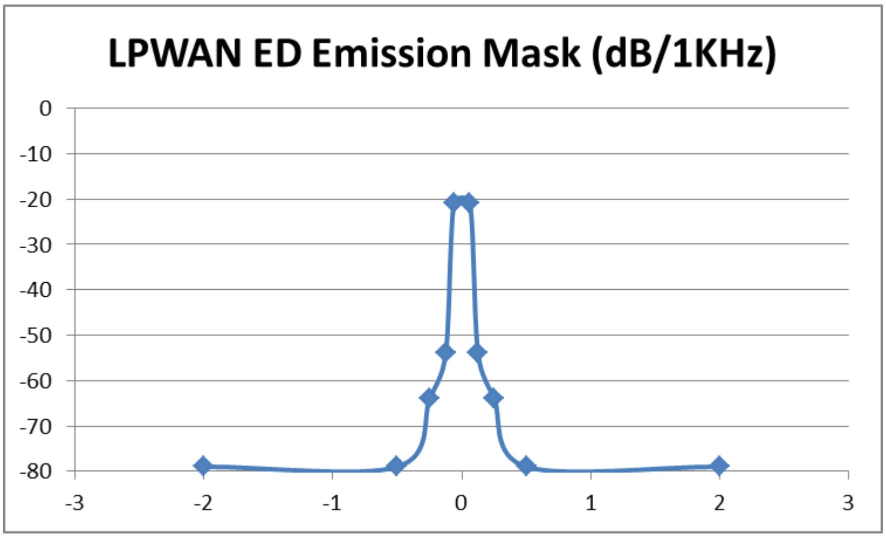

Figure 18: End device emission mask

5.1.2.4 *LPWAN device spurious emissions*

Measurements of the spurious emissions for a LPWAN-CSS signal of 125 kHz bandwidth, centred at 869.525 MHz with a power of 27 dBm (worst case) are shown below (the limits of ERC Recommendation 74-01 are represented by red lines in the figures below).

The emissions below 1 GHz are shown in Figure 19 and Figure 20 (the measurements are carried out with a notch filter for frequency below 1 GHz).

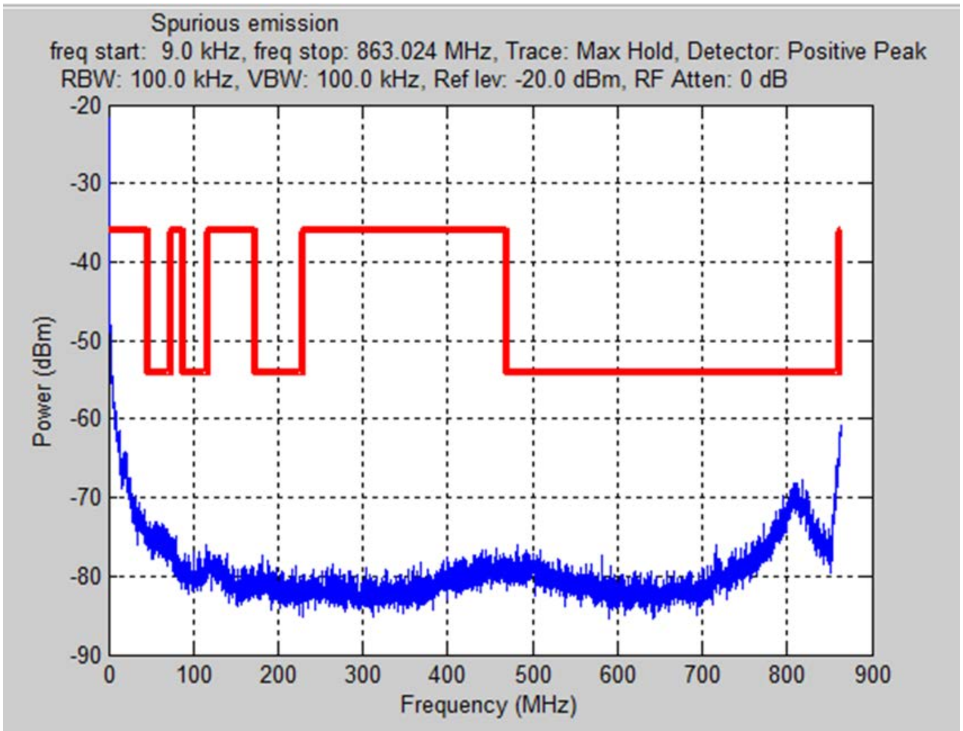

Figure 19: 125 kHz, 869.525 MHz, 27 dBm spurious emissions (conducted) below 1 GHz - 1st part

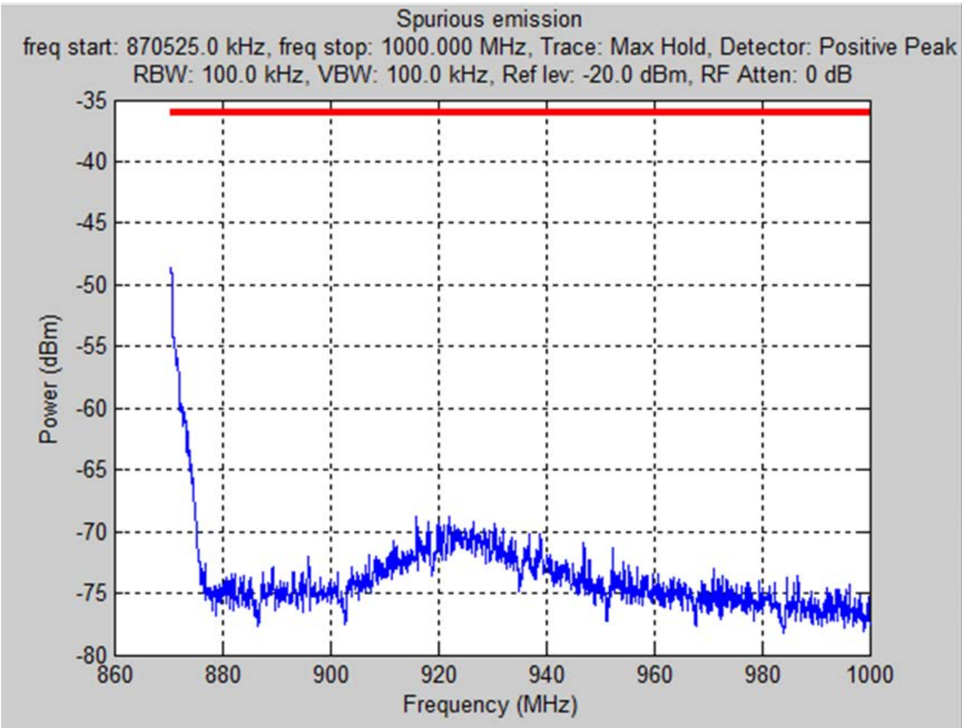

Figure 20: 125 kHz, 869.525 MHz, 27 dBm spurious emissions (conducted) below 1 GHz - 2nd part

5.2 COMPATIBILITY STUDY BETWEEN LTE AND LPWAN SYSTEMS

5.2.1 Parameters for LTE based systems

5.2.1.1 *Base station parameters*

The following parameters are used for LTE systems. The LTE parameters may differ from those provided in ECC Report 240, but take into account the amendments considered for LTE systems in order to enhance the results of the compatibility study with other services and applications within or adjacent to the band.

Table 16: LTE system parameters for BS

LTE BS parameters	Baseline value for BS
Channel bandwidth	3 MHz
Transmit Power (Report ITU-R M.2292 [6])	44 dBm/3 MHz
Antenna configuration	MIMO 2x2
Antenna gain (Report ITU-R M.2292)	15 dBi (Note 1)
Feeder Loss ECC Report 240	2 dB (Note 2)
E.i.r.p. (transmit power dBm + antenna gain dBi - feeder loss dB)	57 dBm/3 MHz (Note 3)
Antenna discrimination	3 dB
Number of resource blocks (RBs) in accordance to the channel bandwidth	6, 15 or 25 RB (1 RB = 180 kHz)
Antenna height (Report ITU-R M.2292)	30 m
Spurious power	(3GPP specification TS 36.104)
Frequency reuse factor	1
Antenna pattern/Number of sectors (Note 2)	Directional/3
Adjacent Channel Leakage Ratio (ACLR)	45 and 65 dB (Note 4)
Reference Sensitivity Quarterly Phase Shift Keying (QPSK)	-116.4 dBm
Duty cycle	100%

Note 1: Antenna gains between 6.5 to 13 dBi are considered in this Report. In ECC Report 240, 13 dBi was used, typical directive antenna (15 dBi) including cable loss (2 dB). Kathrein product datasheet (742 242) used to created SEAMCAT antenna patterns.
Note 2: Report ITU-R M.2292 defines 3 dB, but in ECC Report 240 value of 2 dB was used, since according to manufacturers it is more realistic for the 400 MHz range
Note 3: MIMO 2x2; E.i.r.p = 54 dBm + 3 dB = 57 dBm.
Note 4: Measured LTE ACLR is about 65 dB

5.2.1.2 *LTE BS emission mask*

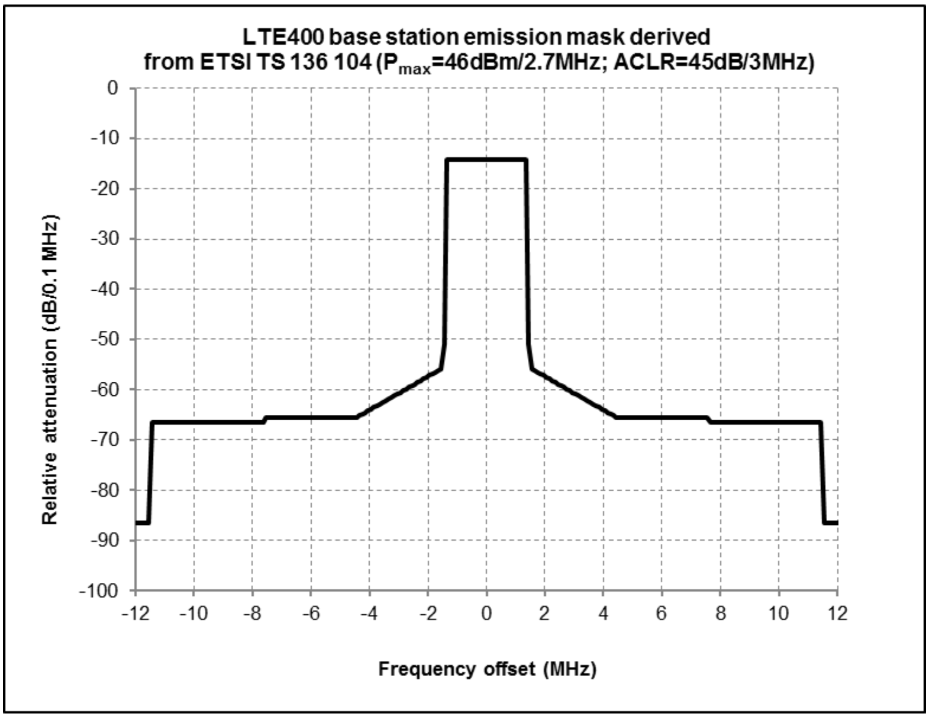

Figure 21: LTE BS emission mask

In addition to the LTE BS emission mask in Figure 21, LTE BS also needs to fulfil protection of own receiver (i.e. spurious emissions limit of -91 dBm/100 kHz for Medium Range BS and -96dBm/100 kHz for Wide Area BS – see section 6.6.4.2 in ETSI TS 136 104 V13.5.0 [13]).

5.2.1.3 *LTE BS receiver selectivity*

Figure 22: LTE BS receiver selectivity

See ETSI TS 136 104 [13], Table 7.5.1-1 and Table 7.6.1.1-1.

Table 17: LTE UE parameters

LTE UE parameters	Baseline value for UE
Transmit Power (Report ITU-R M.2292 [6])	Up to 23 dBm
Antenna gain (Report ITU-R M.2292)	-3 dBi
Antenna pattern	Omni-directional
Channel bandwidth	3 MHz
Antenna height (Report ITU-R M.2292)	1.5 m
BS BW / RBs per BS	3 MHz / 15
e.i.r.p.=Power + Antenna gain	Up to 20 dBm
Body Loss (Report ITU-R M.2292)	4 dB
Wall loss (ECC Report 240)	11 dB
Wall loss standard dev. (ECC Report 240)	6 dB
Average density of active UE (UE/km^2)	Values from Table 3 of ECC Report 240 and with different activity factors and consistent with the environment considered.
Environment	Urban, urban, rural
Distribution of transmitting UE (% indoors / % outdoors) in urban scenario	25% / 75%
Spurious emissions	(Specification in ETSI TS 136 101 V14.3.0)
Adjacent Channel Leakage Ratio (ACLR)	45 dB (Note 1)
Reference Sensitivity Quarterly Phase Shift Keying (QPSK)	-98.4 dBm (see Annex 1)
Transmit power control	See Annex 5 of ECC Report 240 and Annex 6 of ECC Report 239 [7]

Note 1: It assumed a flat ACLR defined in the victim receiver bandwidth.

5.2.1.4 *LTE UE emission mask*

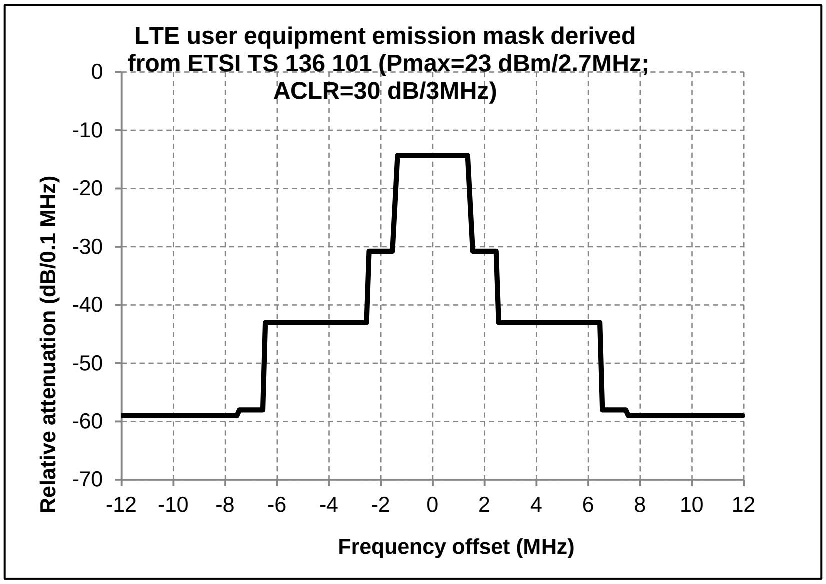

Figure 23: LTE UE emission mask

In addition to the LTE UE emission mask in the above figure, LTE UE also needs to fulfil protection of own receiver (i.e. -50dBm/1MHz).

5.2.1.5 *LTE UE selectivity*

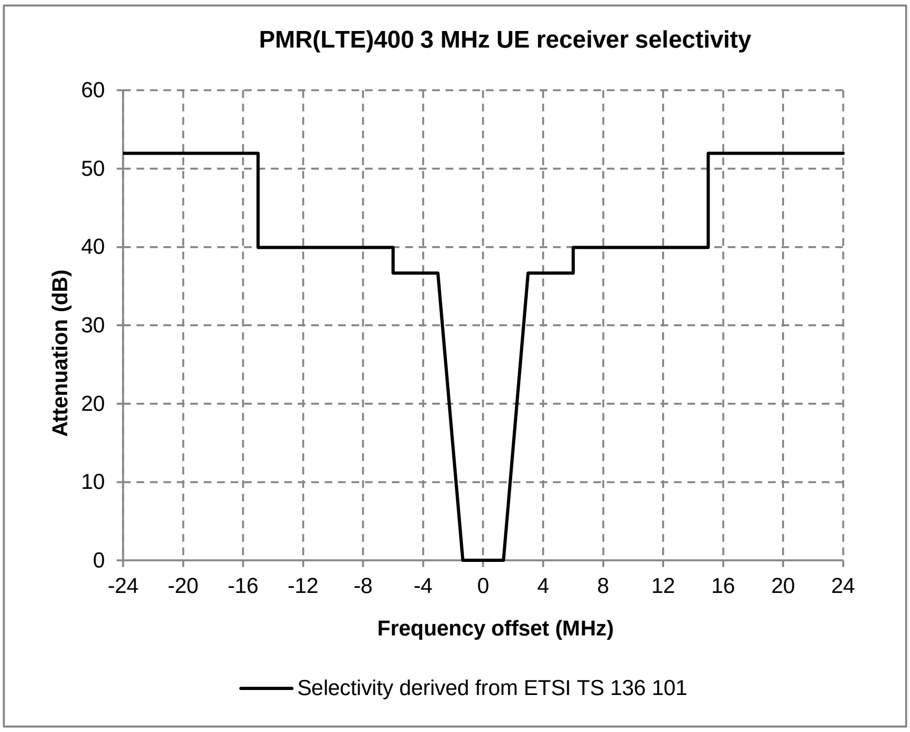

Figure 24: LTE UE selectivity

See ETSI TS 136 101[12]], Table 7.3.1-1: Reference sensitivity Quarterly Phase Shift Keying (QPSK), Tables 7.5.1-1 & 7.5.1-2,

5.2.2 Interference Scenarios

LTE system with 3 MHz bandwidth and LPWAN system with 125 kHz bandwidth. Simulations have been carried out with SEAMCAT tool in the case of adjacent channel with 200 kHz guard band.

Only adjacent channel results are presented as the co-channel case results in, as expected, an unacceptable risk of interference.

Table 18 below presents the LTE/LPWAN scenario analysed.

Table 18: Frequency scenario for LTE and LPWAN

Scenario	LTE BS Frequency	LTE Mobile station (MS) Frequency	LPWAN BS Frequency	LPWAN End Device Frequency
Adjacent channel with BS	425.5 MHz	415.5 MHz	423.7375 MHz	413.7375 MHz

Note 1: Use of 200 kHz guard band between LTE and LPWAN band edges (like standalone NB-IoT system)

This scenario is illustrated in Figure 25 below.

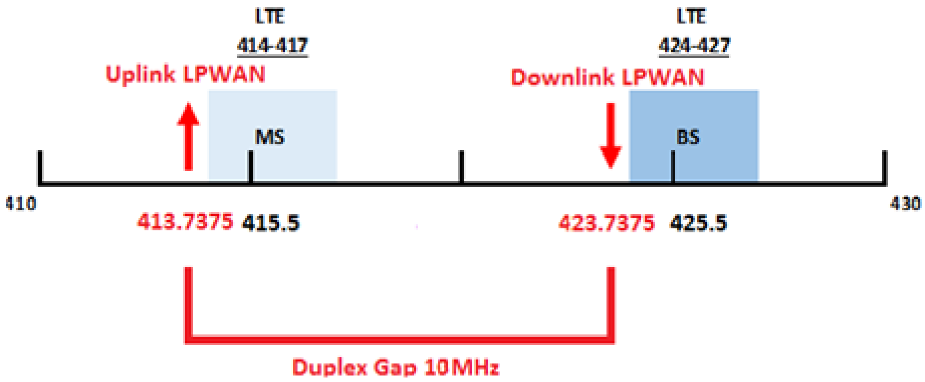

Figure 25: Adjacent channel scenarios for study with LTE

5.2.3 Result of compatibility study between LTE and LPWAN systems

The compatibility study is divided in two parts:

- The first one consists of LPWAN system as interferer and LTE system as victim, presented in Section5.2.3.1;
- The second one consists of LTE system interferer and LPWAN system as victim, presented in Section5.2.3.2.

SEAMCAT tool has been used to simulate the different scenarios. The number of events simulated is set to 50 000.

5.2.3.1 *LPWAN impact on LTE*

The case with the LTE base station in the coverage area of LPWAN base station (6.8 km radius) and the LTE base station in an area of 1 km radius around the LPWAN base station (1 km radius) is simulated. In all the cases, the urban environment it can be considered.

5.2.3.1.1 LPWAN BS impact on LTE BS

The LPWAN base station activity factor is set to 100% to simulate the most critical case. In practice, the activity factor of LPWAN base stations is lower and allows better cohabitation between the systems.

LTE and LPWAN standard technical parameters are used, as presented in section 5.1.

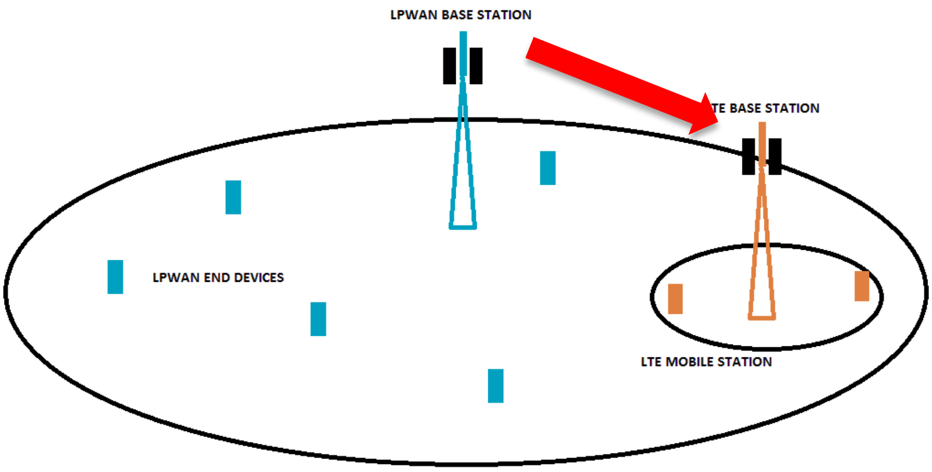

Figure 26: LPWAN BS transmitter to LTE BS receiver

Simulation radius equals to 1 km in urban environment with LPWAN BS 100% activity factor.

In this case, the LTE base station is near LPWAN base station in urban environment. A 1 km maximum separation distance is assumed. However, in the calculation, separation distances between 0 and 1 km have been taken into account.

Interference from LPWAN BS transmitter into the LTE BS receiver is evaluated.

Step 1:

Table 19: LPWAN BS transmitter to LTE BS receiver – Step 1

BS LPWAN activity factor (%)	100
Frequency offset LPWAN BS transmitter and LTE BS receiver (MHz)	**LTE Average bitrate loss (ref. Cell)**
11.7625	64.4%

One can notice that the LTE average bit rate loss is higher than the acceptable 5% threshold in the adjacent frequency cases with the LPWAN BS 100% activity factor values.

The objective is to identify the necessary improvement of the LPWAN BS ACLR which permits an LTE average throughput loss below 5%

Step 2:

Table 20: LPWAN BS transmitter to LTE BS receiver – Step 2

	LPWAN BS Transmitter ACLR Improvement	BS LPWAN activity factor 100%
Frequency offset between LPWAN BS transmitter and LTE BS receiver (MHz)		**LTE Average throughput loss (ref. Cell)**
11.7625	0	64.4
11.7625	10	33.3
11.7625	20	12.9
11.7625	30	4.95

Table 20 shows that a LPWAN ACLR improvement of 30 dB is necessary to reduce the interference on the LTE side. The additional 30 dB can be obtained with the use of a duplexer on the LPWAN BS transmitter. A reduced AF factor will also reduce the potential interference on LTE.

5.2.3.1.2 LPWAN BS impact on LTE UE

In this part, the impact of LPWAN base station transmitter on the LTE user equipment. Parameters are defined in standards [2], [12] and presented in Section 1. The simulation radius is set to 1 km in urban environment.

The activity factor of the LPWAN BS is set to 100%.

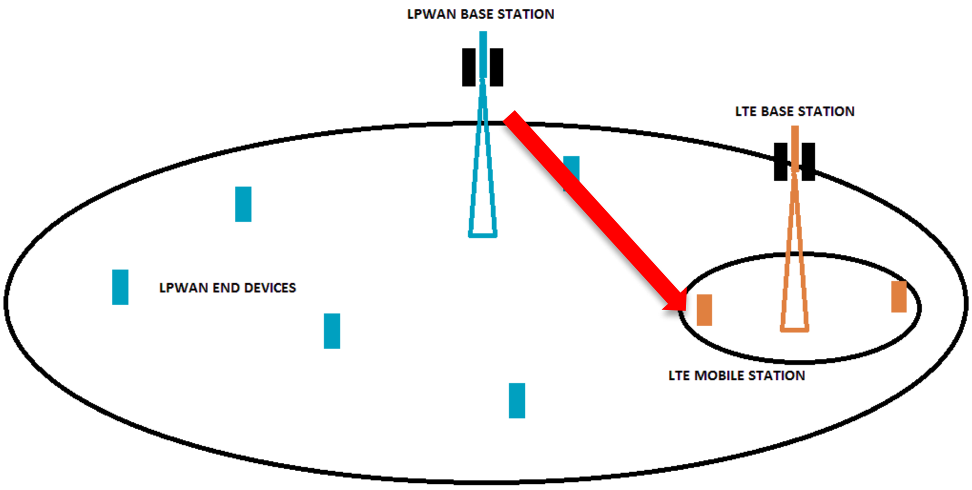

Figure 27: LPWAN BS transmitter to LTE UE

Table 21: LPWAN BS to LTE UE Simulation results

Frequency offset between LPWAN BS transmitter and LTE UE (MHz)	LTE Average bitrate loss (ref. Cell)
Adjacent with 1.7625 MHz guard band	0.788

The LTE UE average bit rate loss is less than 5% in adjacent frequency cases. The interference between LPWAN BS and LTE UE is consequently not an issue.

5.2.3.1.3 LPWAN ED impact on LTE BS

In this part, the potential impact of LPWAN end devices on LTE base station receiver is evaluated. The activity factor (AF) of the end device is set to 100%. This AF is far above the expected activity factor of real deployed networks, which is in the order of 0.1% and in general not more that 10%. It is therefore expected that real-life cohabitation would be much easier than what would be the result of the compatibility study based on 100% AF. As previously, simulation radius is set to 1 km in urban environment.

The different cases with 1 LPWAN end device are studied.

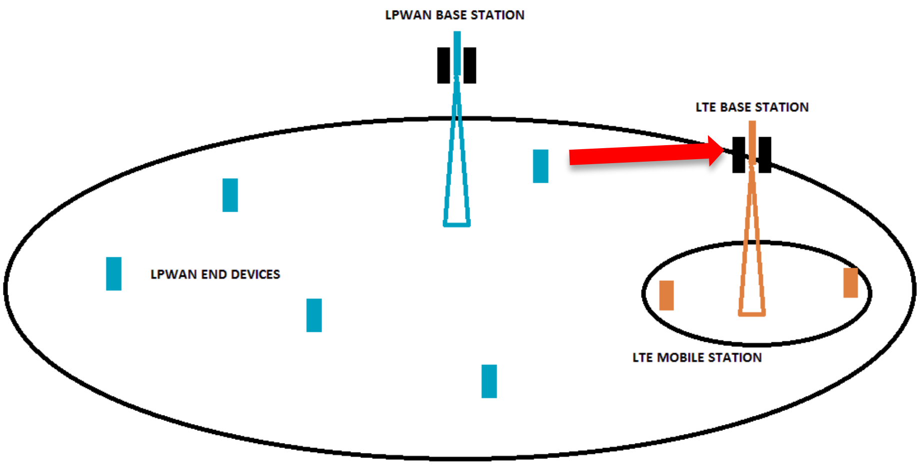

Figure 28: LPWAN ED transmitter to LTE BS receiver

Table 22: LPWAN ED to LTE BS – Simulation results

Frequency offset between LPWAN ED transmitter and LTE BS receiver (MHz)	LTE BS Average bitrate loss (ref. Cell)
1.7625	2.7

The LTE BS average bit rate loss is less than 5% in the adjacent frequency cases with one LPWAN end device.

5.2.3.1.4 LPWAN ED impact on LTE UE

In this part, the impact of one active LPWAN end device on LTE user equipment is evaluated. The activity factor of the end device is set to 100%.

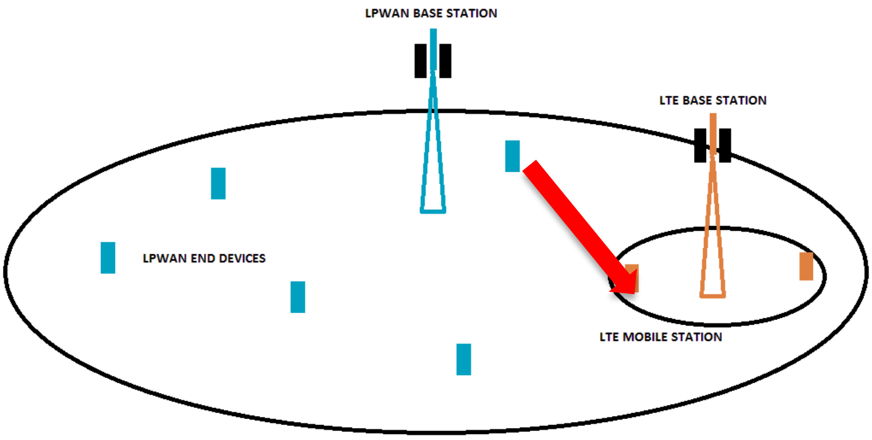

Figure 29: LPWAN ED transmitter to LTE MS receiver

Table 23: LPWAN ED to LTE UE – Case 1 simulation results

Frequency offset (MHz) between LPWAN End Device (ED) transmitter and LTE Mobile Station (MS) receiver	LTE Mobile station (MS) Average bitrate loss (ref. Cell)
-11.7625	0.005

The LTE UE average bit rate loss is less than 5% in the adjacent frequency cases with one active LPWAN end device.

5.2.3.2 *LTE impact on LPWAN*

5.2.3.2.1 LTE BS impact on LPWAN BS

In this part, LTE BS impact on LPWAN BS receiver is evaluated.

The simulation radius is set to 1 km (vicinity between LTE BS and LPWAN BS) in urban environment.

The objective is to adjust LPWAN BS receiver selectivity to obtain a maximum 10% probability of interference (PI) of LPWAN BS receiver in the adjacent frequency cases.

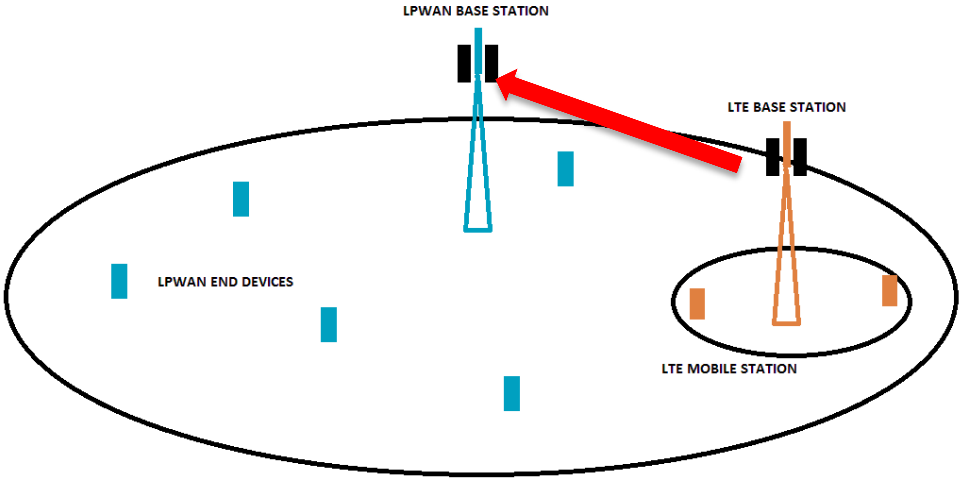

Figure 30: LTE BS transmitter to LPWAN BS receiver

Table 24: LTE BS transmitter to LPWAN BS receiver – Step 1 simulation results

Frequency offset LTE BS Transmitter and LPWAN BS receiver (MHz)	LPWAN Base station Probability of interference (%)
11.7625	67.7

Simulation results show that the interference from LTE BS to LPWAN BS is not acceptable when calculated with the LTE base station Adjacent Channel Leakage Ratio (ACLR) of 45 dB/3MHz derived from the emission mask provided in ETSI TS 136 104, where ACLR is applicable in the adjacent channel. However, ETSI TS 136 104 (see section 6.6.4.2 in V13.5.0) also defines an additional requirement for LTE BS which is protection of own receiver with spurious emissions of -91 dBm/100 kHz for a Medium Range BS and of -96 dBm/100kHz for Wide Area BS,, which corresponds to an ACLR larger than 100 dB/3MHz and is not considered in this simulation. Therefore, the LTE BS unwanted emission level is expected to be below -96 dBm/100 kHz inside and in the vicinity of the BS uplink reception band, thus much lower for the protection of the LPWAN BS than the values used this analysis.

Table 25 presents the interference probability based on the measured LTE BS ACLR of 65 dB and potential LPWAN BS receiver selectivity improvement. It should be noted that the resulting unwanted emissions from LTE BS is much higher if ACLR of 65 dB is applied compared to the case where the minimum requirements for protection of own receiver is fulfilled at the LPWAN BS reception frequency.

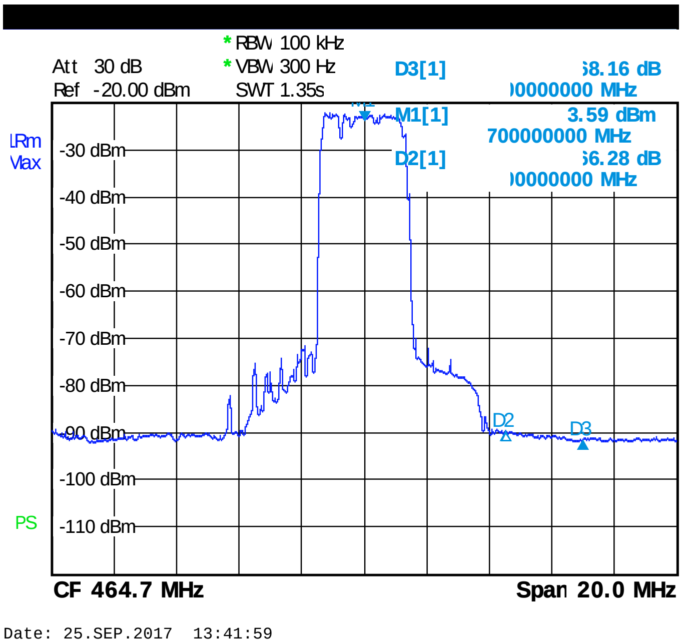

Figure 31: LTE BS transmitter over the air measurement

Table 25: Simulation results with measured LTE BS ACLR of 65 dB to LPWAN BS receiver

LPWAN BS Receiver ACS Improvement	LPWAN Base station Probability of interference (%) – Adjacent frequency with 10.2675 MHz Guard band
0	66.0
10	38.4
20	16.7
30	8.2

From Table 25 it may be noticed that the LPWAN interference probability is lower than the acceptable 10% threshold if an improvement of the LPWAN BS selectivity of 30 dB and on-the air measured LTE BS ACLR (65 dB). Thus compatibility is possible with the current LTE specifications of protection of own reception and an operation of the LPWAN BS reception in the vicinity of the LTE uplink band. An improvement of the LPWAN BS selectivity less than 30 dB would be needed with the 3GPP requirement of -96dBm/100 kHz to protect LTE BS own receiver.

5.2.3.2.2 LTE BS impact on LPWAN ED

In this part, LTE BS impact on LPWAN ED receiver is evaluated.

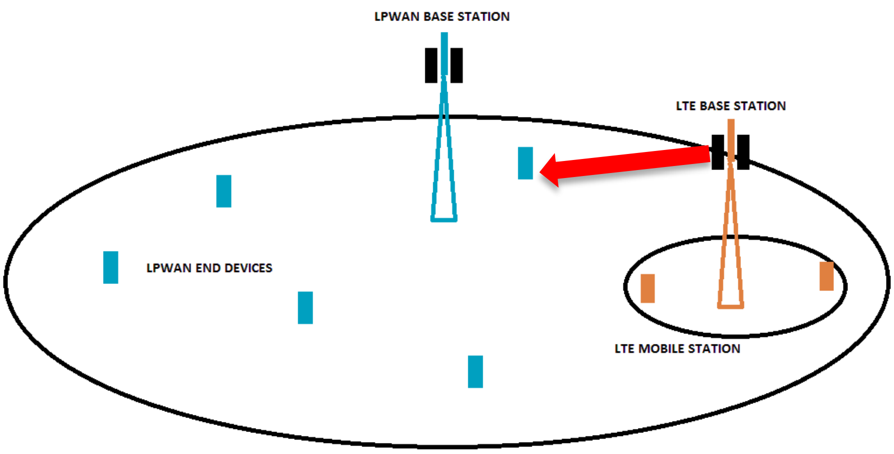

Figure 32: LTE BS transmitter to LPWAN ED receiver

Table 26: LTE BS with 3GPP Spectrum Emission Mask to LPWAN ED – Simulation results

Frequency offset between LTE BS transmitter and LPWAN ED receiver (MHZ)	Used Mask	LPWAN ED Probability of interference (%)
1.7625	LTE 3GPP mask (ACLR 45 dB/3 MHz)	12,6
1.7625	Flat LTE mask (ACLR 45 dB/3 MHz)	10,9

However, in real-life LTE BS out-of-band emission level is expected to be far better than the level defined by from the BS mask in ETSI standards as shown in Figure 31.

Table 27: LTE BS to LPWAN ED – Simulation results with measured LTE BS out-of-band emission level

Frequency offset between LTE BS transmitter and LPWAN ED receiver (MHZ)	LPWAN ED Probability of interference (%)
1.7625	8.5

The compatibility between the LTE BS and the LPWAN ED is possible in the adjacent frequency cases.

5.2.3.2.3 LTE UE impact on LPWAN BS

In this part, LTE UE impact on LPWAN BS receiver is evaluated.

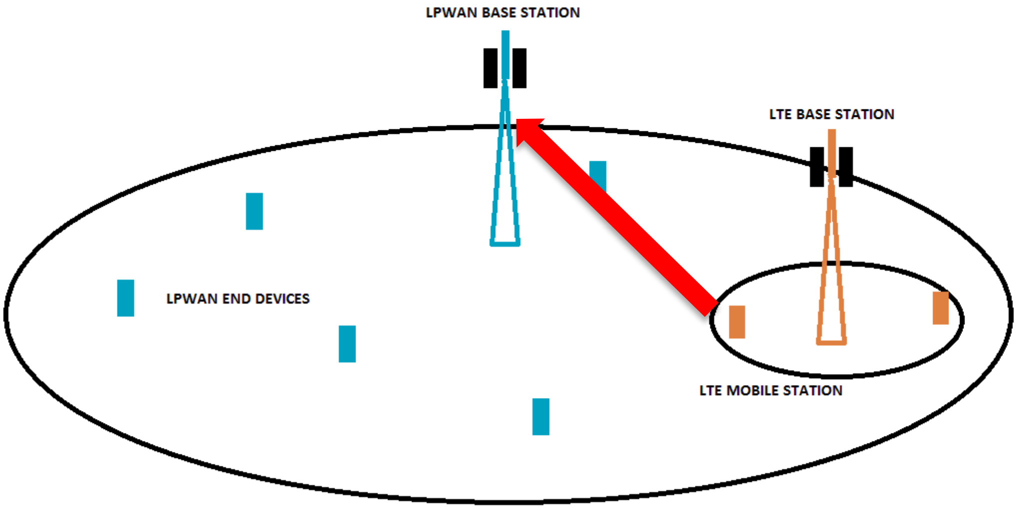

Figure 33: LTE UE transmitter to LPWAN BS receiver

Table 28: LTE UE to LPWAN BS – Simulation results

Frequency offset LTE UE transmitter and LPWAN BS receiver (MHz)	LPWAN Base station Probability of interference (%)
1.7625	5.1

The compatibility between the LTE UE and the LPWAN BS is possible in the adjacent frequency cases without any improvement of the LPWAN BS receiver technical parameters.

5.2.3.2.4 LTE UE impact on LPWAN ED

In this part, LTE UE impact on LPWAN ED receiver is evaluated.

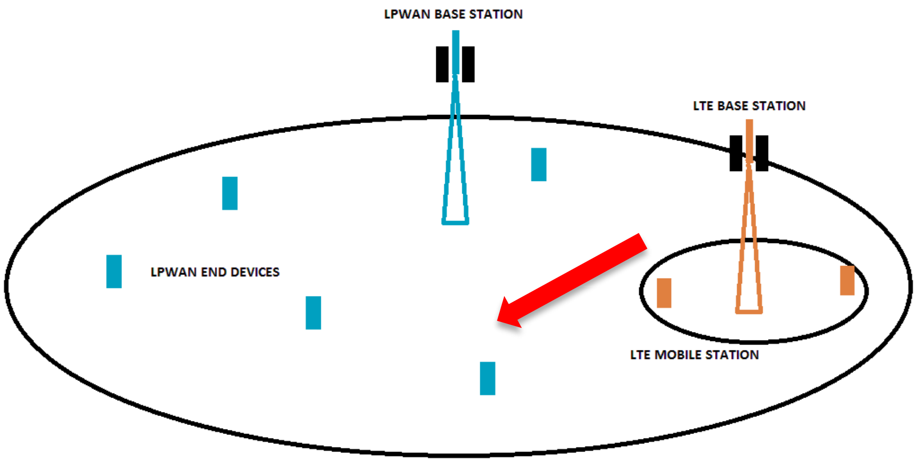

Figure 34: LTE BS transmitter to LPWAN ED receiver

Table 29: LTE Mobile station (MS) to LPWAN ED – Simulation results assuming ACLR = 45 dB

Frequency offset LTE UE transmitter and LPWAN ED receiver (MHz)	LPWAN ED Probability of interference (%)
11.7625	0.02

The compatibility between the LTE UE and the LPWAN ED is possible in the adjacent frequency cases without any improvement of the LTE UE transmitter and LPWAN ED receiver technical parameters. The studies assume LTE UE ACLR of 45 dB, while protection of own receiver will ensure a better Adjacent Channel Leakage Ratio (ACLR) value, thus a reduced interference if the LPWAN operates in the LTE uplink band or in its vicinity.

5.2.4 Conclusions

Compatibility between LTE and LPWAN systems in the 410-430MHz band:

All the initial configurations of LTE systems are based on figures in the corresponding ETSI standards TS 136 101 and TS 136 104 and the stated LPWAN system parameters. LTE parameters were considered as invariant in the simulations, except when considering LTE ACLR in adjacent channel. ACLR was based on the measured LTE signal which is 20 dB better than that derived from the transmitter mask in the ETSI standard. It should be noted that the measured ACLR in the first adjacent channel is expected to be lower than the ACLR in adjacent channels further away from the BS centre frequency. According to the ETSI standard for LTE systems, there are minimum requirements for the protection of own reception which lead to an ACLR higher than 100 dB/3MHz, that will provide lower level of unwanted emissions in the LTE BS uplink reception band and its vicinity compared to the level of unwanted emissions resulting from the measured ACLR value used in the analysis.

Amongst the simulated interference scenarios, in three cases it was necessary to improve the ACLR and the Adjacent Channel Selectivity (ACS) of LPWAN system to ensure compatibility between LTE and LPWAN systems:

- LPWAN BS impact on LTE BS
  - With the initial LPWAN base station transmitter ACLR and LTE base station receiver selectivity defined in ETSI standards, the LTE bit rate loss is higher than 5%. It is necessary to improve the LPWAN base station transmitter ACLR by 30 dB to reduce the bit rate loss below 5% in adjacent band scenario. Compatibility is not achieved in co-channel scenario.
- LTE BS impact on LPWAN BS:
  - With the initial LTE base station transmitter ACLR of 45 dB (which is applicable in adjacent channel) and LPWAN base station receiver selectivity as derived from transmitters masks defined in ETSI standards, the probability of interference is higher than 10%. Based on the measurements, it can be assumed that the LTE base station ACLR is at least 20 dB better than the value defined in ETSI standards, therefore the compatibility is ensured with an improvement of the LPWAN receiver ACS by 30 dB (PI < 10 %). Due to the protection of LTE own reception according to the minimum requirements in the ETSI standards, it is expected that the compatibility between the two systems be much better than the results presented in this analysis when the LPWAN operates in the LTE uplink band and probably in the case of operation close to it. Compatibility is not achieved in co-channel scenario.
- LTE BS Impact on LPWAN ED:
  - It may be needed to improve LTE base station ACLR of 45 dB by several dBs to ensure the compatibility in the adjacent scenario.

Concerning the LPWAN End Device, compatibility is achieved in adjacent band scenarios. Compatibility is not achieved in co-channel scenario. The results in this analysis assume an activity factor of 100% of the LPWAN BS and of LTE BS. In practice, the activity factor of LPWAN BS and LTE BS may be lower. That may reduce the potential impact of on each system on the other, thus improving the compatibility between the two systems.

5.3 COMPATIBILITY STUDY BETWEEN TETRA AND LPWAN SYSTEMS

The compatibility study is divided in two parts:

- The first one consists of LPWAN system as interferer and TETRA system as victim, presented in Section 5.3.1;
- The second one consists of TETRA system interferer and LPWAN system as victim, presented in Section 5.3.2;

- SEAMCAT tool has been used to simulate the different scenarios. The number of events simulated is set to 100 000.

5.3.1 LPWAN impact on TETRA

In this scenario the TETRA base station is in the coverage area of LPWAN base station (6.8 km radius) with a maximum separation distance of 1 km. In all the cases, the urban environment is considered.

5.3.1.1 *LPWAN BS impact on TETRA BS*

The LPWAN base station activity factor is set to 100% to simulate the most critical case. In practice, the activity factor of LPWAN base stations is lower and allows better cohabitation between the two systems.

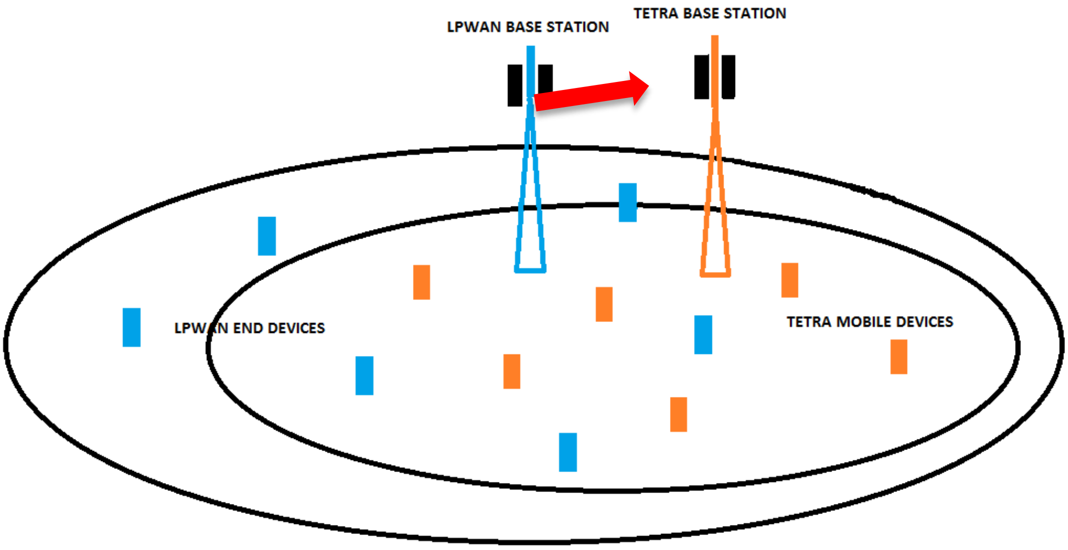

Figure 35: LPWAN BS transmitter to TETRA BS receiver

Simulation radius is equal to 1 km (maximum separation distance between the TETRA and LPWAN base stations) in urban area with LPWAN BS 100% activity factor.

The risk of interference from LPWAN BS transmitter to the TETRA BS receiver is assessed:

Table 30: LPWAN BS transmitter to TETRA BS receiver

BS LPWAN activity factor (%)	100
Frequency offset LPWAN BS transmitter and TETRA BS receiver (MHz)	**TETRA BS Interference Probability (%)**
Adjacent with 9.982MHz guard band	5.8
Adjacent with 9.882MHz guard band	5.9
Adjacent with 9.782KHz guard band	5.8
Adjacent with 9.682KHz guard band	5.9
Adjacent with 9.582KHz guard band	6
Adjacent with 9.482KHz guard band	6

Note that the TETRA average interference probability is about 6%, which is less than the acceptable 10% threshold in the adjacent frequencies with a BS LPWAN AF of 100%. Consequently, it can be concluded that the risk of interference from LPWAN BS to TETRA BS receiver is acceptable.

5.3.1.2 *LPWAN BS impact on TETRA Mobile station (MS)*

In this section, the impact of LPWAN base station transmitter on the TETRA mobile device receiver is analysed.

The simulation radius is set to 1.6 km (LPWAN cell radius – TETRA cell radius = 6.8 – 5.2 km see Figure 36). It corresponds to the worst case with:

- TETRA cell completely included in the LPWAN cell
- TETRA and LPWAN TETRA cells are edge to edge. In this case, the TETRA MS is at the maximum power and can strongly interfere with a LPWAN ED also on its cell edge.
- .The activity factor of the LPWAN base station is set to 100%.

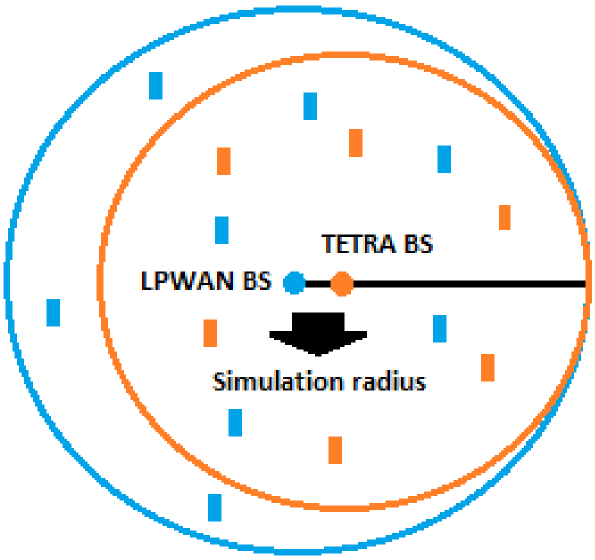

Figure 36: Simulation radius between TETRA and LPWAN base stations

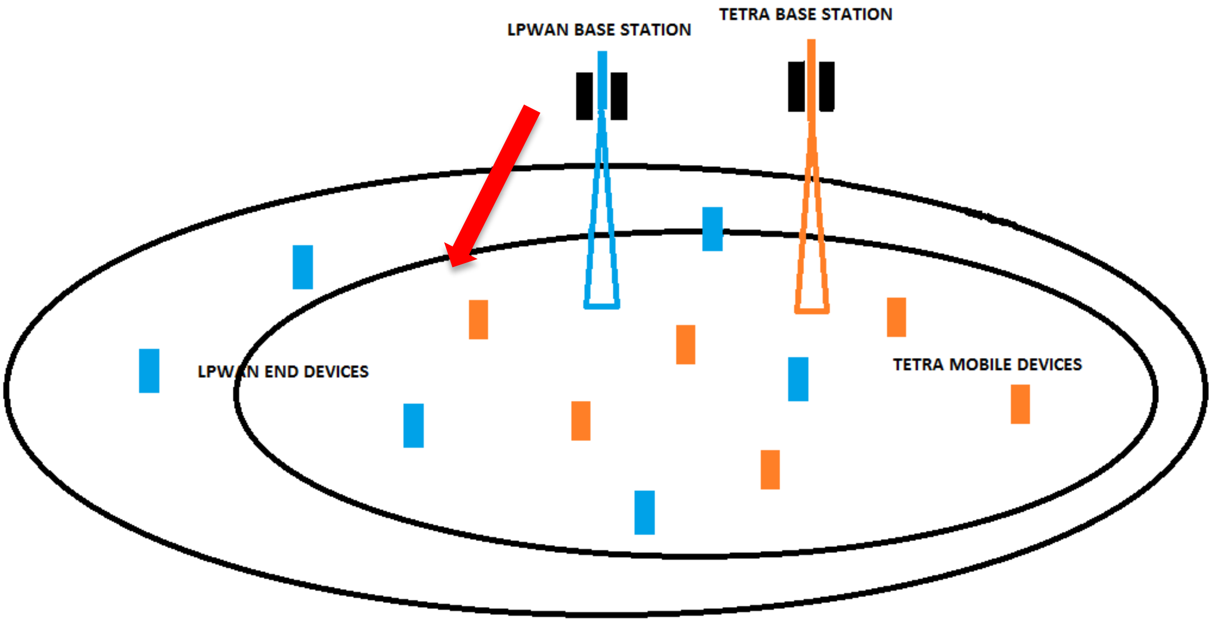

Figure 37: LPWAN BS transmitter to TETRA MS receiver

Table 31: LPWAN BS to TETRA MS Simulation results

Frequency offset between LPWAN BS transmitter and TETRA MS receiver	TETRA Mobile Device Interference probability (%)
Adjacent with 0 kHz guard band	24.4
Adjacent with 100 kHz guard band	3.2

Frequency offset between LPWAN BS transmitter and TETRA MS receiver	TETRA Mobile Device Interference probability (%)
Adjacent with 200 kHz guard band	3.2
Adjacent with 300 kHz guard band	3.2
Adjacent with 400 kHz guard band	3.2
Adjacent with 500 kHz guard band	3.2

Note that the TETRA MS average interference probability is about 3%, which is less than the acceptable 10% threshold in the adjacent frequencies. Consequently, it can be concluded that the risk of interference from LPWAN BS to TETRA MS receiver is acceptable.

Table 32: LPWAN BS to TETRA MS Simulation results

TETRA MS Interference probability (%)
34.6

When assessing the compatibility of LPWAN and TETRA systems using the same frequency, the minimum separation distance between LPWAN and TETRA bases stations is 17 km so that the TETRA mobile device Interference probability is less than 10%

5.3.1.3 *LPWAN ED impact on TETRA BS*

In this section, the potential impact of LPWAN end devices on TETRA Base station receiver is assessed. The activity factor of the end device is set to 100%: this AF is far above the expected activity factor of real deployed networks, which is in the order of 0.1% and in general not more that 10%. It is therefore expected that real-life cohabitation would be much easier than what would be the result of the compatibility based on the value of 100% for the AF. The simulation radius equals to 1.6 km in urban environment.

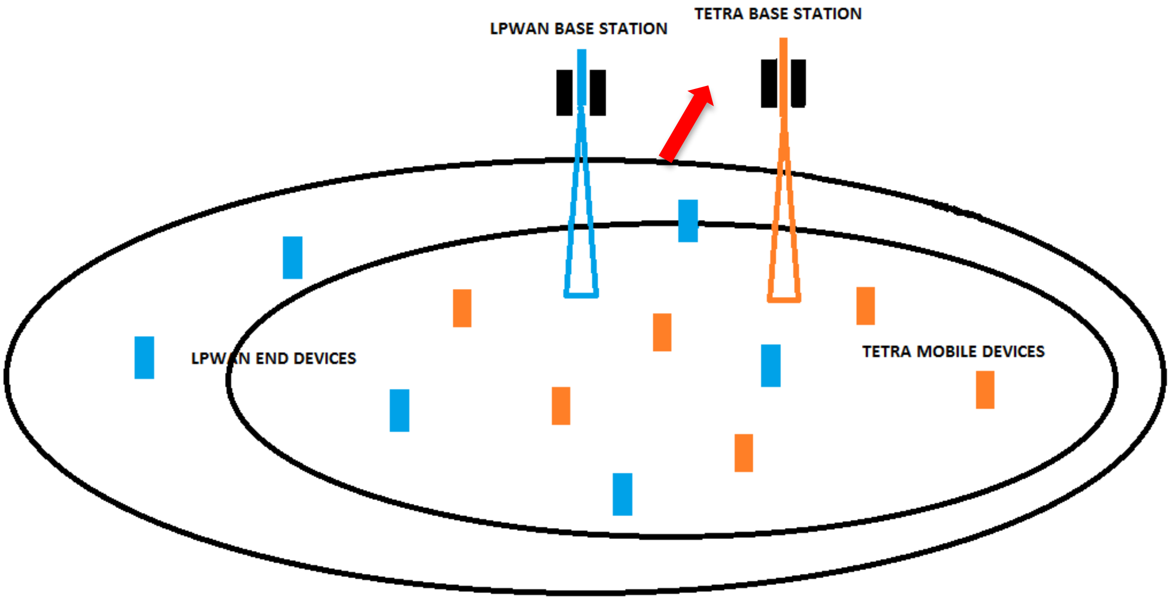

Figure 38: LPWAN ED transmitter to TETRA BS receiver

Table 33: LPWAN ED to TETRA BS – Simulation results

Frequency offset between LPWAN ED transmitter and TETRA BS receiver)	TETRA Base Station Interference probability
Adjacent with 0 kHz guard band	10.4
Adjacent with 100 kHz guard band	0.2
Adjacent with 200 kHz guard band	0.08
Adjacent with 200 kHz guard band	0.05
Adjacent with 200 kHz guard band	0.02
Adjacent with 500 kHz guard band	0.008

Note that the TETRA BS average interference probability is about 0.2%, which is less than the acceptable 10% threshold in the adjacent frequencies. Consequently, it can be concluded that the risk of interference from LPWAN ED to TETRA BS receiver is negligible.

Case of LPWAN and TETRA systems using the same frequency:

Table 34: LPWAN ED to TETRA BS Simulation results

TETRA Base Station Interference probability (%)
13.9

The minimum separation distance between LPWAN and TETRA bases stations using the same frequency is 7.5km so that the TETRA base station interference probability is less than 10%.

5.3.1.4 *LPWAN ED impact on TETRA MS*

In this section, the impact of one LPWAN end device on TETRA Mobile user equipment is assessed. The activity factor of the end device is set to 100%.

The simulation radius is equal to 1.6 km in urban environment.

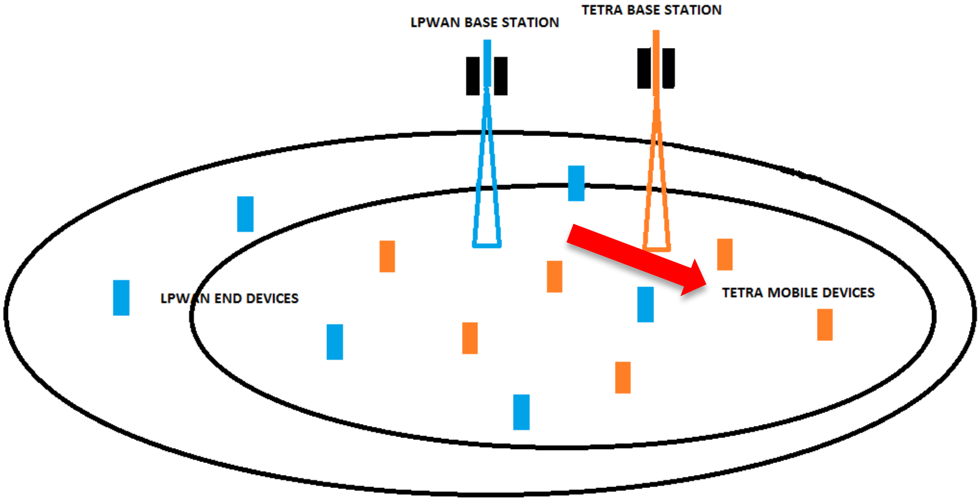

Figure 39: LPWAN ED transmitter to TETRA MS

Table 35: LPWAN ED to TETRA MS – Simulation results

Frequency offset between LPWAN ED transmitter and TETRA MS receiver (MHz)	TETRA MS Interference probability
Adjacent with 10.0 MHz guard band	0.004
Adjacent with 10.1 MHz guard band	0.003
Adjacent with 10.2 MHz guard band	0.005
Adjacent with 10.3 MHz guard band	0.003
Adjacent with 10.4 MHz guard band	0.001
Adjacent with 10.5 MHz guard band	0.004

Note that the TETRA MS average interference probability is about 0.005%, which is less than the acceptable 10% threshold in the adjacent frequencies. Consequently, it can be concluded that the risk of interference from LPWAN ED to TETRA MS receiver is negligible.

5.3.2 TETRA impact on LPWAN

5.3.2.1 *TETRA BS impact on LPWAN BS*

In this section, the TETRA BS transmitter impact on LPWAN BS receiver is assessed.

The simulation radius is equal to 1 km (vicinity between TETRA BS and LPWAN BS) in urban environment.

The objective is to obtain a maximum of 10% probability of interference (PI) of LPWAN BS receiver in the adjacent frequency cases.

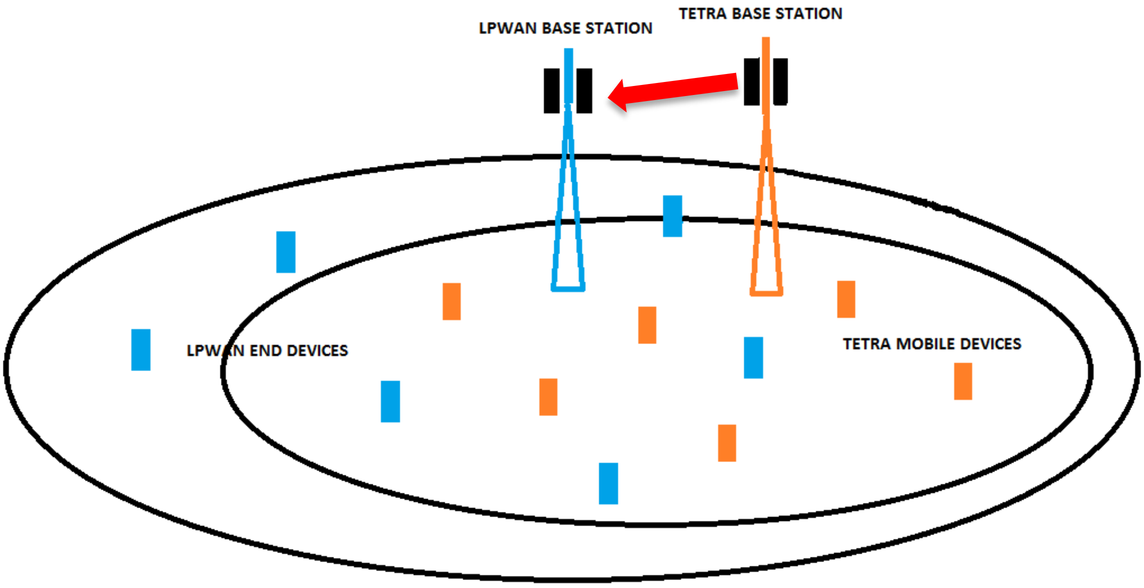

Figure 40: TETRA BS transmitter to LPWAN BS receiver

Table 36: TETRA BS transmitter to LPWAN BS receiver – Step 1 simulation results

Frequency offset TETRA BS Transmitter and LPWAN BS receiver (MHz)	LPWAN Base station Probability of interference (%)
Adjacent with 10 MHz guard band	22.8
Adjacent with 10.1 MHz guard band	22.9
Adjacent with 10.2 MHz guard band	22.7
Adjacent with 10.3 MHz guard band	22.9
Adjacent with 10.4 MHz guard band	23.1
Adjacent with 10.5 MHz guard band	22.8

Note that the LPWAN BS average interference probability is about 23%, which is higher than the acceptable 10% threshold in the adjacent frequencies. Consequently, it can be concluded that there is a risk of interference from TETRA BS to LPWAN BS receiver.

It should be observed that based on the assumptions of the analysis, the TETRA BS e.i.r.p. is 49 dBm, what is almost 15 dB more that the e.i.r.p. of the LPWAN BS. That could justify why the impact of the TETRA BS into the LPWAN system is greater than the one in the reverse way.

Additional simulations have been carried out to determine the minimum separation distance needed to ensure the compatibility of the two systems. The simulation results presented in Table 37 show that a minimum separation distance of 90 m (64 dB minimum coupling loss) between TETRA and LPWAN BS is sufficient to reduce the LPWAN BS average interference probability below 10%. This minimum separation distance can easily be achieved when deploying LPWAN networks.

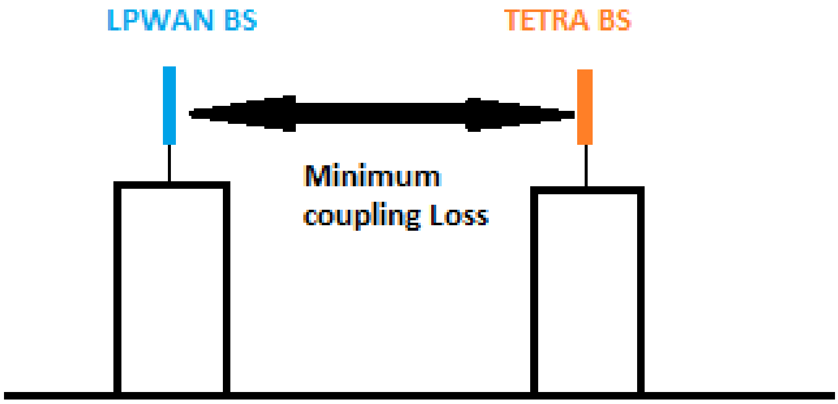

Figure 41: Minimum coupling loss between LPWAN and TETRA base stations

Table 37 TETRA BS transmitter to LPWAN BS receiver – Step 2 simulation results

Frequency offset TETRA BS Transmitter and LPWAN BS receiver (MHz) – MCL= 64 dB	LPWAN Base station Probability of interference (%)
Adjacent with 10 MHz guard band	9.8
Adjacent with 10.1 MHz guard band	9.7
Adjacent with 10.2 MHz guard band	9.9
Adjacent with 10.3 MHz guard band	9.8
Adjacent with 10.4 MHz guard band	9.9
Adjacent with 10.5 MHz guard band	9.8

5.3.2.2 *TETRA BS impact on LPWAN ED*

In this section, TETRA BS transmitter impact on LPWAN End Device receiver is assessed.

The simulation radius is equal to 1.6 km in urban environment.

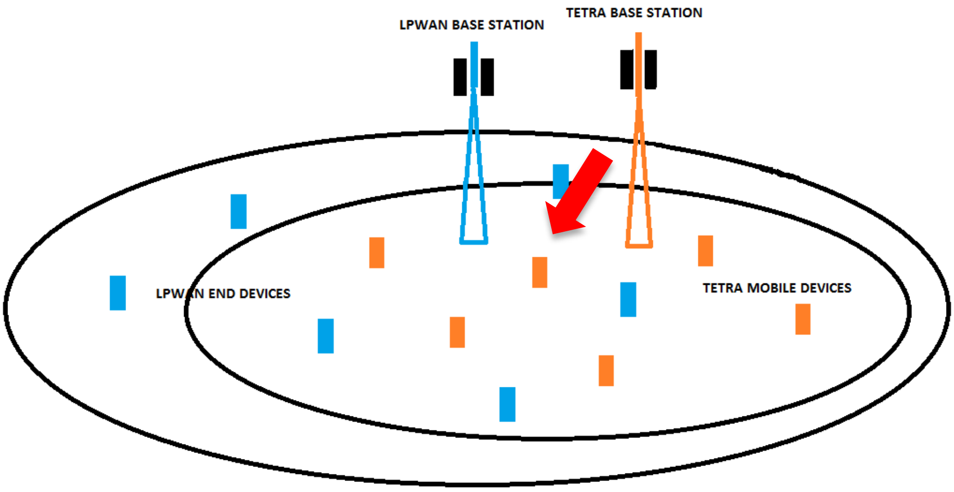

Figure 42: TETRA BS transmitter to LPWAN ED receiver

Table 38: TETRA BS to LPWAN ED – Simulation results

Frequency offset between TETRA BS transmitter and LPWAN ED receiver (MHZ)	LPWAN ED Probability of interference (%)
Adjacent with 0 kHz guard band	94.7
Adjacent with 100 kHz guard band	12.8
Adjacent with 200 kHz guard band	2.8
Adjacent with 300 kHz guard band	1.7
Adjacent with 400 kHz guard band	1.3
Adjacent with 500 kHz guard band	0.81

Note that the LPWAN ED average interference probability is about 3% with a guard band of at least 200 kHz. This Interference Probability (IP) is less than the acceptable 10% threshold in the adjacent frequencies. Consequently, it can be concluded that with a guard band of at least 200 kHz between TETRA BS to LPWAN ED the risk of interference from TETRA BS to LPWAN ED receiver is negligible.

The compatibility between the TETRA Base Station and the LPWAN End device is possible in the adjacent frequency cases with a 200 kHz minimum guard band.

Case of LPWAN and TETRA systems using the same frequency:

Table 39: TETRA BS to LPWAN ED - Simulation results

TETRA Base Station Interference probability (%)
99.2

The minimum separation distance between LPWAN and TETRA bases stations is more than 100 km so that the LPWAN End Device interference probability is less than 10%. It has not been possible to define the minimum separation distance due to Extended Hata propagation model validity maximum distance (less than 100 km).

5.3.2.3 *TETRA MS impact on LPWAN BS*

In this section, the impact of the TETRA User equipment to the LPWAN Base station receiver is assessed.

The simulation radius is equal to 1.6 km in urban area.

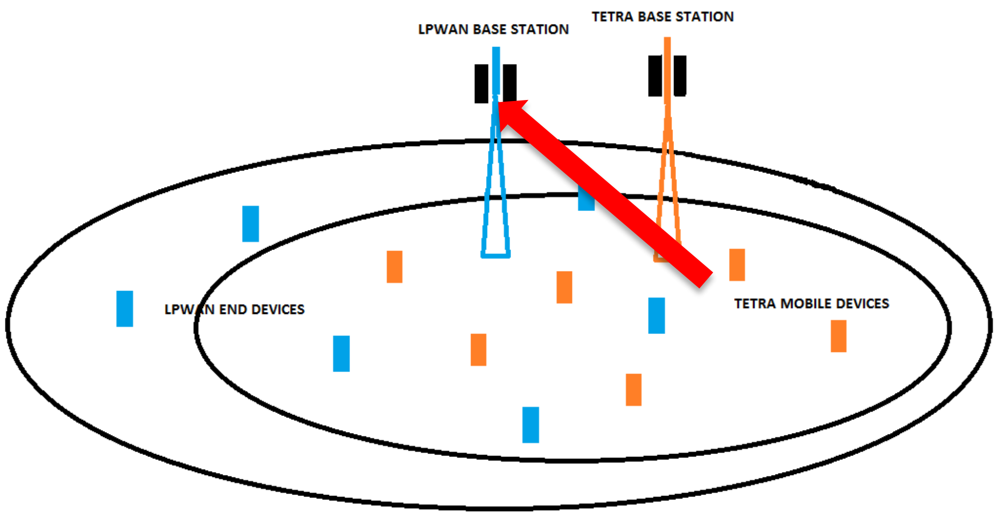

Figure 43: TETRA MS transmitter to LPWAN BS receiver

Table 40: TETRA MS to LPWAN BS – Simulation results

Frequency offset TETRA MS transmitter and LPWAN BS receiver (MHz)	LPWAN Base station Probability of interference (%)
Adjacent with 0 kHz guard band	52.1
Adjacent with 100 kHz guard band	2.7
Adjacent with 200 kHz guard band	0.35
Adjacent with 300 kHz guard band	0.15
Adjacent with 400 kHz guard band	0.1
Adjacent with 500 kHz guard band	0.05

Note that the LPWAN BS average interference probability is about 2.7%, which is less than the acceptable 10% threshold in the adjacent frequencies. Consequently, it can be concluded that the risk of interference from TETRA MS to LPWAN BS receiver is acceptable.

Case of LPWAN and TETRA systems using the same frequency:

Table 41: TETRA MS to LPWAN BS - Simulation results

TETRA Base Station Interference probability (%)
60.9

The minimum separation distance between LPWAN and TETRA bases stations is 28.5 km so that the LPWAN base station interference probability is less than 10%.

5.3.2.4 *TETRA MS impact on LPWAN ED*

In this section, TETRA MS transmitter impact on LPWAN ED receiver is assessed.

The simulation radius is equal to 1.6 km in urban area.

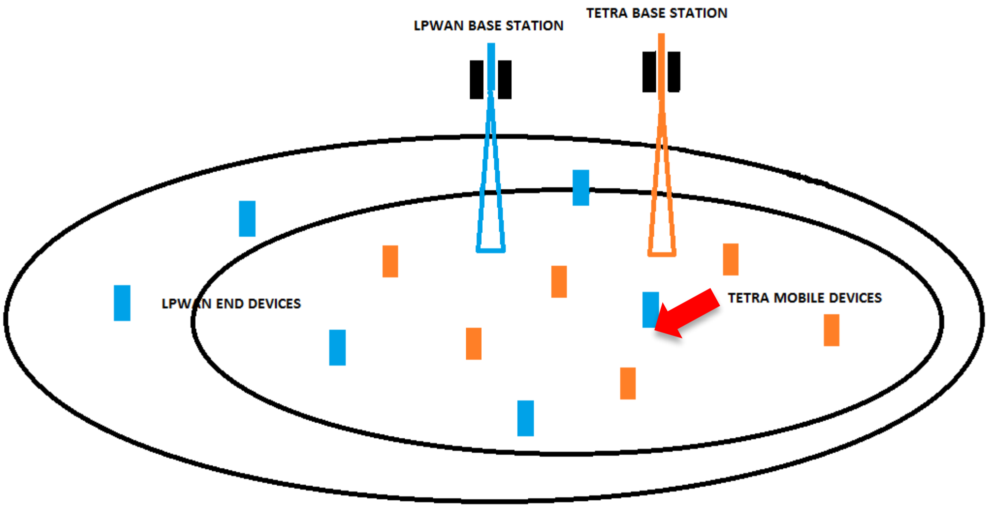

Figure 44: TETRA Mobile station (MS) transmitter to LPWAN ED receiver

Table 42: TETRA MS to LPWAN ED – Simulation results

Frequency offset TETRA MS transmitter and LPWAN ED receiver (MHz)	LPWAN ED Probability of interference (%)
Adjacent with 9.982 MHz guard band	0.001
Adjacent with 9.882 MHz guard band	0.002
Adjacent with 9.782 MHz guard band	0.001
Adjacent with 9.682 MHz guard band	0.001
Adjacent with 9.582 MHz guard band	0.002
Adjacent with 9.482 MHz guard band	0.001

Note that the LPWAN ED average interference probability is about 0.002%, which is less than the acceptable 10% threshold in the adjacent frequencies. Consequently, it can be concluded that the risk of interference from TETRA MS to LPWAN ED receiver is negligible.

5.3.3 Conclusions

The results of the Monte Carlo simulations carried out show that TETRA and LPWAN systems can cohabitate without any major difficulty in the band 410-430 MHz, if the following mitigation techniques are implemented

A guard band of 200 kHz (equivalent to 8 TETRA channels on each side of the LPWAN channel) between the TETRA and the LPWAN. This guard band is needed to minimise the interference from TETRA BS transmitter to LPWAN ED receiver.

A minimum separation distance of 90 m (64 dB minimum coupling loss) between TETRA and LPWAN BS. This minimum separation distance is needed to minimise the interference from TETRA BS transmitter to LPWAN BS receiver and can easily be achieved when deploying LPWAN networks.

It should be observed that based on the assumptions of the analysis, the TETRA BS e.i.r.p. is 49 dBm, which is almost 15 dB more that the e.i.r.p. of the LPWAN BS. That could justify why the impact of the TETRA BS into the LPWAN systems is greater than the one in the reverse way.

In the case of co-channel situation between TETRA and LPWAN systems, the minimum separation distance between base stations is more than 100 km.

5.4 COMPATIBILITY STUDY WITH RADAR SYSTEM VICTIM– LPWAN SYSTEM INTERFERER

5.4.1 The impact of LPWAN 400MHz on RLOC in the 420-450 MHz tuning range is studied with the consideration of emission from base stations (BS) and user equipment (UE).

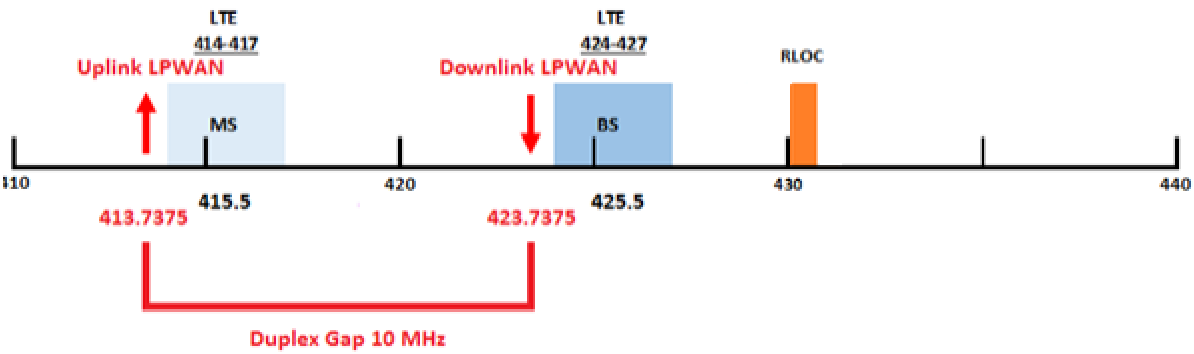

Figure 45: Frequency scenario with RLOC and LPWAN systems

In the following studies, the Radiolocation (RLOC) frequency set to 430 MHz is considered. The LPWAN system consists of uplink centred at 413.7375 MHz and downlink centred 423.7375 MHz with a 125 kHz channel bandwidth.

5.4.2 RLOC station parameters

The radar characteristics are defined in Recommendation ITU-R M.1462.

420-450 MHz is the tuning range of airborne and ground radars

Table 43: Radiolocation (RLOC) station parameter

Military Radars		
Parameters	**Airborne**	**Ground**
Blanking threshold, Bth	-108.9 dBm	-109.9 dBm
I/N	-6 dB	-6 dB
Saturation level	-15 dBm	-10 dBm
GRadar	22 dBi	38 dBi
BRadar	1 MHz	1 MHz
Polarisation	Horizontal	C
He(m)	Up to 9000 m	8 m

A LPWAN network can impact operating radars in several manners. The main cases involved are the following:

Risk of overloading;

- Risk of desensitisation in a co-channel scenario;
- Risk of desensitisation in an adjacent channel scenario (out-of-band and spurious emissions).

In the case of Airborne radar, interference criteria radar is respectively:

- For overloading: PSATURATION = -15 dBm
- For desensitisation: PDESENSITISATION = Bth + I/N = -108.9 - 6 = -114.9 dBm/MHz
- Propagation model: the free space is the most realistic model for a link between an airborne and a ground antenna.

The LPWAN Base Station uses omnidirectional antenna. The airborne antenna height is up to 9000 m. In this case, antenna discrimination between LPWAN and Radiolocation (RLOC) system is considered, $DEC_{Ant} = 22\ dB$ (measured on the PROCOM antenna model). The discrimination antenna with the polarisation discrimination antenna is not cumulated.

In the case of LPWAN End Device, discrimination between LPWAN and RLOC systems cannot be considered. The worst case with an outdoor LPWAN End Device is also considered.

In the case of Ground radar, interference criteria radar is respectively:

- for overloading: PSATURATION = -10 dBm
- for desensitisation: PDESENSITISATION = Bth + I/N = -109.9 - 6 = -115.9 dBm/MHz

Propagation model: The Free space propagation model is used.

The Low Power Wide Area Network (LPWAN) End Device and Base Station use omnidirectional antenna. The Ground radar height is 8m. In this case, no antenna discrimination between LPWAN and RLOC system is considered. $DEC_{Ant} = 0\ dB$.

The worst case with an outdoor LPWAN End Device is considered.

The polarisation of the LPWAN End Device is not considered. It is defined as the $DEC_{Pol} = 0\ dB$.

5.4.3 Minimum Coupling Loss (MCL) calculations for the different interference scenarios

Table 44 presents the calculation of the MAPL and minimum separation distance between the radar and the LPWAN ED/BS.

Table 44: MCL calculations with LPWAN ED/BS and Airborne Radar – blocking case

Victim System						
Radiolocation (RLOC) Airborne System						
		RLOC receiver				
Antenna height	m	up to 9000				
Centre frequency	MHz	430.00				
Effective bandwidth	MHz	1				
Blanking threshold, Bth	dBm	-108.90				
Antenna gain	dBi	22.00				
Cable loss	dB	0.00				
Interferer System		**Uplink**		**Downlink**		
LPWAN System		**ED -> BS**	**Link**	**BS ->ED**	**Link**	
Antenna height	m	30	BS	1.5	UE	
Centre frequency	MHz	413.7375	UE	423.7375	BS	
Effective bandwidth	MHz	0.125	UE	0.125	BS	
Transmitted Power	dBm	23	UE	30	BS	
Antenna gain	dBi	5.6	BS	-3	UE	
Cable loss	dB	2	BS	0	UE	
e.i.r.p.	dBm	20.00		33.60		
RLOC System						
DECant	**dB**	**0.00**		**22.00**		
DECpol	**dB**	**0.00**		**00.00**		
Gant	**dBi**	**22.00**		**22.00**		
Saturation level	dBm	-15.00		-15.00		
Total attenuation required	dB	57.00		48.60		
Dmin Free space propagation model	km	0.04		0.015		

The minimum separation distance between the LPWAN End Device and an Airborne Radar is 40 m.

The minimum separation distance between the LPWAN Base Station and an Airborne Radar is 15 m.

In the case of blocking, any constraint between Airborne Radar and LPWAN ED or BS is not considered.

Table 45 presents the calculation of the MAPL and minimum separation distance between the radar and the LPWAN ED/BS.

Table 45: MCL calculations with LPWAN ED/BS and Ground Radar – Overloading case

Victim System						
Radiolocation						

Victim System						
(RLOC)Ground System						
		RLOC receiver				
Antenna height	m	8				
Centre frequency	MHz	430.00				
Effective bandwidth	MHz	1				
Blanking threshold, Bth	dBm	-109.90				
Antenna gain	dBi	38.00				
Cable loss	dB	0.00				
Interferer System		**Uplink**		**Downlink**		
LPWAN System		**ED -> BS**	**Link**	**BS ->ED**	**Link**	
Antenna height	m	30	BS	1.5	UE	
Centre frequency	MHz	413.7375	UE	423.7375	BS	
Effective bandwidth	MHz	0.125	UE	0.125	BS	
Transmitted Power	dBm	23	UE	30	BS	
Antenna gain	dBi	5.6	BS	-3	UE	
Cable loss	dB	2	BS	0	UE	
e.i.r.p.	dBm	20.00		33.60		
RLOC System						
DECant	dB	0.00		0.00		
DECpol	dB	0.00		0.00		
Gant	dBi	38.00		38.00		
Saturation level	dBm	-10.00		-10.00		
Total attenuation required	dB	68.00		81.60		
Dmin Free space propagation model	km	0.14		0.66		

The minimum separation distance between the LPWAN End Device and a Ground Radar is: 0.14 km.

The minimum separation distance between the LPWAN Base Station and a Ground Radar is: 0.66 km.

Table 46 presents the calculation of the MAPL and minimum separation distance between the radar and the LPWAN ED/BS.

Table 46: MCL calculations with LPWAN ED/BS and Airborne Radar – Desensitisation in a co-channel scenario

Victim System						
RLOC Airborne System						
		RLOC receiver				
Antenna height	m	up to 9000				
centre frequency	MHz	430.00				
Effective bandwidth	MHz	1				
Blanking threshold, Bth	dBm	-108.90				
Antenna gain	dBi	22.00				
Cable loss	dB	0.00				
Interferer System		**Uplink**		**Downlink**		
LPWAN System		**ED -> BS**	**Link**	**BS ->ED**	**Link**	
Antenna height	m	30	BS	1.5	UE	
Centre frequency	MHz	413.7375	UE	423.7375	BS	
Effective bandwidth	MHz	0.125	UE	0.125	BS	
Transmitted Power	dBm	23	UE	30	BS	
Antenna gain	dBi	5.6	BS	-3	UE	
Cable loss	dB	2	BS	0	UE	
e.i.r.p.	dBm	20.00		33.60		
RLOC System						
DECant	dB	0.00		22.00		
DECpol	dB	0.00		00.00		
Gant	dBi	22.00		22.00		
Blanking threshold, Bth		-108.90		-108.90		
I/N	dBm	-6.00		-6.00		
Total attenuation required	dB	147.87		139.47		
Dmin Free space propagation model	km	1374		522		

The minimum separation distance between the LPWAN End Device and Airborne radar is: 1374 km.

The minimum separation distance between the LPWAN Base Station and Airborne radar is: 522 km.

In the case of desensitisation in a co-channel scenario, it can be concluded that the compatibility between airborne radar and LPWAN network (end device and base station) is not possible.

Table 47 presents the calculation of the MAPL and minimum separation distance between the radar and the LPWAN ED/BS.

Table 47: MCL calculations with LPWAN ED/BS and Ground Radar – Desensitisation in a co-channel scenario

Victim System						
RLOC Ground System						
		RLOC receiver				
Antenna height	m	8				
centre frequency	MHz	430.00				
Effective bandwidth	MHz	1				
Blanking threshold, Bth	dBm	-109.90				
Antenna gain	dBi	38.00				
Cable loss	dB	0.00				
Interferer System		**Uplink**		**Downlink**		
LPWAN System		**ED -> BS**	**Link**	**BS ->ED**	**Link**	
Antenna height	m	30	BS	1.5	UE	
centre frequency	MHz	413.7375	UE	423.7375	BS	
Effective bandwidth	MHz	0.125	UE	0.125	BS	
Transmitted Power	dBm	23	UE	30	BS	
Antenna gain	dBi	5.6	BS	-3	UE	
Cable loss	dB	2	BS	0	UE	
e.i.r.p.	dBm	20.00		33.60		
RLOC System						
DECant	dB	0.00		0.00		
DECpol	dB	0.00		0.00		
Gant	dBi	38.00		38.00		
Blanking threshold, Bth		-109.90		-109.90		
I/N	dBm	-6.00		-6.00		
Total attenuation required	dB	164.87		178.47		
Dmin Free space propagation model	km	9730		46560		

The minimum separation distance between the LPWAN End Device and a Ground Radar is: 9730 km.

The minimum separation distance between the LPWAN Base Station and a Ground Radar is: 46560 km.

In the case of desensitisation in a co-channel scenario, it can be concluded that the compatibility between ground radar and LPWAN network (end device and base station) is not possible.

Table 48 presents the calculation of the MAPL and minimum separation distance between the radar and the LPWAN ED/BS.

Table 48: MCL calculations with LPWAN ED/BS and Airborne Radar – Desensitisation in an adjacent channel scenario

Victim System						
RLOC Airborne System						
		RLOC receiver				
Antenna height	m	up to 9000				
centre frequency	MHz	430.00				
Effective bandwidth	MHz	1				
Blanking threshold, Bth	dBm	-108.90				
Antenna gain	dBi	22.00				
Cable loss	dB	0.00				
Interferer System		**Uplink**		**Downlink**		
LPWAN System		**ED -> BS**	**Link**	**BS ->ED**	**Link**	
Antenna height	m	30	BS	1.5	UE	
centre frequency	MHz	413.7375	UE	423.7375	BS	
Effective bandwidth	MHz	0.125	UE	0.125	BS	
Transmitted Power	dBm	23	UE	30	BS	
Antenna gain	dBi	5.6	BS	-3	UE	
Cable loss	dB	2	BS	0	UE	
e.i.r.p.	dBm	20.00		33.60		
Spurious emission level (100 kHz)	dBm	-75.00		-75.00		
Spurious emission level (1 MHz)	dBm	-65.00		-65.00		
Spurious emission level (1 MHz) with 20 dB minimum duplex or attenuation	dBm	-85.00		-85.00		
e.i.r.p. spurious level (1 MHz)	dBm	-88.00		-81.40		
RLOC System						
DECant	dB	0.00		22.00		
DECpol	dB	0.00		00.00		
Gant	dBi	22.00		22.00		
Blanking threshold, Bth		-108.90		-108.90		
I/N	dBm	-6.00		-6.00		
Desensitisation threshold	dBm	-114.90		-114.90		
Total attenuation required	dB	48.90		33.50		
Dmin Free space propagation model	km	0.015		0.0025		

The LPWAN ED and BS spurious emission are based on the measurement presented in Figure 37.

The minimum separation distance between the LPWAN End Device and Airborne radar is: 0.015 km.

The minimum separation distance between the LPWAN Base Station and Airborne radar is less than 3 m.

In the case of desensitisation in adjacent channel scenario, it can be concluded that the compatibility between airborne radar and LPWAN network (end device and base station) is possible without limitation.

Table 49 presents the calculation of the MAPL and minimum separation distance between the radar and the LPWAN ED/BS.

Table 49: MCL calculations with LPWAN ED/BS and Ground Radar – Desensitisation in an adjacent channel scenario

Victim System						
RLOC Ground System						
		RLOC receiver				
Antenna height	m	8				
Centre frequency	MHz	430.00				
Effective bandwidth	MHz	1				
Blanking threshold, Bth	dBm	-109.90				
Antenna gain	dBi	38.00				
Cable loss	dB	0.00				
Interferer System		**Uplink**		**Downlink**		
LPWAN System		**ED -> BS**	**Link**	**BS ->ED**	**Link**	
Antenna height	m	30	BS	1.5	UE	
Centre frequency	MHz	413.7375	UE	423.7375	BS	
Effective bandwidth	MHz	0.125	UE	0.125	BS	
Transmitted power	dBm	23	UE	30	BS	
Antenna gain	dBi	5.6	BS	-3	UE	
Cable loss	dB	2	BS	0	UE	
e.i.r.p.	dBm	20.00		33.60		
Spurious emission level (100 kHz)	dBm	-75.00		-75.00		
Spurious emission level (1 MHz)	dBm	-65.00		-65.00		
Spurious emission level (1 MHz) with 20 dB minimum duplex or attenuation	dBm	-85.00		-85.00		
e.i.r.p. spurious level (1 MHz)	dBm	-88.00		-81.40		

Victim System						
RLOC System						
DECant	dB	0.00		0.00		
DECpol	dB	0.00		0.00		
Gant	dBi	38.00		38.00		
Blanking threshold, Bth		-109.90		-109.90		
I/N	dBm	-6.00		-6.00		
Desensitisation threshold	dBm	-115.90		-115.90		
Total attenuation required	dB	65.90		72.50		
Dmin Free space propagation model	km	0.110		0.232		

The LPWAN ED and BS spurious emission are based on the measurement presented in Figure 37.

The minimum separation distance between the LPWAN End Device and a Ground Radar is: 0.11 km.

The minimum separation distance between the LPWAN Base Station and a Ground Radar is: 0.232 km.

5.4.4 Conclusions

With the RLOC frequency set to 430 MHz and the LPWAN system using the uplink frequency of 413.7375 MHz and downlink frequency of 423.7375 MHz with a 125 kHz channel bandwidth, the minimum separation distances needed to ensure the protection of RLOC are presented in Table 46.

Table 50: LPWAN and RLOC minimum separation distances

Separation Distance between Radars and LPWAN system (km)		Blocking	Desensitisation Co-channel (km)	Desensitisation Adjacent channel (km)
Airborne Radar	LPWAN ED	0.04	1374	0.015
	LPWAN BS	0.015	522	0.0025
Ground Radar	LPWAN ED	0.14	9730	0.110
	LPWAN BS	0.66	46560	0.232

For Airborne

The results of the compatibility studies carried out show that the compatibility between LPWAN system and Airborne radar is possible in the case of adjacent channel scenario with a minimum separation distance of:

- 40 m between the LPWAN End Devices and Airborne;
- 15 m between the LPWAN Base Station and Airborne.

The compatibility between LPWAN system and Ground radar is possible in the case of adjacent channel scenario with a minimum separation distance (due to blocking) of:

- 140 m between the LPWAN End Devices and ground radar;

- 660 m between the LPWAN Base Station and ground radar.

The compatibility between LPWAN system and airborne radar is not possible in co-channel case.

The compatibility between LPWAN system and ground radar is not possible in co-channel case.

5.5 COMPATIBILITY STUDY WITH RADIOASTRONOMY SYSTEM VICTIM – LPWAN SYSTEM INTERFERER

5.5.1 The impact of LPWAN 400 in the band 410-430 MHz on RAS in the band 406.1-410 MHz is studied with the consideration of emissions from base stations (BS) and user equipment (UE)

Recommendation ITU-R RA.769-2 [17] defines threshold levels of -203 dBW (or -173 dBm) for interference detrimental to the RAS for the band 406.1- 410 MHz.

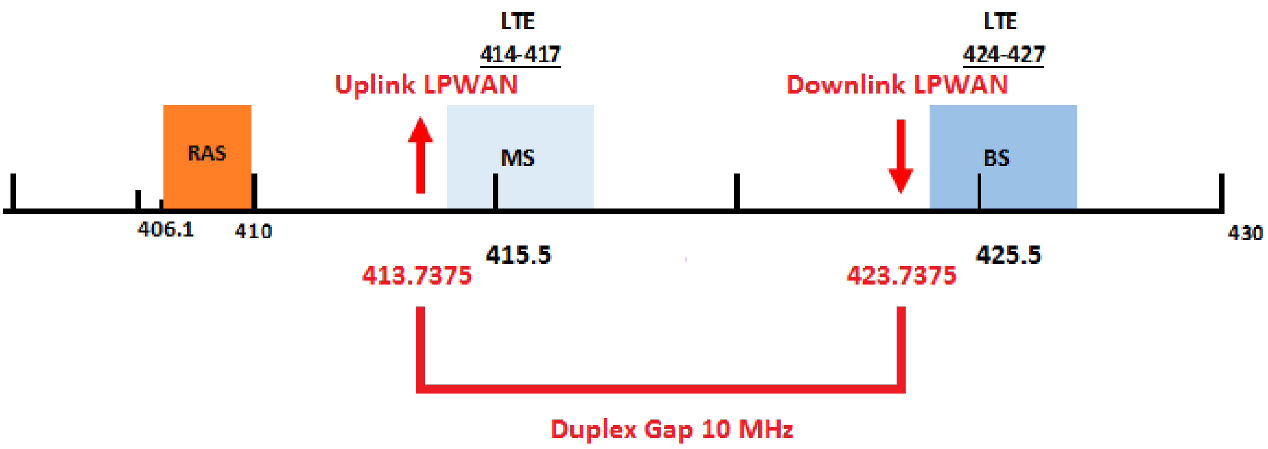

Figure 46: Frequency scenario with RAS and LPWAN systems

Table 51: RAS station parameters

Centre frequency	408 MHz
Bandwidth	3.9 MHz
RAS protection level (in 406.1-410 MHz band)	-173 dBm
Antenna gain	0 dBi
Height	50 m

5.5.2 Propagation model parameters

For the analysis, the propagation model P.452-16, including smooth earth diffraction, troposcatter, and ground clutter attenuations were used. The atmospheric attenuation was assumed to be 0.0 dB/km.

5.5.3 Results

Table 52: MCL calculations with LPWAN ED/BS and RAS system

Victim System						
RAS System						
		RAS receiver				
Antenna height	m	50				
Centre frequency	MHz	408.00				
Effective bandwidth	MHz	3,9				
Receiver protection level	dBm	-173.00				
Antenna gain	dBi	0.00				
Cable loss	dB	0.00				
Interferer System		**Uplink**		**Downlink**		
LPWAN System		**ED -> BS**	**Link**	**BS ->ED**	**Link**	
Antenna height	m	30	BS	1.5	UE	
Centre frequency	MHz	413.7375	UE	423.7375	BS	
Effective bandwidth	MHz	0.125	UE	0.125	BS	
Transmitted power	dBm	23	UE	30	BS	
Antenna gain	dBi	5,6	BS	-3	UE	
Cable loss	dB	2	BS	0	UE	
e.i.r.p.	dBm	20.00		33.60		
Spurious emission level (RBW 100 kHz)	dBm	-64.00		-75.00		SRdoc_TR103 526V1.1.1[54]
Spurious emission level (RBW 3.9 MHz)	dBm	-48.09		-59.09		
Spurious emission level (RBW 3.9 MHz) with 20 dB minimum duplex or attenuation	dBm	-68.09		-79.09		
e.i.r.p. spurious level (RBW 3.9 MHz)	dBm	-71.09		-75.49		
RAS System						
Acceptable I level (3.9 MHz)	dBm	-173.00		-173.00		
Total attenuation required	dB	101.91		97.51		
Dmin ITU-R P.452-16	km	3.05		4.40		

* This value is the calculated average emission of the LPWAN ED in the RAS frequency band.

5.5.4 Conclusions

Separation distance between LPWAN Base Station and RAS:

- The frequency separation between the LPWAN base station and the RAS is 13.7375 (edge to edge). In this case, the emission in the spurious domain is selected;

- The Minimum Coupling Loss (MCL) calculation provides a required minimum path loss equal to 97.51 dB. Using ITU-R Recommendation P.452 propagation model, the calculated separation distance is 4.4 km.

Separation distance between LPWAN End Device and RAS:

- The frequency separation between the LPWAN end device and the RAS is 3.7375 (edge to edge). In this case, the emission in the spurious domain is selected;
- The required minimum path loss is equal to 101.91 dB. Using ITU-R Recommendation P.452 propagation model;
- The calculated separation distance is 3.05 km.

6 LTE IMPACT ON DTT ABOVE 470 MHZ

6.1 INTRODUCTION

The adjacent band compatibility between Long-term Evolution (LTE) systems operating in the band 450-470 MHz with DTT services operating in the broadcast band 470-694 MHz is considered in this Report. Indeed, both BS and UE may create interference into DTT receivers and LTE receivers may be subject to interference from DTT transmitters. The cases of interference from LTE BS and UE into DTT and from DTT to LTE receivers has been previously evaluated and has been presented in ECC Report 240 for the scenario where the band 450-470 MHz was used for LTE-based BB-PPDR. Whilst the results presented in ECC Report 240 remain applicable, this new study considers a new set of systems and parameters, applicable to new use cases involving PMR/PAMR, MFCN and M2M/IoT, which differ from those of LTE-based BB-PPDR considered in ECC Report 240.

For the purpose of this study, the use of the band 450-470 MHz is aligned with 3GPP Band 31, that is the LTE uplink band which starts at 452.5 MHz and the downlink band which starts at 462.5 MHz, as shown in Figure 47.

452.5	457.5	462.5		470
Uplink		Downlink		DTT

Figure 47: Illustrative frequency allocation of the 450-470 MHz

Note: an alternative bandplan would be based on 3GPP Band 72, which was developed for PPDR and PMR use in Europe. Band 72 is defined as 451-456MHz UL, 461-466MHz DL. This gives an additional 1.5 MHz frequency separation with the DTT allocation

The two main methods used for assessing compatibility in the studies are:

- Minimum Coupling Loss (MCL);
- Monte Carlo (MC).

Minimum Coupling Loss (MCL) - this method of calculation, is based on a static geometry and parameters between the interfering and the wanted systems and as such provides an upper bound to the level of expected interference. Generally interference may be lower in systems where the level of interference varies with time, such as with LTE UE because of Transmit Power Control (TPC) mechanism and the fact they move and transmit in an intermittent manner. In such cases a statistical approach, a Monte Carlo simulation, may provide a better indication of likely interference.

Monte Carlo (MC) - to account for the varying nature of interference this method of calculation is used to provide an indication of the probability that a receiver may be subject to interference. The MC calculations as performed are typically only relevant for one moment in time, which whilst useful for understanding loss of data throughput in for example an LTE system, do not characterise the interference that a DTT viewer may experience whilst watching television over a period of time. For this further calculations have been performed to give an indication of probability of interference in a given time interval (see ERC Report 101.)

As indicated in ECC Report 240 (section 3.5.1.3), the Monte Carlo simulation method was originally used to determine the OOBE emission limits of LTE800 base stations in the UHF broadcasting band. The method is described in detail in Annex 4 of ECC Report 240.

Also according to ECC Report 240, several different Monte Carlo simulation methods have previously been used to determine the OOBE emission limits of LTE800 and LTE700 User equipment. Studies conducted in ITU-R/JTG 4-5-6-7 as well as in CPG/PTD have already recognized the need to include time-domain considerations in addition to interference probability (IP) calculations when assessing the interference into the broadcasting service from International Mobile Telecommunications (IMT) UE. The studies in this Report attempt to address this need by including time-domain considerations.

6.2 SUMMARY OF RESULTS FROM ECC REPORT 240

6.2.1 LTE BS impact on DTT

6.2.1.1 *Fixed DTT Reception*

Studies on the protection of DTT above 470 MHz from LTE BS in the band 450-470 MHz were carried out in ECC Report 240 section 3.5.3.1 (Minimum Coupling Loss) and 3.5.1.4 (Monte Carlo).

Especially for the Monte Carlo simulations the interference probability is likely to be different. However, using the same method of interpreting the results, the same conclusion can be drawn.

In particular, the following text, quoted from the executive summary of ECC Report 240 related to PPDR base station impact on DTT above 470 MHz, applies to LTE base station impact on DTT above 470 MHz:

"The results of the theoretical co-existence analyses with DTT demonstrate interferences from the PPDR LTE400 system to DTT reception when the PPDR system is adjacent in the frequency domain to the lower DTT Channel, i.e. Channel 21. Nevertheless, the risk of interference can be reduced by at a set of technical measures including a guard band of up to 3 MHz between DTT and PPDR BSs and an appropriate limit of the corresponding PPDR BS out-of-band emissions. Furthermore additional mitigation measures may be required to solve possible residual interference from PPDR BSs on a case by case basis in a manner similar to the situation between LTE800 and DTT".

LTE BS Out-of-Band Emissions (OOBE)e.i.r.p. levels for protection of DTT above 470 MHz are given in table below.

Table 53: LTE BS OOBE e.i.r.p. levels for protection of DTT above 470 MHz

Frequency range	Condition on Base station in-block e.i.r.p, P (dBm/cell)	Maximum mean OOBE e.i.r.p (dBm/cell)	Measurement bandwidth
For DTT frequencies above 470 MHz where broadcasting is protected	P ≥ 60	-7	8 MHz
	P < 60	P – 67	8 MHz

See ANNEX 6: for a list of possible mitigation techniques (list of mitigation measures).

6.2.1.2 *Portable DTT Reception*

Studies carried out for compatibility between LTE800 and portable DTT reception concluded that portable DTT reception is less susceptible to interference from base stations[7]. Additional studies are not required. If fixed DTT reception is protected from base station interference, portable DTT reception is automatically protected.

6.2.2 LTE UE impact on DTT

ECC Report 240 considered a LTE UE unwanted emission level of -42 dBm/8MHz, this level was initially agreed for allowing coexistence with DTT below 694 MHz with UE transmitting above 703 MHz. Furthermore, ECC Report 240 concluded that Monte-Carlo simulations demonstrated limited probability of interference into to DTT reception for high power UE (37 dBm) with improved Adjacent Channel Leakage Ratio (ACLR) (79 dB, i.e. OOBE of -42 dBm / 8 MHz) in Channel 21.

[7] See "A2.4. Conclusion" of Annex 2 of CEPT Report 30

6.3 MCL ANALYSIS ON THE IMPACT OF LTE UE OOBE LEVEL TO FIXED AND PORTABLE DTT RECEPTION

6.3.1 Out-of-Band Emissions (OOBE) limits (fixed DTT reception)

The UE out-of-band emissions level necessary to limit the increase in interference to 1dB to a TV receiver using a fixed rooftop antenna from interference from a UE located outdoors is calculated in the following chapters using an MCL analysis.

In some studies, the effect of body loss was taken into account for the LTE UE by an additional attenuation of 4 dB (taken from Report ITU-R M.2292 [6]), in order to simulate e.g. handheld devices (mobile terminals). In other studies, this effect was not applied in order to simulate devices not used very close to the human body, e.g. Wi-Fi Routers or nomadic installations.

6.3.1.1 *Assumptions (fixed DTT reception)*

The following assumptions have been used in the analysis of the out-of-band emissions level needed to protect fixed DTT reception.

Table 54: TV receiver parameters

TV Receiver		
Parameter	**Value**	**Unit**
Noise figure	6	dB
Noise equivalent bandwidth	7.6	MHz
Antenna gain (including feeder loss)	9.15	dBi
Antenna height	10	m
Antenna pattern	See pattern below	

Note that the same directional pattern is used both in azimuth and elevation, i.e., the curves represent gθ,(TV)(δθ) or gφ,(TV)(δφ) where δθ and δϕ are azimuth and elevation offsets from bore sight.

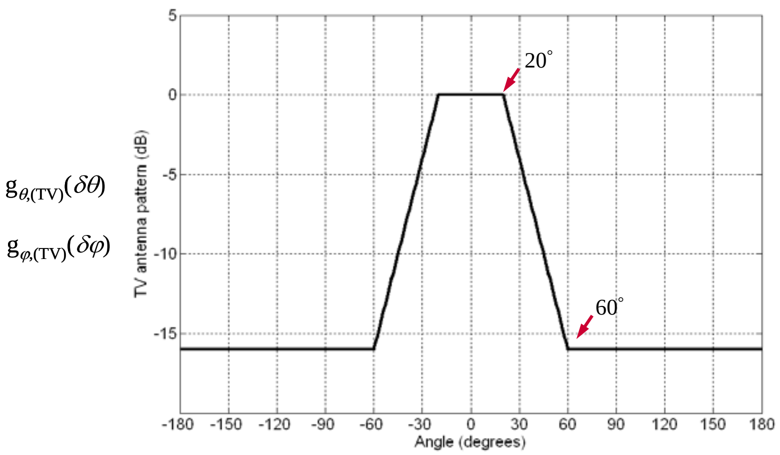

Figure 48: TV receiver antenna pattern

Table 55: LTE UE transmitter parameters

UE Transmitter		
Parameter	**Value**	**Unit**
e.i.r.p. (max)	23	dBm/(5 MHz)
Antenna height	1.5	m
Antenna pattern	Omni-directional	

Table 56: General parameters

UE Transmitter		
Parameter	**Value**	**Unit**
Frequency	455	MHz

In some studies, the effect of body loss was taken into account for the LTE UE by an additional attenuation of 4 dB, in order to simulate e.g. handheld devices (mobile terminals). In other studies, this effect was not applied in order to simulate devices not used very close to the human body, e.g. broadband wireless terminals and mobile TV receivers.

6.3.1.2 *Methodology*

A MCL analysis is used for evaluating the impact of adjacent-channel interference from UEs to DTT receivers. The situation is considered where the DTT signal is received at the reference sensitivity level, the Worst-case separation distance between the TV antenna and the UE is established, accounting for both the path-loss and the elevation pattern of a typical TV antenna, and the out-of-band emissions level which would result in a 1 dB desensitisation of the TV receiver is then evaluated.

It is assumed that the TV antenna is roof mounted (at a height of 10 m) and that the UE is outdoors (at a height of 1.5 m).

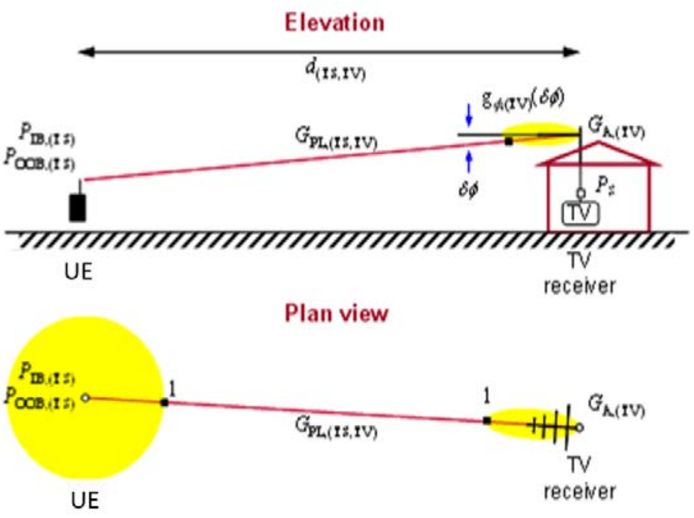

Figure 49: Overview of the MCL analysis

6.3.1.3 *Worst-case UE to TV antenna horizontal separation distance*

The worst-case UE to TV antenna horizontal separation distance is established by considering both the path-loss between the UE and the TV antenna and the elevation pattern of the TV antenna.

For the path-loss the free-space model is used together with the TV antenna elevation pattern from Recommendation ITU-R BT.419-3 [18], see below.

The path gain between the UE and the TV receiver is calculated as follows:

$$G_{PG,(UE,TV)} = G_{PL,(UE,TV)} + G_{A,(TV)} + g_{\varphi,(TV)}\delta\phi$$

where:

- $G_{PG,(UE,TV)}$ = Path gain (dB), between UE and TV receiver;
- $G_{PL,(UE,TV)}$ = Path-loss (dB), calculated using the free-space model;
- $G_{A,(TV)}$ = TV antenna bore-sight gain (dB), including cable losses (9.15 dB);
- $g_{\varphi,(TV)}\delta\varphi$ = TV antenna elevation gain (dB).

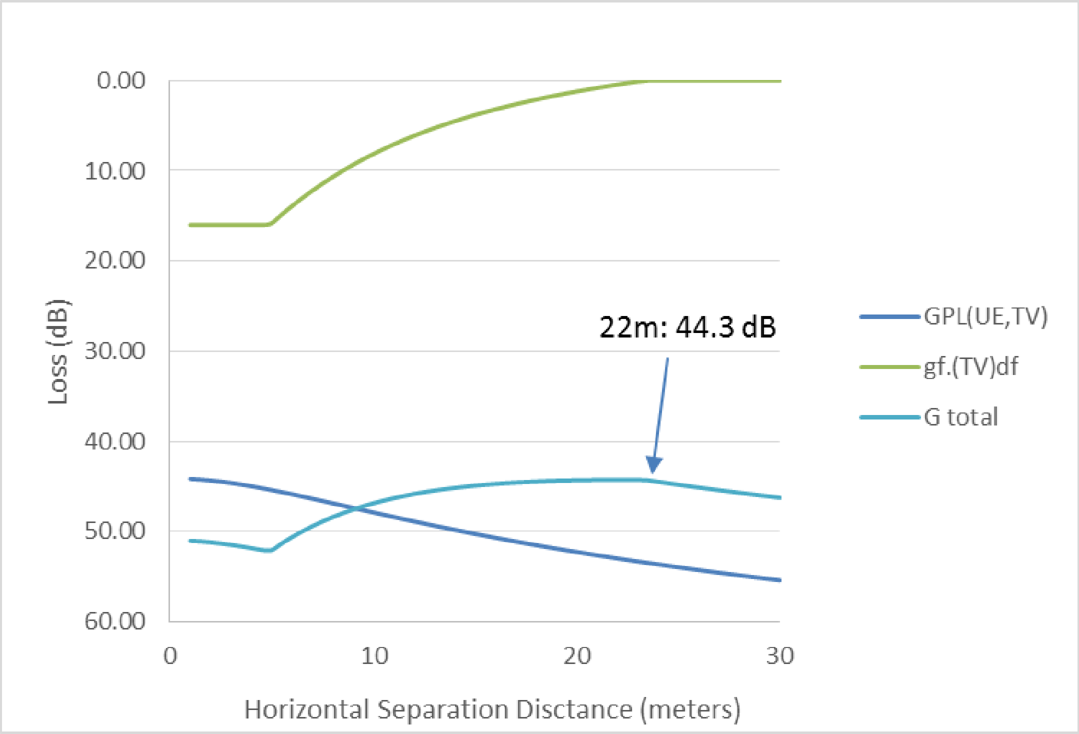

Figure 50: Path loss of the MCL analysis

As it can be seen, the worst-case occurs at a horizontal separation distance of 22 m, where the total coupling gain between the UE and the TV receiver is 44.3 dB.

6.3.1.4 *OOBE calculations*

Having established the total path gain for the worst-case horizontal separation between the UE and TV antenna, the out-of-band emissions needed to meet the 1 dB desensitisation criteria is calculated.

The noise power (PN) at the TV receiver is given by:

$$P_N = 10\log_{10}(kTB) + NF = -99.17 dBm/(8MHz)$$

where:

- k = Boltzmann's constant
- T = Temperature (290 K)
- B = Noise equivalent bandwidth of the TV receiver (7.6 MHz)
- NF = DVB-T2 receiver noise figure (6 dB)

For a 1 dB desensitisation, the target interference level is:

$$P_I = P_N - 5.87 = -105.04\ dBm/(8\ MHz)$$

The interference power in the TV receiver adjacent channel is calculated from a combination of the UE in-block power (23 dBm) and the total path gain (including 4 dB body loss at the UE) at the worst-case distance as follows:

$$P_{AC} = P_{UE,IB} + G_{PG,(UE,TV)} + G_{BL} = 23.0 + (-44.26) + (-4.0) = -25.26\ dBm$$

From the above the Adjacent channel interference ratio (ACIR) can be established as follows:

$$ACIR = P_{AC} / P_I \geq -25.26 - (-105.04) = 79.78\ dB$$

Without body loss (e.g. for a broadband wireless internet terminal) this would be 83.74 dB.

ACIR is related to the adjacent channel selectivity (ACS) of the victim and to the adjacent-channel interference ratio (ACLR) of the interferer via the following expression (linear units):

$$ACLR^{-1} = ACIR^{-1} - ACS^{-1}$$

Adjacent Channel Selectivity (ACS) of the DTT receiver without additional filter is 70 dB.

However, with an assumption about reasonable improvement in TV receiver ACS by means of additional external filtering in the antenna down lead it can be concluded that an ACS figure of 80 dB or better is achievable. Also measurement as reported in ECC Report 240 showed that 80 dB is achievable with current receiver design.

Thus for the purposes of this calculation an ACS value of 80 dB has been used.

$$ACLR = 10\log_{10}\left(1 \Big/ \left(\frac{1}{10^{79.78/10}} - \frac{1}{10^{80/10}}\right)\right) = 92.84\ dB$$

Thus for a UE transmitting at 23 dBm e.i.r.p. the out-of-band emissions will be:

$$23 - 92.84 = -69.84\ dBm/(8\ MHz)$$

This value can be rounded to -70 dBm /8 MHz. This means that an LTE user equipment BEM out-of-band emissions limit of -70 dBm/(8 MHz) for frequencies below 790 MHz is necessary to protect fixed DTT reception.

The following Table 57 summarises the above calculation:

Table 57: Summary of the calculations

Parameter	Unit	Value	Comment
Frequency	MHz	450	F_0

Receiver NF	dB	6.00	NF
Thermal Noise floor (8 MHz)	dBm	-99.19	P_n= 10 log(kTB) + NF + 30
In-block transmit power	dBm	23.00	P_{Tx}
Interferer antenna gain	dBi	0.00	G_{Tx}
e.i.r.p.	dBm	23.00	P(e.i.r.p.) = R_{Tx} + G_{Tx}
Rx Tx horizontal distance	M	22	d_h worst case separation
Tx height	M	1.5	h_{Tx}
Rx height	M	10	h_{Rx}
Path distance	M	23.6	$D=sqrt(dh^2+(h_{Rx}-h_{Tx})^2)$
Free space propagation	dB	52.96	L_{FS}
Rx antenna elevation discrimination	dB	0.45	G_{Dir}
Rx antenna bore-sight gain	dB	9.15	G_{Rx}
Body loss	dB	4	L_{Body}
Wall loss	dB	0	L_{Wall}
Total coupling gain	dB	48.25	$G_{tot} = -L_{FS}+G_{Dir}+G_{Rx}-L_{Body}-L_{Wall}$
I/N	dB	-5.87	
Receiver desensitisation (C/N degradation)	dB	1.00	$D=10log(1+10^{(I/N)/10})$
Adjacent Channel Selectivity (ACS)	dB	70.00	
Additional filtering	dB	10	
Total ACS	dB	80.00	
Adjacent Channel Interference Ratio (ACIR)	dB	79.78	
Interference power	dBm	-105.04	$P_I=P_n+I/N$
Adjacent Channel Leakage Ratio (ACLR)	dB	92.84	
OOBE (Tx)	dBm/8 MHz	-69.84	$OOBE=P_{Tx}-ACLR$

6.3.2 OOBE limits (portable DTT reception)

The UE out-of-band emissions level necessary to protect portable TV reception from interference from a UE is calculated in the chapters below using MCL analysis.

6.3.2.1 *Assumptions (portable DTT reception)*

Table 58: TV receiver parameters

TV Receiver		
Parameter	**Value**	**Unit**
Noise figure	6	dB

TV Receiver		
Noise equivalent bandwidth	7.6	MHz
Antenna gain (including feeder loss)	2.15	dBi
Antenna height	1.5	m
Antenna pattern	Omni-directional	

Table 59: UE transmitter parameters

UE Transmitter		
Parameter	**Value**	**Unit**
e.i.r.p. (max)	23	dBm/(5 MHz)
Antenna height	1.5	M
Antenna pattern	Omni-directional	

Table 60: General parameters

General		
Parameter	**Value**	**Unit**
Frequency	455	MHz
Wall loss (from Recommendation ITU-R P.1812)	10.4	dB

6.3.2.2 *Methodology*

An MCL analysis is used for evaluating the impact of adjacent-channel interference from UEs to DTT receivers. The situation is considered where the DTT signal is received at the reference sensitivity level. The victim TV antenna and the interfering UE are assumed to be in the same building. Some of the MCL calculations assume that they are separated by one internal wall. It can be argued that if the victim and interferer are in the same room then the users of both devices can negotiate a local solution in case of interference, e.g. one of them can move to increase the distance between the victim and interferer, or, if necessary, move to another room. For various assumed values of the UE out-of-band emissions level, the separation distance needed to meet the 1 dB desensitisation criteria is evaluated (taking account of the wall loss). A value for the out-of-band emissions level is then chosen which balances the need to minimise the separation distance and be achievable in a realistic terminal design.

6.3.2.3 *OOBE calculations*

The out-of-band emissions are calculated as follows.

The noise power (PN) at the TV receiver is given by:

$$P_N = 10\log_{10}(kTB) + NF = 99.17\ dBm/(8\ MHz)$$

where:

- k = Boltzmann's constant
- T = Temperature (290 K)

- B = Noise equivalent bandwidth of the TV receiver (7.6 dB)
- Noise Figure (NF) = TV receiver noise figure (6 dB)

For a 1 dB desensitisation, the target interference level (P_I) is:

$$P_I = P_N - 5.87 = -105.04\, dBm/(8\, MHz)$$

The interference power at the source UE (PI,(UE)) is a combination of the UE in-block power (PIB,(UE) = 23 dBm) the Adjacent Channel Selectivity (ACS) of the victim TV receiver and out-of-band emission power of the UE (POOB,(UE)) within the victim receivers channel as follows:

$$P_{I,(UE)} = 10\log_{10}\left(10^{\left(P_{IB,(UE)} - ACS\right)/10} + 10^{P_{OOB,(UE)}/10}\right)$$

For the purposes of this calculation a minimum achievable ACS value of 85 dB has been assumed. This takes into account that an ACS is achievable with current receiver design as shown in ECC Report 240 and some rejection in the TV receiver antenna.

Results have also been calculated for an ACS value of 100 dB to demonstrate the impact of additional rejection filters at the portable TV receiver.

The minimum allowed coupling gain between the interfering UE and the victim TV is therefore the difference between the target interference power (PI) and the interference power at the source UE (PI,(UE)).

$$G_{CG} = P_I - P_{I,(UE)}$$

The total path gain between the interfering UE and the victim TV (GPG,(UE,TV)) is given by the allowed coupling gain GCG minus the wall loss (GWL = -10.4 dB) minus the body loss at the UE (GBL = -4 dB) minus the TV antenna gain (GA,(TV) = 2.15 dBi).

$$G_{PG,(TV,UE)} = G_{CG} - G_{WL} - G_{BL} - G_{A,(TV)}$$

From the total path gain, it is possible to calculate the minimum separation distance needed to meet the 1 dB desensitisation criteria using the free-space path-loss model.

6.3.2.4 *Results*

As indicated above, for various assumed values of the UE out-of-band emissions level, the separation distance needed to meet the 1 dB desensitisation criteria has been evaluated. Results have been obtained for assumed TV ACS values of both 85 dB and 100 dB to assess the impact of rejection filters at the portable TV receiver.

Figure 51 below illustrates the relationship between separation distance and out-of-band emissions. The lower blue curve takes into account -10.4 dB wall loss whereas the upper pink curve does not.

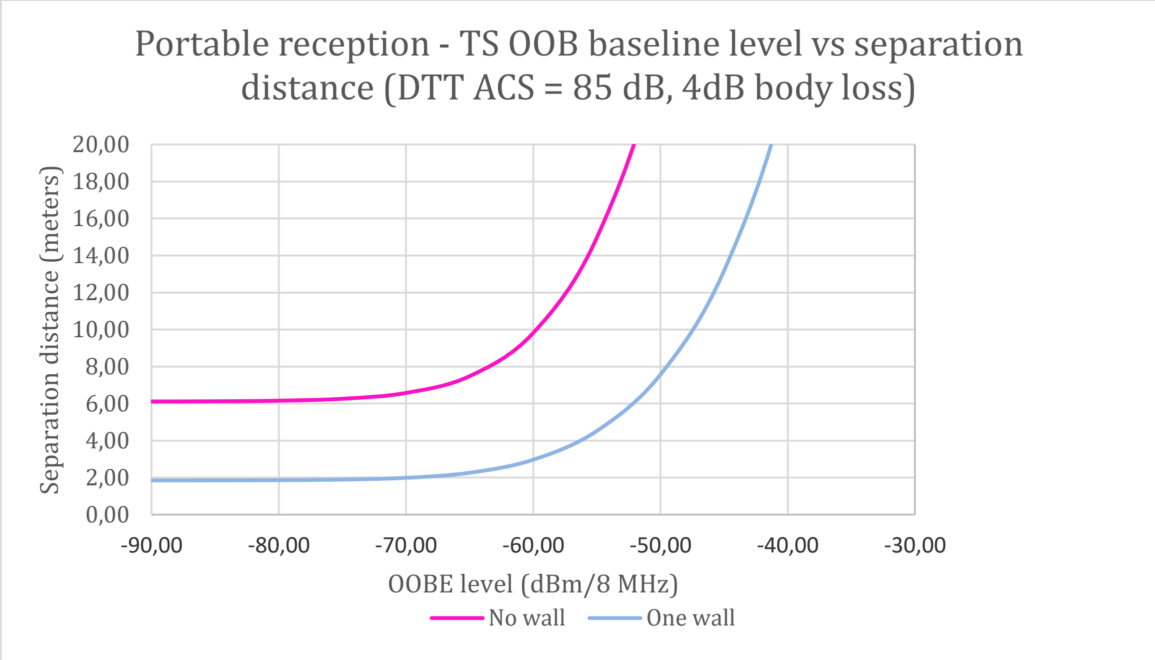

Figure 51: Relationship between separation distance and OOB emissions

As can be seen, the curves have essentially flattened out for a out-of-band emissions level of -75 dBm/(8 MHz) and below i.e. for out-of-band emissions levels lower that -75 dBm/(8 MHz) there is minimal improvement in separation distance. From this it is concluded a UE out-of-band emission level of -75 dBm/(8 MHz) is optimal.

The following Table 61 summarises the calculation of separation distance for the situation where the assumed TV receiver ACS is 85 dB and the out-of-band emissions is set to -75 dBm/(8 MHz) for the various combinations of wall loss and body loss.

Table 61: Calculation of separation distances for ACS = 85 dB

Parameter	Unit	Value	Value	Value	Value	Comment
Frequency	MHz	455	455	455	455	F0
Target performance						
Receiver Noise Figure (NF)	dB	6.00	6.00	6.00	6.00	NF
Thermal Noise floor (9 MHz)	dBm	-99.17	-99.17	-99.17	-99.17	P_n= 10 log(kTB) + NF + 30
Interference-to-Noise Ratio (INR)	dB	-6.00	-6.00	-6.00	-6.00	INR
Target interference power	dBm	-105.17	-105.17	-105.17	-105.17	$P_{Itarget}$= P_n + INR
Victim's performance						
Receiver selectivity (ACS)	dB	85.00	85.00	85.00	85.00	
BEM limits						
In-block transmit power	dBm/ 10MHz	23.00	23.00	23.00	23.00	$P_{ib,tr}$
Interferer antenna gain	dBi	0.00	0.00	0.00	0.00	Ga,i

e.i.r.p.	dBm/ 10MHz	23.00	23.00	23.00	23.00	P_{ib}
Out-of-block	dBm/ 8MHz	-75.00	-75.00	-75.00	-75.00	P_{oob}
"Total" interference at "source"	dBm	-61.79	-61.79	-61.79	-61.79	Linear: $P_x = P_{ib}/ACS + P_{oob}$, where $P_{Itarget} = G\ P_x$
Adjacent Channel Interference Ratio (ACIR) calculation						
Adjacent Channel Leakage Ratio (ACLR)	dB	98.00	98.00	98.00	98.00	P_{ib} - P_{oob}
ACIR	dB	98.21	98.21	98.21	98.21	Linear = 1/((1/ACLR) + (1/ACS))
Coupling calculation						
Coupling gain	dB	-43.48	-43.48	-43.48	-43.48	Linear: $G = P_{Itarget} - P_x$
Link budget						
Interferer body gain	dB	-4.00	-4.00	0.00	0.00	$G_{b,I}$
Wall gain	dB	-10.40	0.00	-10.40	0.00	G_{Wl}
Victim body gain	dB	0.00	0.00	0.00	0.00	$G_{b,v}$
Victim ant. Elevation pattern	dB	0.00	0.00	0.00	0.00	$g_{b,v}$ (assumed zero)
Victim antenna gain	dB	2.15	2.15	2.15	2.15	$G_{a,v}$
Path gain	dB	-31.13	-41.53	-35.13	-45.53	$G_{pl} = G - G_{b,I} - G_{Wl} - g_{b,v}$ -Ga,v $-G_{b,v}$
Geometry						
Protection distance	m	1.89	6.26	3.00	9.92	d, where G_{pl} = 147.56 - 20log10(f) - 20log10(d) dB

- TV ACS = 100 dB

In order to assess the impact of a rejection filter fitted to the portable TV receiver a further set of results are calculated but with an ACS value of 100 dB (rather than 85 dB assumed above).

Figure 52 below provides results where the UE body loss is set to 4 dB.

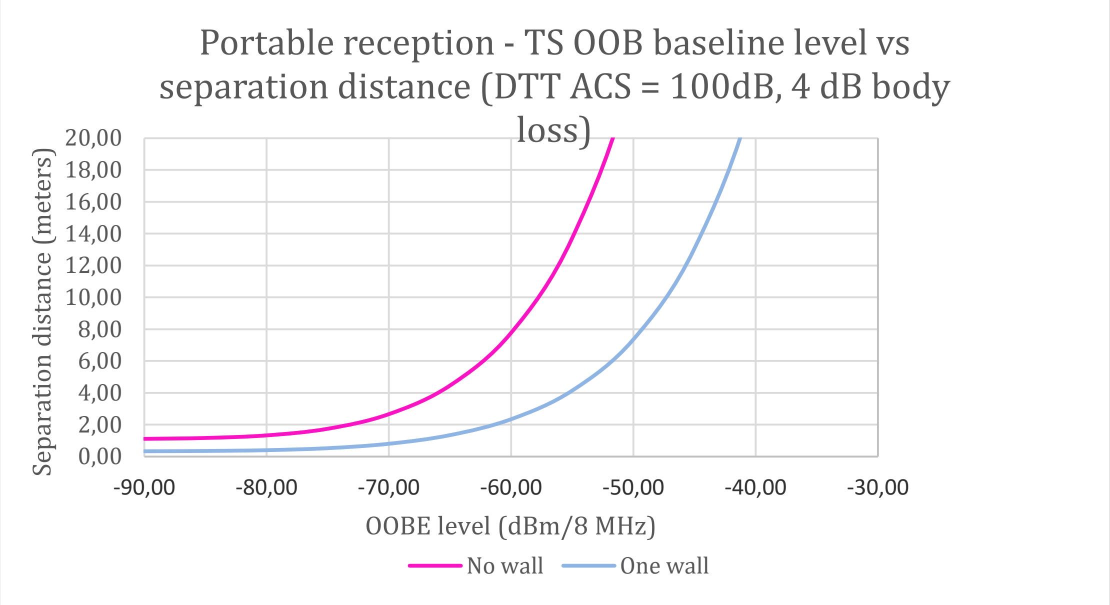

Figure 52: Relationship between separation distance and OOB emissions

Figure 53 below provides results where the UE body loss is set to zero.

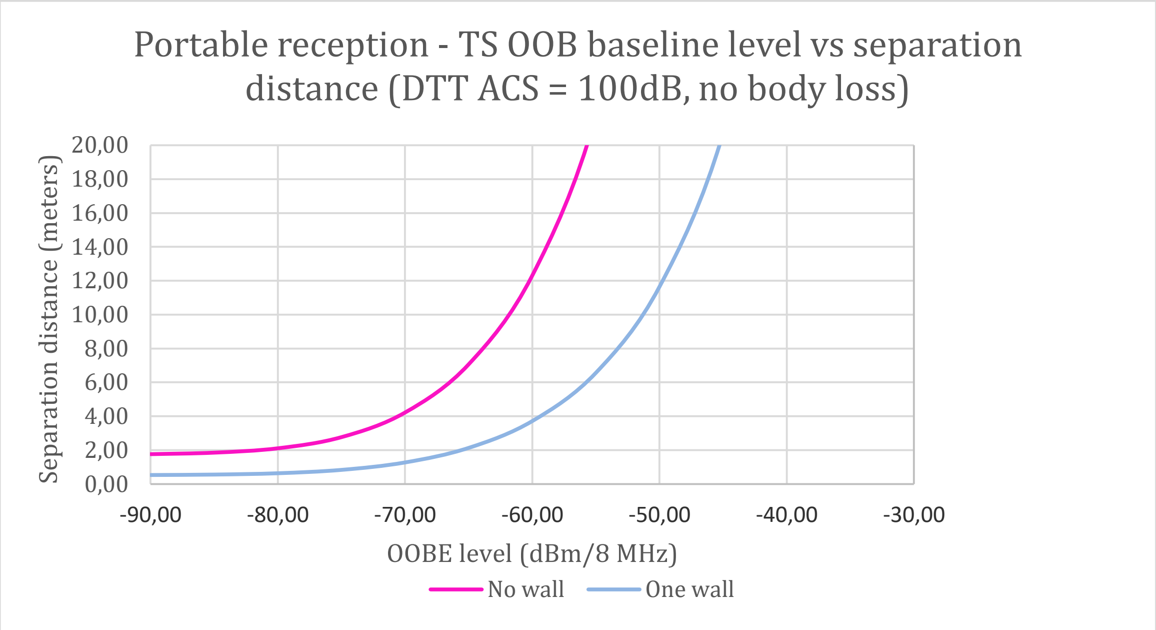

Figure 53: Relationship between separation distance and OOB emissions

Table 62 summarises the calculation of separation distance for the situation where the assumed TV receiver ACS is 100 dB and the out-of-band emissions is set to -75 dBm/(8 MHz) for the various combinations of wall loss and body loss.

Table 62: Calculation of separation distances for ACS = 100 dB

Parameter	Unit	Value	Value	Value	Value	Comment
Frequency	MHz	455	455	455	455	F_0

Target performance						
Receiver Noise Figure (NF)	dB	6.00	6.00	6.00	6.00	NF
Thermal Noise floor (9 MHz)	dBm	-99.17	-99.17	-99.17	-99.17	P_n= 10 log(kTB) + NF + 30
Interference-to-Noise Ratio (INR)	dB	-6.00	-6.00	-6.00	-6.00	INR
Target interference power	dBm	-105.17	-105.17	-105.17	-105.17	$P_{Itarget}$= P_n + INR
Victim's performance						
Receiver selectivity (ACS)	dB	100.00	100.00	100.00	100.00	
BEM limits						
In-block transmit power	dBm/ 10MHz	23.00	23.00	23.00	23.00	$P_{ib,tr}$
Interferer antenna gain	dBi	0.00	0.00	0.00	0.00	$G_{a,i}$
e.i.r.p.	dBm/ 10MHz	23.00	23.00	23.00	23.00	P_{ib}
Out-of-block	dBm/ 8MHz	-75.00	-75.00	-75.00	-75.00	P_{oob}
"Total" interference at "source"	dBm	-72.88	-72.88	-72.88	-72.88	Linear: Px = P_{ib}/ACS + P_{oob}, where $P_{Itarget}$ = G P_x
Adjacent Channel Interference Ratio (ACIR) calculation						
Adjacent Channel Leakage Ratio (ACLR)	dB	98.00	98.00	98.00	98.00	P_{ib} - P_{oob}
ACIR	dB	102.12	102.12	102.12	102.12	Linear = 1/((1/ACLR) + (1/ACS))
Coupling calculation						
Coupling gain	dB	-32.29	-32.29	-32.29	-32.29	Linear: G = $P_{Itarget}$ -P_x
Link budget						
Interferer body gain	dB	-4.00	-4.00	0.00	0.00	$G_{b,I}$
Wall gain	dB	-10.40	0.00	-10.40	0.00	G_{Wl}
Victim body gain	dB	0.00	0.00	0.00	0.00	$G_{b,v}$
Victim ant. Elevation pattern	dB	0.00	0.00	0.00	0.00	$g_{b,v}$ (assumed zero)
Victim antenna gain	dB	2.15	2.15	2.15	2.15	$G_{a,v}$
Path gain	dB	-20.04	-30.44	-24.04	-34.44	G_{pl} = G -$G_{b,I}$ -G_{Wl} -$g_{b,v}$ - Ga,v -$G_{b,v}$
Geometry						
Protection distance	m	0.53	1.75	0.84	2.77	d, where G_{pl} = 147.56 - 20log10(f) - 20log10(d) dB

6.3.3 Summary of the MCL analysis

The MCL studies have shown that the unwanted emissions above 470 MHz need to be adequately limited in order to minimise interference into DTT reception operating in the upper adjacent band.

To protect DTT in Channel 21, the MCL analysis shows that the LTE unwanted emission level should not exceed -70 dBm/8 MHz for fixed reception and -75 dBm/8 MHz for portable reception. This is derived under the following main assumptions:

- DTT receiver sensitivity degradation limited to 1 dB;
- DTT ACS values of 80 dB and 85 dB, respectively
- LTE UE transmitting at 23 dBm.

6.4 MONTE CARLO (SEAMCAT) ANALYSIS

The study analyses the adjacent band compatibility between LTE PMR/PAMR BS and UE systems operating in the 450-470 MHz band and DTT receivers operating at DTT channel 21 (470-478 MHz). This study considers a new set of parameters different from those of LTE BB-PPDR in ECC Report 240. In particular, the maximum UE power that is 23 dBm for LTE PMR/PAMR400, while it is 37 dBm for LTE BB PPDR400. Moreover, in this study, in order to be aligned with 3GPP E-UTRA Operating Band 31, a guard band of 2.5 MHz between the LTE PMR BS channel upper limit and DTT channel 21 lower limit is investigated. The obtained results are compared with those obtained with a guard band of up to 3 MHz as defined between DTT and BB PPDR400 in ECC Report 240.

A Monte Carlo analysis is performed to assess the probability of interference faced by the victim DTT receiver.

For LTE PMR BS, different e.i.r.p. are investigated and their impact on DTT reception is evaluated. The impact of the BS OOBE is also discussed so as to define the optimum ACLR to the BS that would minimise the interference into DTT, while limiting the constraints on the LTE BS system.

The Monte Carlo analysis for the UE case enables to compare the interference with the MCL analysis where the UE is considered to be located at the position that maximizes the interference. Indeed, this situation, although possible, is not representative of real-life operation of the device which may be located anywhere in the vicinity of the DTT receiver (Rx). Therefore, if only the conclusions of the MCL analysis are considered, they may lead to undue constraints for the operation of UE. Additionally, the time aspect of the interference from UE to DTT Rx is considered.

6.4.1 Basic geometry and simulation steps

6.4.1.1 *Geometry of the systems*

The DTT transmitter is placed at the centre of the coverage area as depicted in the figure below:

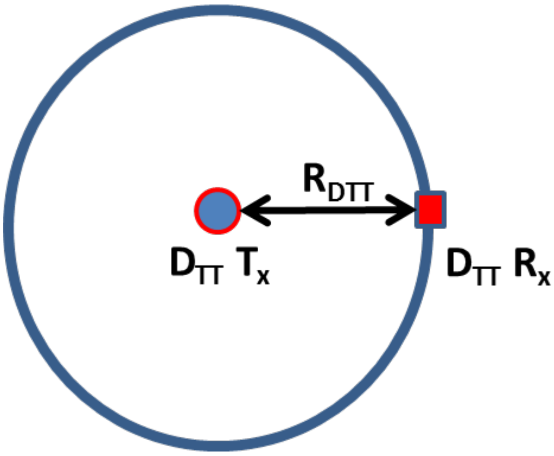

Figure 54: DTT coverage area of radius RDTT

The DTT coverage area is built up according to the link budget analysis presented in Annex 13.

Table 63: DTT BS coverage radius

DTT coverage radius for DTT high power transmitter e.i.r.p. = 85.15 dBm; Minimum median signal level at the cell edge = -68 dBm			
Environment	Urban	Suburban	Rural
DTT transmitter antenna tilt = 0°			
Coverage (km)	40.5	70.5	70.5
DTT transmitter antenna tilt = -1°			
Coverage radius (km) used in simulations	38.6	NC	NC

The LTE PMR base station (BS) is placed at the centre of the cell. Each LTE cell is composed of three sectors as depicted in the following figure. The Cell Radius (R) corresponds to the edge of the hexagon, following the definition of 3GPP. The Cell Range is therefore two times the value of the cell radius (2*R).

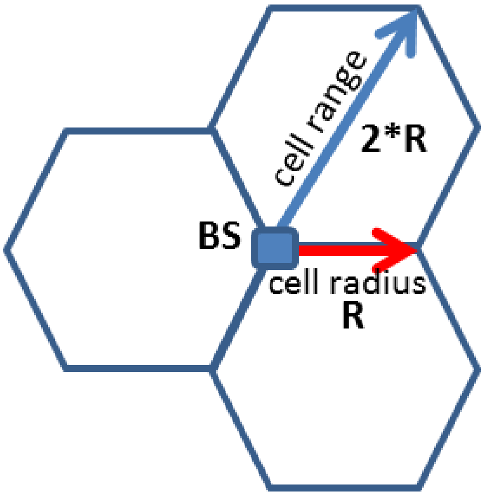

Figure 55: Hexagonal three-sector cell layout (R= Cell radius, 2*R= cell range)

This LTE cell is repeated to build up a perfectly homogeneous single frequency LTE cluster composed of 7 cells (BS) as depicted in the following figure. A cluster of size 7 is composed of 21 (7 x 3) hexagonal-shaped sectors.

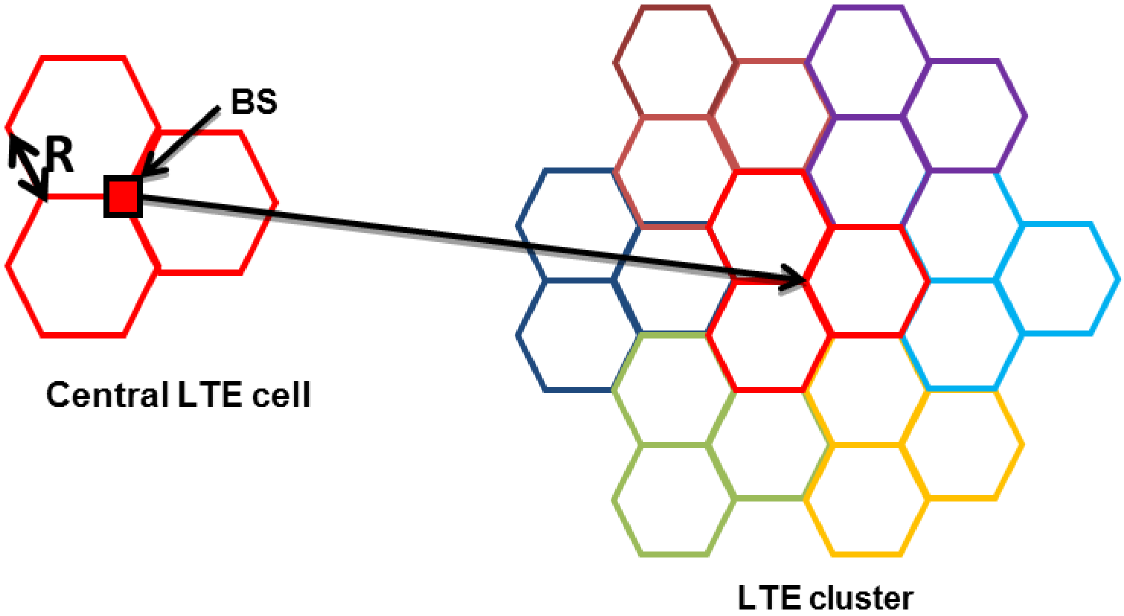

Figure 56: Single frequency LTE cluster

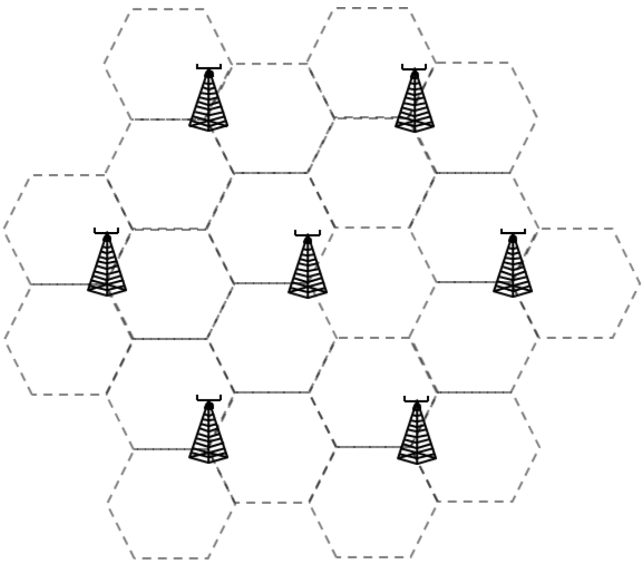

Figure 57: LTE base station positioning in the LTE cell cluster

6.4.2 Coexistence Scenario

The coexistence scenario for the analysis of potential interference from LTE PMR BS or UE to DTT receiver uplink is illustrated in the following figure.

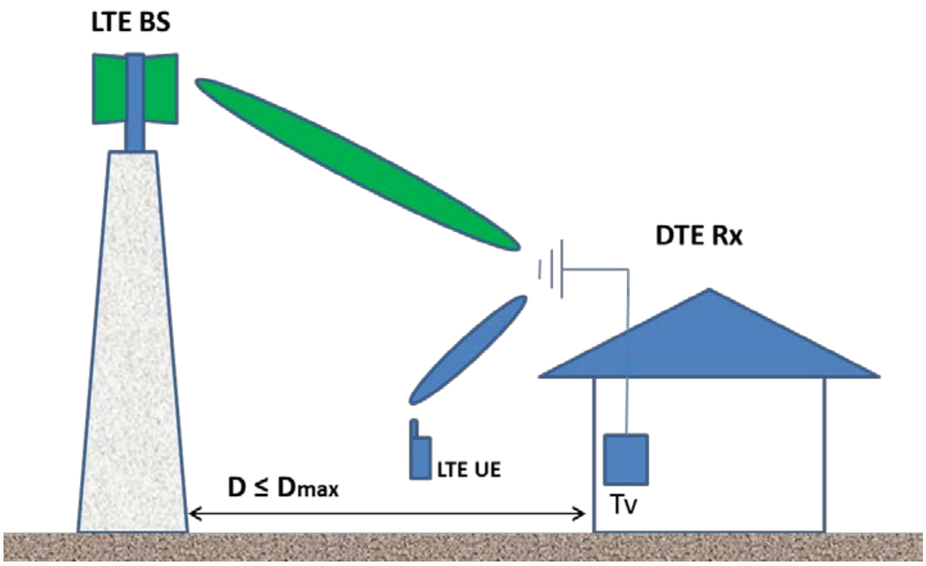

Figure 58: Co-existence scenario

An LTE cell cluster consisting of 7 cells is randomly positioned around the DTT receiver within a distance varying up to the LTE cell range Dmax (see scenario Figures 60 and 61).Dmax is measured between DTT receiver and the LTE cluster centre reference cell site.

Two main scenarios are investigated in this analysis:

- Interference at the DTT cell edge: The DTT receiver is randomly positioned within a 100 m x 100 m pixel at the edge of the DTT cell; this corresponds to the usual analysis performed for the assessment of interference into

DTT systems. The DTT network is designed to ensure the same minimum acceptable quality of service anywhere in the transmitter coverage area. At the DTT cell edge, the receiver receives the lowest wanted signal required to achieve that quality of service, therefore it is the most vulnerable to interference in the area close to the cell edge of the DTT coverage.

- Average interference over the DTT coverage area: the DTT receiver is randomly positioned in the DTT cell surrounded by LTE base stations. This means it will sometimes end up close to the DTT transmitter, sometimes close to the DTT cell edge but also at different locations between these two extremes. This ensures that the statistics of interference is also derived across the DTT cell for the compatibility between LTE BS and DTT. This provides additional information on the compatibility between LTE BS and DTT. It should be noted that this scenario includes also DTT receivers at the DTT cell edge.

6.4.3 Simulation configuration

6.4.3.1 *Simulation setup*

In this section studies performed through Monte Carlo simulations with SEAMCAT I (version 5.1.1) regarding LTE base station impact on DTT reception are presented. A 5 MHz LTE PMR DL system is investigated for the DTT system using DTT channel 21 (470-478 MHz) and the LTE systems using 3GPP band 31 (462.5-467.5 MHz for DL).

The DTT and LTE network parameters used in the simulations are summarized in ANNEX 1:. Some parameters highlighted as following:

- DTT Tx antenna: ITU-R 2383 (1° antenna tilt implemented in the antenna pattern);
- DTT cell range = 38.6 km (may vary depending on the other assumptions);
- DTT Rx antenna: DTT Rx ITU-R BT.419 Spherical Antenna;
- DTT Rx blocking mask: Blocking mask based on measurements. Blocking attenuation = 61 dB at the DTT-LTE BS frequency offset of 9 MHz (Guard band =2.5 MHz). This mask has been derived from measurements carried out in France on recent DTT receivers;
- LTE BS antenna: ITU-R F.1336-4 rec 3, antenna H/V 3 dB beam widths 65° and 15 respectively, this gives an antenna peak gain of 15 dBi (this antenna is used in CEPT Report 53 MC simulations);
- LTE BS antenna tilt: 3° (antenna tilt used in CEPT Report 53 MC simulations in urban environment, also suggested in ITU-R M.2292 [6]);
- LTE BS effective power reduction: 5 dB (2 dB cable loss + 3 dB DTT_H/LTE BS_X antenna discrimination);

The reference LTE BS e.i.r.p. used in the simulations is calculated based on an LTE BS SISO Tx power of 43 dBm, an antenna gain of 15 dBi and power reduction of-2 dB due to cable loss. This gives a reference LTE BS e.i.r.p. of 56 dBm. Moreover, simulations are performed for BS e.i.r.p. from 48 dBm to 62 dBm to get an overview on the impact of different LTE PMR BS e.i.r.p on DTT reception.

The considered DTT Rx protection criterion is C/(N+I) = 21 dB. 200 000 or 400 000 events are generated for each simulation. The outcome of the Monte Carlo simulations takes into account:

- The received interference from the LTE BS unwanted emissions (Interfering Received Signal Strength (iRSS)_unwanted);
- The received interference from LTE BS in-block emissions (IBE) (iRSS_Blocking).

The simulation scenarios include one single DTT BS transmitter with one single DTT receiver in an urban environment.

The propagation models used in the simulations for each type of link are summarised in

Table 64 below:

Table 64: Propagation models used in the simulation

Propagation models used in the simulation	
Link	Propagation model
DTT Tx to Rx	Recommendation ITU-R P.1546
LTE UE to LTE BS	Extended Hata (Urban)
LTE BS to DTT Rx	Extended Hata (Urban)
LTE UE to DTT Rx	Extended Hata (Urban)

6.4.3.2 *Simulation steps*

At each Monte Carlo trial i (i=1, 2, 3,..,M):

The DTT receiver is randomly positioned, following a uniform polar distribution, anywhere in the DTT cell or in a pixel of 100 m x 100 m at the edge of the DTT cell, depending on the scenario investigated. The DTT receiver antenna is directed toward the DTT transmitter in case of fixed rooftop reception.

Around the DTT receiver within a radius of Dmax, a LTE PMR cluster is randomly positioned following a uniform distribution. The position of the cluster is defined by the position of the central cell's BS as depicted in the figure below.

The active LTE user equipment (UE) is randomly positioned, following a uniform distribution, within each cell of the LTE cluster.

The probability of interference is calculated for each simulation based on a high number of events generated:

200000 to 400000 events for assessing the impact of LTE PMR BS on DTT reception, resulting in an accuracy which cannot be better than < 2.6*10-06;

700000 events were simulated for assessing the impact of LTE PMR UE on DTT reception, resulting in an accuracy which cannot be better than < 1.5*10-06.

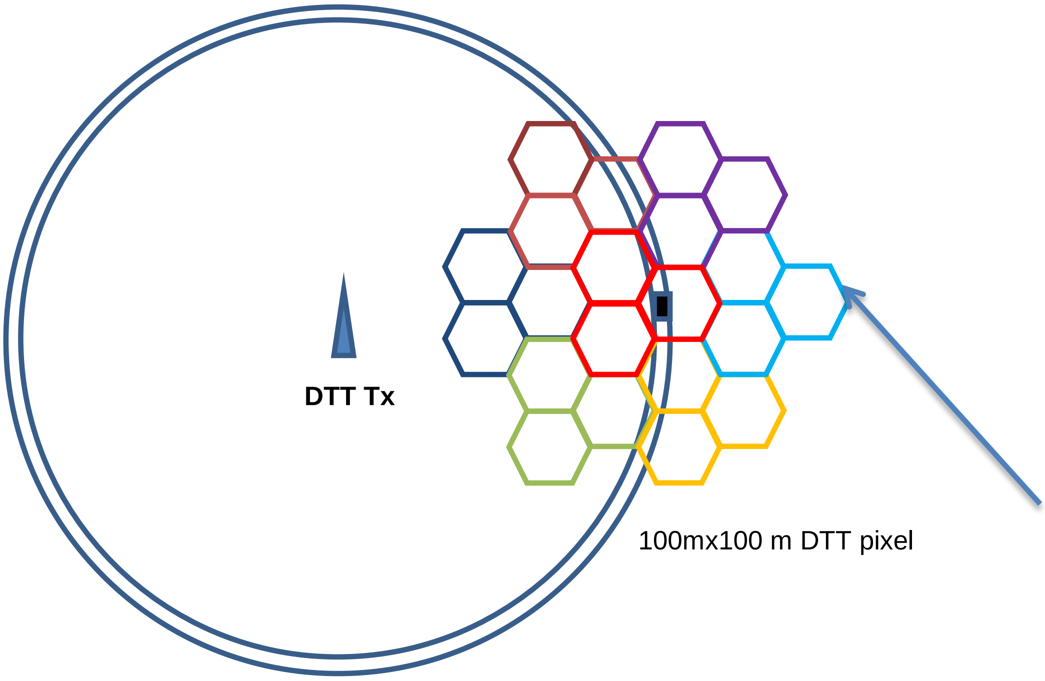

Figure 59: Edge of the DTT coverage area

Position of the LTE PMR cluster around the victim DTT receiver (a single Monte Carlo event):

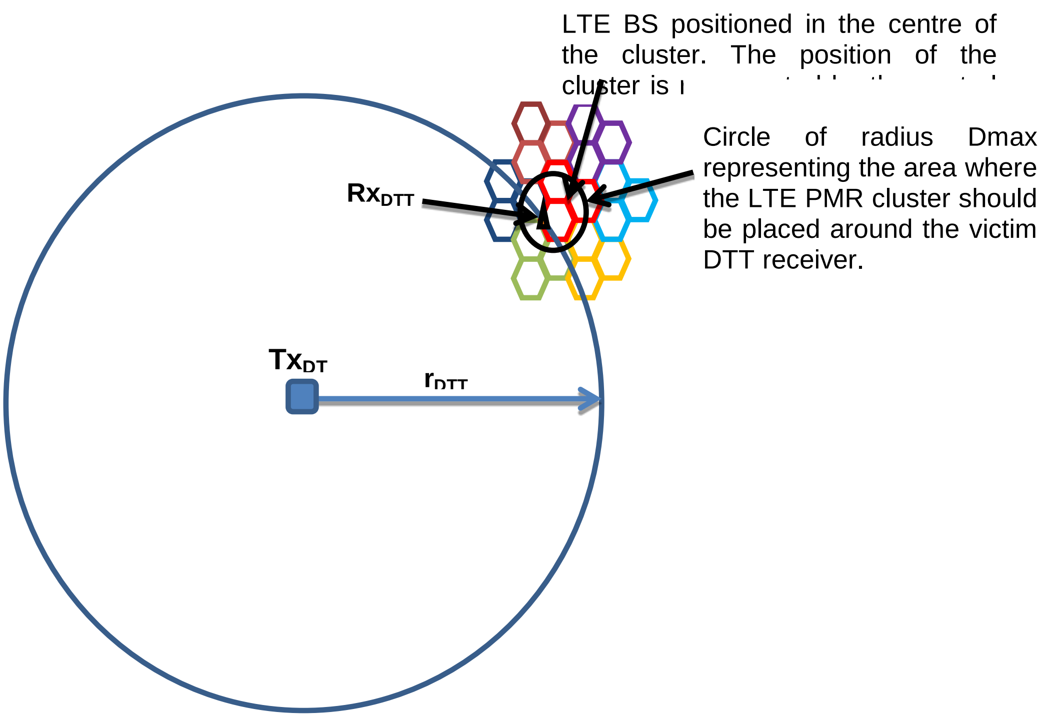

Figure 60: Position of LTE cluster around DTT receiver at cell edge

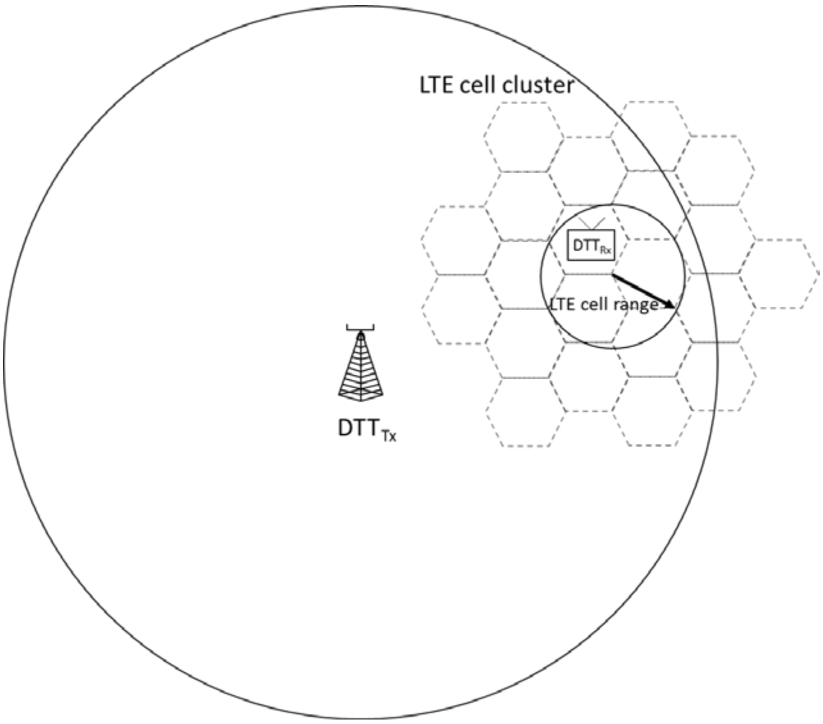

Figure 61: Example of layout in one snapshot of LTE cell cluster and DTT system in compatibility scenario in the average case. The DTT receiver has been randomly positioned in the DTT cell with the LTE centre BS positioned within the distance of the LTE cell range of the DTT receiver

6.4.4 LTE BS impact on DTT reception

The considered DTT Rx protection criterion is C/(N+I) = 21 dB. For a good statistical accuracy, 400000 events are generated for each simulation.

6.4.4.1 *Assessment of compatibility between DTT and LTE PMR.*

The analysis is based on the following assumptions:

Interference at the DTT cell edge: the DTT receiver at the DTT coverage edge is uniformly located in an area of 100 m x 100 m (one pixel). This corresponds to the most sensitive case for DTT reception scenario;

Average interference over the DTT coverage area: the DTT receiver is uniformly located in the coverage area of the DTT transmitter. Additionally, in order to assess the variation of the probability of interference as a function of the distance between the DTT transmitter and receiver, the DTT receiver is uniformly located in an area of 100 m x 100 m (one pixel) at different distances from the transmitter in the coverage area. This sensitivity analysis allows assessing the advantage of a high level of wanted DTT signal that may increase the protection criterion C /(N + I), thus reducing the impact of the interfering signal. This also helps to better understand the results of the analysis of the average interference over the DTT coverage area.

The position of the interfering link (IL) is set to be dynamic relative to the victim DTT receiver (Rx) so that the LTE cluster reference cell is located in the vicinity of the DTT receiver, uniformly positioned within an area limited by a circle of radius Dmax = PMR BS cell range whose centre is the DTT Rx.

The outcome of the Monte Carlo simulation provides:

- The received interference from the LTE BS unwanted emissions (iRSS_unwanted);
- The received interference from the LTE BS in block emissions (iRSS_Blocking);

The probability of interference of the DTT receiver (PI) from LTE systems, as well as the probability of DTT coverage with interference was studied.

The reported received useful and interfering signal levels (dRSS, iRSS Unwanted and iRSS Blocking …) correspond to the median values. They are reported in order to evaluate which contribution impacts more the DTT Rx. Note that at the DTT cell edge the minimum median useful signal level (dRSS) is always about -68 dBm/8 MHz. The calculated probability of interference takes into account mutually the interference from the LTE in block (blocking) and unwanted emissions as well as the overloading due to very high interfering signal levels (> -8 dBm) at the DTT Rx input.

The interference from LTE systems to DTT reception depends on the power (e.i.r.p.) of the base station that is received by the DTT receiver. Different BS configurations may lead to an increase or a reduction of the LTE BS e.i.r.p., compared to a reference value of 56 dBm/5MHz used in this analysis.

For example, the use of MIMO/MISO antennas would permanently contribute to an additional 3dB to the e.i.r.p.

A reduction of the channel bandwidth of the system may also leads to a change of the corresponding e.i.r.p. (e.g. from 56 dBm/5MHz to 54 dBm/3MHz), while a change over the time of the LTS BS activity (traffic load) could result in an instantaneous variation of the mean e.i.r.p. over the occupied bandwidth. Such traffic change over the time can be modelled for example with the network activity factor. How to take into account the activity factor depends on the analysis to be performed and can be done in various ways.

In this Report, a sensitivity analysis with an activity factor of 50% is carried out (see ANNEX 2: on activity factor). This activity factor is modelled in the Monte Carlo simulation as a reduction of 3 dB of the BS e.i.r.p.

6.4.4.2 *Results of the simulations*

Impact of the guard band reduction on DTT reception

A guard band of up to 3 MHz between DTT and BB-PPDR is defined in ECC Report 240 to minimise the interference from BB-PPDR base stations to DTT reception. Besides, 3GPP E-UTRA operating in Band 31 provides only a guard band of 2.5 MHz between the E-UTRA BS upper channel and DTT Channel 21. Thus, the impact of the reduction of the guard band between DTT and LTE PMR, from 3 MHz to 2.5 MHz, on the PI of DTT reception at the DTT cell edge is assessed.

The results of the simulations are presented in Figure 62 and Table 65.

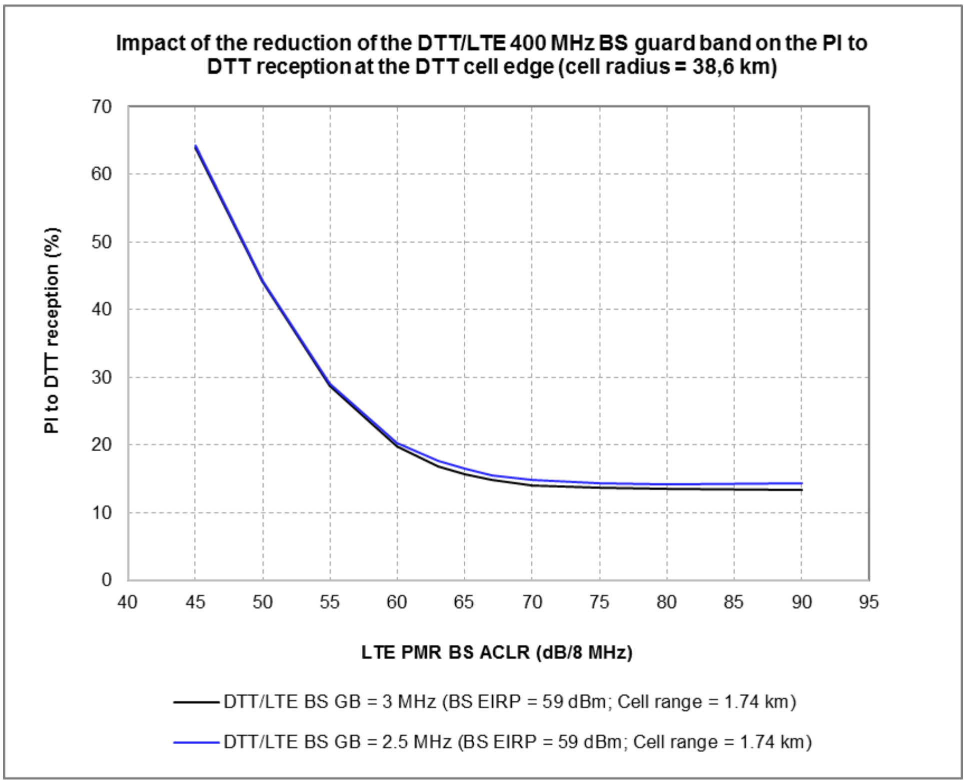

Figure 62: Impact of the guard band reduction on the DTT reception at the DTT cell edge

Table 65: Impact of the guard band reduction on the DTT reception at the DTT cell edge

Probability of interference to DTT reception at the DTT cell edge (dRSS=-68 dBm) LTE PMR 5 MHz BS interfering signal (e.i.r.p = 59 dBm); PMR cell range = 1.74 km; P of DTT coverage without interference = 95%; Number of events simulated = 400 000					
		DTT/ PMR Guard band = 3 MHz		DTT/ PMR Guard band = 2.5 MHz	
PMR BS ACLR (dB/8 MHz)	PMR BS OOBE (dBm/8 MHz)	PI (%)	P of non-coverage* (%) with interference	PI (%)	P of non-coverage* (%) with interference
45	14	63.95	68.95	64.19	69.19
50	9	44.12	49.12	44.29	49.29
55	4	28.69	33.69	29.06	34.06
60	-1	19.77	24.77	20.37	25.37
63	-4	16.89	21.89	17.68	22.68
65	-6	15.72	20.72	16.55	21.55
67	-8	14.88	19.88	15.58	20.58

Probability of interference to DTT reception at the DTT cell edge (dRSS=-68 dBm) LTE PMR 5 MHz BS interfering signal (e.i.r.p = 59 dBm); PMR cell range = 1.74 km; P of DTT coverage without interference = 95%; Number of events simulated = 400 000					
70	-11	14.06	19.06	14.9	19.9
75	-16	13.65	18.65	14.43	19.43
80	-21	13,47	18,47	14.27	19.27
90	-31	13.4	18.4	14.31	19.31
* P of non-coverage = PI + 5% of non-coverage where PI is assumed to be equivalent to a reduction of the coverage of the DTT network.					

The simulation results show that:

- the impact of the LTE PMR400 (5 MHz) BS MIMO/MISO with an e.i.r.p of 59 dBm on the DTT reception above 470 MHz, with a guard band of 3 MHz, is similar to that of the LTE BB PPDR400 (3 MHz) BS with an e.i.r.p of 60 dBm (see ECC Report 240);
- the optimal Adjacent Channel Leakage Ratio (ACLR) value needed to minimise the PI from LTE PMR BS to DTT reception at the cell edge is 67 dB/8 MHz;
- the reduction of the DTT/LTE PMR guard band from 3 MHz to 2.5 MHz has a low impact on the PI to DTT reception at the DTT cell edge. It increases the PI to DTT reception only from 14.9% to 15.6% for a LTE PMR BS ACLR of 67 dB/8 MHz.

Additionally, it can be noticed that from an ACLR value of 67 dB/8 MHz, increasing the BS ACLR does not provide significant improvement on the probability of interference of the DTT receiver at the cell edge.

Impact of each component of the received interference into the DTT receiver

The probability of interference is assessed for the baseline e.i.r.p. of 56 dBm, at the DTT coverage cell edge and assuming full traffic buffer as well as 50% activity factor (modelled as a reduction of 3 dB in e.i.r.p. which leads to e.i.r.p. = 53 dBm). The components of the received interference (i.e. LTE BS OOBE and in IBE (In-Block Emission)) are reviewed in order to assess how they contribute individually to the overall interference faced by the DTT receiver.

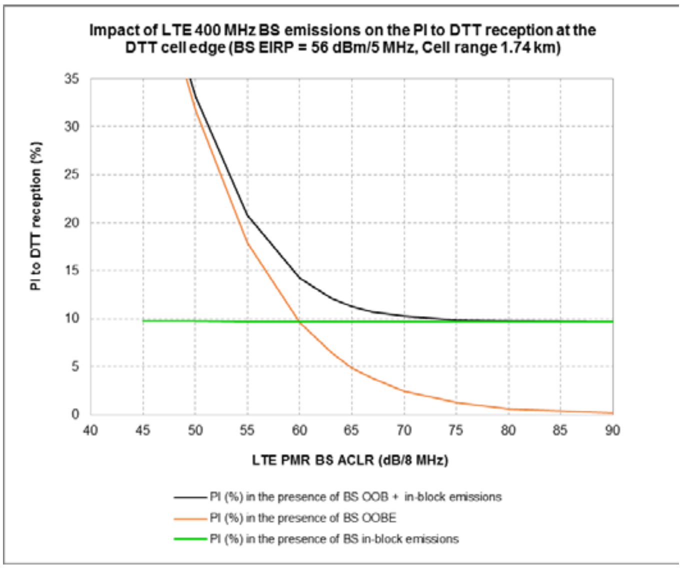

Figure 63: Impact of the different components of the interference from the LTE PMR BS on DTT reception at the DTT cell edge

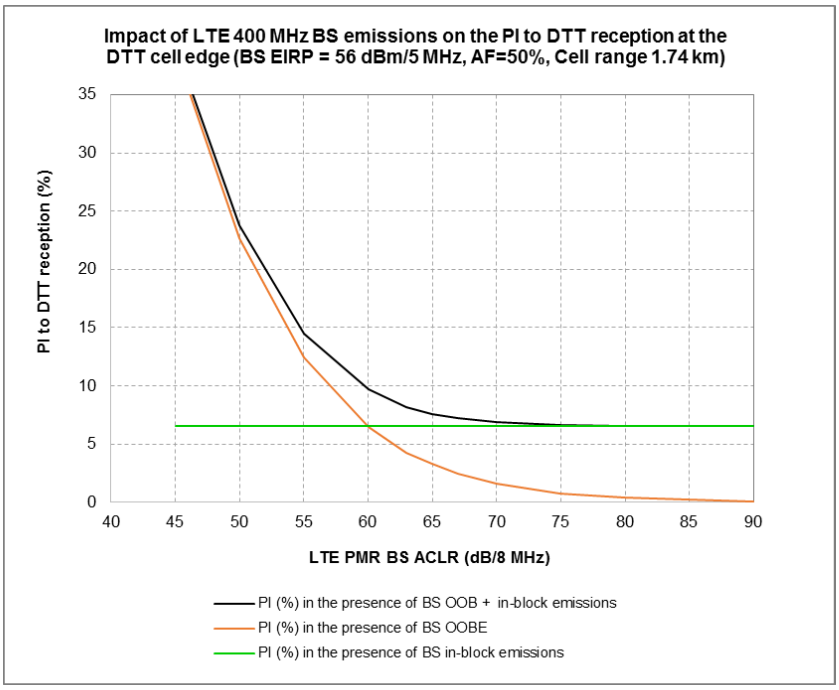

Figure 64: Impact of the different components of the interference from the LTE PMR BS (with activity factor of 50% equivalent to e.i.r.p. = 53 dBm) on DTT reception at the DTT cell edge

The previous Figure 63 and Figure 64 show the variation of the PI to DTT cell edge as a function of the LTE BS ACLR, for each component of the LTE signal contributing to the total interference into the DTT receiver (LTE BS OOB and in-block emissions (IBE)). The Out-of-Band Emissions (OOBE) interference results directly from the combination of the BS e.i.r.p. and ACLR, while the in-block emissions interference results from the combination of the BS e.i.r.p. and the DTT receiver ACS (adjacent channel selectivity). The total interference received by the DTT receiver is the combination of these two sources of interference (OOB+ IBE), which defines the PI to DTT as shown by the black curve.

It is noted that for the full buffered case as well as 50% activity factor case, the PI caused by IBE (blocking surpasses the PI caused by unwanted emissions (OOBE) from the LTE BS when LTE ACLR exceeds 60dB/8MHz.The overall interference meets the receiver blocking curve for areas around ACLR = 70 dBm/8MHz. Between ACLR values of 60 and 70 dBm/8MHz although the receiver blocking is the dominant effect, the BS OOBE continues to contribute to the interference and improving the BS ACLR slightly reduces the PI into the DTT receiver. Finally, above the ACLR value of 70 dBm/8MHz, the contribution of the LTE BS OOBE in the overall interference becomes insignificant compared to the impact of the LTE BS IBE attenuated by the DTT receiver (Rx ACS) so that improving the LTE BS ACLR does not impact anymore the PI.

The impact of the LTE PMR BS on DTT reception for different network configurations such as activity factor, e.i.r.p., system bandwidth etc., was studied.

Report ITU-R M.2292 [6] defines the maximum International Mobile Telecommunications (IMT) (LTE) base station output power as 43 dBm/5 MHz, 46 dBm/10 MHz and 46 dBm/20 MHz. Actually, in some cases, for the same cell range defined by the uplink budget, the reduction of the system bandwidth may imply the reduction of the BS power. That is the reduction of the BS power as a function of the system bandwidth. This power reduction can be justified from the fact that the reduction of the system bandwidth means the increase of the user terminal (UE) sensitivity. However, one can also keep the BS power unchanged to benefit from an additional SNR margin on downlink.

Indeed, it is obvious that reducing the LTE PMR BS power while keeping cell range unchanged, thus reducing the SNR margin on downlink, will result in a lower PI of LTE PMR BS to DTT reception, but the ACLR value needed to minimise the PI from LTE PMR BS to DTT reception should remain unchanged (67 dB/8 MHz), according to the results given in Figure 65.

Simulations are performed to get an overview on the impact of different LTE PMR BS transmitter e.i.r.p. on DTT reception. For each e.i.r.p., the ACLR of the LTE PMR BS is improved and the resulting PI reported, so as to assess the optimal ACLR value that minimises the impact of the LTE PMR BS for the corresponding e.i.r.p..

The results of the simulations are presented in Figure 65.

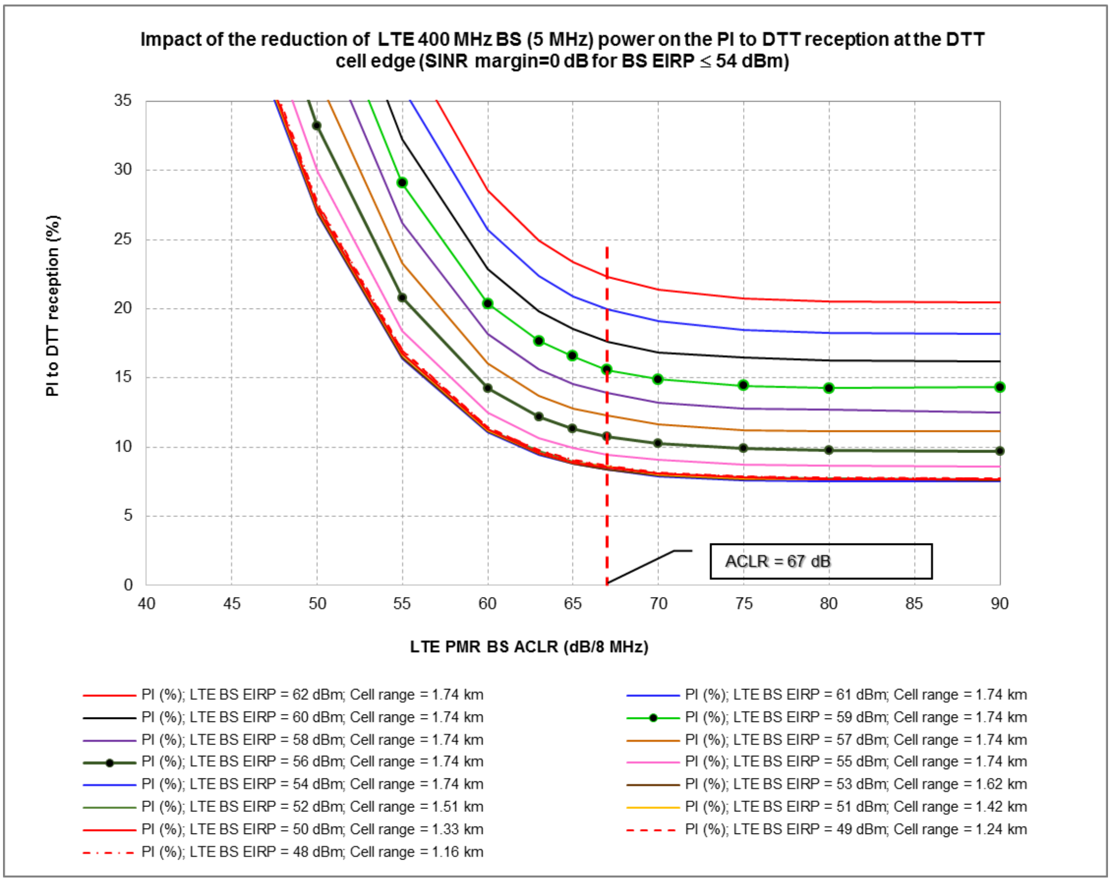

Figure 65: Impact of the LTE PMR BS transmitted power on DTT reception at the DTT cell edge

Figure 65 presents the curves of PI to DTT reception as a function of the LTE PMR BS e.i.r.p. and Adjacent Channel Leakage Ratio (ACLR). These different PI curves showing the impact of the LTE BS on DTT reception for BS e.i.r.p. from 48 dBm to 62 dBm cover a wide range of possible configurations or assumptions for the LTE 400 MHz systems and networks.

For example, assuming the reference e.i.r.p. of 56 dBm for a system bandwidth of 5 MHz, the use of MIMO 2x2 or MISO 2x1[8] antennas at the LTE BS would lead to an increase of 3 dB in the e.i.r.p., which corresponds to the PI curve of 59 dBm in the figure.

An indication of the effect of the activity factor, if modelled as simple power reduction of the e.i.r.p. on the PI is shown in Figure 65. An activity factor of 50 % is represented as a reduction of 3 dB of the e.i.r.p. (note that the activity factor should not affect the LTE cell range), i.e. The 56 dBm PI curve would be representative of an e.i.r.p. of 59 dBm and an activity factor of 50 %.

Similarly, the consideration of an activity factor of 50%, modelled as a reduction of 3 dB of the e.i.r.p. , is represented by the PI curve of 53 dBm and an activity factor of 25% would therefore be the PI curve of 50 dBm.

[8] 2 BS Tx and 1 UE Rx

Furthermore, the baseline e.i.r.p. of 56 dBm would be representative of an e.i.r.p. of 59 dBm and an activity factor of 50%.

Also, for the baseline e.i.r.p. of 56 dBm, assuming simultaneously a MISO 2x1 antenna at the LTE BS and a reduced activity factor of 50%, the resulting e.i.r.p. remains unchanged, i.e. 56 dBm.

Finally, a 3 MHz system would have 2 dB less in e.i.r.p. compared to the 5 MHz system, which corresponds to the PI curve of 54 dBm from the baseline assumption. A 1.4 MHz system bandwidth would therefore be represented with the PI curve of 50 dBm. Note that, as explained previously, a reduction of the system bandwidth does not always necessarily imply a reduction of the BS e.i.r.p..

Based on this figure it can be concluded that:

- All the curves for the different e.i.r.p show similar behaviour with the reduction of the PI to DTT following the improvement of the ACLR of the LTE PMR BS. The improvement of LTE PMR BS ACLR from 45 to 67 dB/8 MHz reduces considerably the PI to DTT reception (from 51.4% down to 10.74% for 5 MHz bandwidth and a LTE PMR BS e.i.r.p. of 56 dBm) while the improvement of the ACLR beyond 67 dB does not improve notably the PI for low values of e.i.r.p. (the PI is reduced from 10.74% down to 9.71% for an ACLR improvement of 23 dB from 67to 90 dBm/8MHz). Note that the improvement from 60 to 67dB/8 MHz corresponds to a larger reduction of PI, from 14% to 10.74% for a LTE PMR BS EIRP of 56 dBm and bandwidth of 5 MHz and from 11.25% to 8.75% for a LTE PMR BS EIRP of 53 dBm and a bandwidth of 5 MHz. This is due to the limiting factor of the DTT receiver ACS which is 61 dB.
- For all values of e.i.r.p., the ACLR value needed to minimise the PI from LTE PMR BS to DTT reception is always 67 dB/8 MHz; for lower values of ACLR (e.g. 55 or 60 dB/8 MHz), the PI on DTT reception is increased and for higher values of ACLR (e.g. 70 or 75 dB/8 MHz) although there is a reduction of the PI, there is no major improvement of the PI for e.i.r.p. lower than 58 dBm. An ACLR of 67 dB/8MHz appears to be a good tradeoff . This ACLR of 67 dB results in a BS OOBE e.i.r.p limit of -7 dBm/8 MHz for a BS e.i.r.p of 60 dBm above 470MHz.
- A reduction of the BS e.i.r.p. leads to a shift of the PI curve on the vertical axis down to a minimum PI value representing a ceiling, which cannot be further reduced by reducing the BS e.i.r.p.. This phenomenon appears to be linked to the BS density in the LTE network. Actually, with the reduction of e.i.r.p., the choice of a balanced link budget between downlink and uplink (Signal to Interference and Noise Ratio (SINR) margin=0 dB) leads to a reduction of the LTE cell range. This tends to create an interference to DTT receivers which does not take further advantage of the reduction of the LTE BS e.i.r.p. from 54 dBm and lower.
- The reduction of the cell range due to e.i.r.p. for a constant as well as balanced SINR margin means a higher density of LTE PMR base stations and potentially higher costs for the network deployment.
- Additionally, taking into account the activity factor helps appreciating the instantaneous impact of LTE BS into DTT reception and the evolution over the time of such impact for a single LTE BS depending on the traffic over the LTE network. However it should be noted that the assumption of low activity factor is not well suited for the assessment of interference from LTE into DTT reception, given that the DTT receiver and the LTE BS are at fixed locations from each other and that the interference on the DTT receiver is assessed over a period of one hour and a BS may transmit full buffer during this period. Therefore, for this analysis where the interference into DTT may vary over the time and given that within a busy hour time window a base station will transmit many times using maximum power, only the peak power of the interference (corresponding to full buffer traffic) from LTE PMR BS would be of interest in order to define adequate measures for the protection of DTT reception.

Impact of LTE PMR BS in the coverage area of the DTT receiver

As previously underlined in this study, the interference is assessed based on the protection criterion C/(N+I). This criterion takes into account the wanted DTT signal (C) and the interfering LTE BS signal (I) as well as the noise generated in the DTT receiver (N). When the wanted DTT signal is strong enough, the DTT receiver is more robust to the interference and there could be no disruption to the service. Therefore, for a given LTE interfering signal level I1 and a wanted DTT signal level C1 for which a receiver at the DTT cell edge would suffer from service degration, a receiver located closer to the DTT transmitter with a higher wanted signal level (C2 > C1) may continue to operate well under a similar interfering signal level (I2 =I1).

To verify this assertion, the interference into DTT reception is assessed in the whole DTT coverage area in order to appreciate the various behaviour of receivers dependanting on their location relative to the DTT transmitter. Two cases are evaluated, the first one consisting of the interference for the DTT receivers located anywhere in the whole DTT coverage area, and the second case consisting of DTT receivers located within a pixel of 100 m x 100 m at a defined distance from the DTT transmitter. Following figures illustrate the results of this analysis.

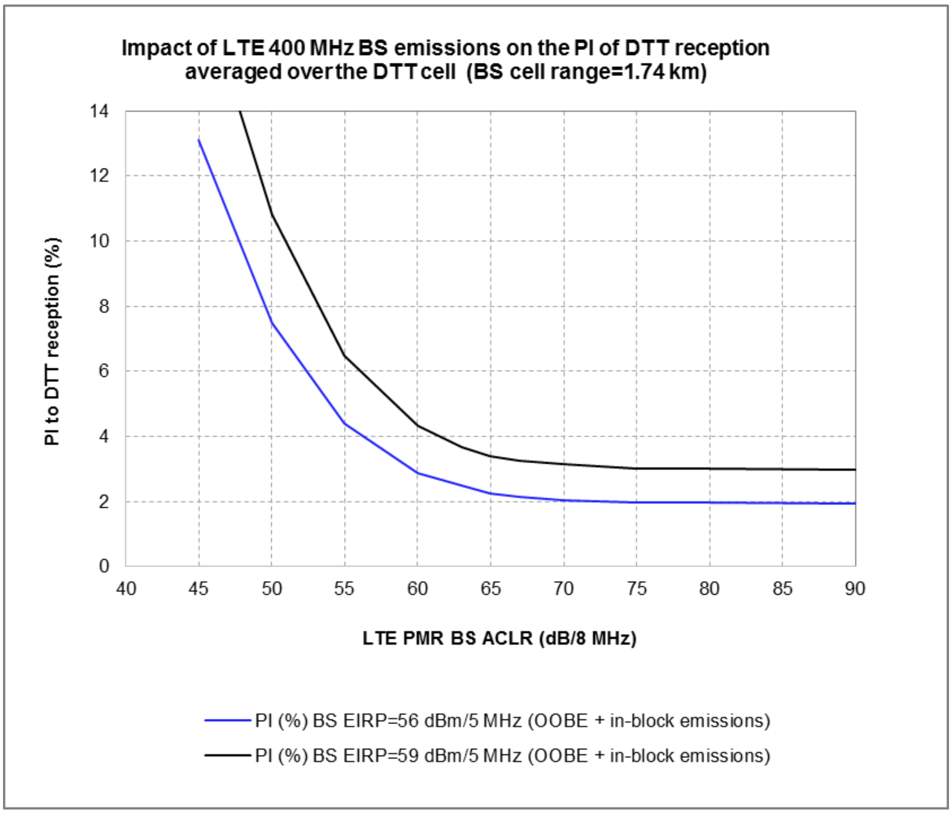

Figure 66: Impact of the LTE PMR BS on DTT reception average over thein the DTT cellcoverage area

The values of the curves in the above figure are reported in the table below.

Table 66: Probability of interference to DTT reception averaged over the DTT cellin the DTT coverage area

Probability of interference to DTT reception in the DTT coverage area LTE PMR BS interfering signal; PMR cell range = 1.74 km; P of DTT coverage without interference = 95%; Number of events simulated = 400000						
	e.i.r.p. = 56 dBm			e.i.r.p. = 59 dBm		
LTE 400 BS ACLR (dB/8 MHz)	PI (%) in the presence of BS OOB + + IBE (BS IERP = 56 dBm/5 MHz)	Median iRRS Unwanted (dBm)	DTT received signal level (dBm)	PI (%) in the presence of BS OOB + + IBE (BS IERP = 59 dBm/5 MHz)	Median iRRS Unwanted (dBm)	DTT received signal level (dBm)
45	13.1	-90.08	-51.61	18.1	-87.08	-51.67
50	7.5	-95.07	-51.65	10.8	-92.08	-51.67
55	4.38	-100.07	-51.65	6.48	-97.08	-51.67

Probability of interference to DTT reception in the DTT coverage area LTE PMR BS interfering signal; PMR cell range = 1.74 km; P of DTT coverage without interference = 95%; Number of events simulated = 400000						
60	2.87	-105.08	-51.61	4.33	-102.08	-51.67
63	2.47	-108.07	-51.65	3.68	-105.08	-51.67
65	2.26	-110.08	-51.67	3.4	-107.12	-51.67
67	2.14	-112.08	-51.61	3.26	-109.07	-51.68
70	2.04	-115.09	-51.65	3.13	-112.07	-51.68
75	1.97	-120.09	-51.65	3.02	-117.07	-51.68
80	1.95	-125.09	-51.65	3	-122.07	-51.68
90	1.94	-135.07	-51.65	2.96	-132.07	-51.67

The curves show that the probability of interference (PI) averaged over the DTT cell is lower compared to the PI calculated at the DTT cell edge.. For high value of Adjacent Channel Leakage Ratio (ACLR), e.g. 70 dBm/8MHz where the curves flatten to meet their floor, the PI is decreased from 14.9% at the cell edge to 3.13% in the average case for e.i.r.p. = 59 dBm and from 10.24% at the cell edge to 2% in the average case for e.i.r.p. = 56 dBm. It is recalled that the curve for e.i.r.p. = 56 dBm would also represent the curve for e.i.r.p. = 59 dBm assuming an activity factor of 50%. With ACLR improvement from 45dB/8MHz to 60dB/8MHz the PI is reduced from 13.1% to 2.87% for e.i.r.p. 56dBm and the PI is reduced from 18.1% to 4.33% for e.i.r.p. 59dBm. The PI with ACLR=67dB/8MHz is 2.14% for e.i.r.p. 56dBm and 3.26% for e.i.r.p. 59dBm.

In order to see the impact in the coverage area for each component of the interference as well as a reduced traffic of the BS (activity factor of 50% modelled as a reduction of 3 dB of e.i.r.p.) the following two figures illustrate the impact for a LTE BS at baseline e.i.r.p. using MIMO/MISO antenna (equivalent to e.i.r.p. = 59 dBm) and the baseline e.i.r.p. with 50% activity factor (equivalent to e.i.r.p. = 53 dBm).

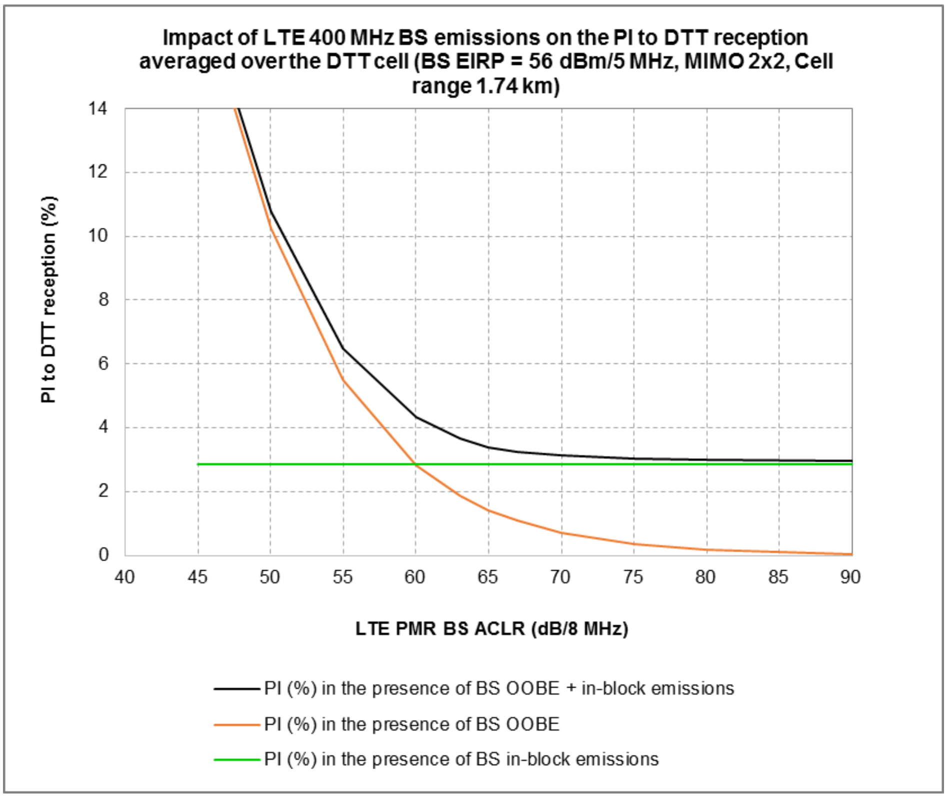

Figure 67: Impact of LTE PMR on the DTT reception (baseline + MIMO equivalent to e.i.r.p. = 59 dBm), DTT receiver randomly positioned in the DTT coverage area

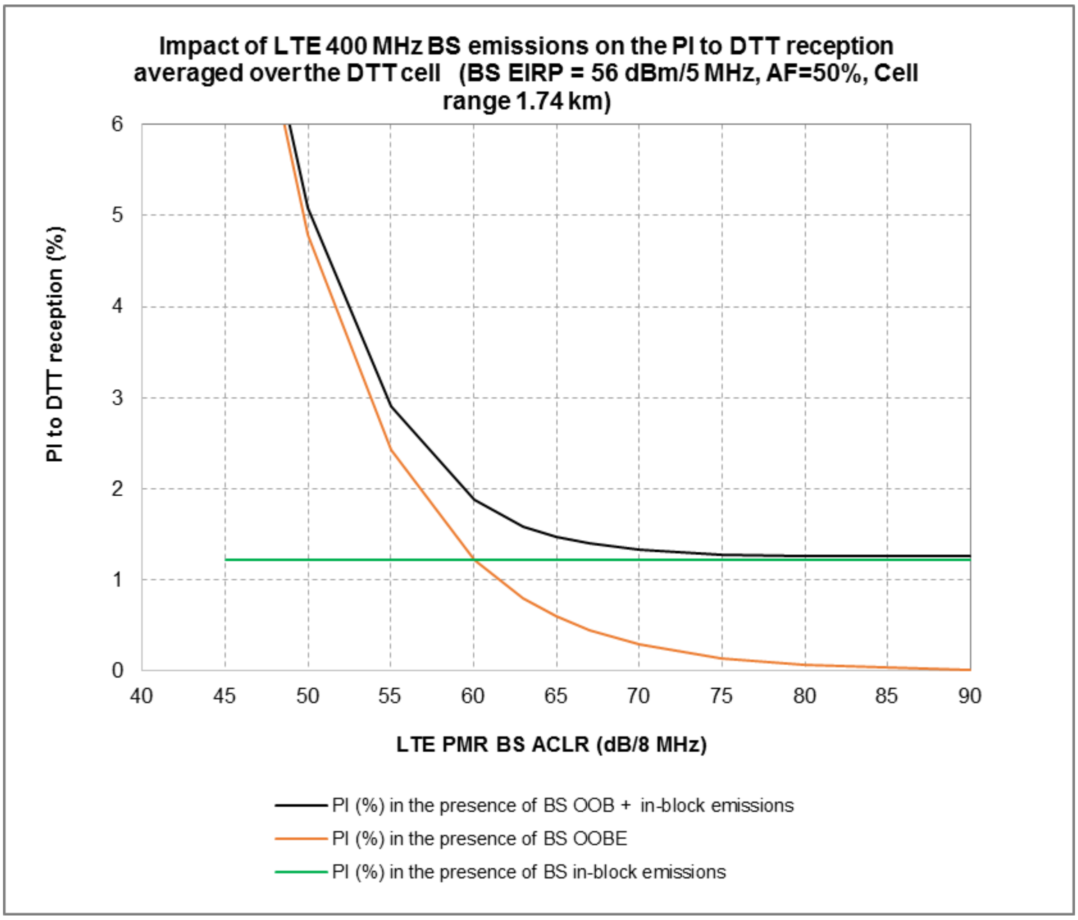

Figure 68: Impact of LTE PMR on the DTT reception (baseline + activity factor of 50% equivalent to e.i.r.p. = 53 dBm), DTT receiver randomly positioned in the DTT coverage area

From Figure 67it can be seen that the curve of PI meets the blocking curve for an ACLR of about 75 dB/8MHz. Although the receiver ACS has the dominant effect on the PI starting at 60 dB/8MHz, improving the ACLR reduces the PI from 4.33% for ACLR = 60 dB/8MHz to 3.26% for ACLR= 67 dB/8MHz .

From Figure 68it can be seen that PI is reduced when the BS is not fully buffered. In this case the curve of overall PI also meets the blocking curve for an ACLR of about 75 dB/8MHz. Although the receiver ACS has the dominant effect on the PI starting at 60 dBm/8MHz, improving the ACLR reduces the PI from 1.87% for ACLR = 60 dB/8MHz to 1.4% for ACLR= 67 dB/8MHz.

However, it should be noted here that averaging the PI to DTT over the whole DTT cell (R=38.6 km) does not permit to identify interferences for the most sensitive cases.

In order to assess the evolution of PI throughout the DTT cell, the interference is assessed in the DTT coverage area for different distances between the DTT transmitter and receiver. The results are presented in the figure below and the values reported in Table 67 and Table 68.

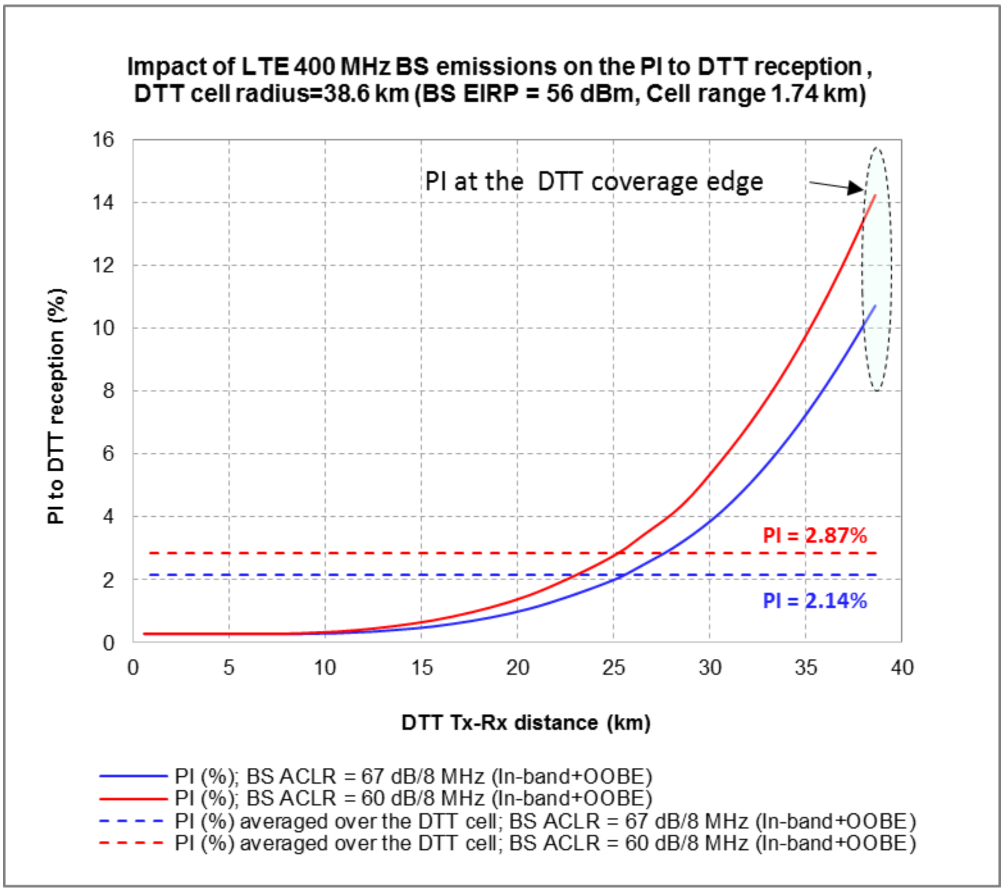

Figure 69: Impact of the LTE PMR BS on DTT reception in the DTT coverage area for different distances between DTT Tx and DTT Rx

Table 67: Impact of the LTE PMR BS transmitted power on DTT reception in coverage area for different DTT Tx-Rx distances and BS ACLR = 67 dB/8MHz

Probability of interference* to DTTB reception in the DTTB coverage area (dRSS = -68 dBm) LTE PMR (5 MHz, Guard Band = 2.5 MHz) ; LTE BS ACLR = 67 (dB/8MHz) BS interfering signal e.i.r.p. = 56 dBm ; PMR cell range = 1.74 km; P of DTT coverage without interference = 95%; Number of events simulated = 400000				
DTT Tx -Rx distance (km)	DTT Rx PI (%); BS ACLR = 67 dB/8 MHz (IBE +OOBE)	Median iRRS Unwanted (dBm)	Median iRRS Blocking (dBm)	DTT received signal level (dBm)
38.6	10.72	-111.86	-104.77	-68.13
36.6	8.71	-111.86	-104.77	-66.69
34.6	6.92	-111.86	-104.77	-65.19
32.6	5.41	-111.86	-104.77	-63.69

Probability of interference* to DTTB reception in the DTTB coverage area (dRSS = -68 dBm) LTE PMR (5 MHz, Guard Band = 2.5 MHz) ; LTE BS ACLR = 67 (dB/8MHz) BS interfering signal e.i.r.p. = 56 dBm ; PMR cell range = 1.74 km; P of DTT coverage without interference = 95%; Number of events simulated = 400000				
30.6	4.17	-111.86	-104.77	-62.09
28.6	3.22	-111.86	-104.77	-60.48
26.6	2.5	-111.88	-104.8	-58.77
24.6	1.9	-111.88	-104.8	-57.01
20.6	1.08	-111.88	-104.8	-53.27
16.6	0.6	-111.88	-104.8	-49.06
12.6	0.36	-111.88	-104.8	-44.32
8.6	0.28	-111.88	-104.8	-38.88
4.6	0.28	-111.83	-104.75	-35.87
0.6	0.28	-111.83	-104.75	-18.86

Table 68: Impact of the LTE PMR BS transmitted power on DTT reception in coverage area for different DTT Tx-Rx distances and BS ACLR = 60 dB/8MHz

Probability of interference* to DTTB reception in the DTTB coverage area (dRSS = -68 dBm) LTE PMR (5 MHz, Guard Band = 2.5 MHz) ; LTE BS ACLR = 60 (dB/8MHz) BS interfering signal e.i.r.p. = 56 dBm ; PMR cell range = 1.74 km; P of DTT coverage without interference = 95%; Number of events simulated = 400000				
DTT Tx -Rx distance (km)	DTT Rx PI (%); BS ACLR = 60 dB/8 MHz (IBE +OOBE)	Median iRRS Unwanted (dBm)	Median iRRS Blocking (dBm)	DTT received signal level (dBm)
38.6	14.24	-104.83	-104.75	-68.12
36.6	11.63	-104.83	-104.75	-66.69
34.6	9.35	-104.83	-104.75	-65.19
32.6	7.42	-104.83	-104.75	-63.69
30.6	5.8	-104.83	-104.75	-62.09
28.6	4.4	-104.86	-104.77	-60.48
26.6	3.45	-104.85	-104.76	-58.8
24.6	2.63	-104.83	-104.75	-57.02
20.6	1.51	-104.83	-104.75	-53.28

Probability of interference* to DTTB reception in the DTTB coverage area (dRSS = -68 dBm) LTE PMR (5 MHz, Guard Band = 2.5 MHz) ; LTE BS ACLR = 60 (dB/8MHz) BS interfering signal e.i.r.p. = 56 dBm ; PMR cell range = 1.74 km; P of DTT coverage without interference = 95%; Number of events simulated = 400000				
16.6	0.832	-104.83	-104.75	-49.08
12.6	0.46	-104.83	-104.75	-44.33
8.6	0.298	-104.88	-104.8	-38.88
4.6	0.29	-104.81	-104.73	-35.86
0.6	0.29	-104.85	-104.76	-18.86

Based on the analysis performed and the results presented above it can be concluded that:

- The reduction of the Out-of-Band Emissions (OOBE) of the LTE PMR BS with a higher ACLR reduces the interference into DTT reception.
- DTT receivers close to the DTT transmitter are more robust to interference. When the distance from the DTT transmitter increases, the DTT receiver becomes more and more sensitive to the interference from LTE PMR BS due to the lower strength of the wanted DTT signal received.
- The analysis in the whole DTT coverage area is not sufficient by itself to provide the information required to take appropriate measures for the protection of DTT reception. The probability of interference is much higher at the cell edge and in areas close to the cell edge compared to areas where the DTT receiver is close to the DTT transmitter. Also, DTT receivers closer to the DTT transmitter contribute significantly to the reduction of the average interference resulting in a lower PI to DTT .
- There might not be the same need for uniform solution to mitigate the LTE BS interference throughout the whole DTT coverage area. Therefore, there could be a relaxation on filtering for LTE PMR BS located closer to the DTT transmitter. According to the results presented in Figure 69, an ACLR of 60 dB/8MHz could be sufficient for LTE PMR BS located around the DTT receivers which are at a distance lower than 25 km from their transmitter.

Different approaches can be followed in order to define the framework for the introduction of LTE systems where DTT is deployed:

- An approach based on a constant ACLR of the LTE BS transmitter;
- An approach based on a constant OOBE limit of the LTE BS transmitter;
- A combination of the two methods.

The figure below illustrates how each method would impact the PI of LTE BS to DTT reception.

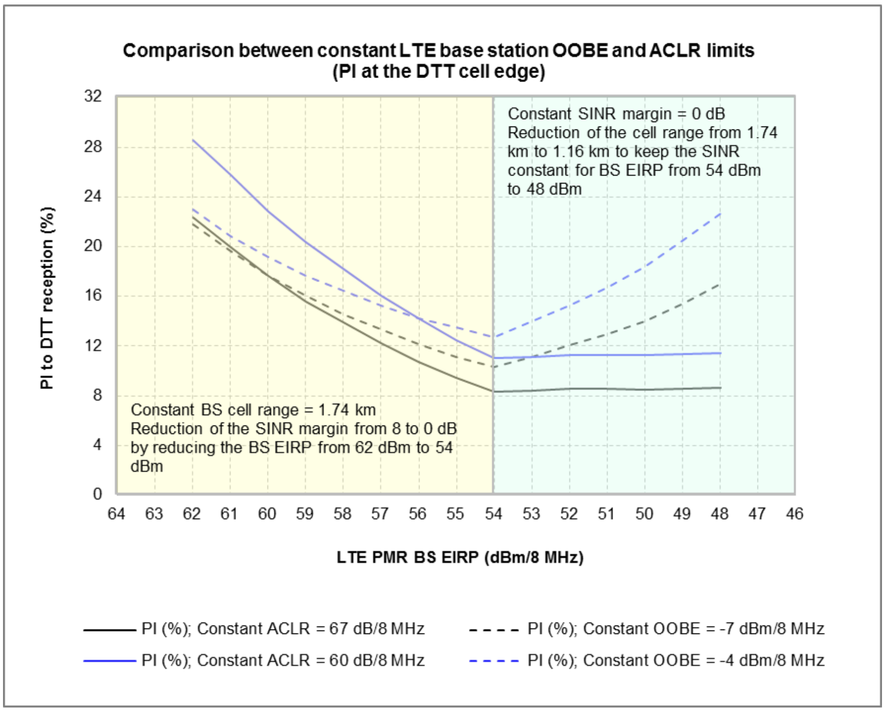

Figure 70: Comparison between constant OOBE and fixed ACLR for the PI at the DTT cell edge

The figure above shows the evolution of the PI to DTT for a constant ACLR of the LTE BS and for a fixed OOBE of the LTE BS. In this figure, e.i.r.p. is higher than 54 dBm correspond to a constant coverage approach where he reduction on e.i.r.p. implies a reduction of the Signal to Interference and Noise Ratio (SINR) margin that is balanced at 54 dBm. For e.i.r.p. below 54 dBm, they correspond to a constant throughput approach where the SINR margin is fixed at 0 dB, which implies that a reduction of the e.i.r.p. reduces the LTE cell range.

From the curves it can be concluded that in general a constant ACLR provides lower PI than a constant Out-of-Band Emissions (OOBE), except for high values of e.i.r.p. where limiting the OOBE shows better results given that the level of the signal resulting from the difference between e.i.r.p. and ACLR is greater than the constant OOBE (i.e. e.i.r.p.–constant ACLR > constant OOBE). Consequently, for high values of e.i.r.p., the constant ACLR would generate more interference and for low e.i.r.p. values, a constant OOBE level would generate more interference than a constant ACLR of the LTE BS where e.i.r.p.-constant ACLR < constant OOBE (see ACLR = 67 dB/8MHz vs OOBE = -7 dBm/8MHz and ACLR = 60 dB/8MHz vs OOBE=-4 dBm/8MHz). If a constant OOBE value is defined, it will not be possible to minimise the PI to DTT reception in the case of low e.i.r.p. for LTE PMR BS as clearly shown in the figure.

Finally, it can be observed than under the constant throughput approach, where the LTE cell range is reduced with a reduction of the e.i.r.p., while the PI keeps constant for constant ACLR given that the limiting factor is the receiver ACS, the PI increases in the case of constant OOBE limit due to the reduction of the distance between the transmitting LTE BS and the DTT receiver.

As a result from this analysis that can be seen in the figure above, it can be concluded that the optimal solution would consist of having a constant OOBE limit for high values of e.i.r.p. and a constant ACLR for lower values of e.i.r.p., with a boundary at e.i.r.p. = 60 dBm for black curves and e.i.r.p. = 56 dBm for blue curves. Such an approach that was used in CEPT Report 30 and ECC Report 240 would ensure that the PI of LTE into DTT reception is minimised for any LTE BS e.i.r.p..

Implementation of the required ACLR for the LTE PMR BS

Simulations performed show that the interference from LTE PMR BS to DTT reception is not acceptable for the LTE base station emission mask derived from ETSI TS 136 104 (ACLR = 45 dB/8MHz), and additional reduction of the LTE BS OOBE is required by about 22 dB to achieve an ACLR of 67 dB/ 8MHz.

Although this seems to be a constraint for the deployment of LTE networks in the 400 MHz band, measurements performed on existing equipment reveal that LTE BS already deployed on the field present a reduction of more than 65 dB in the adjacent channel, as illustrated in the figure below (see also Section A9.5).

It is therefore expected that LTE PMR BS provided for the operation in the 400 MHz be capable of fulfilling, without any difficulty, the requirement of ACLR = 67 dB/8MHz when the protection of DTT reception is required.

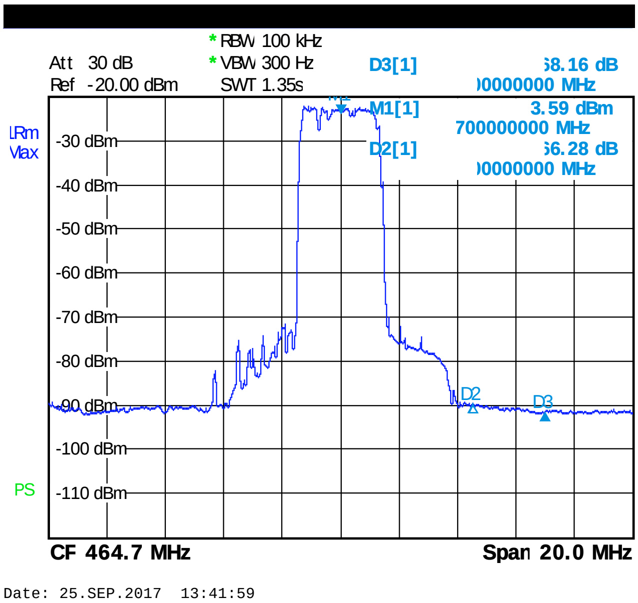

Figure 71: LTE BS transmitter over the air measurement

6.4.4.3 *Conclusions*

The simulation results show that the impact of the LTE PMR (5 MHz) BS with an e.i.r.p of 59 dBm on the DTT reception above 470 MHz, with a guard band of 3 MHz, is similar to that of the LTE based BB-PPDR (3 MHz) BS with an e.i.r.p. of 60 dBm. The reduction of the guard band between DTT and LTE PMR from 3 MHz to 2.5 MHz has a minor impact on the PI to DTT reception at the DTT cell edge. It increases the PI to DTT reception only from 14.9% to 15.6% for a LTE PMR BS ACLR of 67 dB/8MHz.

The improvement of LTE PMR BS ACLR from 45 to 67 dB/8 MHz reduces considerably the PI to DTT reception on Channel 21 from 68.2% down to 17.6% for a LTE PMR BS e.i.r.p. of 60 dBm. Note that the improvement from 60 to 67dB/8MHz is from 22.5% to 17.64%. The improvement of the ACLR beyond 67 dB, corresponding to an OOBE level of -7 dBm/8 MHz, does not improve notably the PI to DTT reception due to the limiting factor of the DTT ACS which is 61 dB.

Finally, it is concluded that the maximum out-of-band emissions limit of -7 dBm/8 MHz for e.i.r.p equal to or higher than 60 dBm/8MHz and a constant ACLR of 67 dB for e.i.r.p. lower than 60 dBm/8MHz ensure to minimize the impact of LTE PMR systems into DTT reception in the 400 MHz band under any condition. Based on information from existing equipment already deployed in the 400 MHz band, the proposed value of ACLR = 67 dB/8MHz can be fulfilled by LTE BS equipment. These values are similar to those defined for LTE based BB-PPDR base stations in ECC Decision (16)02 which could therefore apply to LTE PMR base stations in the 400 MHz band as well.

At a national level, the out-of-band limit might be relaxed. For example, with a sparse network deployment, using high remote sites, such as those used for DTT, the probability of interference to DTT reception is significantly reduced. Such a deployment has been successfully implemented in Scandinavian countries. Also, the requirement on the ACLR of the LTE PMR BS can be relaxed when the victim DTT receiver is located close to the DTT transmitter so that the received DTT signal is strong enough to mitigate the interferer. Further mitigation measures, as described in ANNEX 9: may allow solving possible remaining interference, on a case by case basis.

6.4.5 LTE eMTC and NB-IoT impact on DTT reception

6.4.5.1 *Analysis*

LTE BS cell range used in the eMTC and NB-IoT studies is 5.868 km.

Table 69: LTE eMTC BS impact on DTT reception

LTE eMTC BS Probability of interference on DTT reception averaged over its coverage area LTE BS cell range = 5.868 km Number of events simulated = 200 000			
LTE centre Frequency	LTE system bandwidth	LTE Transmitted power	Probability of interference
465 MHz	5 MHz	43 dBm	0.19%
466 MHz	3 MHz	41 dBm	0.15%
466.8 MHz	1.4 MHz	37.5 dBm	0.15%

LTE Guard band (GB) NB-IoT

The LTE system in this study is LTE eMTC with GB NB-IoT added. 5 MHz LTE system is simulated as this leaves enough bandwidth available in the guard band for GB NB-IoT to be deployed.

Table 70: LTE eMTC BS :with GB NB-IoT Probability of interference on DTT reception averaged over its coverage area

LTE eMTC BS :with GB NB-IoT Probability of interference on DTT reception averaged over its coverage area LTE BS cell range = 5.868 km Number of events simulated = 200 000			
LTE centre Frequency	LTE system bandwidth	LTE Transmitted power	Probability of interference
465	5 MHz	43 dBm	0.25%

LTE standalone NB-IoT

The LTE system in this study is 200 kHz LTE standalone NB-IoT.

Table 71: LTE standalone NB-IoT impact on DTT reception

LTE standalone NB-IoT BS with Probability of interference on DTT reception averaged over its coverage area LTE BS cell range = 5.868 km Number of events simulated = 200 000			
LTE centre Frequency	LTE system bandwidth	LTE Transmitted power	Probability of interference
467.2	200 kHz	43 dBm	0.02%

6.4.5.2 *Conclusion*

The SEAMCAT Monte Carlo studies show a probability of interference on DTT reception of 0.19% and below for LTE eMTC BS impact on DTT reception. When GB NB-IoT is added on top of 5 MHz LTE eMTC the probability of interference is 0.25%. The SEAMCAT Monte Carlo study on LTE NB-IoT BS standalone shows probability of interference of 0.02% on DTT reception. It is therefore concluded that LTE eMTC BS emission limits specified in 3GPP TS 36.104 Table 6.6.3.2.1-1, 6.6.3.2.1-2 and 6.6.3.2.1-3 provides sufficient protection for DTT reception. It is also concluded that LTE NB-IoT standalone BS emission limits specified in 3GPP TS 36.104 Table 6.6.3.2E-1 provides sufficient protection for DTT reception.

6.4.6 LTE UE impact on DTT reception

6.4.6.1 *Principle of the analysis*

For this scenario, the interfering user equipment (UE) is randomly positioned, following a uniform distribution, within each cell of the LTE PMR cluster around the DTT receiver (Rx) and within an area that is determined by the LTE cell range (see the Figure 72). The Monte Carlo analysis is performed to assess how much the DTT receiver is statistically impacted by the variations of the operation of UE, which implies mutually:

- The UE position around the DTT Rx;
- The UE effective power defined by the power control mechanism of the system;
- The number of simultaneously transmitting UE;

The impact of the propagation channel variations.

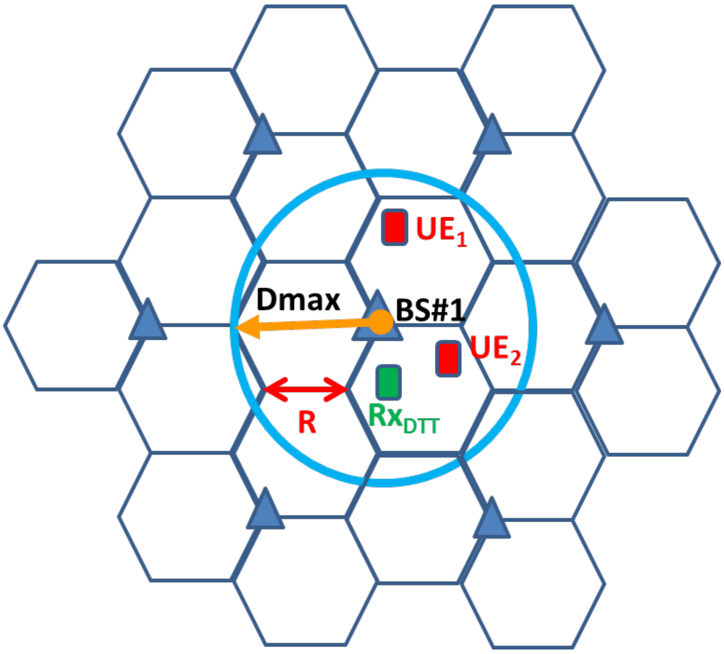

Figure 72: Position of interfering UEs around the DTT receiver inside the cluster

The simulations are carried out with a guard band of 2.5 MHz for three different UE densities as shown in the table below.

Table 72: LTE PMR UE densities

Environment	Urban			
LTE PMR sector range (km)	LTE PMR Sector area (km2)	N_active_UE/sector	Number of RB/UE	Density (1/km2)
1.74	1.966	1	25	0.509
		2	12	1.017
		4	6	2.034

UE OOBE limits are defined for full channel bandwidth occupation in 3GPP specification TS 36.101. Both simulations and laboratory measurements show that when a UE is transmitting in a partial band depending on the number of resource blocks used, its OOBE level is reduced, thus a correction factor should be applied. The correction factor of UE OOBE form 25 RB (1 UE) to 12 RBs or more (2 UE or more) is 7 dB.

Most of the simulations are carried out for 5 MHz (25 RB) LTE PMR system.

6.4.6.2 *Considerations on the time aspect in the assessment of interference*

Description

The objective of this section is to reconcile the use of Monte Carlo approach with the need to take into account time element by converting the Probability of Interference (PI) into a probability which would better reflect the impact of interference on the TV viewer.

Method

If Interference Probability (IP) is the interference probability derived from the Monte Carlo simulations and C is the number of network state changes during a certain time window (TW), assuming that two consecutive network states are independent (not correlated), then the probability of TV viewer observing LTE UE causing at least one harmful interference to DTT reception is given by:

$$Pd = 1 - (1 - PI)^{C}$$

Such probability Pd could be understood as the probability of having a disruption of duration DT (decorrelation time) when watching TV during a given TW (time window). This time window should reflect what is considered acceptable for the TV viewer.

C is calculated as follows

C = TW/DT

where:
- TW: time window;
- DT: average "decorrelation" time between two consecutive network states for one active uplink data user.

The average "decorrelation" time reflects the fact that when a terminal is interfering with the broadcasting receiver, it will keep the resource of the network for a certain time before this resource is allocated to another terminal which may, or may not, cause interference to the broadcasting receiver.

Some contributions to the third mobile-DTT correspondence group meeting in October 2013 indicate a TW equal to one hour. The basis for this value could be an average viewing time for a given TV program.

The range of DT could be:
- from 1 ms which is the subframe time: it is not realistic to assume that each terminal will transmit;
- to the full time window. If this time window is as large as one hour, this is neither realistic since it would assume that each terminal is permanently transmitting traffic data (other than signalling). In addition, for such large time, the movement of the terminal would also create another dimension of decorrelation, since the interference potential could significantly vary between the positions of the terminal during one hour.

Moreover, DT depends on the UE density and the services used by the latter as well as their mobility. For a given service and UE density:
- Time interval has to be short enough so that the network state does not change during the time interval;
- Time interval has to be large enough so that the consecutive network states are de-correlated.

But it is felt possible to derive an average "decorrelation" time considering the various International Mobile Telecommunications (IMT) services. Time window method has been used to evaluate the impact of LTE-700 and LTE based BB-PPDR on DTT reception:

In the first case, based on the information provided by the mobile operators, DT of 1 s, 10 s and 100[9] s were used to calculate the probability of disruption (Pd) to DTT reception.

In the second case, the operation of the BB-PPDR UE is only considered effective during short-term interventions, the birth and death process of the UEs represented by Markov chain. Consequently, DT used was very long: 1.85 to 20 min (see ECC Report 239).

[9] These values of DT (i.e. 1, 10 and 100 seconds) are indicative intervals between two consecutive network states for one active uplink data user, but are not representative for a specific type of network.

In this study it can be considered that the operation of the LTE PMR UE will not be limited only to short-term interventions as BB PPDR. On the other hand, their density and the services used by the latter as well as their mobility will be more limited than LTE-700/LTE-800. Consequently, DTs of 10 s, 30 s and 60 s have been used to calculate the LTE PMR Pd to DTT reception. DT of 1 s is considered to be too short in the case of LTE PMR networks.

Results

The results of the simulations are summarised in Table 73 and Table 74.

Table 73: Impact of the LTE PMR UE on DTT reception

Probability of interference to DTT reception at the DTT cell edge (dRSS = -68 dBm) LTE PMR (5 MHz) UE interfering signal (e.i.r.p = 20 dBm); DTT/ PMR Guard Band = 2.5 MHz; PMR cell range 1.74 km				
Time window (s)	3600			
N_active_UE/sector	Number of RB/UE	Density (1/km2)	PI	PI (%)
1	25	0.508521838	3.52E-05	0.00352
2	12	1.017043677	4.11E-05	0.00411
4	6	2.034087353	1.06E-04	0.01060

Table 74: Impact of the LTE PMR UE on DTT reception

Probability of disruption of DTTB reception during a time window at the DTT cell edge (dRSS = -68 dBm) LTE PMR (5 MHz) UE interfering signal (e.i.r.p = 20 dBm); DTT/ PMR Guard Band = 2.5 MHz; PMR cell range 1.74 km			
Time window (s)	3600		
N_active_UE/sector	Number of RB/UE	PI	PI (%)
1	25	3.52E-05	0.00352
2	12	4.11E-05	0.00411
4	6	1.06E-04	0.01060
Decorrelation time (s)	10	C (N of network state changes)	360
N_active_UE/sector	Number of RB/UE	Pd	Pd (%)
1	25	0.01259	1.26
2	12	0.01469	1.47
4	6	0.03744	3.74
Decorrelation time (s)	30	C (N of network state changes)	120
N_active_UE/sector	Number of RB/UE	Pd	Pd (%)
1	25	0.00422	0.42

Probability of disruption of DTTB reception during a time window at the DTT cell edge (dRSS = -68 dBm) LTE PMR (5 MHz) UE interfering signal (e.i.r.p = 20 dBm); DTT/ PMR Guard Band = 2.5 MHz; PMR cell range 1.74 km			
2	12	0.00492	0.49
4	6	0.01264	1.26
Decorrelation time (s)	60	C (N of network state changes)	60
N_active_UE/sector	Number of RB/UE	Pd	Pd (%)
1	25	0.00211	0.21
2	12	0.00246	0.25
4	6	0.00634	0.63

The above results show that, with a LTE PMR UE ACLR of 65 dB/8 MHz, resulting in a UE OOBE level of -42 dBm/8 MHz for a maximum transmitted power of 23 dBm, the interference from LTE UE to DTT receiver is very low, when the UE Tx power range is from -40 to 23 dBm (use of the LTE power control). For all the used UE densities, the probability of interference (PI) and probability of disruption (Pd) to DTT reception are less than 0.02% and 4% respectively.

The results also show that the PI to DTT reception increases with the increase of the number of active UE per cell. It is important to know if this increase is mainly due to the in-block emission (IBE) or OOBE of UE. This point has been verified by simulation. The obtained results are presented in Table 75: Impact of the LTE PMR UE OOBE on DTT reception

below.

Table 75: Impact of the LTE PMR UE OOBE on DTT reception

Impact of the LTE PMR UE OOBE on DTT reception (dRSS = -68 dBm) in the presence of more than 1 UE per BS cell (e.i.r.p = 20 dBm)					
N_active UE/sector	Number of RB/UE	ACLR* (dB/8 MHz)	iRRS Unwanted (dBm)	iRRS Blocking (dBm)	Interference Probability (IP)
2	12	65	-176.19	-168.98	4.11E-05
2	12	70	-180.86	-168.64	3.93E-05
4	6	65	-168.89	-161.67	1.06E-04
4	6	75	-179.25	-162.04	1.03E-04
*Effective ACLR = 72, 77, 72 and 82 dB/8 MHz, due to occupation bandwidth correction factor of 7 dB					

The results presented in the above table reveal that the increase of the IP to DTT reception with the increase of the number of active UE per cell is mainly due to the in-block emission (IBE) of UE. The improvement of the OOBE level below -42 dBm/8 MHz of UE would not improve notably the PI due to the limiting factor of the UE IBE power (23 dBm).

Conclusions

In the case of a moving source of interference (LTE PMR user equipment), the implementation of interference mitigation techniques is much more difficult than in the case of a fixed source of interference (LTE PMR base station) as the interference is transient and therefore difficult to identify. Also, because of the unpredictable nature of the interference coming from a moving source, the PI to DTT reception needs to be low.

The results of the study reveal that, with a LTE PMR UE ACLR of 65 dB/8 MHz resulting in a UE out-of-band emissions level of -42 dBm/8 MHz above 470MHz, the interference from LTE UE to DTT receiver is very low, in particular when the UE Tx power range is from -40 to 23 dBm (use of the LTE power control) For all the used UE densities, the probability of interference (PI) and probability of disruption (Pd) to DTT reception are less than 0.02% and 4% respectively.

Note that the PI to DTT reception increases with the increase of the number of active UE per cell, but this increase is mainly due to the in-block power of UE. The improvement of the OOBE of the UE does not improve notably the PI due to the limiting factor of the UE in-block power (23 dBm).

Consequently, it is concluded that the OOBE limit of -42 dBm/8 MHz, defined for the UE of LTE based BB-PPDR in ECC Report 240 as well as in ECC Decision (16)02, also applies to the UE of LTE PMR.

Given the high number of events considered, it is reasonable to assume that this analysis and the resulting conclusions above encompass the MCL Worst-case study.

6.4.7 LTE NB-IoT UE impact on DTT reception

SEAMCAT simulations between NB-IoT UE and DTT Channel 21 have been performed using the parameters described in A1.1 and A1.6 and assuming a NB-IoT UE unwanted emission level above 470 MHz of -42 dBm/8MHz. BB-PPDR devices were used in ECC Report 240 which compared to NB-IoT devices, can use many RBs simultaneously, have higher transmit power and are mainly outdoor.

Two scenarios have been simulated. Scenario 1 describes the case on which fixed DTT receivers are located at the DTT cell edge while in scenario 2 DTT receivers are randomly located within the DTT cell area. The NB-IoT network is intentionally placed around the DTT receiver to ensure proximity between the NB-IoT UE and the DTT receiver. In both scenarios the NB-IoT UEs are placed within 50 meters of the DTT receivers. 3 MHz bandwidth is used for the LTE base station where 15 UEs are actively transmitting in both of the scenarios with one RB each of 180 kHz. Transmit power for the NB-IoT UEs are power controlled between -40 to 23 dBm.

Table 76: Probability of interference for scenarios 1 and 2

Scenario	Pinterference (%)
Scenario 1	4.59
Scenario 2	0.00

Note: UEs are placed within 50 meters of the DTT receivers; therefore these results are not comparable to the PMR UE impact on DTT reception.

6.5 OVERALL CONCLUSIONS ON THE LTE IMPACT ON DTT ABOVE 470 MHZ

The studies carried out in this Report for LTE based PMR systems in the 400 MHz band concluded on a set of out-of-band emissions (OOBE) from base stations and user equipment based on their ACLR.

6.5.1 Conclusion on the LTE BS impact on DTT

The compatibility studies are carried out in this report for LTE based PMR systems in the 400 MHz band with various base station (BS) e.i.r.p. in the range of 48-62 dBm and with a DTT receiver ACS of 61 dB. The analyses concluded that an ACLR of 67 dB/8MHz would be required to minimise the interference from LTE BS to DTT reception, irrespective of the bandwidth and the activity factor as long as the LTE BS e.i.r.p. is below 60 dBm. For a BS e.i.r.p above 60 dBm, the ACLR needs to be improved in such a way that the BS OOBE do not exceed the value of -7 dBm/8MHz.

It should be noted that all BS in the modelled LTE network may not operate at the same time with full buffer packet traffic. Therefore, although the optimal ACLR for LTE BS remains the same, when there is intermediate protection for DTT service, the requirement of LTE BS ACLR could be relaxed (e.g. -4 dBm/8MHz corresponding to an ACLR of 60 dB/8MHz).

These requirements for LTE PMR base stations are summarised in Table 77 below.

Table 77: PPDR LTE 400 Base Station e.i.r.p. and OOBE levels for protection of DTT above 470 MHz

Frequency range	Condition on Base station in-block e.i.r.p. P (dBm/cell)	Maximum mean OOBE e.i.r.p (dBm/cell)	Measurement bandwidth
For DTT frequencies above 470 MHz where broadcasting is protected (NOTE 1)	P ≥ 60	-7	8 MHz
	P < 60	(P – 67)	8 MHz
For DTT frequencies above 470 MHz where broadcasting is subject to an intermediate level of protection or when mitigation techniques are used (NOTE 2)	P ≥ 56	-4	8 MHz
	P < 56	(P – 60)	8 MHz

NOTE 1: Based on these results, it can be concluded that the limits defined for the base stations of LTE based BB-PPDR in ECC Decision (16)02, should apply to the base stations of LTE based PMR/PAMR as well.

NOTE 2: At a national level where the proposed implementation differs from usual mobile network deployment the OOBE limits of BS might be relaxed (See ANNEX 9 for a list of possible mitigation techniques / measures).

Other mitigation mechanisms (beyond the BEM baseline) would ultimately be required if the protection delivered by the BEM only is considered insufficient by administrations, e.g. by means of additional measures at the national level, see Annex 9.

Additionally, based on the results presented in this report, it can be concluded that LTE eMTC and NB-IoT BS provide a better context of compatibility with DTT than LTE BS.

6.5.2 Conclusion on the LTE UE impact on DTT

The MCL studies have shown that the unwanted emissions above 470 MHz need to be adequately limited in order to minimise interference. To protect DTT in Channel 21 on the criteria of a receiver sensitivity degradation limited to 1 dB, the MCL analysis shows that the LTE unwanted emission level should not exceed -70 dBm/8 MHz for fixed reception and -75 dBm/8 MHz for portable reception. This is derived under the condition of DTT ACS values of 80 dB and 85 dB, respectively.

It should be noted that LTE includes power control for the UEs and that the UEs are moving devices. Monte Carlo simulations are therefore useful to assess the impact of LTE UE into DTT, provided however that time can be taken into consideration (i.e. to assess the probability of disruption to DTT reception in 1 hour).

From the Monte Carlo simulations including time-domain considerations, it is concluded that the OOBE limit of -42 dBm/8 MHz, defined for the UE of LTE based BB-PPDR in ECC Decision (16)02, also applies to the UE of LTE PMR/PAMR. This requirement for LTE PMR UE is summarised in Table 78below.

Table 78: LTE UE OOBE level for protection of DTT above 470 MHz

Frequency range	User equipment maximum mean OOBE	Measurement bandwidth
For DTT frequencies above 470 MHz where broadcasting is protected	- 42 dBm	8 MHz

NB-IoT UE can coexist with DTT.

7 IMPACT OF LTE AT 410-430 MHZ ON RADARS

7.1 INTRODUCTION

This Report analyses the conditions required for the deployment of Long-term Evolution (LTE) systems in the band 410-430 MHz without causing harmful interference to radiolocation systems operating in the overlapped band 420-430 MHz or in the adjacent band (430-440 MHz). The analysis focuses mainly on the impact of LTE BS on radar receiver. The effect of the LTE based BB-PPDR UL on the radiolocation system was already addressed in the ECC Report 240 with 37 dBm e.i.r.p. of UE. Additionally, in ECC Report 240 it is demonstrated that compared to saturation, desensitisation of the radar receiver is the most constraining impact from LTE systems.

It is recalled that in Article 5 of the Radio Regulations (RR), the allocation in Region 1 to the radiolocation service is secondary in the band 420-430 MHz and primary in the band 430-440 MHz. Therefore, the base station transmitting in the band 420-430 MHz operates under a co-channel basis with radars within this band whereas it operates under adjacent band basis when the radar operates above 430 MHz. Given the allocation in the RR, the protection of radiolocation systems is mandatory only for the band 430-440 MHz, although minimization of interference within the band 420-430 MHz is also desirable.

The previous calculations contained in ECC Report 240 showed that LTE based BB-PPDR systems operating in the band 420-430 MHz would cause severe desensitisation of radars. Indeed, on co-channel case, to avoid the radar receiver desensitisation, calculations lead to an exclusion zone larger than 400 km for airborne radars considering free space propagation loss and the range of 230 km for ground radars considering a statistic propagation model (EPM73) (see section 3.7 of ECC Report 240).

Additional calculations showed that for LTE based BB-PPDR base stations operating in the band 420-430 MHz with a deterministic propagation model (taking into account terrain and clutter data) and at a determined location, calculations lead to a needed exclusion zone of about 120 km on co-channel situation and 40 km on adjacent channel situation around ground radar. However, these analysis performed rely on some deterministic propagation models using parameters which depend on the location considered, therefore the resulting conclusions may not be valid for all places and environments and therefore the results should not be generalized so as to derive conclusions which apply everywhere and in all circumstances. In any case, these results confirm those already recorded in ECC Report 240 if no mitigation technique is applied on LTE systems, i.e. the separation distance needed between LTE systems and radars would not be negligible.

In ECC Report 240, the conducted study shows that LTE-based PPDR systems operating in the 420-430 MHz cannot work co-channel with radiolocation radars, because PPDR systems would cause severe desensitisation of radars resulting in wide exclusion zones (more than 400 km). Operation in adjacent band requires exclusion zones of 2.3 km and 3.8 km for airborne and ground radiolocation radars respectively, due to saturation phenomenon which cannot be solved with filtering. Therefore co-located operation of PPDR networks and radiolocation radars is not possible. Out of band emissions of LTE systems falling into radiolocation radars band need to remain below -114 dBm/MHz in order to avoid desensitisation.

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7.2 ASSUMPTIONS AND CALCULATION METHOD

7.2.1 General assumptions

The following inputs were taken into account:

- The band 410-430 MHz is allocated to the mobile, except aeronautical mobile service on a primary basis, according to the Radio Regulations (RR);
- The band 420-430 MHz is also allocated to the radiolocation service on a secondary basis in all ITU-R Regions (the radiolocation service is allocated for 29 CEPT countries out of 48 on a secondary basis and the only exception is the UK where it is allocated on a primary basis based on RR footnote No. 5.269);

- Only fixed and mobile applications have been registered in the band 410-430 MHz according to the ITU database and BR IFIC;
- Radars operating on a primary basis have been registered to the ITU only above 430 MHz;
- The LTE parameters are based on 3GPP Release 12 and the radar parameters are based on Recommendation ITU-R M.1462;
- The LTE uplink (UL) is located in the band 410-420 MHz and the downlink (DL) is located in the band 420-430 MHz (duplex spacing is always 10 MHz);
- The band 420-430 MHz is heavily used by both narrowband (NB) and wideband (WB) PMR/PAMR with no reported interference issues;
- The exclusion zone is 40 km of the Fylingdales Radar station for frequencies between 420 MHz and 450 MHz according to Ofcom UK (i.e. Ofcom does not allow any Business Radio assignments, within 40 km);
- There are countries (e.g. Croatia, Hungary and Serbia) that have already concluded multilateral preferential frequency agreement in the band 410-430 MHz making it possible that systems using channel bandwidth higher or equal to 1.4 MHz may also be introduced without having to take into account the secondary radiolocation service.

7.2.2 Assumptions for radiolocation

Radiolocation systems in the band 420-430 MHz extend over a very long range, and uses include object identification, tracking, and cataloguing. Radar characteristics are defined in Recommendation ITU-R M.1462 [15]. This band is also listed in the NATO Joint Civil/Military Frequency Agreement (NJFA) and NATO harmonised for these radiolocation systems.

The band 420-450 MHz is the tuning range of airborne, shipborne and ground based radars, as described in ITU-R Recommendation M.1462. There is no information about transportable radars in Recommendation ITU-R M.1462, but these radars are likely to have lower sensitivity (lower antenna gain). This Report focuses on fixed ground and airborne radars, because these are the most sensitive to the interference.

Radiolocation applications operating in 420-450 MHz are not limited to French and UK territories as it could be concluded based on EFIS database. Indeed, usage of systems includes at least the areas over international waters (i.e. generally 12 NM -nautical miles- away from the coasts considering low water marks) in particular for aeronautical radars. With this regard, radiolocation applications operating from around 22 km away from the coasts of any country need to be protected from any possible harmful Out-of-Band Emissions (OOBE)falling in 430-440 MHz as radiolocation is a primary service in this band. For the analysis, only radar desensitisation is evaluated as this is the condition that determines the most the cohabitation with LTE systems (e.g. separation distances) compared to saturation or the radar receiver. To avoid radar desensitisation, a power level of -114 dBm/MHz or below is permitted for the interferer, in accordance with ECC Report 240.

7.2.3 Assumptions for LTE based BB-PPDR

In order to evaluate co-existence, the following assumptions were used in the calculations for ground and airborne radars:

- Several LTE carrier bandwidths (1.4 MHz, 3 MHz and 5 MHz) were applied;
- Conditions for the co-existence of LTE and radars were based on the impact of LTE on radars and not focused on the impact of radars on LTE networks;
- The calculations focused mainly on the LTE downlink band (420-430 MHz), due to the fact that radar operating band is overlapping within this sub-band;
- The mobile terminals in the LTE uplink band (410-420 MHz) do not impact on desensitisation of the radar receiver, because the low power (23 dBm) UEs and UL band does not overlap with radars;
- LTE parameters were derived from existing 3GPP LTE specifications (Release 12 [29], [30]).

In order to evaluate co-existence, the following assumptions were used in the calculations for ground radars in adjacent scenario:

- Real environment (terrain and topographical conditions) was used to investigate the interference situations (e.g. hilly and flat rural areas);

- More sophisticated and calibrated radio wave propagation models such as General Okumura-Hata (COST-231) and MYRIAD were used in the selected areas;
- Virtual LTE network was planned with real antenna parameters (Kathrein for LTE BSs and omnidirectional for UEs) and real LTE parameters (3GPP Release 12);
- The planning consideration for the traffic was to build a network with a 50% static load inside of each cell and a 50% load at the cell border. This means it is not created a location based traffic map and not calculated with dynamic Monte-Carlo simulation in the territory, which is good assumption to assess the interfering signal to the ground radar receiver. Taking into consideration our method to assess the ground radar interfering signal to the downlink of the LTE network (420-430 MHz), it is perfectly appropriate to use static steady load, set to 50%, as a general average load (this is a normal assumption of radio planners).

7.2.4 Basic parameters for LTE based BB-PPDR and radars

The following parameters are considered for LTE and radar systems. The LTE parameters are similar to those provided in ECC Report 240, but take into account the amendments considered to enhance the results of the previous study and facilitate the compatibility. With respect to radar parameters, they are similar to those of ECC Report 240 and compliant to Recommendation ITU-R M.1462.

Table 79: LTE and radar parameters

LTE		Military radars		
	Base station		Airborne	Ground
B_{LTE} [MHz]	1.4, 3, 5	B_{RADAR} [MHz]	1	1
P_{LTE} [dBm]	43 dBm / 5MHz 41 dBm / 3MHz 37.5 dBm/ 1.4MHz	B_{th} [dBm]	-108.9	-109.9
G_{LTE} [dBi]	15	I/N [dB]	-6	- 6
Feeder Loss [dB]	2	P_{PS} [dBm] (B_{th}+I/N)	-114.9	-115.9
e.i.r.p.$_{LTE}$ [dBm]	56 dBm / 5MHz 54 dBm / 3MHz 50.5 dBm / 1.4MHz	G_{RADAR} [dBi]	22	38.5
Emission mask	Annex 13	Saturation level [dBm]	-15	-10
h_{LTE} [m]	30	h_{RADAR} [m]	> 9000	8
Polarisation	Vertical	Polarisation	Horizontal	Circular
		Antenna type d_{RADAR}	Yagi or planar array	Planar array diameter 22 m
		Antenna beamwidth	3-20° elevation (depending on scan type) 6° azimuth	2.2° elevation 2.2° azimuth
		Sidelobes (receive) [dB]		-30

7.2.5 Calculation method

7.2.5.1 *Method for ground radars in co-channel scenario*

To avoid radar desensitisation, the required propagation loss is calculated as follows:

$$L_{prop} \geq e.i.r.p._{LTE} - P_{ps} + G_{RADAR} + 10\log\left(\frac{B_{RADAR}}{B_{LTE}}\right) - DEC_{pol} - DEC_{ant}$$

For the various LTE bandwidths, this corresponds to:

1.4 MHz LTE carrier: $L_{prop} = 50.5 - (-115.9) + 38.5 + 10\log(1/1.4) - 1.5 - 3 = 198.9\ dB$

3 MHz LTE carrier: $L_{prop} = 54 - (-115.9) + 38.5 + 10\log(1/3) - 1.5 - 3 = 199.2\ dB$

5 MHz LTE carrier: $L_{prop} = 56 - (-115.9) + 38.5 + 10\log(1/5) - 1.5 - 3 = 198.9\ dB$

The necessary propagation loss is around 200 dB.

7.2.5.2 *Method for ground radars in adjacent channel scenario*

To avoid radar desensitisation, the required propagation loss is calculated as follows:

$$L_{prop} \geq e.i.r.p._{unwantedemLTE} - P_{ps} + G_{RADAR} - DEC_{pol} - DEC_{ant}$$

The worst-case scenario assumes coupled main lobes, DEC_{pol} = 1.5 dB, DEC_{ant} = 0 dB.

For the various LTE bandwidths, this corresponds to:

1.4 MHz LTE carrier: $L_{prop} \geq (50.5 - 45) - (-115.9) + 38.5 - 1.5 - 0 = 158.4\ dB$

3 MHz LTE carrier: $L_{prop} \geq (54 - 45) - (-115.9) + 38.5 - 1.5 - 0 = 161.9\ dB$

5 MHz LTE carrier: $L_{prop} \geq (56 - 45) - (-115.9) + 38.5 - 1.5 - 0 = 163.9\ dB$

The necessary propagation loss is around 160 dB for the three cases.

Assuming non-coupled main lobes, the side lobe of the radar antenna can be considered. The side lobe is attenuated by a minimum of 30 dB, and the path loss will be modified with DECant = 30 dB within this range.

The necessary propagation loss is around 130 dB.

1.4 MHz LTE carrier: $L_{prop} \geq (50.5 - 45) - (-115.9) + 38.5 - 1.5 - 30 = 128.4\ dB$

3 MHz LTE carrier: $L_{prop} \geq (54 - 45) - (-115.9) + 38.5 - 1.5 - 30 = 131.9\ dB$

5 MHz LTE carrier: $L_{prop} \geq (56 - 45) - (-115.9) + 38.5 - 1.5 - 30 = 133.9\ dB$

For ground radar, the Free-space model, which requires clear Fresnel zone, would not be the most realistic propagation model to consider. For instance on the Earth, with distances of over 400 km (referring to ECC Report 240) it demands more than 14 000 m BS antenna height, if the radar antenna height is 8 m, which is clearly unrealistic. That is the consequence of the curvature of the Earth.

7.2.5.3 *Method for airborne radars in co-channel scenario*

To avoid radar desensitisation:

$$L_{prop} \geq e.i.r.p._{LTE} - P_{ps} + G_{RADAR} + 10\log\left(\frac{B_{RADAR}}{B_{LTE}}\right) - DEC_{pol} - DEC_{ant}$$

The necessary propagation loss is around 180 dB.

1.4 MHz LTE carrier: $L_{prop} = 50.5 - (-114.9) + 22 + 10\log(1/1.4) - 1.5 - 1.7 = 182.7\ dB$

3 MHz LTE carrier: $L_{prop} = 54 - (-114.9) + 22 + 10\log(1/3) - 1.5 - 1.7 = 182.9\ dB$

5 MHz LTE carrier: $L_{prop} = 56 - (-114.9) + 22 + 10\log 81/5) - 1.5 - 1.7 = 182.7\ dB$

7.2.5.4 *Method for airborne radars in adjacent channel scenario*

To avoid radar desensitisation:

$$L_{prop} \geq e.i.r.p._{unwantedemLTE} - P_{ps} + G_{RADAR} - DEC_{pol} - DEC_{ant}$$

The necessary propagation loss is around 140 dB.

1.4 MHz LTE carrier: $L_{prop} \geq (50.5 - 45) - (-114.9) + 22 - 1.5 - 1.7 = 139.2\ dB$

3 MHz LTE carrier:

5 MHz LTE carrier: $L_{prop} \geq (56 - 45) - (-114.9) + 22 - 1.5 - 1.7 = 144.7\ dB$

7.2.6 Propagation models

Free space model is generally considered for MCL analysis and reveals adequate for the study implying the airborne radar. However, for ground radars it represents the worst case for compatibility as it does not take into account other phenomena except the frequency and distance losses. To evaluate necessary separation distances between LTE and ground radar systems, different propagation models can be considered.

Interference from LTE systems could be reduced in areas where the propagation environment is subject to obstacles between the LTE transmitting system and the radar receiver, given that those obstacles may provide additional power reduction to the interfering signal. In such case, adequate channel propagation model with corresponding terrain model are required. As an illustration, Figure 73 below illustrates the distance separation corresponding to a given attenuation in free space. It shows how much distance separation can be saved depending on a given power loss reduction. For initial high propagation loss (zone 1), a 10 dB propagation loss reduction from 150 dB down to 140 dB (e.g. from obstacle) leads to a reduction of 1200 km of the separation distance, where an additional 10 dB of propagation loss (zone 2) gives a supplementary reduction of 400 km for the separation distance.

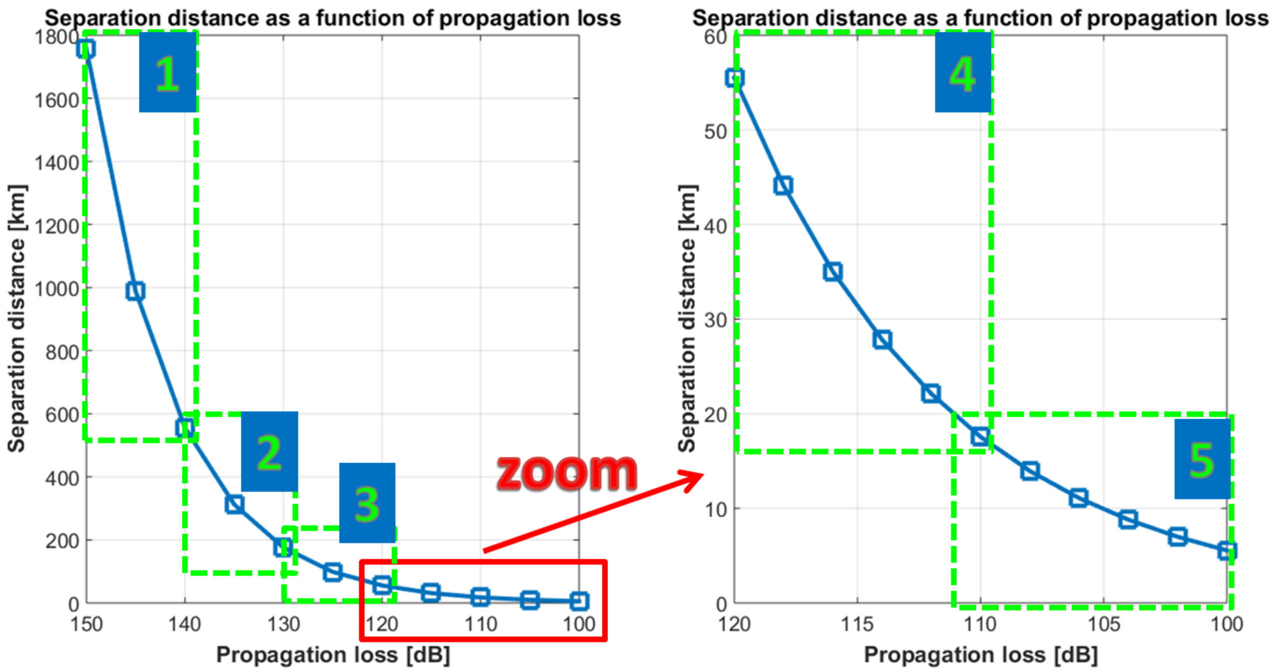


Figure 73: Free space distance in function of propagation loss

For a generic study, propagation model must permit to evaluate separation distances for most of cases, so the chosen model(s) must be adapted to the configuration of the study (frequency, nature of link…), and must be well known and recognized. To illustrate some cases of the study, examples with models using “digital terrain and clutter data” can be used but given the potential impact of the terrain model on the required separation distance, the applicability of the results and their conclusions would need to be considered with caution. Furthermore, they must be well identified as particular cases that are valid only in the location where calculation has been done. In particular, deterministic propagation models are more appropriate when coordination needs to be done or when a national context needs to be clarified (Annex 10.8).

Most propagation models need to be tuned (calibrated) by being compared to measured propagation data; otherwise accurate path loss predictions will be impossible to obtain. Tuned propagation models can be calibrated to the GIS (Geographic Information System) data that takes into account the clutter data and coverage.

The accuracy of the models that predict path loss depends on the input parameters and the utilised propagation mechanism. For these reasons tuned propagation models provide more realistic and accurate result because these models use digital maps tuned by measurements. These models can be well applicable for ground radars in adjacent channel scenario. However, it should be noted that the results obtained are valid essentially for places where calculations have been performed. For this reason, results obtained with deterministic models cannot be used to build a conclusion for a general case. Statistic models give a right idea of result independently of the area (A10.8).

EPM73 and ITU-R P.526-13 models can be used to calculate propagation path loss, for both co-channel and adjacent scenarios. These models are not valid for an “air-to-ground” link (Hmax: 3000 m), so free space propagation model is used in this case.

7.2.7 Decoupling factors

Considering the difference of polarisation between LTE BSs and radars, a mitigation factor of 1.5 dB is taken into account.

In the case of cohabitation, the antenna tilt of the LTE BS (3°) leads to the need of using a decoupling antenna factor (DECant), in the link budget:

- In a first step, a value of 3 dB can be used in the budget link, as it has been done in ECC Report 240;
- In a second step, a value of 10 dB is used, which may reflect much more decoupling effect due to site configuration or environmental context;
- For airborne radars the decoupling antenna factor depends on the radar positions. The decoupling antenna factor also depends on the LTE BS antenna mask, and the airborne radar pattern. Assuming the LTE BS antenna is not tilted, and the airborne radar antenna main lobe can scan ±60° elevation and 360°azimuth. The attenuation of LTE BS antenna (Kathrein, K742 242) has been calculated for several airborne positions and angles which could be considered as DEC_{ant} factor. These values can be found in Annex 10.

These values were considered for both the co-channel and the adjacent channel scenarios.

7.3 MITIGATION TECHNIQUES

Using proper mitigation techniques on LTE network, the separation distance (exclusion zone) between LTE BSs and radars can be reduced in both co- and adjacent channel scenarios for ground and airborne radars.

7.3.1 Power reduction

Reducing the output power of LTE BS decreases the separation distance. The effect of power reduction is significant in co-channel scenario. In adjacent channel scenario the 3GPP mask defines the absolute level of unwanted emission, independently by the output power. For example, if the LTE bandwidth is 5 MHz in co-channel scenario the next table represents the decrease of exclusion zone depending on reduction of power:

Table 80: Power reduction (5 MHz LTE, co-channel scenario)

P_{LTE} (dBm)	P_{LTE} (W)	e.i.r.p. (dBm)	L_{prop} (dB)	d (ITU-R P.526-13) (km)
46	40	60	202.9	120
43	20	57	199.9	115
40	10	54	196.9	110
37	5	51	193.9	105

Note: h_1 = 30 m, h_2 = 8 m, f = 420 MHz

7.3.2 Antenna height

Reducing the antenna height of LTE BS decreases the separation distance. The effect of the height reduction in co-channel scenario is slight.

In adjacent channel scenario the antenna tilting and rotation is more significant. That is why, these modifications are preferred.

7.3.3 Antenna tilt and direction

The LTE BS antenna tilt decreases the separation distance in both co- and adjacent channel scenarios. It can be calculated with the following formulas:

In co-channel scenario:

$$L_{prop} \geq e.i.r.p._{LTE} - P_{ps} + G_{RADAR} + 10\log\left(\frac{B_{RADAR}}{B_{LTE}}\right) - DEC_{pol} - DEC_{ant} - L_{MASK}(\Theta, \varphi)$$

In adjacent channel scenario:

$$L_{prop} \geq e.i.r.p._{unwantedemLTE} - P_{ps} + G_{RADAR} - DEC_{pol} - DEC_{ant} - L_{MASK}(\Theta, \varphi)$$

Where $L_{MASK}(\Theta, \varphi)$ is the antenna mask loss value for elevation and azimuth angles. The elevation angle represents antenna tilt, the azimuth angle represents antenna direction.

Example:

$$L_{MASK}(\Theta, \varphi) = L_{MASK}(358°, 45°) = 1.9 + 4.7 = 6.6\ dB$$

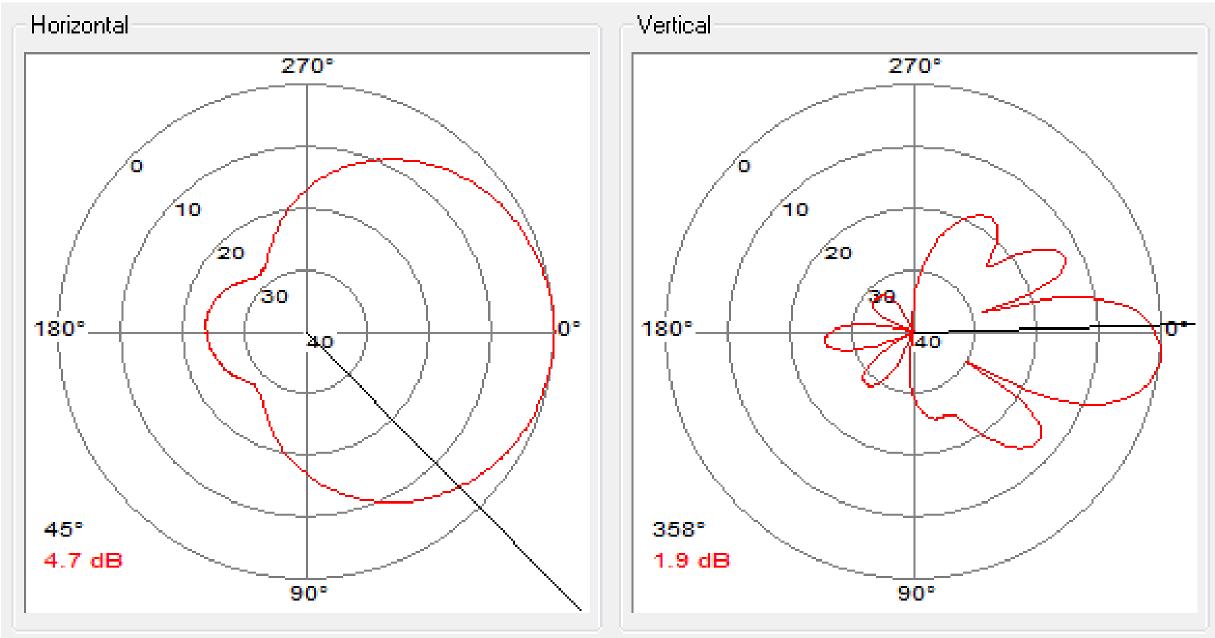


Figure 74: L_{MASK} example (Kathrein 742 242, 358°, 45°)

In co-channel scenario, 5 MHz LTE, e.i.r.p. LTE = 56 dBm (@20W)

$$L_{prop} \geq e.i.r.p._{LTE} - P_{ps} + G_{RADAR} + 10\log\left(\frac{B_{RADAR}}{B_{LTE}}\right) - DEC_{pol} - DEC_{ant} - L_{MASK}(358°, 45°)$$

$$L_{prop} \geq 56 - (-115.9) + 38.5 + 10\log\left(\frac{1}{5}\right) - 1.5 - 3 - 6.6 \geq 192.3\ dB$$

(non-coupled main lobes)

Necessary propagation loss of 192.3 dB corresponds to 102 km (ITU-R P.526-13, h_1 = 30 m, h_2 = 8 m, f = 420 MHz).

In adjacent channel scenario, 5 MHz LTE, e.i.r.p. $_{LTE}$ = 56 dBm (@20W)

$$L_{prop} \geq e.i.r.p._{unwantedemLTE} - P_{ps} + G_{RADAR} - DEC_{pol} - DEC_{ant} - L_{MASK}(358°, 45°)$$

$$L_{prop} \geq 11 - (-115.9) + 38.5 - 1.5 - 30 - 6.6 \geq 127.3\ dB$$ (non-coupled main lobes)

Necessary propagation loss of 127.3 dB corresponds to 20 km (ITU-R P.526-13, h_1 = 30 m, h_2 = 8 m, f = 420 MHz).

7.3.4 Filtering

Using additional LTE BS filtering (10-60 dB) will reduce the Out-of-Band Emissions (OOBE)and therefore the separation distances can be reduced significantly between the LTE BS and radars in adjacent channel scenario. In the case of interference occurring due to intermodulation products within radar receiver, additional filtering for better radar selectivity could be deployed.

7.4 RESULTS AND ANALYSIS

Results are summarised below and detailed in ANNEX 10:.

7.4.1 Ground radars

According to the simulations, the required separation distance is around 120 km in the co-channel scenario (between LTE BSs and ground radars), depending on the bandwidth of the LTE.

For any adjacent channel, the required separation distance (for ground radars) is less than 40 km over smooth Earth (EPM73 and ITU-R P.526-13).

7.4.2 Airborne radars

In this case, it can be assumed that radars will always be at a distance of 9000 m or above from the base stations, which corresponds to its minimum flight altitude.

9000 m corresponds to a Free space loss of 104 dB, at 420 MHz. This means that about 12 dB are missing in the budget link for spurious emissions and about 35 dB for OOBE (see table A10.4: adjacent channel necessary propagation losses of 140.9 dB for OOBE and 115.9 dB for spurious).

The band 430-440 MHz is allocated to radiolocation on a primary basis. Therefore, to keep the airborne radar free of interference in this band, three possible solutions could be considered:

1. Reduction of the unwanted emissions in the band 430-440 MHz:
   - OOBE which fall into the band 430-440 MHz should be reduced by 35 dB;
   - Spurious emissions should be reduced by 11 dB.

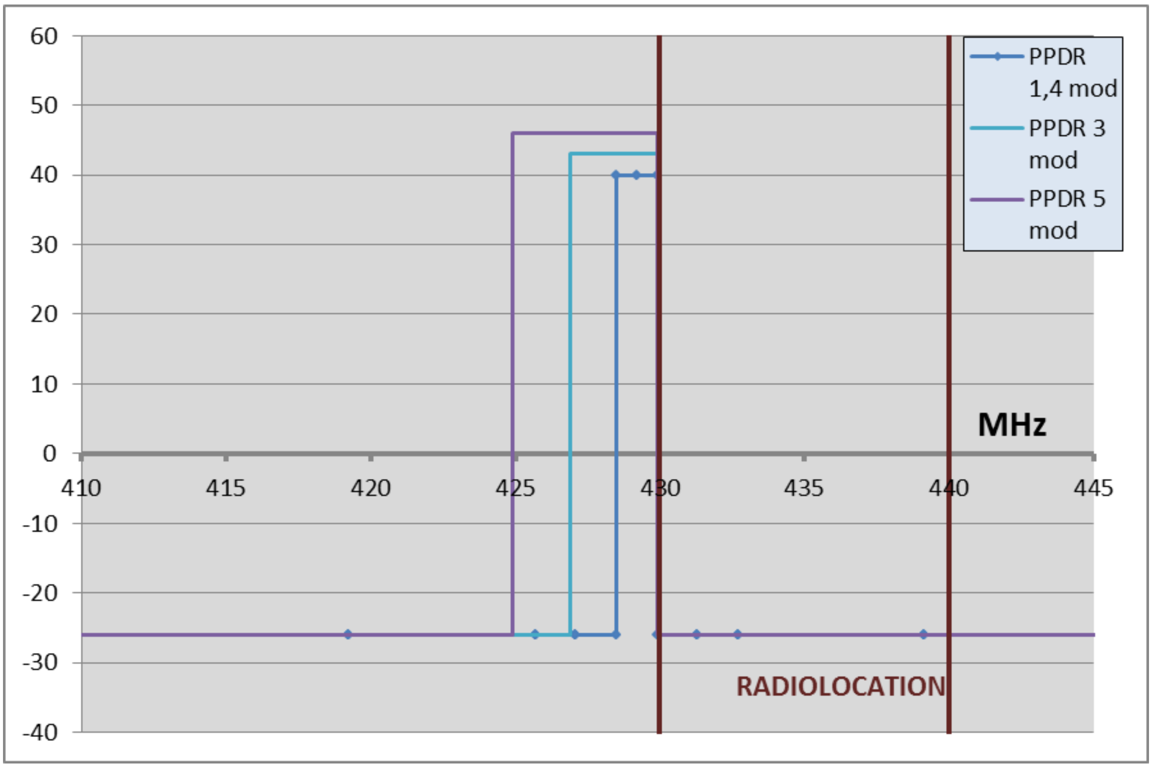


Figure 75: LTE emission mask with reduced OOBE

With a lower OOBE level, a frequency guard band of 100 kHz could be sufficient and the minimum frequency separation (Δ F) of the LTE centre frequency to the 430 MHz boundary are:

- 1.4 MHz LTE carrier: Δ F = 0.8 MHz;
- 3 MHz LTE carrier: Δ F = 1.6 MHz;
- 5 MHz LTE carrier: Δ F = 2.6 MHz.

2 Use of a guard band between 430 MHz and LTE centre frequency (ANNEX 10:):

- This solution insures that OOBE remain essentially in the band 420-430 MHz and only spurious emissions fall above 430 MHz;
- To complete this solution, spurious levels needs also be reduced by at least 11 dB.

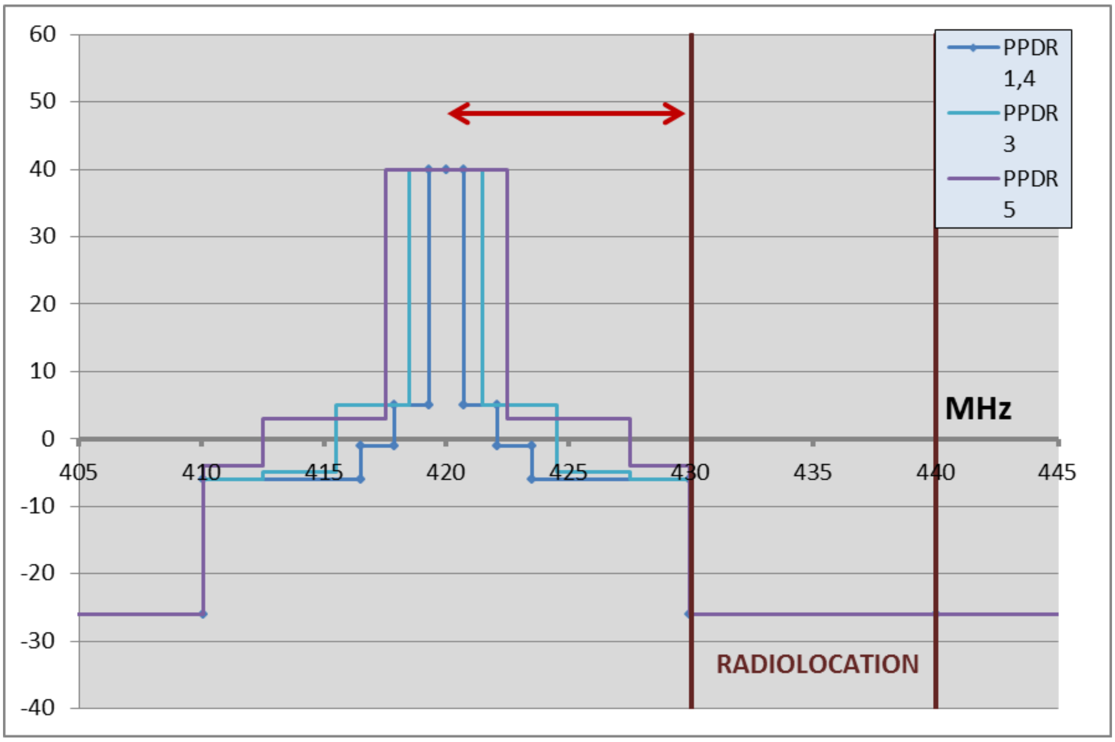


Figure 76: LTE emission mask with legacy OOBE and increased frequency separation to 430MHz

Without changing OOBE level, guard band should be as follows (Δ F to the 430 MHz boundary):

- 1.4 MHz LTE carrier: Δ F = 9.95 MHz ;
- 3 MHz LTE carrier: Δ F = 9.95 MHz ;
- 5 MHz LTE carrier: Δ F = 9.95 MHz.

3 A combination of the two previous approaches to insure that OOBE remains in the band 420-430 MHz.

- a frequency margin between 430 MHz and LTE centre frequency, and
- a reduction of the OOBE level which could also be obtained with a reduction of the LTE transmitted power (e.i.r.p), assuming that OOBE are reduced by the same value.

An example is given in ANNEX 12:

For airborne radars, the separation distance remains more than 400 km required if no particular mitigation technique is applied. It should be noted that the radio horizon basically limits the maximum value of separation distance between LTE BS and radars considering free space propagation and line of sight regarding flight level.

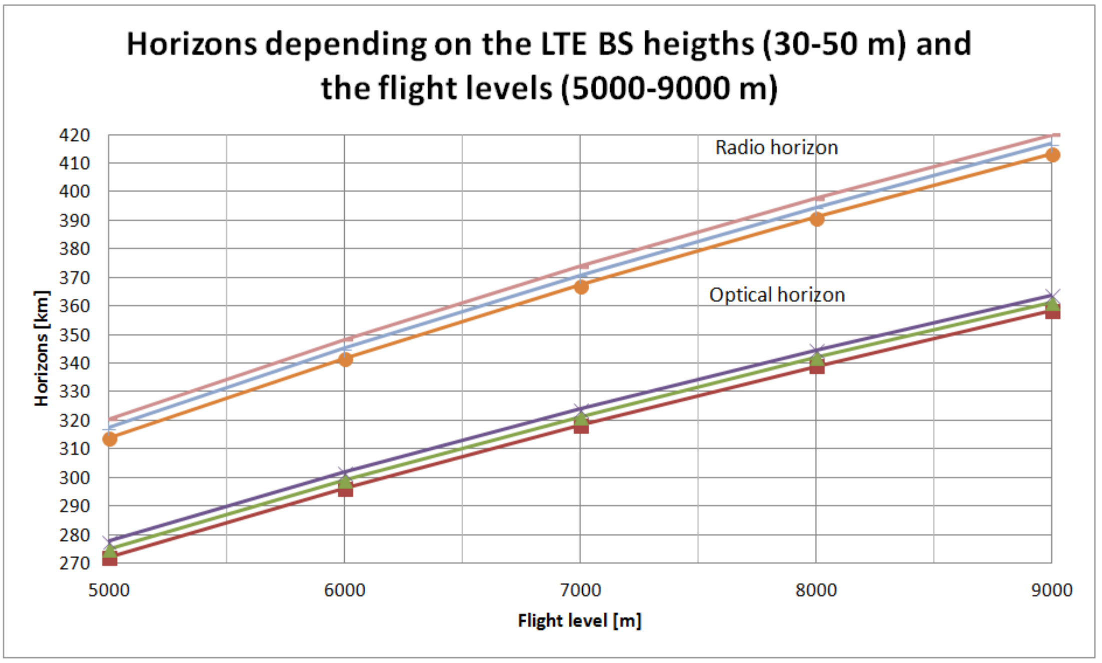


Figure 77: Optical and radio horizon at 420 MHz

7.5 CONCLUSIONS

The analysis focused on the impact of LTE based BB-PPDR into radar systems and investigated several propagation models and scenarios for co-channel (420-430 MHz) and adjacent channel (430-440MHz) operation of the two systems.

7.5.1 Conclusions in co-channel scenario

According to the simulations results, it can be concluded that LTE BSs should be excluded within a radius of about 120 km around ground radars in the co-channel scenario, the radius depending on the bandwidth of the LTE system.

For airborne radars, the separation distances are greater than 120 km.

Based on this result, it can be concluded that:

- Coordination between radars and LTE based BB-PPDR applications can be done only in the case of fixed ground radars;
- The use of 420-430 MHz by transportable ground radars or airborne radars will most likely become difficult in areas where LTE networks will be deployed due to large separation distances required to avoid radar desensitisation;
- Although airborne radars could continue to operate (with degraded performances) in remaining radiolocation bands (430-450 MHz), the saturation of transportable ground radar could lead to make them not usable in areas where LTE networks are deployed (depending on the BS density, e.i.r.p, etc.…).

7.5.2 Conclusions in adjacent channel scenario

For any adjacent channel, the required separation distance to protect radars from LTE OOBE is less than 40 km or 50 km depending on propagation model used for ground radar.

Applying digital terrain based propagation models (General 450 and MYRIAD), the minimum required separation distance (for ground radars) could be varied from 1.5 km to 28 km (depending on the channel bandwidth and the distance of the carrier frequencies). It should be noted that this is a much more realistic situation because the ground radar is directed towards the air and the LTE BS antenna is directed to its UEs (downtilted) so the main lobes cannot be coupled. However, these results (obtained with General 450 and MYRIAD) are valid only for the location where calculation has been performed.

For airborne radars, the separation distance remains more than 400 km required if no particular mitigation technique is applied.

Using additional filtering the co-existence can be achieved between LTE BS and airborne radars. In case of 5 MHz bandwidth the minimum required separation distance could be varied from 2.2 to 56.8 km with 30 dB filtering, from 0.7 to 18 km with 40 dB filtering, and from 0.07 to 1.8 km with 60 dB depending on ∆fc.

Based on this result, it could be concluded that without appropriate technical measures applied on LTE base stations, ground transportable and airborne radars will suffer from an unacceptable degradation of their performances[10] as access to the core radiolocation band (430-440 MHz, radiolocation on a primary basis) will be compromised.

Additionally, even though a significant improvement in term of a reduction of the separation distance, required to protect radars, could be achieved (compared to the figures reported in ECC Report 240), deployment of LTE networks without any mitigation techniques would harmfully impact them in neighbouring countries and over international waters.

7.6 SUGGESTED SOLUTION

7.6.1 Considerations

Considering that co-channel scenarios need large separation distances, a coordination procedure will be needed for both ground and airborne radars, but in practice any coordination could be implemented only for ground radars with fixed location. Such coordination procedure may need mitigation techniques (such as deterministic propagation model, BS power reduction, antenna discrimination through height or tilt and azimuth) to facilitate coexistence possibilities on a case by case basis.

In addition, in order to ease the protection of radars in co-channel situation but also to ensure that radar applications could continue to operate in the adjacent channel (430-440 MHz where radiolocation is a primary service), one of the following solutions has to be applied:

- maintaining a guard band below 430 MHz;
- LTE systems have to reduce their OOBE levels of around 35 dB and then a 100 kHz guard band could be sufficient between LTE and radars. This reduction of OOBE could be made by means of an external filter or by reducing the BS transmitted power.

7.6.2 Proposed solutions

It should be noted that a filter achieving a deep attenuation of at least 35 dB within a 1 MHz guard band would be very challenging to design and could be too expensive. Experience in the 800 MHz band provides filters achieving an attenuation of 17 dB 1 MHz after its cut-off frequency. In general it is expected that filters providing 50 to 60 dB of attenuation at 5 MHz further the cut-off frequency could be found on the market at fair rate. Based on the later filter in can be realistically extrapolated that the ∆dB = 40 dB attenuation is achievable after ∆f = 2.5 MHz from the filter cut-off frequency.

[10] Taking into account that 420-430 MHz is unusable and that 440-450 MHz (radiolocation on secondary) status, is already interfered by a heavy use of applications under mobile service.

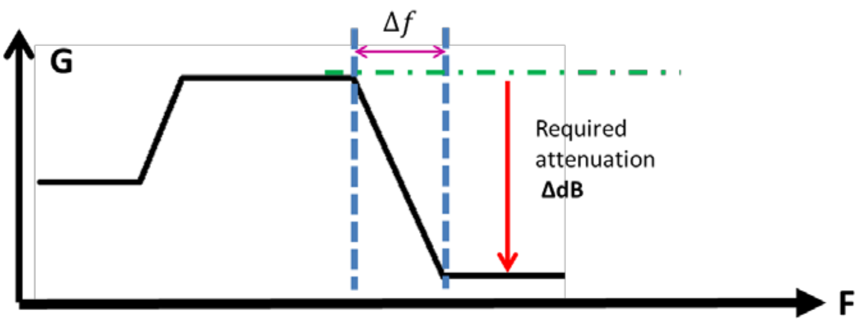


Figure 78: Required frequency for the filter to meet the required attenuation

ANNEX 10: illustrates how the values of ΔdB were derived, considering different antenna decoupling attenuation. The 2.5 MHz corresponds to a band edge to band edge guard band as illustrated below, meaning that the LTE BS centre frequency should not be higher than 430 – 2.5 – BLTE/2 MHz.

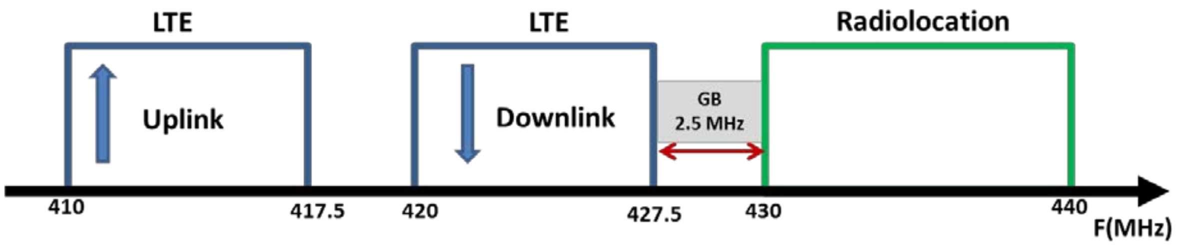


Figure 79: Proposed guard band between LTE and radar systems

7.6.3 Suggested frequency arrangement

In order to protect the radars it is suggested that 2.5 MHz minimum guard band should be applied at upper ends of the 410-420/420-430 MHz, assuming an additional reduction of 40dB is provided for OOBE of the LTE BS (on the basis of the value specified in the 3GPP standard)

Any LTE channel with 1.4 MHz, 3 MHz, and 5 MHz bandwidth should be entirely placed in the tuning range of 410-417.5/420-427.5 MHz applying 100 kHz channel spacing starting at 410.7/420.7 MHz and finishing at 416.8/426.8 MHz (for 1.4 MHz bandwidth).

8 LTE IMPACT ON RADIO ASTRONOMY AT 406.1-410 MHZ

The impact of Long-term Evolution (LTE) activities in the band 410-430MHz on RAS in the band 406.1-410 MHz is studied with the consideration of emission from base stations (BS) and user equipment (UE).

8.1 STUDY PARAMETERS

The LTE parameters used for this study, as listed in Table 81, are obtained from Annex 1 of this Report.

Table 81: LTE and RAS parameters

LTE			RAS Station
	Base Station	User Equipment	
Transmit power	43 dBm/5 MHz	23 dBm	
Centre frequency	422.5, 423.5, 425, 426.5 MHz	412.5, 413.5, 415, 416.5 MHz	408.05 MHz
Bandwidth	5 MHz	5 MHz	3.9 MHz
OOB	Annex 1	Annex 1	
Spurious power	-96 dBm/100 kHz	Annex 1	
Antenna gain	15 dBi	-3 dBi	0 dBi
Feeder Loss	2 dBm	0 dBm	
Body loss		4 dB	
Wall loss		11 dB	
Wall loss st.dev.		6 dB	
Deployment density	0.0057 km^2	0.027 km^2	
Duty cycle	100%	100%	
Height (m)	30 m	1.5 m	50 m
Distribution of transmitting UE (% indoor/ % outdoor)		25% / 75%	

8.2 MATRIX LABORATORY SOFTWARE (MATLAB) ANALYSIS

For the analysis, the propagation model described in Recommendation ITU R P.452-16 including free space, smooth earth diffraction, tropospheric scatter, ducting, and ground clutter attenuations was used. The atmospheric attenuation was approximated to be 0.0 dB/km. The MCL calculations are performed for single and aggregate emitters and operational bandwidth of 5 MHz for both base stations (BS) and user equipment (UE) with duty cycles of 100%. For indoor usage a wall attenuation of 11 dB and a general body loss of 4 dB were considered for the user equipment in the calculations. The deployment of UE is split to 75% outdoor and 25% indoor use. Recommendation ITU-R RA.769-2 [17] provides threshold levels of -203 dBW (or -173 dBm) for interference detrimental to the RAS for the band 406.1-410 MHz. The receiver antenna gain is assumed 0 dBi and the typical height of the receiver is taken to be 50 m.

In order to protect the radio astronomy stations it is suggested that 1 MHz guard band should be applied at the lower end of the band 410-420 MHz. The simulations for the UE therefore assume the transmission band edge at 411 MHz.

8.2.1 Compatibility studies with 1 MHz guard band

The results of the compatibility study with MATLAB and ITU-R P.452-16 [33] are summarised in Table 82. In the case of a single base station emitting at a direct line of sight of a RAS station (i.e., the Worst-case scenario), the obtained Minimum Coupling Loss (MCL) is 106 dB, which translates to a separation distance of 17 km. In the aggregation study with statistical Monte-Carlo simulation using 15 000 trials with 500 devices and a deployment density of 0.0057 km^2, an MCL of 93 dB or alternatively a separation distance of 1 km is obtained. For these calculations a spurious emission limit of -96 dBm/100 kHz was adopted for the BS, meant for the protection of the base station from its own receiver or other BS transmitters. It should be noted that it was assumed that the spurious emission limit gained from this filter is maintained throughout the RAS band 406.1-410 MHz. Should the filter apply to the UE frequency range only, then the elevated spurious emissions of -26 dBm/MHz in the RAS band will result in increased MCL of up to 165 dB and separation distances of more than 500 km between a RAS station and the base stations. For the outdoor user equipment the separation distances for single emitter and aggregate cases become 78 km and 326 km, respectively. For indoor usage and additional wall attenuation of 11 dB reduces the separation distances for single emitter and aggregate cases to 34 km and 190 km, respectively.

Table 82: Compatibility results with MATLAB ITU-R-P.452

	LTE Base Station		Mobile Station			
Bandwidth of 5 MHz	Single Interferer	Aggregate Interference	Single Interferer		Aggregate Interference	
			indoor	outdoor	indoor	outdoor
Single emitter emissions in 406.1 - 410 MHz (dBW)	-97.1		-52.1	-41.1		
Aggregate power received by RAS station in 406.1 - 410 MHz (dBW)		-200.7			-165.6	-149.5
Protection Level (dBW)	-202.9	-202.9	-202.9	-202.9	-202.9	-202.9
MCL (dB)	105.8	92.8	150.8	161.8	153.8	164.8
Separation distance (km)	17	1	34	78	190	326
Required reduction in spurious emissions (dB)	30.0	2.2	56.3	67.3	37.2	53.3
single emitter emission limits in RAS band (dBm/MHz)	-103.0	-77.2	-84.3	-84.3	-74.4	-79.3

The path-loss profiles for single emitter base stations and user equipment computed with different propagation models in Recommendations ITU-R P.452-14, P.452-16, P.525-2, and P.1546 are shown in Figure 80. The separation distances are obtained by intercepting the MCL plot with that of the path-loss profiles. In conclusion, despite a 1 MHz guard band, compatibility will be very difficult to maintain with the UE due to high levels of out-of-band emissions. The mobile usage of the UE will make it particularly difficult to protect the RAS stations from interference.

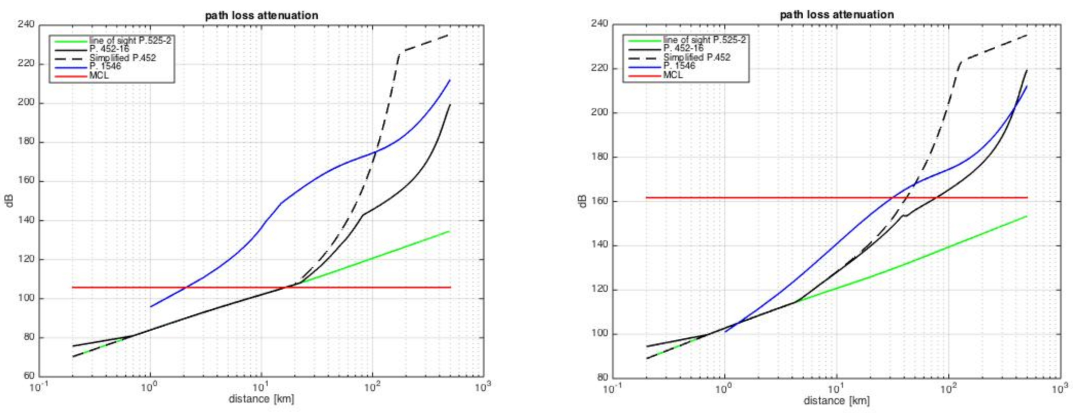


Figure 80: Path-loss profiles for single emitter base stations (left) and user equipment (right) considering different propagation models described in Recommendations ITU-R P.452-14, P.452-16, P.525-2, and P.1546. The reported calculations results are based on Recommendation ITU-R P.452-16

8.2.2 Effect of the guard band between LTE and RAS

The studies were done using MCL approach calculating interference from single and aggregate interferer scenarios for the UE into the RAS band.

The interference from single and aggregate LTE UE Tx having 5 MHz bandwidth was calculated. The guard band was set from the 410 MHz band edge. The results of the compatibility studies are summarised in the table below.

Table 83: Separation distances (km) between LTE UE and RAS assuming different guard bands

Guard band between LTE UE and RAS, MHz	Single interferer, indoor	Single interferer, outdoor	Aggregate interferer, indoor	Aggregate interferer, outdoor
1	34	78	190	326
2	33	75	185	322
3	31	67	171	312
4	29	57	148	296
5	23	41	103	261

Guard band values between 1 MHz and 5 MHz for single and aggregate LTE UE having 5 MHz bandwidth and the RAS allocation were studied. Calculations showed that the separation distances needed to protect RAS stations do not vary drastically over the range of the guard bands, and that compatibility with the aggregate interference from the UE, particularly outdoor usage, will require very large separation distances. A more detailed study using SEAMCAT is provided in the next section.

8.3 SEAMCAT ANALYSIS

8.3.1 Introduction

ECC Decision (16)02 [4]addresses the harmonised conditions for the implementation of BB-PPDR radio systems. Paragraph 3 of Decides section of this Decision presents several frequency allocation options for introducing BB-PPDR in the band 450-470 MHz. This approach of several frequency allocation options could also be used for 410-430 MHz. Shifting the operating frequencies on LTE UE and LTE BS could reduce interference on RAS service operating in the band 406.1-410 MHz. Following studies were done in order to estimate the effect of the guard band between the RAS and possible LTE systems in the band 410-430 MHz.

In the studies, interference into RAS receiver (RAS Rx) from multiple LTE UE transmitters (UE Tx) and LTE BS transmitters (BS Tx) was evaluated. The studies were carried out for the maximum bandwidth (5 MHz) for both base stations and user equipment using SEAMCAT.

8.3.2 Study parameters

The LTE UE and BS (5 MHz) parameters, as well as RAS parameters used for these studies are listed in Table 81 UE density is 0.0342 km^2.

BS deployment density for RAS scenario is defined as 0.0057 km^2. This leads to an area of 175.857 km^2 occupied by one BS. In SEAMCAT, Tri-sector hexagon type was chosen. Following equation is used to calculate Cell range - 2R. (In SEAMCAT, this R is defined as “Cell radius”. Cell range = 2R):

$$\text{Deployment density} = \frac{1}{\text{Cell area}} = \frac{1}{3(\frac{3\sqrt{3}}{2}R^2)}\,. \qquad (1)$$

It follows from equation (1) that R = 4.75 km.

According to the ECC Report 240, average density of active UE is 0.027 km^2 for RAS scenario, while deployment density of BS is 0.0057 km^2. This leads to the average of 4 UE per BS. For the studies, Tri-sector BSs were taken and UEs density was increased to 6 UE per BS or 2 UE per 1 sector. Therefore, UE density in the study was increased to 0.0341 km^2.

Usually LTE networks are not fully loaded, so 10 resource blocks (RB) were taken per UE. LTE UE emission mask was based on 3GPP TS 36.101 V9.2.0 and adjusted using approach described in ECC Report 240 (Table 62) to correspond with 2 UE per sector using 10 RB.

Offset	Mask	Ref. BW
-33	-59	100
-5	-59	100
-5	-48	1 000
-3,4	-48	1 000
-3,4	-36	1 000
-3	-36	1 000
-3	-33	1 000
-1,4	-33	1 000
-1,4	-38	30
-1	-38	30
-1	0	5 000
1	0	5 000
1	-38	30
1,4	-38	30
1,4	-33	1 000
3	-33	1 000
3	-36	1 000
3,4	-36	1 000
3,4	-48	1 000
5	-48	1 000
5	-59	100
33	-59	100

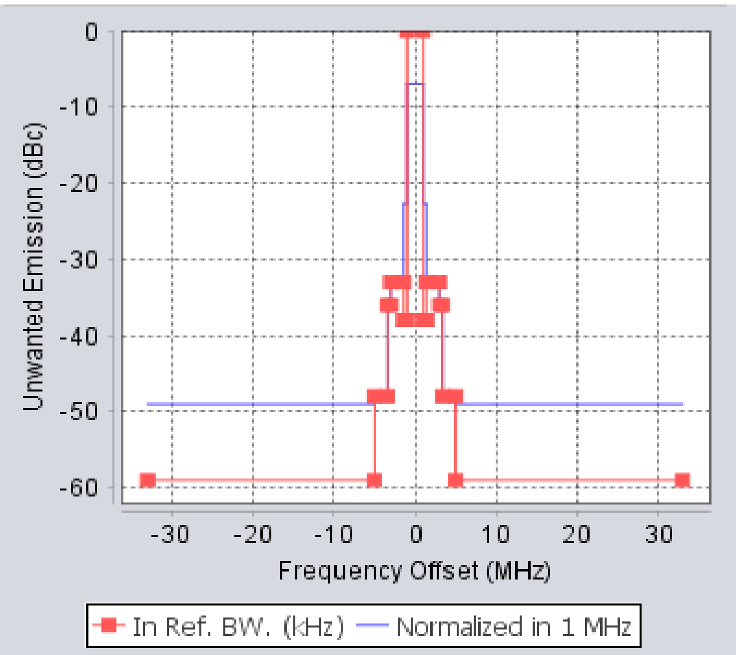


Figure 81: LTE UE emission mask in SEAMCAT

LTE BS emission mask is based on 3GPP TS 36.104. Spurious emission level is adjusted to -139 dBm/100 kHz so that it corresponds to the BS spurious power equal to -96 dBm/100 kHz and BS transmitting power as in Table 81.

Offset	Mask	Ref. BW
-30	-139	100
-3,5	-139	100
-3,5	-32	30
-2,5	-32	30
-2,5	0	5 000
2,5	0	5 000
2,5	-32	30
3,5	-32	30
3,5	-139	100
30	-139	100

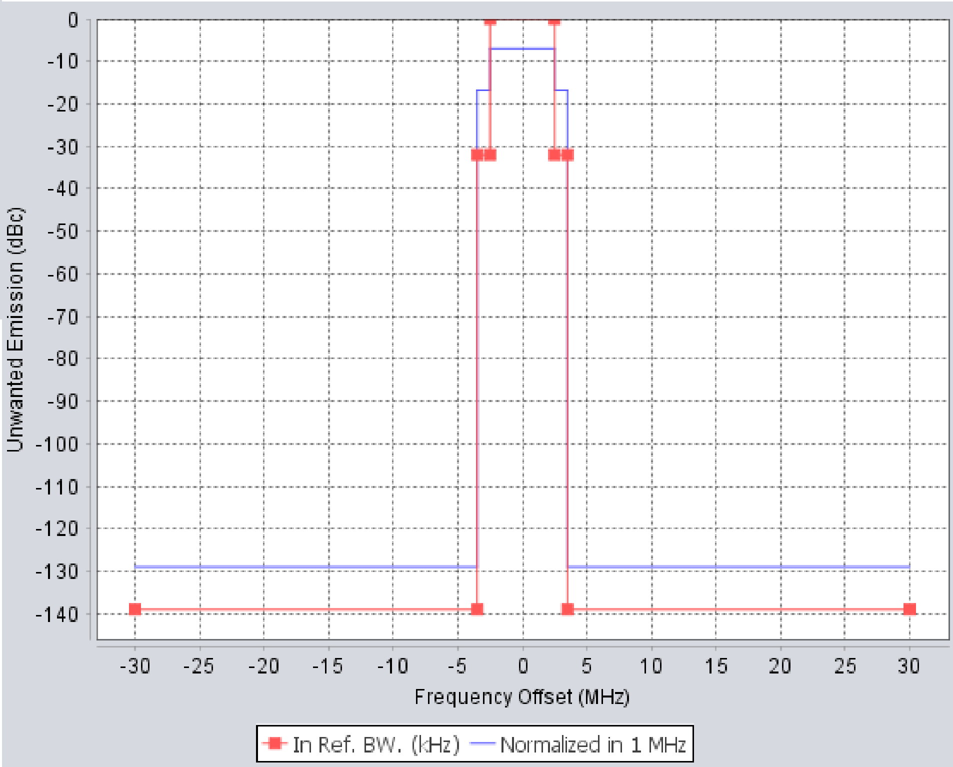


Figure 82: LTE BS emission mask in SEAMCAT

8.3.3 Simulation Method

A "static" model, also referred to as a "snapshot" Monte-Carlo model, was employed by means of SEAMCAT. This model sets up a random distribution of users based on one time instant correspondent with a network configuration and considered service characteristics. A set of statistics which accurately reflects these scenarios is derived by simulating several such snapshots. Investigation of the coexistence of an LTE based BB-PPDR network with Radio Astronomy Station (RAS) was performed by using SEAMCAT v.5.1.0.

During the simulations, unwanted signal levels from all BSs and UEs were included and then compared with the protection level of RAS. RAS protection level used in this study is -173 dBm as in Recommendation ITU-R RA.769-2 with time percentage of 2%. Propagation models described in Recommendations ITU-R P.1546-5 [10] and P.452-16 were used in the studies.

A cellular environment (hexagonal cluster) was used for modelling in SEAMCAT consisting of 19 cells (2-tiers tri-sector 3GPP layout) and wrap-around technique to reduce the number of cells required in the simulations of endless network and consequently to enable faster simulation run times. The geographical separation of the victim receiver and interferer LTE network was modelled by specifying the modelled cellular cell as laying at the edge of the network and thus as if the cellular system extending to one side only. For this simulation, right-hand side network was applied. This is illustrated in the Figure 82, where DE is RAS distance from the network edge, DC is distance from hexagonal cluster centre, RC is cluster maximum range, and α is central (network visibility) angle.

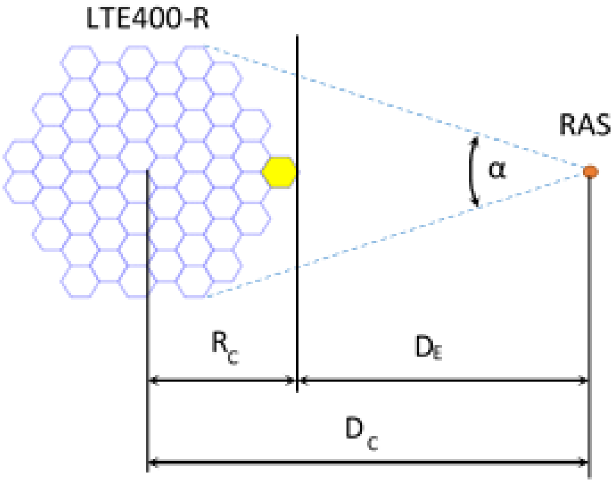


Figure 83: Layout used in Monte Carlo simulation

The set of simulations was done using UE power control settings showed in Figure 84.

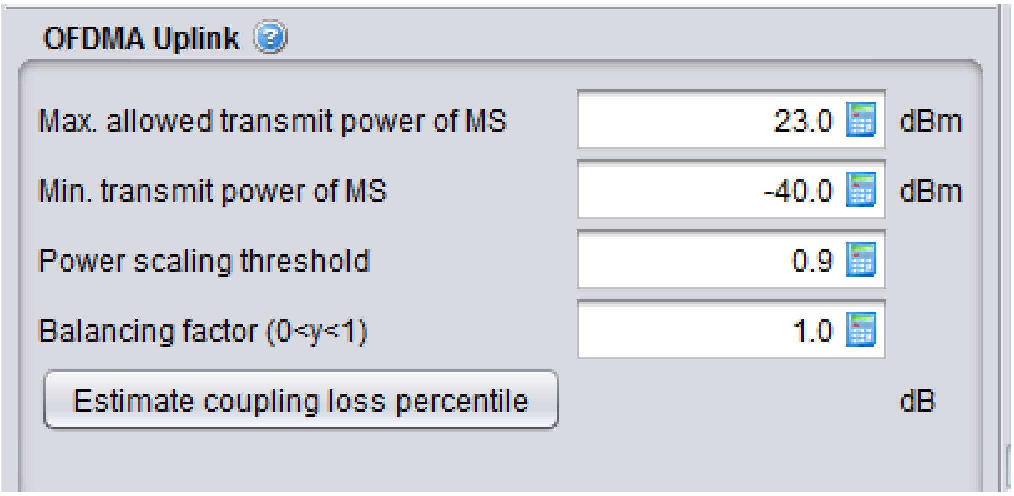


Figure 84: UE power settings for the simulations

The simulation was performed using 100000 snapshots in each scenario. Interference probability dependence on the distance from the network edge for various values of guard band is presented in Figure 85 and Figure 86. Interference criterion I/N was applied for the victim receiver.

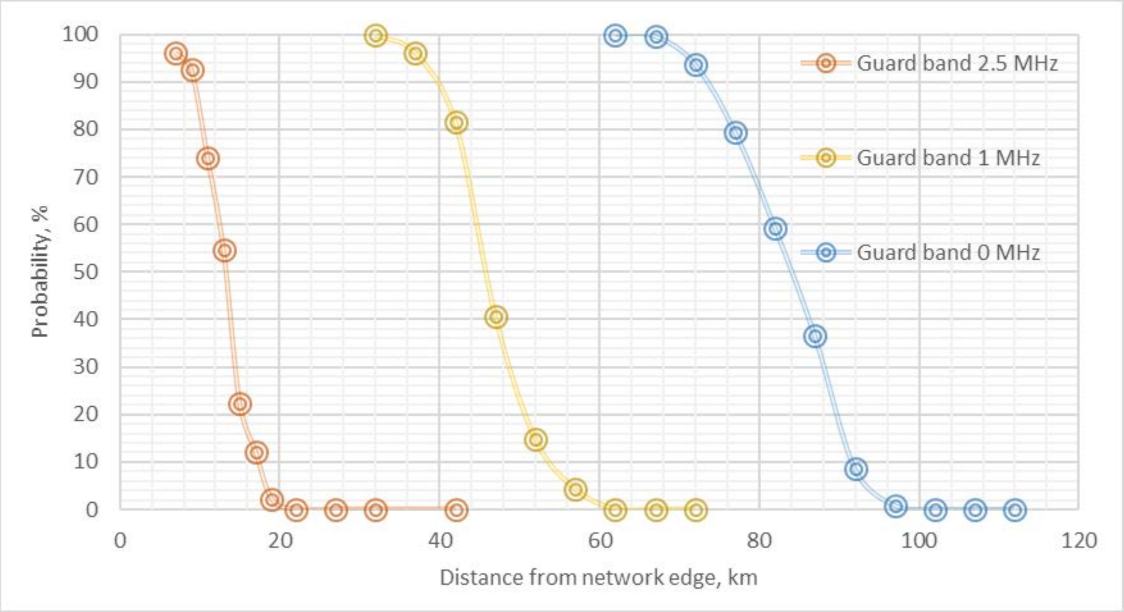


Figure 85: Interference probability dependence on distance from the LTE network edge using ITU-R P.1546-5

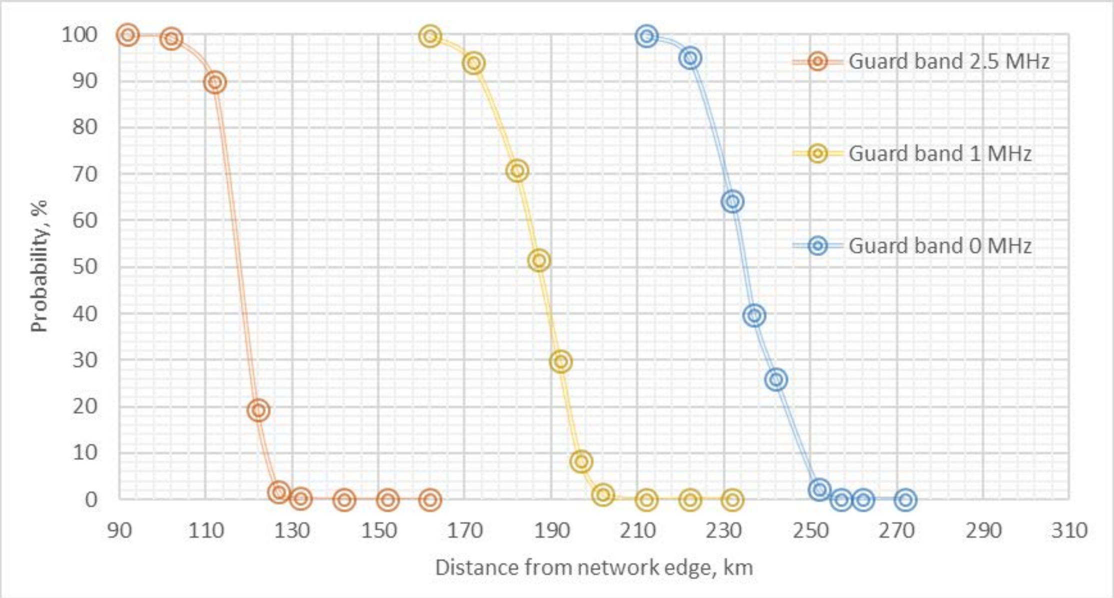


Figure 86: Interference probability dependence on distance from the LTE network edge using ITU-R P.452-16

The SEAMCAT translation mode was used, to calculate the probability of interference as a function of the total output power of interferer transmitters. The 5% interference probability level as a trigger was chosen to evaluate the power supplied value to victim receiver at various RAS distances from the interferer LTE network edge. The results are presented in Figure 87 and Figure 88.

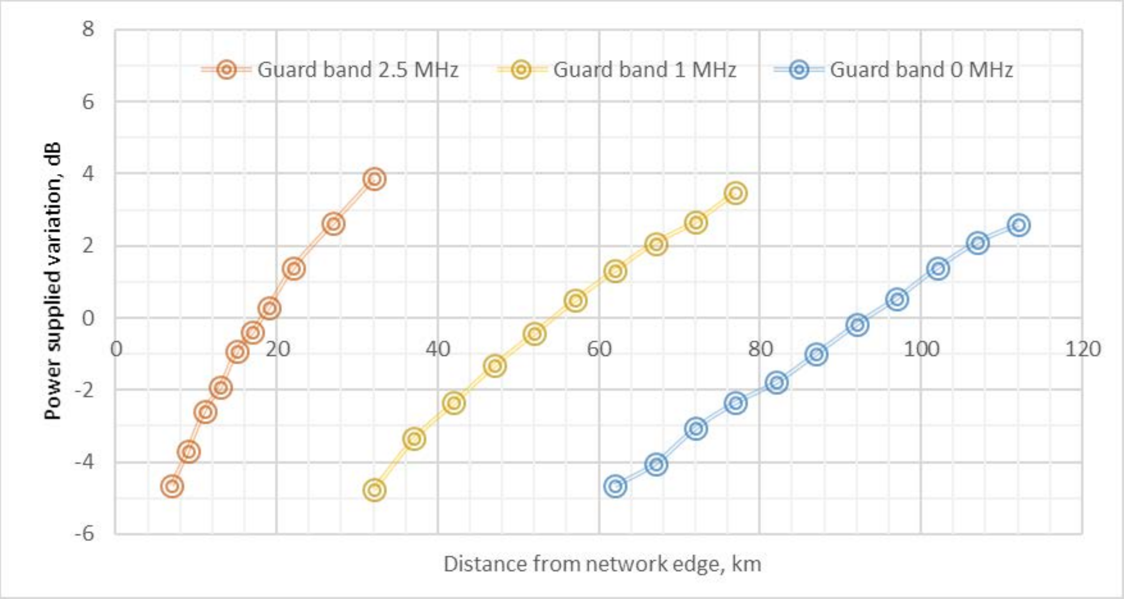


Figure 87: Power supplied dependence on RAS distance from the interferer LTE network edge for various guard bands to keep 5% interference probability using ITU-R P.1546-5

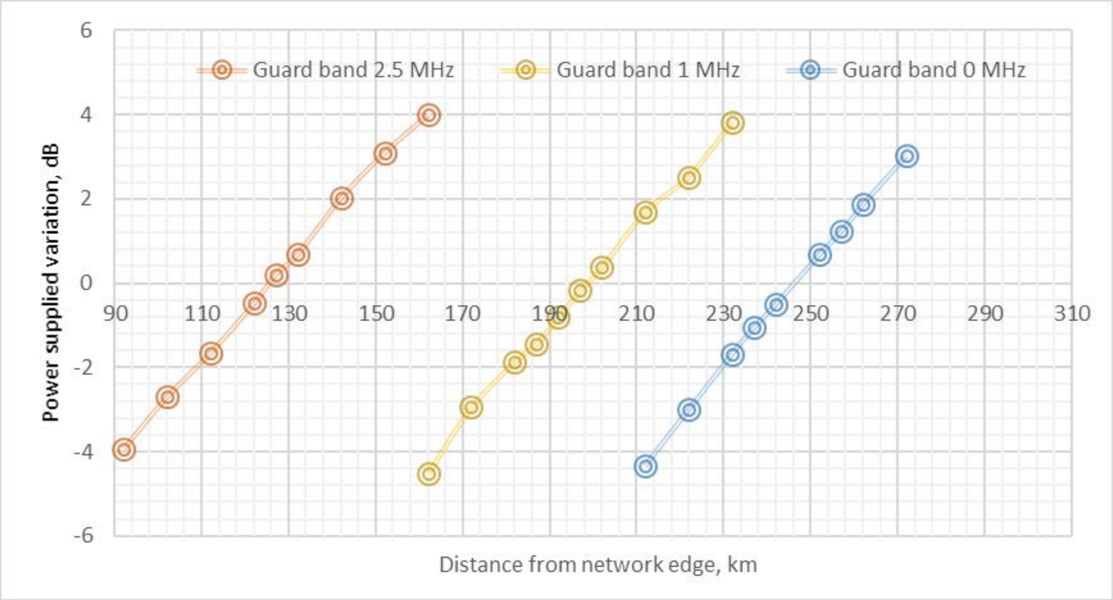


Figure 88: Power supplied dependence on RAS distance from the interferer LTE network edge for various guard bands to keep 5% interference probability using ITU-R P.452-16

The increase of power supplied at bigger distances means that the interfering signal probability at victim receiver is less than the 5% level, and therefore, the number of interferers can be increased to keep the same 5% probability level of interference. And on the contrary, the less distances can be assured by decreasing the interferers number.

This way, the number of interferers (114 UE + 19 BS) used in SEAMCAT simulations can be easily recalculated to another number by introducing the effective cluster of interferers in the form of the part of the circular ring of the same width as the hexagonal cluster dimensions 2Rc and having the same area, interferers number (density) and the distance from the RAS receiver to the ring centre Dc, Figure 89.

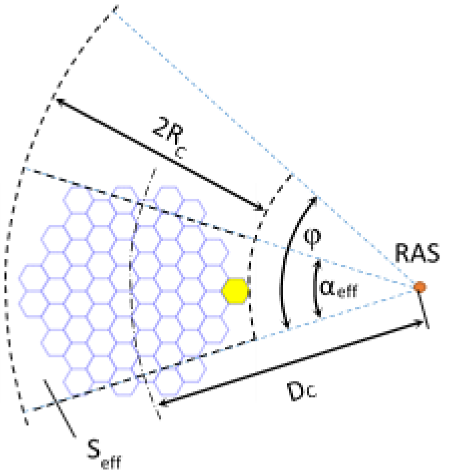


Figure 89: Effective area of part of ring to generate the same interfering signal at RAS receiver

Formulas for the recalculations are as follows:

$$\alpha_{eff}[\deg] = \frac{360}{2\pi} \cdot \frac{S_{eff}}{2R_C D_C}, \qquad (2)$$

$$S_{eff} = 19 \cdot \left(3 \cdot \frac{3 \cdot \sqrt{3}}{2} \cdot R^2\right), \qquad (3)$$

$$K[dB] = 10 \cdot \log\left(\frac{\varphi}{\alpha_{eff}}\right), \qquad (4)$$

where K is the interferer signal power gain factor, φ is required central (network visibility) angle.

For example, given guard band value 2.5 MHz, one right-hand side cluster area S_{eff} = 3341.288 km^2, cluster range R_C = 38 km, the distance from RAS receiver to cluster centre DC = 56 km (distance from cluster edge $D_E = D_C - R_C$ = 18 km), interference probability 5% and for required angle φ = 360 degree (closed circular ring around the RAS placed in the ring centre) the power gain factor is K = 9.033 dB. In case of the closed circular ring the correction factor is introduced to keep the same BS and UE transmitter's density in the ring area:

$$G[dB] = 10 \cdot \log\left(\frac{D_{rec}}{D_C}\right). \quad (5)$$

Finding the intersection point x = Drec of two curves, one is the correction factor dependence on distance plus power gain factor, G(x) + K, and another is a propagation model losses dependence on distance, L(x) – L(DC), x > DC, by means of numerical solving a system of two equations, gives the recalculated distance DE = (Drec - RC) from the interferer network edge that is increased to about 116.4 km to keep the same 5% interference probability. The weighted average of the propagation model losses in numerical calculations is taken with weighted coefficients proportional to the distance from the RAS receiver to the corresponding cluster point.

It should be noted that the simulation of interference in SEAMCAT is not confined to the case of one LTE cluster. Number of clusters, their sizes and distances from the victim's receiver, guard bands and propagation models could be different.

8.3.4 SEAMCAT results using different guard bands

The interference from all LTE BSs and LTE UEs Tx into RAS Rx station was calculated. RAS stations operate in the band 406.1-410 MHz . Therefore, the guard band was estimated from the 410 MHz edge. LTE UE 412.5 MHz centre frequency is considered to use 0 MHz guard band. LTE BS 422.5 MHz centre frequency is shifted 10 MHz away from the UE frequency.

Separation distance is considered to be inner radius of the ring, equal to Dc – Rc. The results of the compatibility studies are summarised in Table 84 and Table 85.

Table 84: Separation distances needed to protect RAS station at the 5% interference level

Guard band between LTE UE and RAS, MHz	Number of hexagon-clusters	Number of interfering BS	Number of interfering UE	Separation distance, km		Effective network visibility angle, deg	
				P.1546-5	P.452-16	P.1546-5	P.452-16
0	1	19	114	93.5	245.6	19.2	8.9
1	1	19	114	54.8	197.8	27.1	10.7
2.5	1	19	114	18.0	126.3	45.0	15.3
0	2	38	228	113.2	268.5	33.3	16.4
1	2	38	228	70.4	220.2	46.5	19.5
2.5	2	38	228	27.5	151.0	76.9	26.7

Table 85: Separation distances needed to protect RAS station given its full circular environment

Guard band between LTE and RAS, MHz	Power Gain factor, dB	Transmitter density correction factor, dB	Number of interfering BS	Number of interfering UE	Separation distance, km
P.1546-5					
0	12.740	3.266	758	4543	241.0
1	11.226	3.794	604	3621	184.4
2.5	9.033	4.407	419	2514	116.4
P.452-16					
0	16.078	1.488	1084	6502	361.3
1	15.276	1.820	974	5840	320.7
2.5	13.707	2.592	810	4859	260.6

8.3.5 Conclusion on SEAMCAT analysis

In this Report, several options of the guard bands between aggregated impacts from LTE based BB-PPDR UEs and BSs into RAS stations were analysed. Performed calculations showed that the separation distances needed to protect RAS station given its full circular environment are as follows for ITU-R P.1546-4:

- At least 117 km using 2.5 MHz guard band;
- At least 185 km using 1 MHz guard band;
- At least 241 km using 0 MHz guard band.

for ITU-R P.452-16

- At least 261 km using 2.5 MHz guard band;
- At least 321 km using 1 MHz guard band;
- At least 362 km using 0 MHz guard band.

The calculated separation distance from one LTE hexagonal cluster consisting of 19 cells are as follows for ITU-R P.1546-4:

- At least 18 km using 2.5 MHz guard band;
- At least 55 km using 1 MHz guard band;
- At least 94 km using 0 MHz guard band.

for ITU-R P.452-16

- At least 127 km using 2.5 MHz guard band;
- At least 198 km using 1 MHz guard band;
- At least 246 km using 0 MHz guard band.

Studies were done in rural environment with land propagation model described in Recommendations ITU-R P.1546-5 [10] and P.452-16. In real life situations, separation distances could be lower because of the specifics of the propagation environment, e.g. terrain constraints, clutter obstacles.

8.3.6 Comparison of propagation models on real terrain

A difference between propagation models ITU-R P.1546 and ITU-R P.452 was evaluated. For this purpose LTE network of 114 UEs was taken. UEs were randomly placed within a rectangular area of 3356 km^2 (76x44.158 km^2) in the territory of Lithuania. A global interfering signal from all 114 UEs was calculated at points placed at every 25-km beginning from the closest edge of the rectangular network. The receiver parameters were taken the same as the RAS station (Table 81). Propagation loss was evaluated as the difference between the total signal of all UE transmitters and the received signal at the RAS receiver. Calculated propagation losses together with actual ground profile are presented in the figure below. Propagation model ITU-R P.452 requires the use of terrain profile in order to obtain accurate propagation losses. In case of not using terrain profile propagation losses may be overestimated. A statistical assessment of exclusion zones around RAS sites could be obtained by applying ITU-R P.1546. For more precise exclusion zone ITU-R P.452 might be applied with real terrain data.

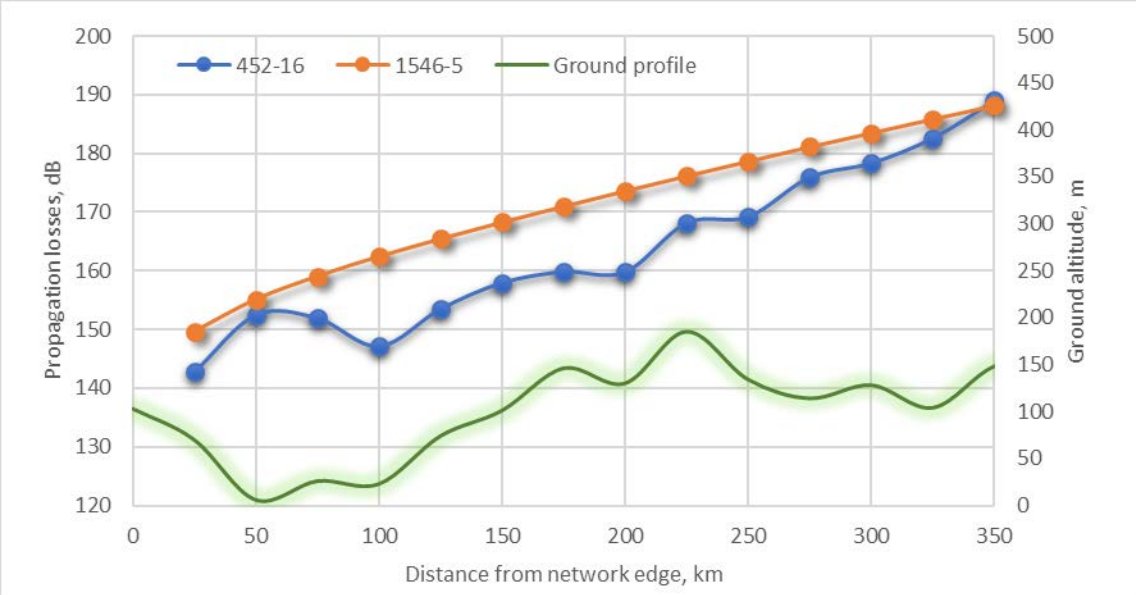


Figure 90: Comparison between P.1546-5 and P.452-16 propagation models

8.4 CONCLUSIONS

Two studies by using different statistical calculation methods were used for evaluation of interference from LTE based BB-PPDR systems operating in the band 410-430 MHz into radio astronomy stations in the band 406.1-410 MHz. One study was done by using SEAMCAT and propagation model described in Recommendations ITU-R P.1546-5 [10] and P.452-16 [33] with different network layout when aggregated effect of BSs and UEs were taken into account; another one - using MATLAB program and propagation model described in Recommendation ITU-R P.452-16. The previous methodology used in ECC Report 240 involved simplified propagation model described in Recommendation ITU-R P.452-14. The new study with MATLAB also considered a guard band of 1 MHz for base stations and larger guard bands of up to 5 MHz for user equipment, both indoor and outdoor usage.

Generic compatibility calculations for LTE systems in the band 410-430 MHz and radio astronomy operating in the band 406.1-410 MHz showed that compatibility may be achievable by implementing emission-free zones around RAS stations.

Analysis by using SEAMCAT showed that for LTE PPDR network completely surrounding RAS station, exclusion zone extended up to 241 km with Recommendation ITU-R P.1546-5 and 362 km with Recommendation ITU-R P.452-16 around RAS when no guard band was used Exclusion zone extended up to up to 117 km with Recommendation ITU-R P.1546-5 and 261 km with Recommendation ITU-R P.542-16 when 2.5 MHz guard band was used. Separation distances became smaller when LTE network's layout comprises a part of the ring placed on one side of RAS. They shrank down to 94 km with Recommendation ITU-R P.1546-5 and 246 km with Recommendation ITU-R P.542-16 when no guard band was used between systems. And they shrank to 18 km with Recommendation ITU-R P.1546-5 and 127 km with Recommendation ITU-R P.452-16 when 2.5 MHz guard band was used. Such case could be met when coordination of different systems between two countries occurs.

It is a difference between results for different propagation models Recommendation ITU-R P.1546-5 and Recommendation ITU-R P.452-16. Protection of investigated services could be insured by applying distances given by using ITU-R P.1546-5, for more precise exclusion zone ITU-R P.452-16 might be applied with real terrain data.

Analysis by using MATLAB with Recommendation ITU-R P.452-16 for the outdoor UE, considering a 1 MHz guard band, the separation distances for single emitter and aggregate cases become 78 km and 326 km, respectively. For indoor usage and additional wall attenuation of 11 dB the separation distances for single emitter and aggregate cases are reduced to 34 km and 190 km, respectively. The separation distances decrease with larger guard bands; for example, with a guard band of 5 MHz the separation distances for single emitter and aggregate cases of outdoor UE become 41 km and 261km, respectively. Moreover if the BS filter is applied to the UE frequency range and not further, the elevated spurious emissions of -26 dBm/MHz in the RAS band will result in increased separation distances of more than 500 km between a RAS station and the base stations.

Analyses show that co-existence between LTE systems (including BB-PPDR) and radio astronomy is feasible in the whole considered tuning range of 410-417.5/420-427.5 MHz, provided that certain measures are ensured. Sufficient mitigation techniques may be adopted, such as appropriate guard band and/or specific requirements on LTE network's layout, if required. However, the appropriate protection methods for RAS stations could be managed at national level and with international coordination. Given the limited number of radio astronomy stations (see Table 87) it is expected a need of coordination for the deployment of LTE stations at distances lower that 250 km from a RAS station located in a neighbouring country.

8.5 LIST OF RAS STATIONS IN EUROPE OPERATING IN THE 400 MHZ BAND

Table 86: RAS stations in Europe operating in the 400 MHz band

Observatory	Administration	Coordinates	Elevation (m AMSL)
e-callisto solar network	Germany, Italy, Belgium, Ireland, Finland, Czech Republic		
Lustbühel	Austria	47°04'03" N, 15°29'34" E	483
Humain	Belgium	50°11'31" N, 05°15'19" E	293
Metsähovi	Finland	60°13'04" N, 24°23'35" E	61
Nançay	France	47°23'00" N, 02°12'00" E	150
Effelsberg	Germany	50°31'32" N, 06°53'00" E	369
Thermopiles	Greece	38°49'00'' N, 22°41'00" E	
Medicina	Italy	44°31'14" N, 11°38'49" E	28
Noto	Italy	36°52'33" N, 14°59'20" E	90
Sardinia	Italy	39°29'34" N, 09°14'42" E	600
Westerbork	Netherlands	52°55'01" N, 06°36'15" E	16
Bleien	Switzerland	47°20'26" N, 08°06'44" E	469
Kayseri	Turkey	38°42′37″ N, 35°32′43″ E	1054
Cambridge	United Kingdom	52°09'59" N, 00°02'20" E	24
Jodrell Bank	United Kingdom	53°14'10" N , -02°18'26" E	78

9 LTE IMPACT ON FIXED SERVICE

9.1 INTRODUCTION

Long-term Evolution (LTE) transmitters may cause interference to Fixed Service. The compatibility between LTE systems and FS is considered in this Report, assessing the LTE BS and LTE UE impact on FS receivers and vice versa.

9.2 INVESTIGATION METHOD

The LTE impact on the operation of FS systems operated from 410.0-410.8 MHz and 420.0 – 420.8 MHz and vice versa was investigated using an MCL calculation. The result parameter is the missing coupling loss, the difference between the minimum coupling loss (MCL)11 and the realised coupling loss (RCL)12, which is presented as arrays of MCL (f,l) (see Figure 91).

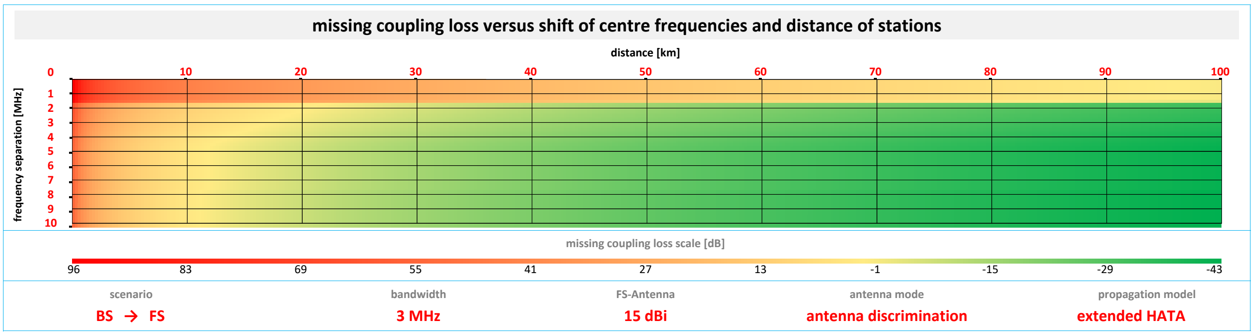


Figure 91: Example result array with continuous transfer of regions of MCL values

Since the interesting "0" cannot be tracked easily "red/green" arrays were produced for an easier interpretation. These allow clearly distinguishing between combinations of the frequency separations (Δf) and distances providing sufficient coupling loss (in green) from those which do not (in red, see Figure 92)

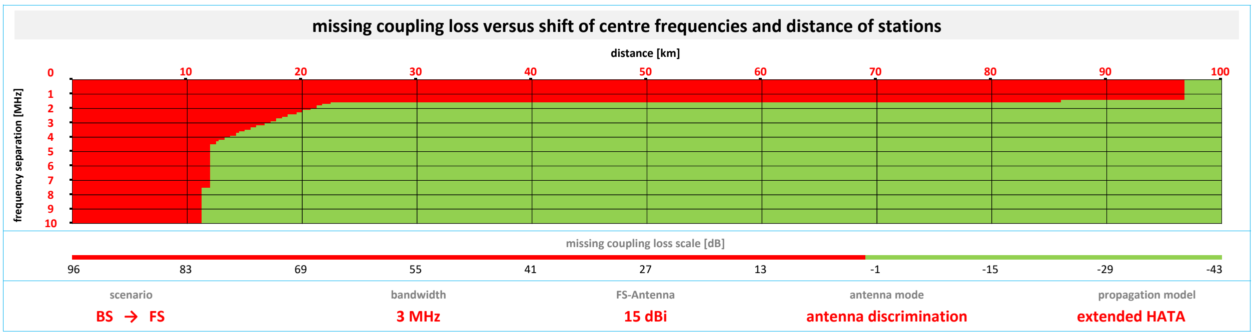


Figure 92: Example result array with discrete regions[13] of MCL values

[11] Considered between ILT and VLR to ensure the operation of the victim system link without interference

[12] realised by the arrangements in the scenario

[13] Note that the scale for this display option still informs about the range of mCL values

9.3 INVESTIGATION OPTIONS

9.3.1 Output power of the FS transmitter

In the simulation the e.i.r.p. of the FS station did not exceed -15 dBW (15 dBm) and was always below this limit.

9.3.2 Antenna performance

There is a large number of antennas available for the use in this band. It was agreed to use two antennas of a different performance in gain:

- an antenna with an azimuthal half power beamwidth of 19° providing a gain of 15 dBi;
- an antenna with an azimuthal half power beamwidth of 150° providing a gain of 5 dBi.

9.3.3 Antenna mode: Main beam coupling

In worst-case scenarios a main beam coupling option between the systems is considered for each configuration. This option regards cases where the main beams of both station antennas are pointing at each other. In contrast to that also an antenna discrimination has been optioned.

9.3.4 Antenna mode: Antenna discrimination

Considering a statistical azimuthal decoupling, if an antenna is directive than there is a certain probability that the main beam is not pointing in a certain direction considering a given scenario. The more the directivity (and with this its gain) of the antenna is the higher that probability will be.

Recognizing a gain of 15.56 dBi and providing an azimuthal half power beamwidth of 19°) the random probability of pointing in the main beam direction will be $\frac{19°}{360°} = 5.28$ or, if to be taken into account in a link level equation

$$a_{ant-azimuth} = 10 \cdot log\left(\frac{19°}{360°}\right) = -12.77\ dB \qquad \textbf{eq 1}$$

In case of the low gain antenna with a gain of 5 dBi and providing an azimuthal half power beamwidth of 150°) the random probability of pointing in a certain direction will be $\frac{150°}{360°} = 41.66\%$, or if to be taken into account in a link level equation

$$a_{ant-azimuth} = 10 \cdot log\left(\frac{150°}{360°}\right) = -3.8\ dB \qquad \textbf{eq 2}$$

For the BS the probability to be directed towards a FS station was assumed to be 100%. This assumption was made because it has to provide a comprehensive coverage.

Remark: These decoupling factors express a statistical unlikelihood and are strictly spoken bound to the condition of an equal distribution in the azimuthal antenna pointing what might be disturbed by the limitations of the radio site acquisition. Nevertheless, this method is used to assess the statistical unlikelihood of a main beam coupling.

Remark: The values for the antenna discrimination according to eq 1 and eq 2 are quite close to the main beam gain of the related antenna. It can therefore be expected that the impact of the main beam gain on the result will nearly vanish in case of the antenna mode option ”antenna discrimination”.

Considering a elevational decoupling

If the stations get close to each other an additional elevation decoupling will become effective. The value of this decoupling depends not only from the distance of one station to the other but also on the difference in their antenna heights.

It shall be noted that the antenna heights of the LTE BS (h_{BS} = 30 m) and the FS (h_{FS} = 26 m) are not that different. Taking into account the range of simulation distances l (0.25...100 km) between the stations this effect will be negligible in all scenarios involving BSs and FS.

Even for the scenarios introducing an LTE UE antenna height of 1.5 m the effect is just faintly to be noticed in the very first steps of the scenario distances. However it is taken into account.

9.3.5 Influence of the bandwidth of the LTE system

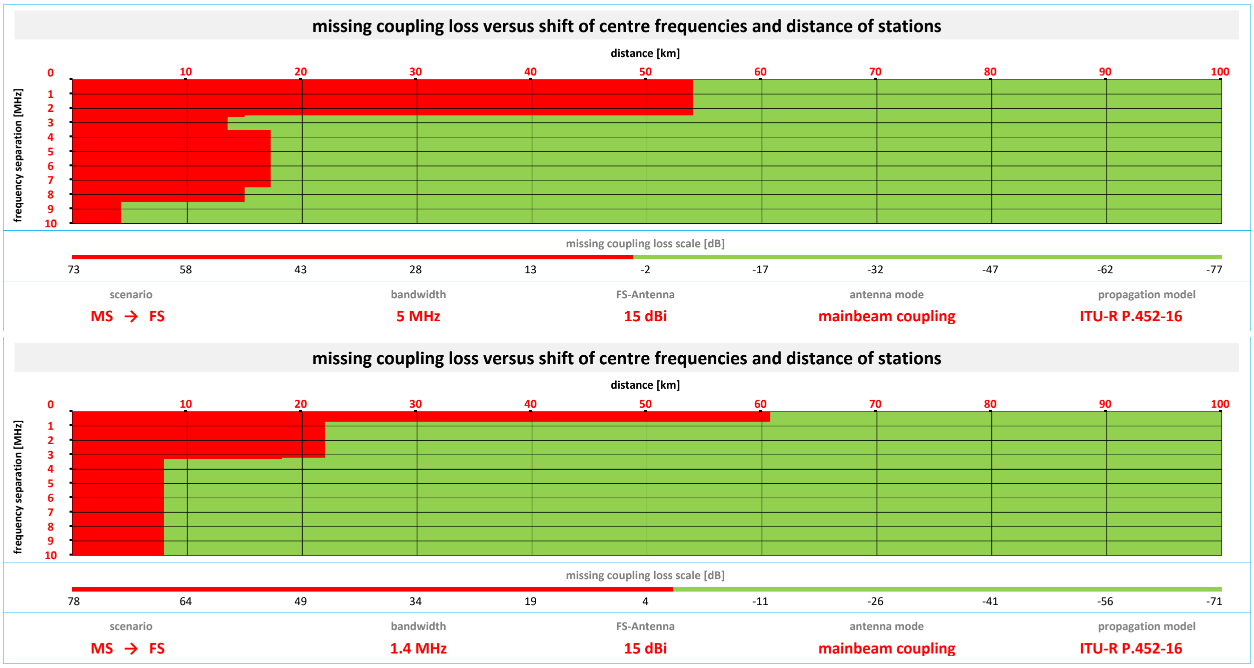


Figure 93: Influence of the LTE system bandwidth 1.4 MHz and 5 MHz

Figure 93 confirms the result formulated in section 9.4.1 and shows that an increase of the LTE system bandwidth will enlarge the frequency range with interference to be expected.

Remark: It shall be noted that the transmitter output power values of the LTE BS serve for a constant power spectral density with respect to the system bandwidth. This means that for scenarios where the LTE BS is the Interfering Link Transmitter (ILT) the results will be independent from the bandwidth.

Remark: For the LTE UE that is different. Since its transmitter output power will always be 23 dBm the system with the smallest bandwidth will provide the largest power spectral density. Therefore, if scenarios involve LTE UE the system bandwidth considered is preferably 1.4 MHz.

9.3.6 Influence of the antenna performance

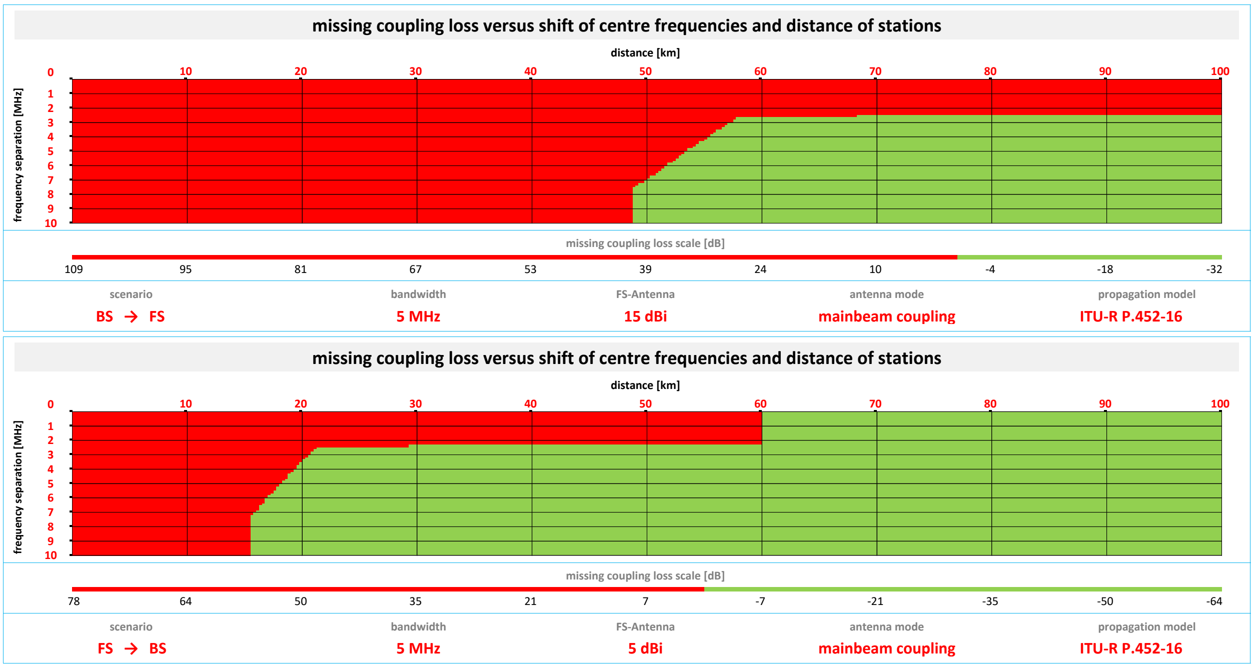


Figure 94: Influence of the main beam gain of the FS Antenna in case of main beam coupling

Figure 94 indicates that the protection distance will change remarkably if a main beam coupling is assumed. This change exactly equals the difference in the propagation loss of the model selected.

As expected the influence of the antenna main beam gain nearly vanishes if the antenna discrimination as described in clause 9.3.4 is considered (see Figure 95). This results from the fact that the antenna discrimination values are in the range of the main beam gain of the antenna considered.

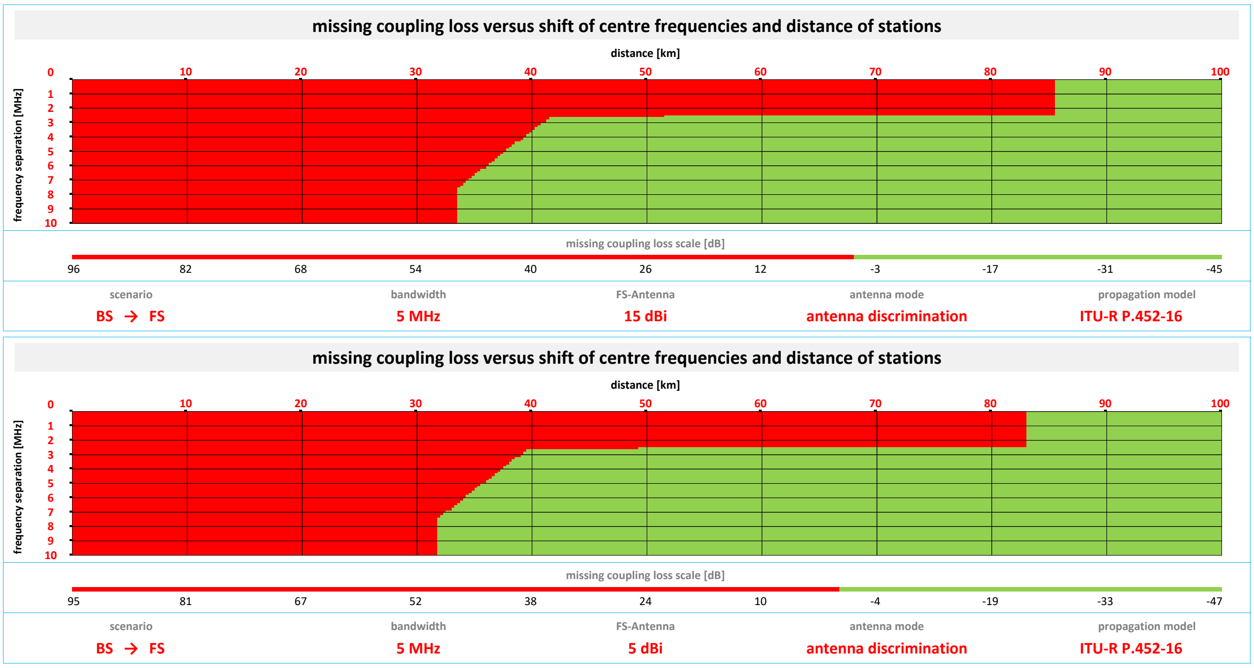


Figure 95: Influence of the main beam gain of the FS Antenna in case of antenna discrimination

9.3.7 Influence of the antenna mode

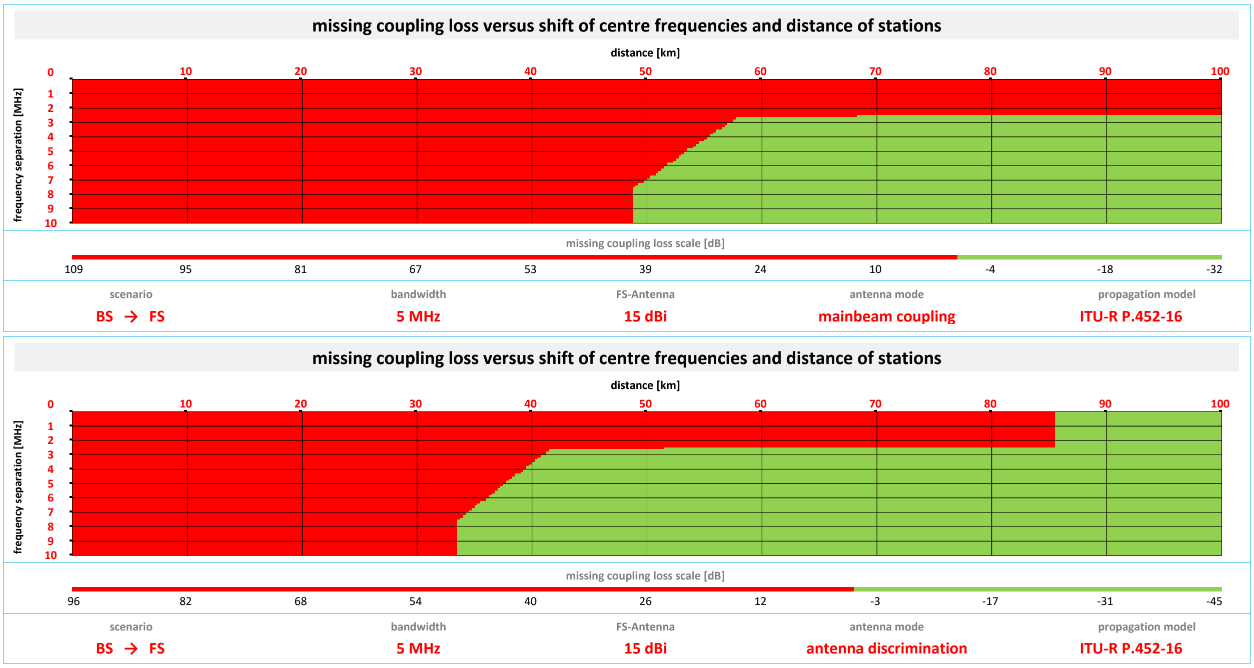


Figure 96: Influence of the antenna mode in case of a higher gain antenna

Figure 96 shows a difference in the minimum protection distances depending on the option whether the antenna discrimination as described in 9.3.4 is used or not.

This effect depends on the main beam gain of the antenna (compare Figure 96 and Figure 97) and becomes more decisive as the gain increases.

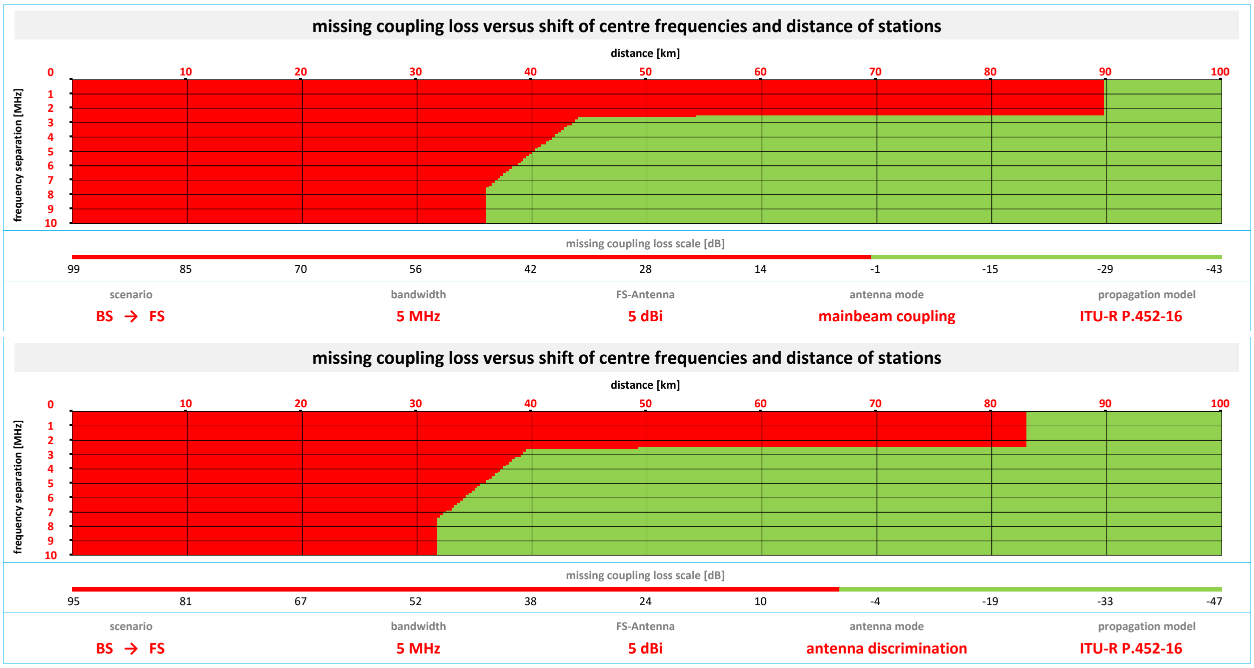


Figure 97: Influence of the antenna mode in case of a low gain antenna

9.3.8 Influence of the propagation model used

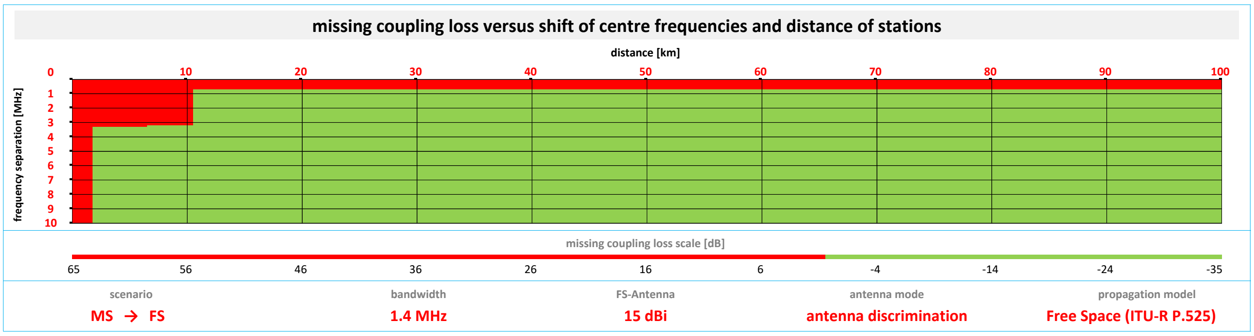


Figure 98: Result from the free space propagation model

The free space propagation model always delivers the most critical results for the evaluation of a scenario. It might be considered as a worst-case scenario and was therefore also used in clause 9.4.1. For the scenario shown in Figure 98 no co-frequency use will be possible. Depending on the frequency separation between the systems the protection distance is 10.25 km (Δf ≤ 3.2 MHz) or 1.75 km (Δf > 3.2 MHz).

Figure 99 displays the results for the same scenario but using the extended HATA propagation model. Even for the LTE UE wanted frequency range only a protection distance of about 4 km is necessary. For frequency separations of Δf > 0.7 MHz a protection distance of only 250 m is already sufficient to prevent an interference in the FS receiver caused by the LTE UE.

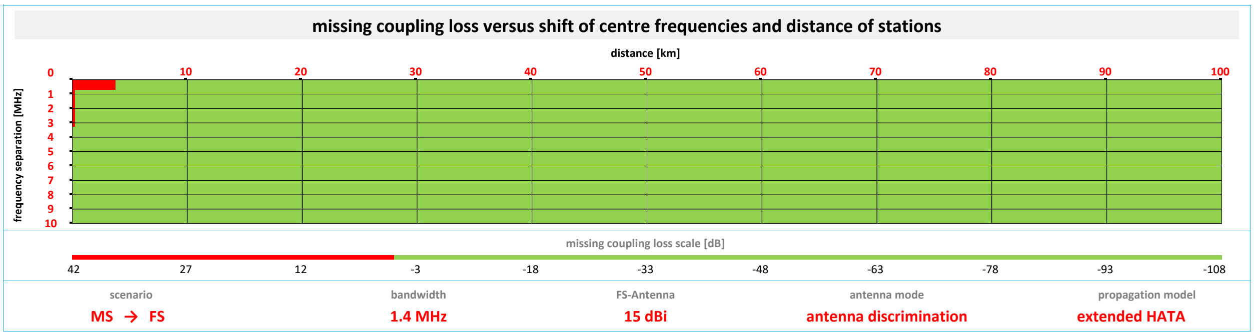


Figure 99: Result from the extended HATA propagation model

Figure 100 finally uses Recommendation ITU-R P.452-16 for the prediction of the propagation path loss. It suggests protection distances of 45 km in the co-frequency case (Δf = 0), 11 km for 0.8 MHz ≤ Δf ≤ 3.2 MHz and 2 km for Δf > 3.2 MHz.

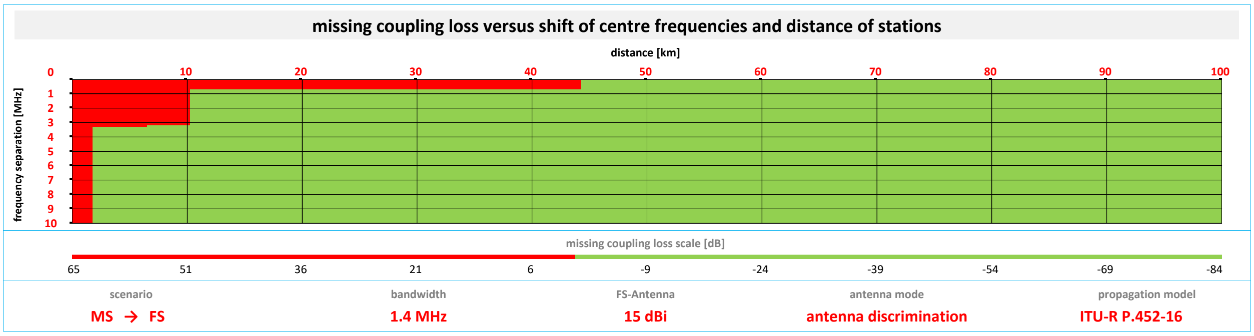


Figure 100: Result from the propagation model described in Recommendation ITU-R P.452-16

9.3.9 Propagation models used

The loss data for all propagation models used was drawn from the SEAMCAT software using the function "Test Propagation Models". As step size in distance for the simulation 0.25 km has been selected. The considered range is 0.25…100 km.

For the analysis of the results of this investigation, following propagation models were decided to be used for the mentioned scenarios:

9.3.10 Propagation model: Free Space (Recommendation ITU-R P.525 [32])

This model is used for a worst-case prediction for scenarios between LTE BS/LTE UE and FS (and vice versa) as one option. More realistic estimations for these combinations are expected by using the propagation model described in Recommendation ITU-R P.452-16 (LTE BS ↔ FS) [33] or the extended HATA propagation model (LTE UE ↔ FS).

9.3.11 Propagation model: extended HATA

This model is used to achieve realistic predictions for all scenarios involving an LTE UE in an urban environment as one option. Worst-case estimations for these scenarios are gained by using the free space propagation model.

9.3.12 Propagation model: Recommendation ITU-R P.452-16

This model is used for the scenarios between an LTE BS and FS as the option to gain more realistic predictions

9.3.13 System decoupling due to frequency separation

The decoupling of the considered systems due to their frequency separation was calculated using an adapted approach of the parameter NFD as described in [45].

$$P_{VLR} = P_{ILT} - NFD_{mc}(\Delta f)$$ **eq 3**

In the fixed service (FS) the use of the NFD approach is very common (see [45]).

It shall be noted that the masks used in the investigation were extended in their frequency range to cover at least ± 10 MHz from their centre frequencies to produce NFDmc results. For that purpose the attenuation of the outermost frequency points of the mask were considered to be constant over the larger frequency range. This is certainly a worst-case approach compared to real system behaviour which of course will show an increasing attenuation considering larger frequency separations Δf.

The step size in frequency[14] used in the study was chosen to be 0.1 MHz.

An example of the frequency decoupling between an LTE UE using a bandwidth of 1.4 MHz and a FS system is given in Figure 101.

The consideration is made both for the cases that

- the LTE UE interferes with the FS station (scenario UE → FS, in red), and
- the FS station interferes with the LTE UE (scenario FS → UE, in blue).
-

For the scenario UE → FS the NFDmc(Δf=0) = -18.45 dB because the ratio of bandwidths involved:

$$NFD_{mc}(\Delta f = 0) = 10 \cdot log\left(\frac{0.02MHz}{1.4MHz}\right) = -18.45\ dB$$ **eq 4**

[14] For the frequency axis in the grid result data array

The extreme values of decoupling (≈ -120 dB) result from a Δf where half of the FS system mask still overlaps with the LTE UE system mask. This is an undefined state of calculation which however doesn't affect the results since Δf > 10 MHz are neither considered.

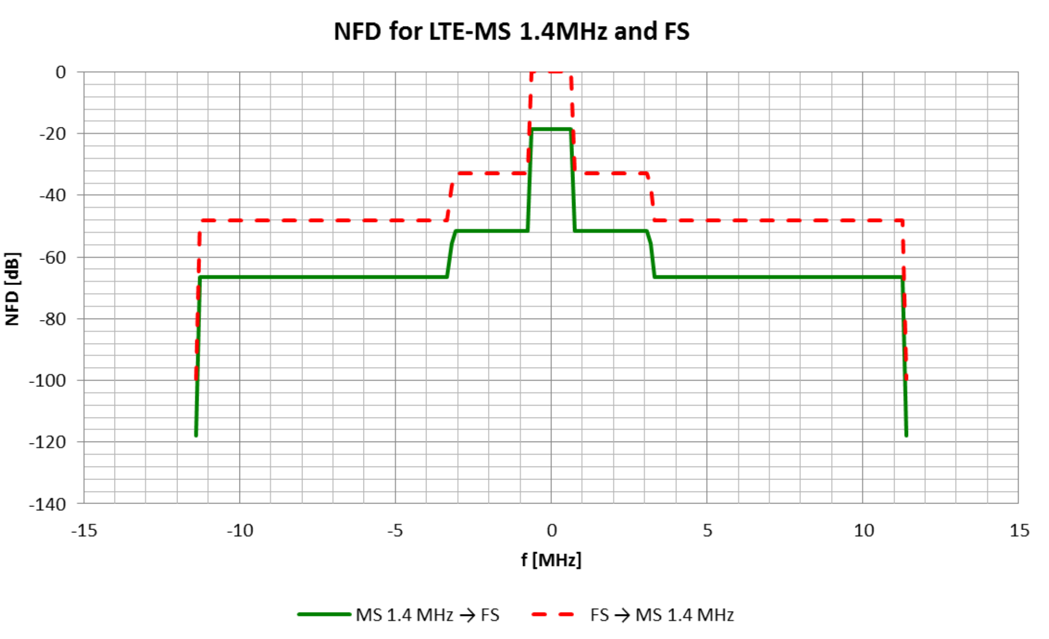


Figure 101: Decoupling loss between an LTE-UE 1.4 MHz and a FS station as a function of frequency

Remark: Please note that the NFDmc as used in this document covers an addition compared to the definition of the NFD in clause 4.2.4 of [45]: The shape and bandwidth of both masks (Tx and Rx) is taken into account. According to clause 4.2.4 in [45] the NFDmc is always =0 in the co-frequency case. As it can be seen in Figure 101 this is not the case for the NFDmc as used in this document. This issue is also taken into account and described in [47]. In its technical meaning the NFDmc can be considered as equal to the Adjacent Channel Leakage Ratio (ACLR). The difference is that in case of ACLR an ideal receiver filter (rectangular shaped) is assumed. In case of NFDmc a realistic filter is used.

9.4 ASSESSMENT

In total, 144 scenarios have been produced. Following cases have been chosen to derive the main findings of the study:

Table 87: Scenarios used to derive the results of the study

Scenario								protection distance [km]	
No.	Scenario	Figure	environ-ment	propagation model	gain [dBi]	antMode	considered as…	co-frequency	adjacent frequency range
1	BS→ FS	Figure 102	any	FreeSpace	15	mB	worst-case	not possible	not possible
2	FS→ BS	Figure 102	any	FreeSpace	15	mB	worst-case	not possible	≥ 28.25
3	FS→ UE	Figure	any	FreeSpace	15	mB	worst-case	not	≥ 1

		103						possible	
4	UE→ FS	Figure 103	any	FreeSpace	15	mB	worst-case	not possible	≥ 8.25
5	BS→ FS	Figure 104	rural	P.452-16	15	AD	use[15] case	≥ 86	≥ 33.75
6	FS→ BS	Figure 104	rural	P.452-16	15	AD	use case	≥ 50.5	≥ 6.5
7	BS→ FS	Figure 105	rural	P.452-16	5	AD	use case	≥ 83.25	≥ 32
8	FS→ BS	Figure 105	rural	P.452-16	5	AD	use case	≥ 62.25	≥ 15.25
9	FS→ UE	Figure 106	urban	extended HATA	15	AD	use case	≥ 1.25	-
10	UE→ FS	Figure 106	urban	extended HATA	15	AD	use case	≥ 4	-
11	FS→ UE	Figure 107	urban	extended HATA	5	AD	use case	≥ 2	-
12	UE→ FS	Figure 107	urban	extended HATA	5	AD	use case	≥ 3.5	-
13	FS→ UE	Figure 105	urban	extended HATA	15	mB	critical case	≥ 2.75	-
14	UE→ FS	Figure 108	urban	extended HATA	15	mB	critical case	≥ 9	0.5

9.4.1 Worst-case estimation

Figure 102 shows the most a most critical scenario between a FS station and an LTE BS. The antenna main beam gain is fully considered, the antennas are pointing at each other and the used propagation model (free space propagation) provides the least propagation losses physically possible between the stations.

According to this estimation the LTE BS will always impose an interference problem to the FS receiver. Even a distance of 100 km and a frequency separation of 10 MHz will not allow an operation without interference (see Figure 102). Given a decrease of 20 dB / decade in free space propagation the theoretical distance for a sufficient decoupling of the systems would be about 700 km.

The FS transmitter can also not be operated without interference within a distance of 100 km in a co-frequency case.

Outside the wanted signal frequency range of the LTE BS the protection distance between the FS transmitter station and the base station receiver has to be between 20…40 km depending on the bandwidth and the frequency separation between the systems.

The main reason for the different results of the two scenarios in Figure 102 is the national legislation on the maximum e.i.r.p. (= 15 dBm) for the FS transmitter. In case of using an antenna providing a main beam gain of 15 dBi the transmitter output power has to be decreased to -0.65 dBm.

As worst-case estimation it can be concluded that no sharing of a common frequency range between LTE and FS will be possible. For the scenario BS→FS this is also not possible even in the adjacent frequency range.

Compatibility between the systems in adjacent frequency ranges requires a protection distance of about 8 km for the scenario UE → FS. In the opposite direction the protection distance requirement decreases to 1 km.

[15] Considered as to be more realistic than the presented worst-case estimation.

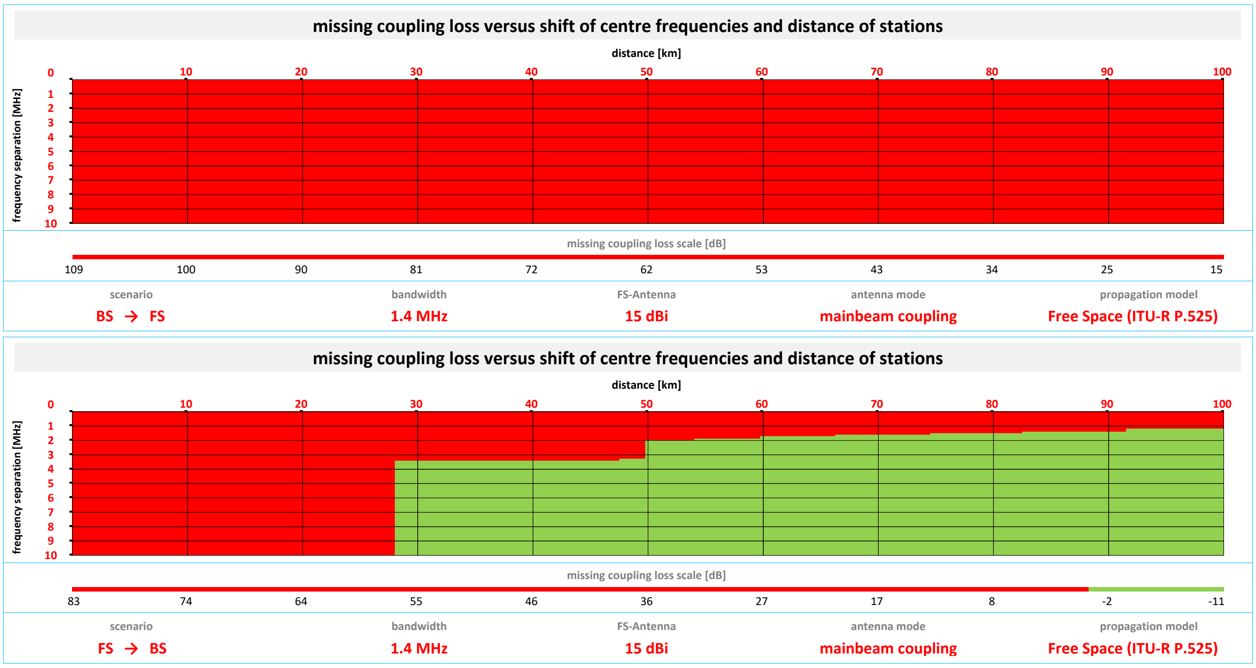


Figure 102: Worst-case assessment of compatibility and sharing between LTE BS and FS using the free space propagation model and pointing the higher gain antennas towards each other

Although the worst-case scenarios involving the LTE UE show a significant relaxed estimation, a sharing between the LTE system and the FS an interference-free operation will also not be possible, see Figure 103.

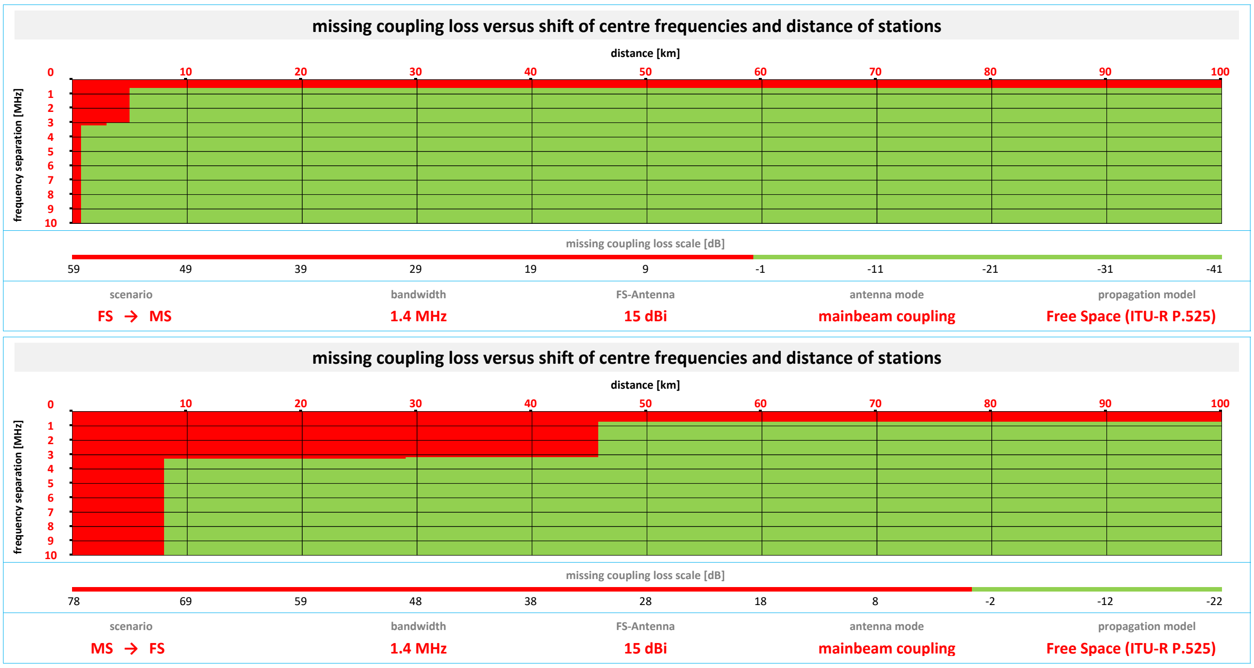


Figure 103: Worst-case assessment of compatibility and sharing between LTE UE and FS using the free space propagation model and pointing the higher gain antennas towards each other

9.4.2 More realistic estimation

This sub-section provides a more realistic estimation on the sharing and compatibility situation between LTE systems and FS stations. The antenna discrimination is taken into account and the propagation model used refers to the most commonly used one for the relevant scenario.

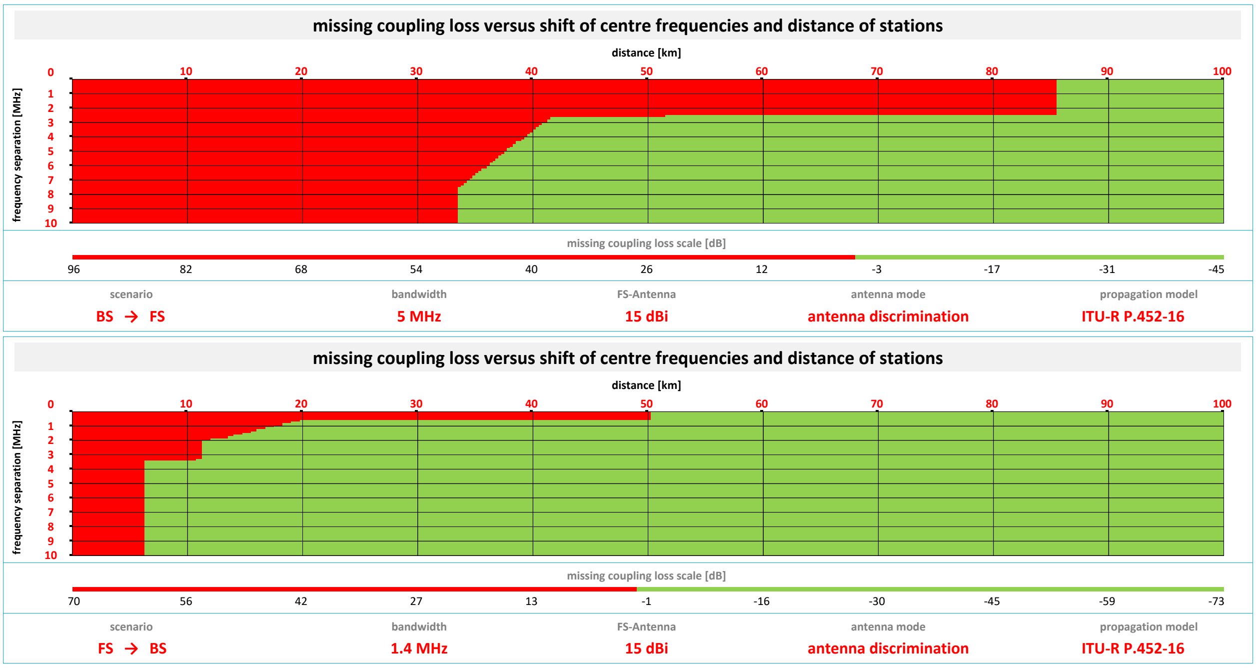


Figure 104: More realistic assessment of compatibility and sharing between LTE BS and FS using the propagation model described in Recommendation ITU-R P.452-16, the high gain antenna and assuming an antenna discrimination

As already mentioned in clause 9.3.4, the impact of the antenna gain performance nearly vanishes if the antenna discrimination is used (compare scenarios "BS → FS" in Figure 104 and Figure 105).

The reason for the lower protection distance for the scenario "FS → BS" in Figure 104 compared to Figure 105) is the national legislation on the maximum e.i.r.p. for the FS. The output power of the FS transmitter has to be decreased remarkably compared to the use case with a low gain antenna.

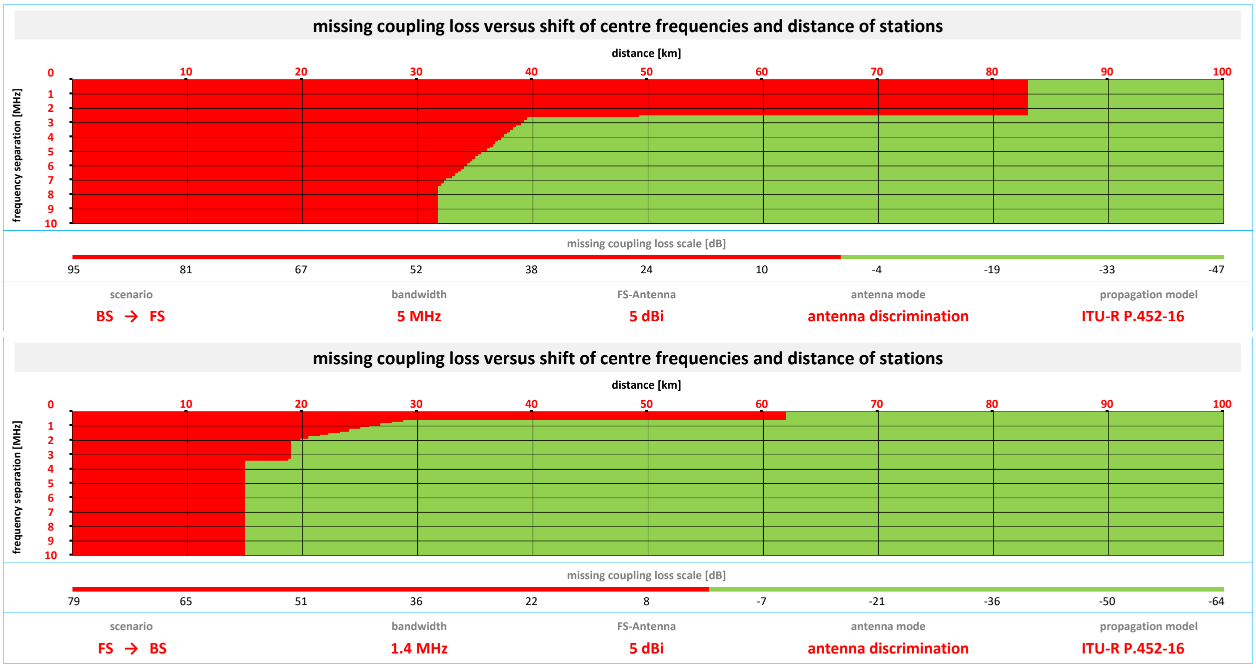


Figure 105: More realistic estimation of compatibility and sharing between LTE-BS and FS using the propagation model described in Recommendation ITU-R P.452-16, the low gain[16] antenna and assuming an antenna discrimination

From the following results, it can be drawn that for use cases of LTE UE and FS stations:

- a sharing of a common frequency range is possible with a low risk of interference;
- a compatible use in adjacent frequency ranges will doubtlessly be possible without any risk of interference.

[16] When additionally statistical antenna discrimination is taken into account, please remember that in this case the difference in antenna gain performance nearly vanishes (as described in clause 9.3.4).

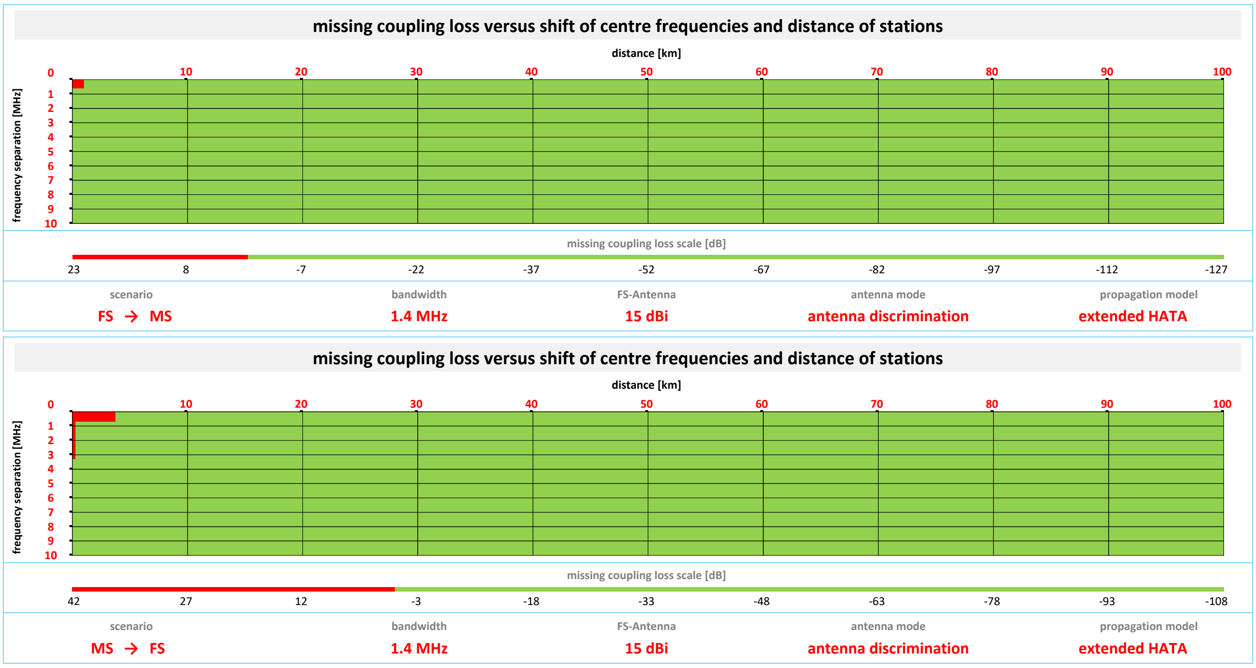


Figure 106: More realistic estimation of compatibility and sharing between LTE UE and FS using the extended HATA propagation model, the higher gain antenna and assuming an antenna discrimination

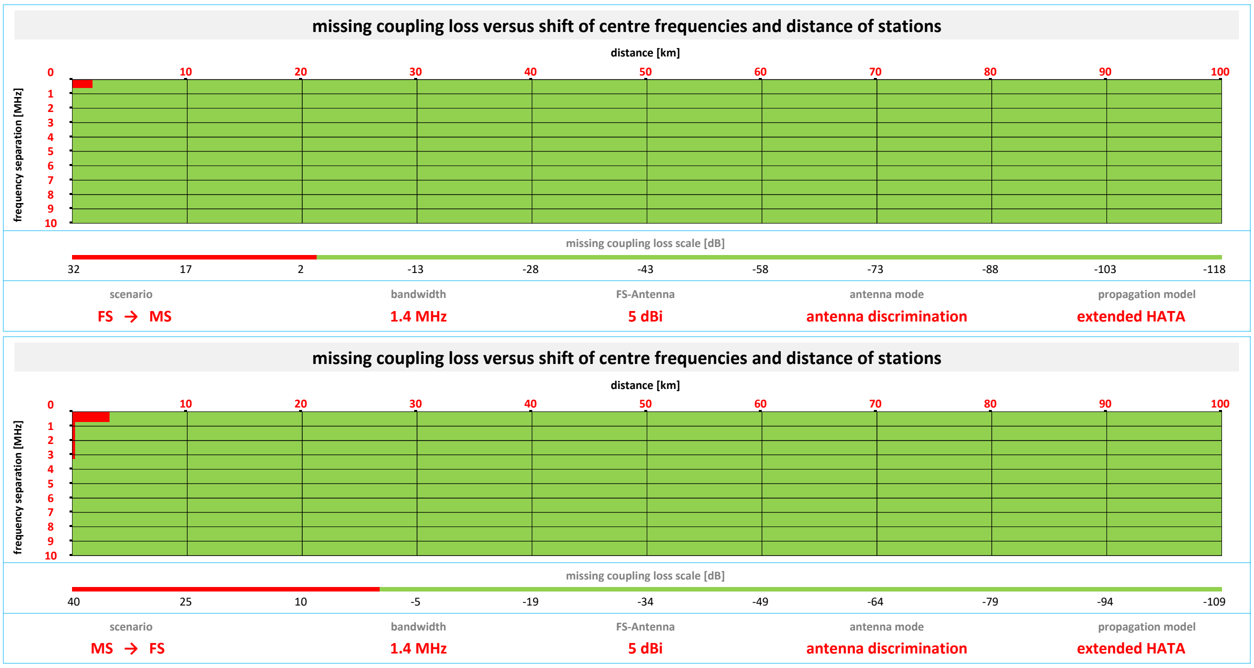


Figure 107: More realistic estimation of compatibility and sharing between LTE UE and FS using the extended HATA propagation model, the low gain antenna and assuming an antenna discrimination

In the last result array shown in Figure 108 a main beam coupling is assumed between the FS station and the LTE UE. Remaining the extended HATA propagation model in use this can be considered as a mixed form (worst-case/use case) of scenario. Even so a noticeable risk might be seen in the sharing.

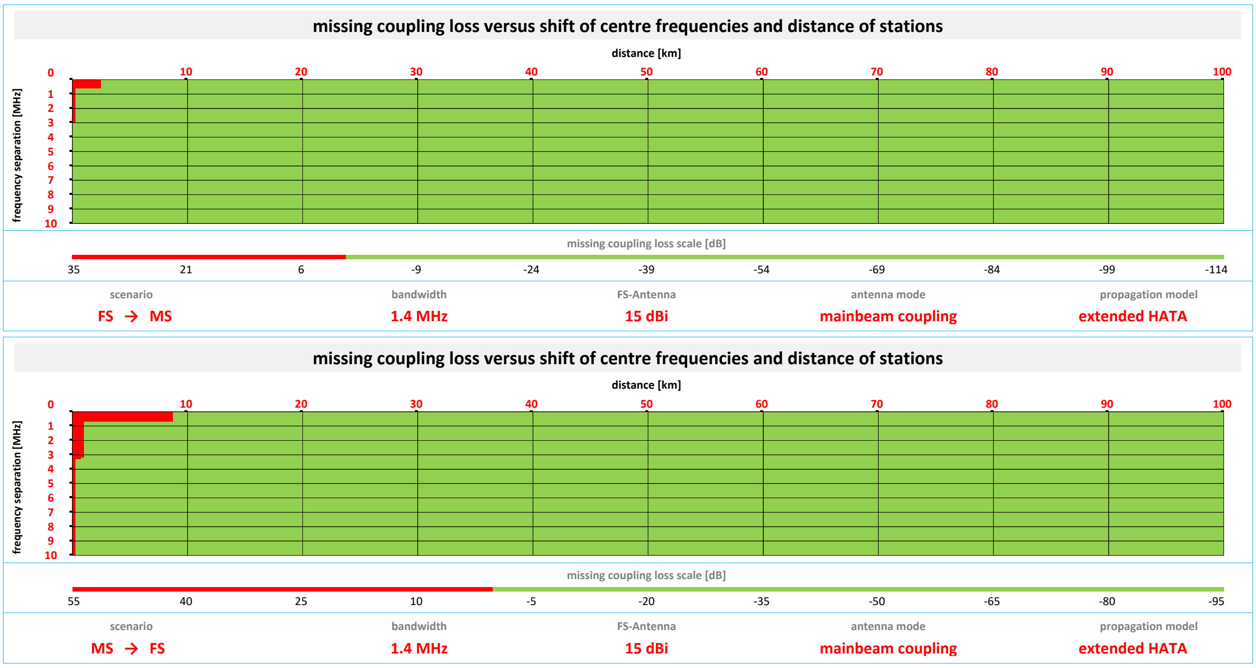


Figure 108: More realistic estimation of compatibility and sharing between LTE UE and FS using the extended HATA propagation model, the higher gain antenna in the main beam coupling mode

9.5 RESULTS OF THE INVESTIGATION

Worst-case estimations predict neither the possibility of sharing a common frequency range nor a compatible use between LTE and the FS in adjacent bands.

More realistic estimations suggest protection distances of up to 85 km in co-frequency scenarios. In adjacent frequency ranges the required protection distances decrease to up to 35 km. LTE UE doesn’t seem to cause or suffer from interference then.

9.5.1 Worst-case estimation

The worst-case estimation implies free space propagation between the stations and the condition that both antennas are pointing towards each other. The FS antenna employs the height gain option (15 dBi).

According to the worst-case estimation the sharing of a common frequency range will not be possible between LTE and the FS.

Their compatibility if used in adjacent frequency ranges is limited the remaining scenarios and would require protection distances of about 30 km.

Table 88: Worst-case estimation of sharing and compatibility of LTE and FS

Scenario	protection distance if used… [km]	
	co-frequency	in an adjacent frequency range
BS → FS	no sharing	no compatibility
FS → BS	no sharing	> 28
FS → Mobile station (MS)	no sharing	> 1
MS → FS	no sharing	> 8

9.5.2 More realistic estimation

This estimation aims at a more realistic estimation and implies the propagation model described in Recommendation ITU-R P.452-16 between the LTE BS and the FS station. Between the LTE UE and the FS station the extended HATA propagation model is used. An antenna discrimination as described in 9.3.4 was applied.

If more realistic investigation options are used a sharing of a common frequency range will be possible between LTE BS and the FS if protection distances of about 85 km are kept. Their compatibility if used in adjacent frequency ranges can be expected, if protection distances of about 35 km are respected.

LTE UE satisfies sharing requirements for operation distances larger than 4 km to the FS station. If used in an adjacent frequency range, no interference for operational distances larger than 0.5 km is expected.

Table 89: More realistic estimation of sharing and compatibility of LTE and FS

scenario	protection distance if used… [km]	
	co-frequency	in an adjacent frequency range
BS → FS	≥ 86	≥ 33.75
FS → BS	≥ 62.25	≥ 15.25
UE → FS	≥ 4	-
FS → UE	≥ 2	-

10 LTE IMPACT ON PMR LINKS IN AUDIO-VISUAL PRODUCTION

This section provides information about a specific compatibility analysis between Analogue PMR and Long-term Evolution (LTE) systems. It illustrates the situation of “mobile” PMR networks where the BS of the networks can be moved depending on the need. This is the case for PMSE PMR links used in the audio-visual production which could be located nearby LTE BS such as those used by a PPDR network.

10.1 CO-LOCATION SCENARIOS

The studies contained in ECC Report 240 [1] considered that there is a limited correlation between the locations of PMSE and LTE based PPDR equipment. During major events, a variety of equipment for wireless communications is used. Not only for safety communications and audio connections, but also communication equipment for television, police and ambulance authorities. All these applications need transmitting frequencies. By nature, LTE equipment is going to be deployed in the same areas where PMSE operations are going to be deployed. In particular:

- LTE MS/BS equipment could be quite close to the PMSE equipment;
- LTE MS/BS equipment are expected to be used at the same locations where PMSE will be deployed to cover some events (sport, concerts…), therefore, if there is any potential of interference, interference will occur each time an LTE MS/BS is located nearby a PMSE MS/BS. In such a situation, the equipment will be operated in the same areas or along the same routes, which was not considered in the current simulations given in ECC Report 240 for Analogue PMR.

It should be noted that PMSE are constrained in terms of location, since they would be located in the vicinity of the events they are covering or within a studio. In case of events, this implies that there are limited possibilities for coordination with LTE-based PPDR equipment deployed to ensure the security during those events.

10.2 AIRBORNE SCENARIOS

With regard to the interference resulting from the LTE BS on PMSE MS, the studies relating to Analogue PMR (see ECC Report 240) considered terrestrial MS, while in the case of audio-visual production, the MS may also be airborne in helicopters or in airplanes. The propagation model which was considered in the existing compatibility study given in ECC Report 240 is Extended Hata (Urban). This propagation model does not fit in the case where the potential victim is airborne. It should be noted that the frequencies operated in such cases are internationally coordinated and that the deployment of LTE equipment in one country may have an impact on the neighbouring countries.

10.3 TDD SCENARIOS

The overall channel plan given in Recommendation T/R 25-08 for the bands 406.1-430 MHz and 440-470 MHz is provided below:

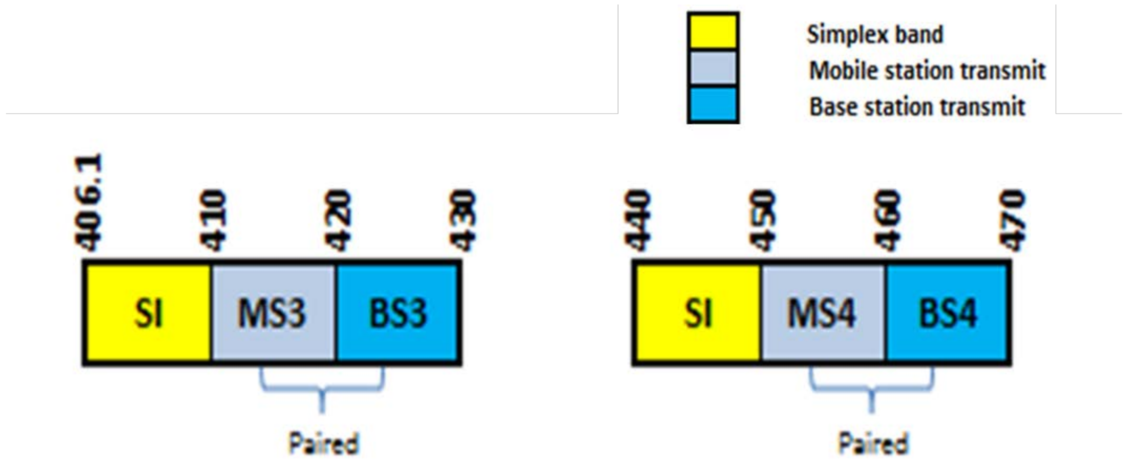


Figure 109: Recommendation T/R 25-08 Channel Arrangement

ECC Report 240 considered the following situation:

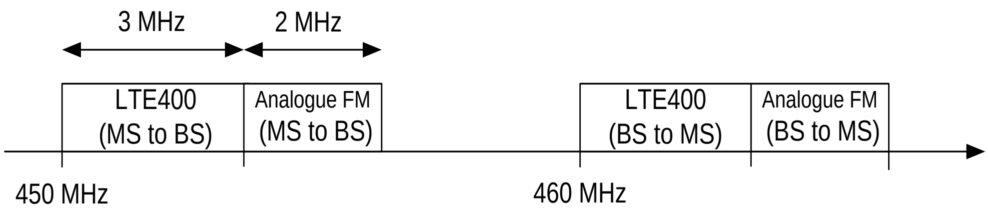


Figure 110: LTE impact on PMSE (Analogue FM) in ECC Report 240

This leads to a frequency separation of 10 MHz between the MS considered in the studies, and 5 MHz while investigating the impact of LTE BS on PMSE BS. However, it should be noted that Analogue FM BS and MS could be deployed not in conformity with the “CEPT” arrangement given in Recommendation T/R 25-08 resulting in a much smaller frequency separation. In particular, frequencies might be used by TDD systems which mean that a given frequency could be operated by both MS and BS for links of audio-visual production.

10.4 PARAMETERS FOR PMSE USED IN AUDIO-VISUAL PRODUCTION

The PMSE equipment uses a raster of 12.5 kHz and/or 25 kHz. The corresponding characteristics as given in ECC Report 240 are considered also taking into account of the following:

The PMSE BS used in audio-visual production is connected with various receivers such as crew, motorbikes, helicopters, airplanes… This implies that the directivity of the antenna is limited. Typical BS antennas are omnidirectional with a maximum antenna gain of 3 dBi. The maximum e.i.r.p. for the BS is 13 dBW.

In typical scenarios, to reduce the potential interference to other users of the spectrum, the power may not exceed 0 dBW for the MS.

10.5 MINIMUM COUPLING LOSS (MCL) CALCULATIONS

ECC Report 240 considered the scenario as given in Figure 110. Similar scenarios were considered, however, additional scenarios specific to the Audio-Visual production are considered (such as the TDD case).

MCL calculations are presented in the following chapters. These calculations assume unwanted emission levels defined in the 3GPP specifications. It should be noted that the 3GPP minimum requirements are specified for maximum output power, both for BS and UE. The LTE networks use UL power control and thus devices will transmit at different power depending on the distance to the connected BS, this translates into different level of unwanted emissions (always less than the 3GPP minimum requirements). The LTE network is also considered to be transmitting constantly in the calculations.

10.5.1 LTE UE impact on PMSE

10.5.1.1 *LTE UE impact on PMSE MS*

The studies in ECC Report 240 considered a frequency offset of more than 10 MHz between the LTE UE and the PMSE MS. It implies that the transmitter (Tx) unwanted emissions of the system are going to be -50 dBm/MHz, as the PMSE UL overlaps with the LTE 3GPP UL definition. The following Table 90 table provides the results of calculations to assess the separation distances considering a frequency offset of 10 MHz. It should be noted that considering the Extended Hata (Urban) model, the distance is more than 60 meters. Additional propagation models are also considered for the purpose of comparison.

Table 90: LTE UE impact on 12.5 kHz PMSE MS

Parameter	Extended Hata Urban	Extended Hata SRD	Free space	Dual Slope model (BreakPoint at 5 m)
Unwanted emission conducted power	-50 dBm/1 MHz	-50 dBm/1 MHz	-50 dBm/1 MHz	-50 dBm/1 MHz
Gain	-3 dB	-3 dB	-3 dB	-3 dB
Body loss	4 dB	4 dB	4 dB	4 dB
e.i.r.p. in the direction of the PMSE equipment	-57 dBm/1 MHz	-57 dBm/1 MHz	-57 dBm/1 MHz	-57dBm/1 MHz
e.i.r.p. in the direction of the PMSE equipment	-78 dBm/8 kHz	-78dBm/8 kHz	-78 dBm/8 kHz	-78 dBm/8 kHz
PMSE sensitivity	-117 dBm	-117 dBm	-117 dBm	-117 dBm
PMSE sensitivity + 3 dB	-114 dBm	-114 dBm	-114 dBm	-114 dBm
C/I	21 dB	21 dB	21 dB	21 dB
I	-135 dBm	-135 dBm	-135 dBm	-135 dBm
Gain	0 dBi	0 dBi	0 dBi	0 dBi
Attenuation to meet the criterion	57 dB	57 dB	57 dB	57 dB
Distances	36 m	36 m	36 m	15 m

Assuming 4 dB body loss, it can be seen that considering a frequency offset of 10 MHz, the separation distances between the LTE UE and the PMSE MS, based on MCL calculations, would be at least 60 m.

10.5.1.2 *LTE UE impact on PMSE BS*

For this case, ECC Report 240 considered the two systems operating in adjacent blocks of spectrum. This is further considered in the following tables where a frequency offset of 500 kHz is considered between the frequency used by the PMSE BS and the edge of the LTE UE band.

Table 91: LTE UE impact on 12.5 kHz PMSE BS – 500 kHz frequency offset

Parameter	1.4 MHz	3 MHz	5 MHz	Reference TS 36.101 (3/5 RB)
Unwanted emission conducted power	-10 dBm/30 kHz	-13 dBm/30 kHz	-15 dBm/30 kHz	-10 dBm/1 MHz
Gain	-3 dB	-3 dB	-3 dB	-3 dB
Body loss	4 dB	4 dB	4 dB	4 dB
e.i.r.p. in the direction of the PMSE equipment	-22.74 dBm/8 kHz	-25.74 dBm/8 kHz	-27.74 dBm/8 kHz	-38 dBm/8 kHz
PMSE sensitivity	-120 dBm	-120 dBm	-120 dBm	-120 dBm
PMSE sensitivity + 3 dB	-117 dBm	-117 dBm	-117 dBm	-117 dBm
C/I	21 dB	21 dB	21 dB	21 dB
I	-138 dBm	-138 dBm	-138 dBm	-138 dBm
Gain	3 dBi	3 dBi	3 dBi	3 dBi
Attenuation to meet the criterion	118.26 dB	115.26 dB	113.26 dB	103 dB
Distances	0.95 km	0.834 km	0.685 km	0.35 km

The separation distances, based on MCL calculations, are ranging from 350 m to about 1 km assuming 4 dB body loss.

At a frequency offset of 1 MHz, the Tx power will be -10 dBm/1 MHz, therefore a distance of 0.554 km and 0.35 km considering 4 dB body loss.

10.5.2 LTE BS impact on PMSE

10.5.2.1 *LTE BS impact on PMSE MS*

In this case, the systems are assumed to operate in adjacent block. The following Table 92 provides results for a frequency offset of 500 kHz.

Table 92: LTE BS impact on 12.5 kHz PMSE MS – 500 kHz frequency offset

Parameter	1.4 MHz	3 MHz	5 MHz
Unwanted emission conducted power	-4.57 dBm/100 kHz	-6.67 dBm/100 kHz	-7.7 dBm/100 kHz
Gain	13 dBi	13 dBi	13 dBi
e.i.r.p. in 8 kHz	-2.54 dBm/8 kHz	-4.64 dBm/8 kHz	-5.67 dBm/8 kHz
PMSE sensitivity	-117 dBm	-117 dBm	-117 dBm
PMSE sensitivity + 3 dB	-114 dBm	-114 dBm	-114 dBm
C/I	21 dB	21 dB	21 dB
I	-135 dBm	-135 dBm	-135 dBm
Gain MS PMSE	0 dBi	0 dBi	0 dBi
Attenuation to meet the criterion	132.46 dB	130.36 dB	129.33 dB
Distance	2.4 km	2.1 km	1.96 km

Table 93 provides results for a frequency offset of 1 MHz.

Table 93: LTE BS impact on 12.5 kHz PMSE MS – 1 MHz frequency offset

Parameter	Reference ECC/DEC/(16)02	1.4 MHz	3 MHz	5 MHz
e.i.r.p.	-43 dBm/100 kHz			
Unwanted emission conducted power		-8.14 dBm/100 kHz	-8.3 dBm/100 kHz	-8.4 dBm/100 kHz
Antenna gain	13 dBi	13 dBi	13 dBi	13 dBi
e.i.r.p. in 8 kHz	-53.97 dBm/8 kHz	-6.11 dBm/8 kHz	-6.3 dBm/8 kHz	-6.37 dBm/8 kHz
PMSE sensitivity	-117 dBm	-117 dBm	-117 dBm	-117 dBm
PMSE sensitivity + 3 dB	-114 dBm	-114 dBm	-114 dBm	-114 dBm
C/I	21 dB	21 dB	21 dB	21 dB
I	-135 dBm	-135 dBm	-135 dBm	-135 dBm
Gain MS PMSE	0 dBi	0 dBi	0 dBi	0 dBi
Attenuation to meet the criterion	81 dB	128.89 dB	128.7 dB	128.6 dB
Distances	90 m	1.9 km	1.88 km	1.87 km

Based on MCL calculations, at 1 MHz, the separation distances are more than 1 kilometre except if the e.i.r.p. limit of -43 dBm/100 kHz given in ECC/DEC/(16)04 is implemented resulting in separation distances lower than 100 m.

10.5.2.2 *LTE BS impact on PMSE BS*

The following Table 94 provides the separation distances assuming a frequency offset of at least 5 MHz as in ECC Report 240 [1].

Table 94: LTE BS impact on 12.5 kHz PMSE BS – 5 MHz frequency offset

Parameter	Reference ECC/DEC/16(02)	1.4 MHz	3 MHz	5 MHz	
e.i.r.p.	-43 dBm/100 kHz				-80 dBm/100kHz
Unwanted emission conducted power		-16 dBm/100 kHz	-15 dBm/100 kHz	-14 dBm/100 kHz	-96 dBm/100kHz
Antenna gain	13 dBi	13 dBi	13 dBi	13 dBi	13 dBi
e.i.r.p. in 8 kHz	-54 dBm/8 kHz	-14 dBm/8 kHz	-13 dBm/8 kHz	-12 dBm/8 kHz	-91 dBm/8 kHz
PMSE sensitivity	-120 dBm	-120 dBm	-120 dBm	-120 dBm	-120 dBm
PMSE sensitivity + 3 dB	-117 dBm	-117 dBm	-117 dBm	-117 dBm	-117 dBm
C/I	21 dB	21 dB	21 dB	21 dB	21 dB
I	-138 dBm	-138 dBm	-138 dBm	-138 dBm	-138 dBm
Gain MS PMSE	3 dBi	3 dBi	3 dBi	3 dBi	3 dBi
Attenuation to meet the criterion	87 dB	124 dB	125 dB	126 dB	47 dB
Distances	0.795 km	8.94 km	9.5 km	10.17 km	0.008 km

Considering the general spurious emissions limits given in 3GPP TS 36.104 [13], coexistence is unlikely to be reached due to large separation distances. Considering level given in ECC/DEC/(06)02 [44] (e.i.r.p. limit of -43 dBm/100 kHz) are much smaller. Coexistence is achieved if the BS spurious meets the minimum requirements of -96 dBm/100kHz emissions in emissions in the band 450-455 MHz (3GPP TS 36.104 [13]).

10.5.3 Additional scenario's compared to ECC Report 240

In case of TDD links are considered, then both the MS and the BS will be operating on the same frequency, resulting in frequency offsets smaller than those considered in ECC Report 240. This section considers the case of LTE UE impact on PMSE MS and LTE BS impact on PMSE BS. This could also happen if the PMSE MS is transmitting in the frequency range 455-460 MHz.

10.5.3.1 *LTE UE impact on PMSE MS*

The following Table 95 provides the results for a frequency offset of 500 kHz.

Table 95: LTE UE impact on 12.5 kHz PMSE MS – 500 kHz frequency offset

Parameter	1.4 MHz	3 MHz	5 MHz	Reference TS 36.101 (3/5 RB)
Emission limits (dBm)	-10 dBm/30 kHz	-13 dBm/30 kHz	-15 dBm/30 kHz	-10 dBm/1 MHz
Gain	-3 dB	-3 dB	-3 dB	-3 dB
Body loss	4 dB	4 dB	4 dB	4 dB
e.i.r.p. in the direction of the PMSE equipment	-20 dBm/8 kHz	-23 dBm/8 kHz	-25 dBm/8 kHz	-38 dBm/8 kHz
PMSE sensitivity	-117 dBm	-117 dBm	-117 dBm	-117 dBm
PMSE sensitivity + 3 dB	-114 dBm	-114 dBm	-114 dBm	-114 dBm
C/I	21 dB	21 dB	21 dB	21 dB
I	-135 dBm	-135 dBm	-135 dBm	-135 dBm
Gain	0 dBi	0 dBi	0 dBi	0 dBi
Attenuation to meet the criterion	112.26 dB	109.26 dB	107.26 dB	97 dB
Distances	126 m	102 m	97 m	81 m

10.5.3.2 *LTE BS impact on PMSE BS*

The following Table 96 provides the results for a frequency offset of 500 kHz.

Table 96: LTE BS impact on 12.5 kHz PMSE BS – 500 kHz frequency offset

Parameter	1.4 MHz	3 MHz	5 MHz
Tx power	-4.57 dBm/100 kHz	-6.67 dBm/100 kHz	-7.7 dBm/100 kHz
Antenna gain	13 dBi	13 dBi	13 dBi
e.i.r.p. in 15 kHz	-2.54 dBm/8 kHz	-4.64 dBm/8 kHz	-5.67 dBm/8 kHz
PMSE sensitivity	-120 dBm	-120 dBm	-120 dBm
PMSE sensitivity + 3 dB	-117 dBm	-117 dBm	-117 dBm
C/I	21 dB	21 dB	21 dB
I	-138 dBm	-138 dBm	-138 dBm
Gain MS PMSE	3 dBi	3 dBi	3 dBi
Attenuation to meet the criterion	138.46 dB	136.36 dB	135.33 dB
Distances	22.4 km	20 km	18.8 km

10.5.4 Conclusions for the MCL calculations

Considering scenarios similar to those considered in ECC Report 240,

- Relating to the impact of LTE BS on PMSE BS (receiving in 453-455 MHz);

- With the general spurious emissions limits given in 3GPP TS 36.104 [13], coexistence is unlikely to be reached due to large separation distances;
- Coexistence is expected between if the LTE BS spurious meets the minimum requirements of -96 dBm/100kHz emissions in emissions in the band 450-455 MHz (3GPP TS 36.104 [13]);
- The implementation of the limit given in ECC/DEC/(16)02 [4] (e.i.r.p. of -43 dBm in 100 kHz) at 1 MHz, will significantly improve the compatibility between LTE BS and PMSE MS;
- Separation distance between the LTE UE and PMSE MS is about 15 m.

Considering scenarios differing from those considered in ECC Report 240, TDD case or MS transmitting in 455-460 MHz, the achieved separation distances are larger. For scenarios where the PMSE and the LTE systems are operated in adjacent blocks, the separation distances are between 81 m to 126 m for LTE UE on PMSE MS with 500 kHz frequency offset). The level for the unwanted emissions in the 1 MHz outside from the LTE band should be clarified since the operation of the PMSE may be limited in this frequency range due to the risk of interference resulting from LTE systems.

Due to possible co-location of LTE based PPDR equipment and PMSE, the potential of interference is quite high, this is further considered in the following section.

10.6 SEAMCAT CALCULATIONS

The scenarios considered in this section are based on those considered in ECC Report 240. It is noted that the frequency ranges identified for LTE based PPDR in ECC/DEC/(16)02 [44] are slightly different.

In ECC Report 240, the situation described in the following figure was considered.

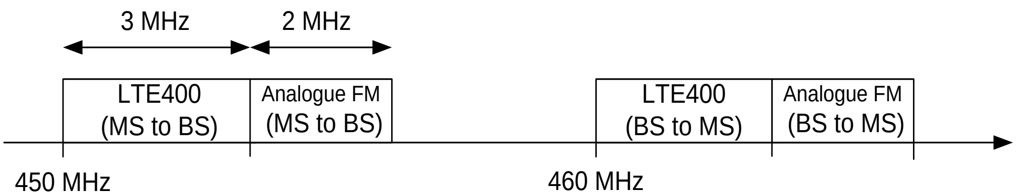


Figure 111: LTE on Analogue FM in Compatibility studies in ECC Report 240

In ECC/DEC/(16)02, the following frequency ranges were identified:

"*The range can offer national flexibility, e.g. in the context of additional spectrum beside the 700 MHz range. 1.4 MHz, 3 MHz, and 5 MHz LTE FDD channelling arrangements could be implemented in the paired frequency arrangements in 450.5-456.0 MHz / 460.5-466.0 MHz and 452.0-457.5 MHz / 462.0-467.5 MHz. These options are based on a set duplex spacing of 10 MHz.*"

In addition, the frequency range 406.1-430 MHz is under consideration.

However, the conclusions will still be valid considering the frequency offset between the possible interferer and the possible victim.

10.6.1 LTE BS impact on PMSE MS (12.5 kHz and 25 kHz)

The three-sector LTE BS transmits at 461.5 MHz whereas the PMSE MSs receives signals coming from 25 kHz PMSE BS transmitting 463-465 MHz. The victim frequency is randomly chosen (discrete distribution option) in SEAMCAT.

The limit for a frequency offset of -43 dBm at 1 MHz for the e.i.r.p. of the BS is also implemented in the simulations, although it can be noted that this requirement in ECC/DEC/16/02 applies at 1MHz from the offset from the BS transmit band edge.

A possible co-location scenario between LTE BS and the PMSE BS is considered in the simulations. In addition, the interference probability on a 100 m area around the BS is calculated.

The following Table 97 provides the interference probability as calculated with SEAMCAT.

Table 97: LTE BS impact on PMSE MS (12.5 kHz and 25 kHz)

PMSE bandwidth	Interference Probability	Reference
12.5 kHz		
	9% (PPDR BR radius: 3.75 km)	ECC Report 240 + -43 dBm e.i.r.p. at 1 MHz Victim in adjacent block (2 MHz)
	63%	-43 dBm e.i.r.p. at 1 MHz Victim in adjacent block (2 MHz) Distance less than 100 m
	99%	-43 dBm e.i.r.p. at 1 MHz Victim in adjacent block (1 MHz) Distance less than 100 m
	27%	-43 dBm e.i.r.p. at 1 MHz 1 MHz guard band (victim in 1 MHz block) Distance less than 100 m
25 kHz		
	9% (PPDR BR radius: 3.75 km)	ECC Report 240 + -43 dBm e.i.r.p. at 1 MHz Victim in adjacent block (2 MHz)
	60%	-43 dBm e.i.r.p. at 1 MHz Victim in adjacent block (2 MHz) Distance less than 100 m
	98%	-43 dBm e.i.r.p. at 1 MHz Victim in adjacent block (1 MHz) Distance less than 100 m
	21%	-43 dBm e.i.r.p. at 1 MHz 1 MHz guard band (victim in 1 MHz block) Distance less than 100 m

10.6.2 LTE BS impact on PMSE BS (12.5 kHz and 25 kHz)

The three-sector LTE BS transmits at 461.5 MHz whereas the PMSE MSs receives signals coming from 25 kHz PMSE MS transmitting between 453 and 455 MHz. The victim frequency is randomly chosen (discrete distribution option) in SEAMCAT.

A possible co-location of the LTE BS and the PMSE BS, is considered in the simulations. In addition, the interference probability on a 100 m area around the BS is calculated.

Table 98 provides the interference probability as calculated with SEAMCAT.

Table 98: LTE BS impact on PMSE BS (12.5 kHz and 25 kHz) - 5 MHz guard band

PMSE bandwidth	Interference Probability	Interference Probability with minimum requirements for protection of BS receiver of own or different BS	Reference
12.5 kHz	0.65 % (LTE BS radius: 3.75 km)	0.02%	-96 dBm/100kHz conducted power Victim in 2 MHz block with 5 MHz guard band
	69.15%	10.5%	-96 dBm/100kHz Victim in 2 MHz block with 5 MHz guard band Distance less than 100 m (Victim in 453-455 MHz)
25 kHz	0.55% (LTE BS radius: 3.75 km)	0.01%	-96 dBm/100kHz conducted power Victim in 2 MHz block with 5 MHz guard band
	66%	9%	-96 dBm/100kHz conducted power Victim in 2 MHz block with 5 MHz guard band Distance less than 100 m (Victim in 453-455 MHz)

Table 99 provides the TDD case, i.e. the PMSE MS could be transmitting in the 2 MHz adjacent to the block where the LTE BS is transmitting.

Table 99: LTE BS impact on PMSE BS (12.5 kHz and 25 kHz) - adjacent block

PMSE bandwidth	Interference Probability	Reference
12.5 kHz	97%	-43 dBm e.i.r.p. at 1 MHz Victim in adjacent block (2 MHz) Distance less than 100 m
	100%	-43 dBm e.i.r.p. at 1 MHz Victim in adjacent block (1 MHz) Distance less than 100 m
	95%	-43 dBm e.i.r.p. at 1 MHz 1 MHz guard band (victim in 1 MHz block)

PMSE bandwidth	Interference Probability	Reference
		Distance less than 100 m
25 kHz	95%	-43 dBm e.i.r.p. at 1 MHz Victim in adjacent block (2 MHz) Distance less than 100 m
	100%	-43 dBm e.i.r.p. at 1 MHz Victim in adjacent block (1 MHz) Distance less than 100 m
	95%	-43 dBm e.i.r.p. at 1 MHz 1 MHz guard band (victim in 1 MHz block) Distance less than 100 m

10.7 CONCLUSIONS

Considering scenarios similar to those considered in ECC Report 240, relating to the impact of LTE based PPDR BS on PMSE BS (receiving in 453-455 MHz):

- With the general spurious emissions limits given in 3GPP TS 36.104 [13], coexistence is not possible due to large separation distances.
- Coexistence is expected between if the LTE BS spurious meet the minimum requirements of -96 dBm/100kHz emissions in emissions in the band 450-455 MHz (3GPP TS 36.104 [13]).
- The implementation of the limit given in ECC/DEC/(16)02 [4] (e.i.r.p. of -43 dBm in 100 kHz) at 1 MHz, will significantly improve the compatibility between LTE BS and PMSE MS when the PMSE MS is within 100 m of the LTE BS.

.Considering scenarios differing from those considered in ECC Report 240, for example, TDD case or MS transmitting in 455-460 MHz, the achieved separation distances are larger and the risk of interference is quite high, in particular when the PMSE BS is located nearby the LTE PPDR BS and receiving in the first megahertzs adjacent to the LTE band.

Based on MCL calculations, the separation distance between LTE based PPDR UE and PMSE MS is of the order of 10 m, leading to a risk of interference if they are operated in the same location.

Similar conclusions apply for the lower band, 410-430 MHz.

11 LTE IMPACT ON PAGING

In Germany and France, paging applications are operating in the band 430-470 MHz as narrowband Point-to-Multipoint (NB-PMP) systems. The NB-PMP systems are unidirectional radio systems for digital data that pages all or groups of appropriately equipped receivers in a predefined area and delivers short messages. They provide a solution for the delivery of short messages to large receiver populations, and are optimized to guarantee very high levels of reliability and latency as required by safety services, to be cost-efficient, and to support energy-efficient operation of low-cost receivers. A typical application of NB-PMP systems is cost-efficient alerting services for European citizens.

Applications based on NB-PMP radio systems comprise but are not limited to:

- alerting services for first responders and/or service personal for critical infrastructure in case of disasters or any other kind of events of relevance;
- unidirectional information services supporting applications in the area of smart energy management e.g. secure and reliable control of distributed small load and production facilities in the low voltage grid level
- update or maintenance of information provided to industry and consumer products (weather stations, cognitive pilot channel for radio equipment without bidirectional connectivity (e.g. PMSE equipment)).

NB-PMP can provide better coverage and higher availability than competing alerting systems (e.g. sirens, send emails or SMS, TETRA with call out service), and the limited complexity of the receivers allows an economically reasonable application of NB-PMP in applications than other systems. In addition, battery stand-by-times in the order of month or years can be realized that are often required by fire departments, utility companies, etc.

A recent ETSI report TR 103 102 V1.1.1 [23] lists the societal benefits of NB-PMP systems and provides an overview on the market potential for the European market.

11.1 PAGING APPLICATIONS

Some million fixed-frequency receiver terminals[17] are using radio paging networks in Germany and France. In the whole Germany approximately 800 paging base stations send information in the simplex mode to many mobile and fixed receivers. In France about 400 paging base stations send information in the simplex mode to many mobile and fixed receivers.

Among a wide range of other applications, today's paging applications cover e.g.

- Alerting services for fireman, ambulances, medical staff, service personal of utility companies, some of which are safety critical and require a very high level of availability, outdoor and indoor coverage, and support of paging receivers carried at the body;
- Remote control for secure smart energy grid operation where the paging receivers are often located in basements.

Paging services use 20 and 25 kHz carriers in the band 430-470 MHz as a tuning range (where the sub-bands 448.4125-448.4375 MHz, 448.4625-448.4875 MHz, 465.96-465.98 MHz, 466.0375-466.0625 MHz, 466.0625 MHz - 466.0875 MHz, 466.1625 MHz – 466.1875 MHz, 466.22 MHz - 466.24 MHz and 466.19375 MHz – 466.21875 MHz are identified for paging systems) and are thus potentially affected by LTE systems.

[17] receivers

11.2 TECHNICAL PARAMETERS OF PAGING SYSTEM

Technical parameters for the paging transmitter and receiver are given in section A1.9.

11.3 SEAMCAT SIMULATIONS

11.3.1 Basic parameters

In order to assess the impact that an LTE system may have on paging services, simulations were performed using SEAMCAT. Two cases were investigated:

- a. Interference and blocking from LTE BS into a paging receiver (LTE BS impact on paging Mobile station (MS));
- b. Interference and blocking from LTE UE into a paging receiver (LTE UE impact on paging MS).

Interference into the paging BS is no critical scenario, as in paging systems only the Downlink is used.

For the LTE system, the following parameters are applied:

Table 100: LTE BS parameters in simulation

LTE BS Parameters	Value for BS
Transmit Power (Report ITU-R M.2292 [6])	41 dBm / 3 MHz
Centre frequency	463.5 MHz and 461.5 MHz
Antenna gain (Report ITU-R M.2292)	15 dBi
Antenna Pattern/ Number of Sectors	Directional / 3
Reference Sensitivity	-135 dBm / 3 MHz
Number of Resource Blocks (RBs) per sector	6 + 6 RBs, serving UE's with 1 RB each
Frequency Reuse Factor	1
Duty cycle	100%
Cell Range	17 km (rural indoor UE's) 5.868 km (urban indoor UE's)

Table 101: Paging parameters in simulation

Paging Parameters	Value for Tx	Value for Rx
Maximum Transmit Power	50 dBm	
Bandwidth	20 and 25 kHz	20 and 25 kHz
Carrier Frequencies	448.475 MHz (25 kHz) 465.970 MHz (20 kHz)	448.425 MHz (25 kHz) 465.970 MHz (20 kHz)
Antenna pattern	Omni-directional	Omni-directional
Antenna gain	0 dBi	-3 dBi
Antenna height	30-100 m	1.5 m
Typical Maximum BS to Receiver Distance	27 km (rural) / 9 km (urban)	

Paging Parameters	Value for Tx	Value for Rx
Cell Radius	18 km (rural) / 6 km (urban)	
Reference Sensitivity		-110 dBm
Adjacent Channel Sensitivity		60 dBm
Body Loss		10 dB
Wall Loss		10 dB
Wall loss standard deviation		6 dB
Location		100% outdoor

11.3.2 LTE BS impact on paging system receivers

Table 102: SEAMCAT simulation results for the LTE BS vs paging

BS Density (BS/ km^2)	Cell Radius (km)	Probability of Interference With BS spectrum emission mask according to ETSI standard operating band unwanted emission limits 465.96 – 465.98 MHz (20 kHz)				Probability of Interference With 25 dB additional attenuation compared to BS spectrum emission mask according to ETSI standard operating band unwanted emission limits 465.96 – 465.98 MHz (20 kHz)			
		Unwanted emissions		Unwanted emissions+ blocking		Unwanted emissions		Unwanted emissions+ blocking	
Freq. Gap between LTE/Paging		1 MHz	3 MHz	1MHz	3MHz	1 MHz	3 MHz	1 MHz	3 MHz
0.0018	8.5	11.2%	5.2%	11.2%	5.2%	0.5%	0.19%	0.76%	0.63%
0.015	2.93	10.8%	4.8%	10.8%	4.8%	0.43%	0.18%	0.68%	0.56%

The outage percentages remaining with 25 dB additional attenuation, are mainly caused by unwanted emissions

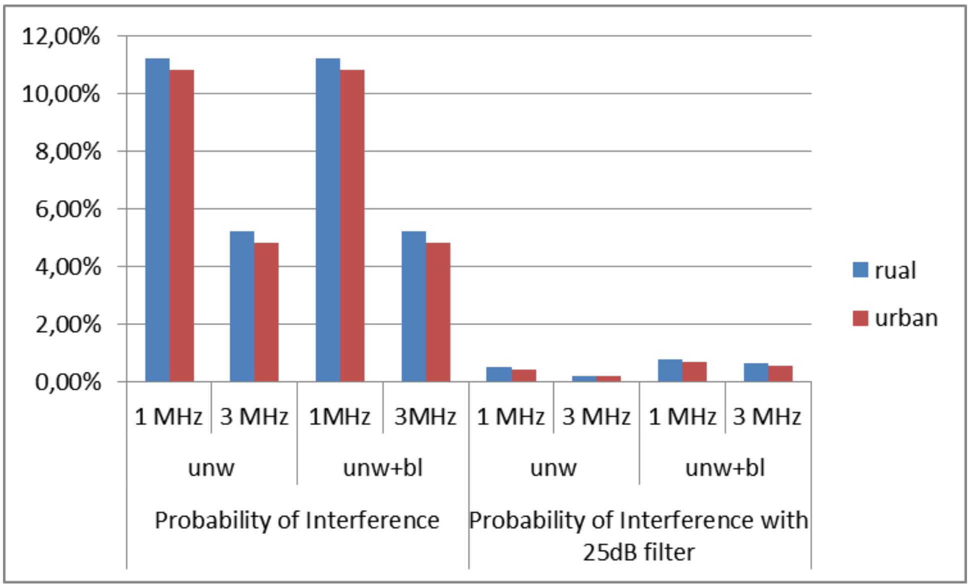


Figure 112: Probability of interference (due to unwanted emissions and blocking) depending on frequency separation (1 and 3 MHz) and use of additional filter

11.3.3 LTE UE impact on paging system receivers

Note: An LTE Cell Range of 5.868 is used to calculate the UE Density.

Table 103: SEAMCAT simulation results for the LTE UE vs paging

Density (UE/km^2)	Interference Probability with Minimum Requirements (%)	
	448.4125 – 448.4375 MHz (25 kHz)	448.4625 – 448.4875 MHz (25 kHz)
0.089	0.004	0.003
0.179	0.009	0.007
0.268	0.008	0.001
0.358	0.011	0.007
0.447	0.009	0.004
0.537	0.012	0.016

The following comments should be considered:

- The simulations considered two frequencies 448.4625 – 448.4875 MHz (25 kHz) and 448.4125 – 448.4375 MHz (25 kHz), the results of the simulations are different, while one would expect similar results, since the level of unwanted emissions are the same at the two frequencies;
- It Is not clear why a protection distance of 100 m was implemented;
- For a frequency offset larger from 2.5 MHz, the attenuation of 73 dBc/100 kHz is implemented. This corresponds to a level of 23 dBm – 73 dBc = - 50 dBm/100 kHz well below the 3GPP recommended level (-70 dBm/Hz or – 50 dBm/100 Hz or -20 dBm/100 kHz).

11.4 CONCLUSIONS

The results of SEAMCAT simulation considering the impact of BS on paging receiver indicate that the level of interference strongly depends on the LTE cell radius. It is also seen that a decrease of the level of unwanted emissions by additional filtering improves the compatibility. The simulations considered an offset of 970 kHz and 3 MHz, if the offset between the paging frequency and the edge of the LTE system is smaller, then, the probability of interference will be higher. In case of reducing the out of band emissions 25 dB below 3GPP emission mask of the LTE BS , the compatibility between LTE BS and the paging system is good.

Additional simulations may be needed to consider the impact of 5 MHz and 1.4 MHz systems and the impact of the Mobile station (MS).

12 LTE IMPACT ON SRD SYSTEMS

Automotive wireless systems on the bases of non-specific short range devices are according to ETSI EN 300 220-1 and -2 [9]. These SRDs operate at 433 MHz and are used to enable remote keyless entry systems and tire pressure monitoring systems. The purpose of this study is to evaluate the impact of the LTE operating below 430 MHz on the automotive systems operating in the 433 MHz SRD band (ERC/REC 70-03 [8]).

The most critical scenario by far is the definition for permitted spurious emissions of -36 dBm @ 100 kHz.

A limit for spurious emissions of -96 dBm/100 kHz would solve the problem (see 12.4.6).
As such, the scenario described in chapter 12.4.5 that involves an interference probability (= engine does not start) of approx. 83% is reduced to 0.001% (see 12.4.6)

With regard to the SRDs, there is no technical possibility of becoming significantly more robust in the future to resist the impact of spurious emissions attributed to LTE (a smaller bandwidth would also result in a lower data rate and at best would give rise to just a few dB of improvement).

12.1 SCENARIO: BLOCKING (CALCULATION WITHOUT THE EFFECTS OF SPURIOUS EMISSIONS)

12.1.1 User equipment

Isolation = $P_{INT} + dB_{BW} + MC_{INT} + G_{VICT} + G_{INT} - (S_{VICT} - C/I_{VICT})$

where:

- P_{INT} = +26 dBm =+23 dBm e.i.r.p. - (-3 dBi)
- dB_{BW} = -9.29 dB = 10*log (0.165 MHz/1.4 MHz)
- MC_{INT} = 0 dB
- G_{VICT} = -5 dBi (car); -20 dBi (key)
- G_{INT} = -3 dBi
- S_{VICT} = -108 dBm
- C/I_{VICT}= 0 dB (Value for C/I is included in Blocking)
- Isolation = 116.71 dB (car)
- Isolation = 101.71 dB (key)

taking into account

- Blocking = 70 dB (car); 55 dB (key)
- Physical separation = 25 dB (car) (free space @ 1 m @ 430 MHz)
  = 19 dB (key) (free space @ 0.5 m @ 430 MHz)
- MCL = 21.71 dB (car)
  = 27.71 dB (key)

-> Insufficient separation/isolation

NOTE: Although the free space model is not valid for such short distances close to the antenna, it is used here as a very rough approximation. The resulting computed separation distance is, therefore, not accurate, but can be considered to be of the same order of magnitude as the physical distance.

12.1.2 Base station

Isolation = $P_{INT} + dB_{BW} + MC_{INT} + G_{VICT} + G_{INT} - (S_{VICT} - C/I_{VICT})$

where:

P_{INT} = +35 dBm = +46 dBm e.i.r.p. - (+11 dBi)

- dB_{BW} = -9.29 dB = 10*log (0.165 MHz/1.4 MHz)
- MC_{INT} = 0 dB
- G_{VICT} = -5 dBi (car); -20 dBi (key)
- G_{INT} = 11 dBi
- S_{VICT} = -108 dBm
- C/I_{VICT} = 0 dB (Value for C/I is included in Blocking)
- Isolation = 139.71 dB (car)
- Isolation = 124.71 dB (key)

taking into account

- Blocking = 70 dB (car); 55 dB (key)
- Physical separation = 59 dB (car) (free space @ 50 m @ 430 MHz)
  = 59 dB (key) (free space @ 50 m @ 430 MHz)
- MCL = 10.71 dB (car)
  = 10.71 dB (key)

-> Insufficient separation/isolation

12.2 SCENARIO: SPURIOUS EMISSIONS IN BAND (WITHOUT THE EFFECTS OF SENSOR SATURATION)

12.2.1 User equipment

Isolation = $G_{VICT} + G_{INT} - (S_{VICT} - C/I_{VICT}) + f\ (dB_{cINT}, P_{INT})$

- where:
- f (dB_{cINT}, P_{INT}) = -33.8 dBm =-36 dBm @ 100 kHz + 10*log (165 kHz/100 kHz)
- G_{VICT} = -5 dBi (car); -20 dBi (key) G_{INT}= 0 dBi
- (power above is emitted from antenna -> antenna gain is not required here)
- SVICT = -108 dBm
- C/IVICT = 13 dB
- Isolation = 82.2 dB (car)
- Isolation = 67.2 dB (key)

taking into account

- Blocking = 0 dB (car); 0 dB (key) (in-band -> 0 dB blocking)
- Physical separation = 25 dB (car) (free space @ 1 m @ 430 MHz)
  = 19 dB (key) (free space @ 0.5 m @ 430 MHz)

MCL = 57.2 dB (car)
= 48.2 dB (key)

-> Insufficient separation/isolation!

-> This interference can also not be counteracted with a better blocking response by the receiver! This measure would only bring about an improvement for future wireless concepts in the aforementioned scenarios in chapter 12.1.

-> The permissible spurious emissions limit would have to be reduced by 60 dB to ensure that the above scenario does not lead to any problems:

Permissible spurious emissions: -96 dBm @ 100 kHz

12.3 INTERFERENCE INFLUENCE STATIC DISTRIBUTION INTO ACCOUNT

A vehicle key can be located in almost any area in the vehicle:

- in the centre console;
- in a pants pocket;
- in the chest pocket;
- in a handbag
- in a jacket pocket;
- in the trunk;
- inadvertently fallen onto the floor;
- ...

Adding to this is the fact that every individual has different bodily dimensions, creating even more variations of possible locations of a key in the vehicle. The preferred driving position also differs from person to person, giving rise to still greater variance.

If one considers the possible propagation paths of an electromagnetic wave emitted by a key, additional dispersions also arise:

- different vehicle geometries;
- different load states in the vehicle (1 individual, several individuals, with luggage, etc.);
- driving position (height);
- distance between front and rear seats;
- variation in vehicle bodies, size of glass roof, steel roof, convertible;
- ...

All aforementioned items lead to the situation whereby one is not in a position to take reproducible measurements in the vehicle.

This is why at Daimler, a decision was made to use the level distribution for evaluation purposes.

For in-vehicle measurements in a defined vehicle area (e.g. seat surface), the key is placed in different positions as a permanent transmitter while at the same time continually moved in its temporal coordinates.

The following excerpt from the measurement description illustrates the approach by example.

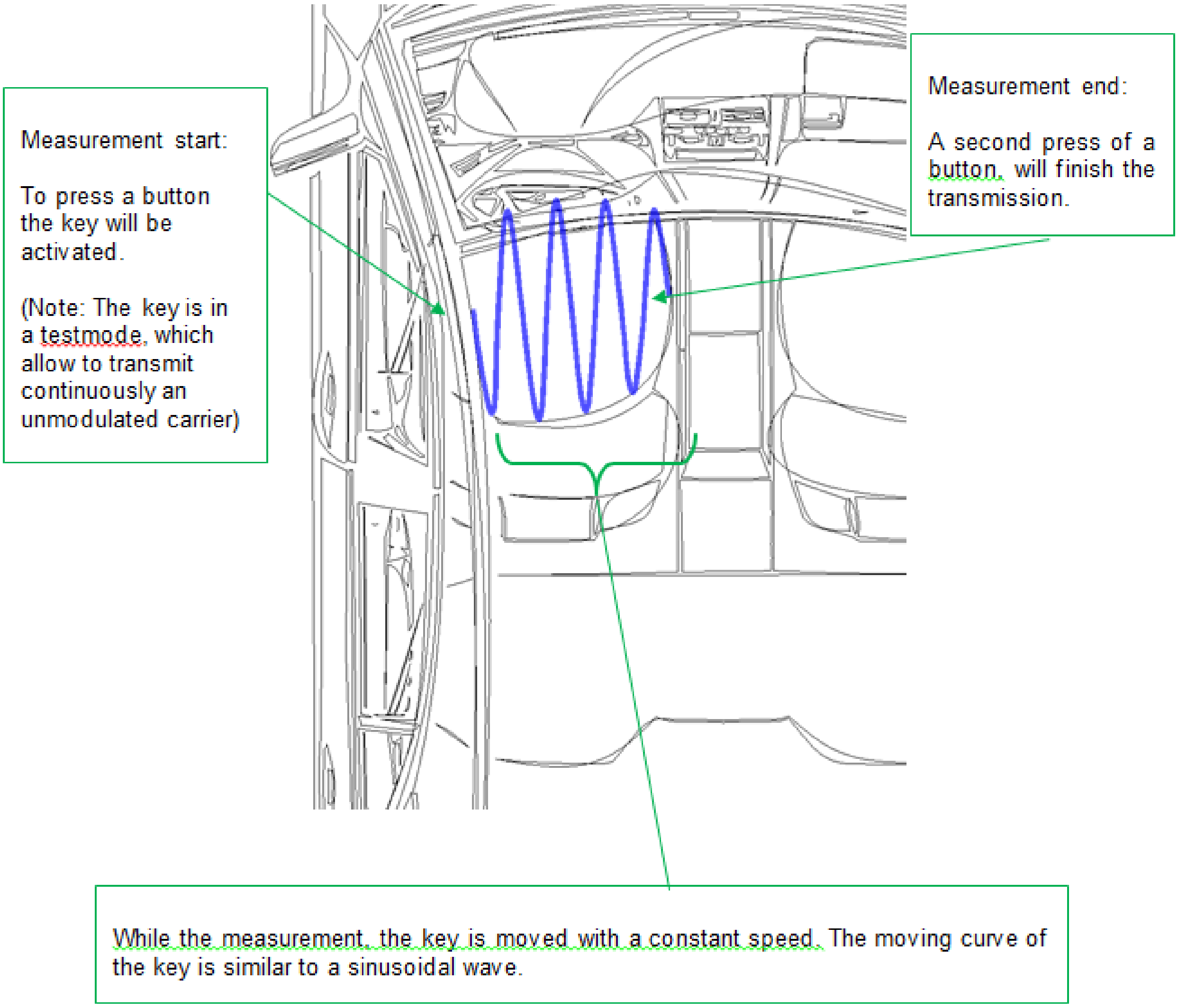


Figure 113: In-vehicle measurement

At the same time, the power received by the vehicle antenna (50 ohms) is recorded. The following figure includes a practical measurement example.

- Transmitter: Key with a transmission power of -24 dBm e.i.r.p. (worst case);
- Readings: Reception level at 50 ohms directly at the antenna base;
- Key moved in the vicinity of the driver's seat;
- Receiving antenna: rear window.

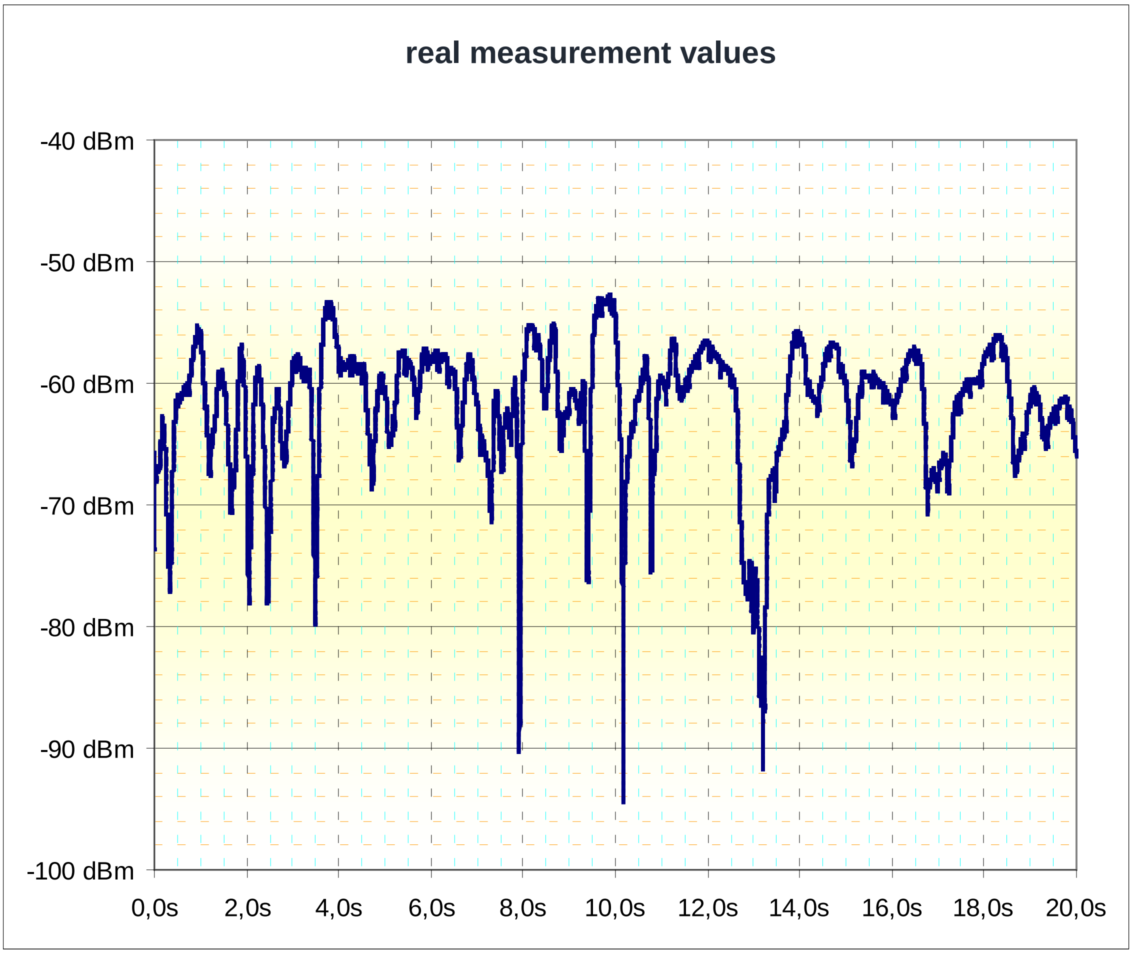


Figure 114: Example of a real measurement (receiving level)

The probability density of the received levels for the above measurement is:

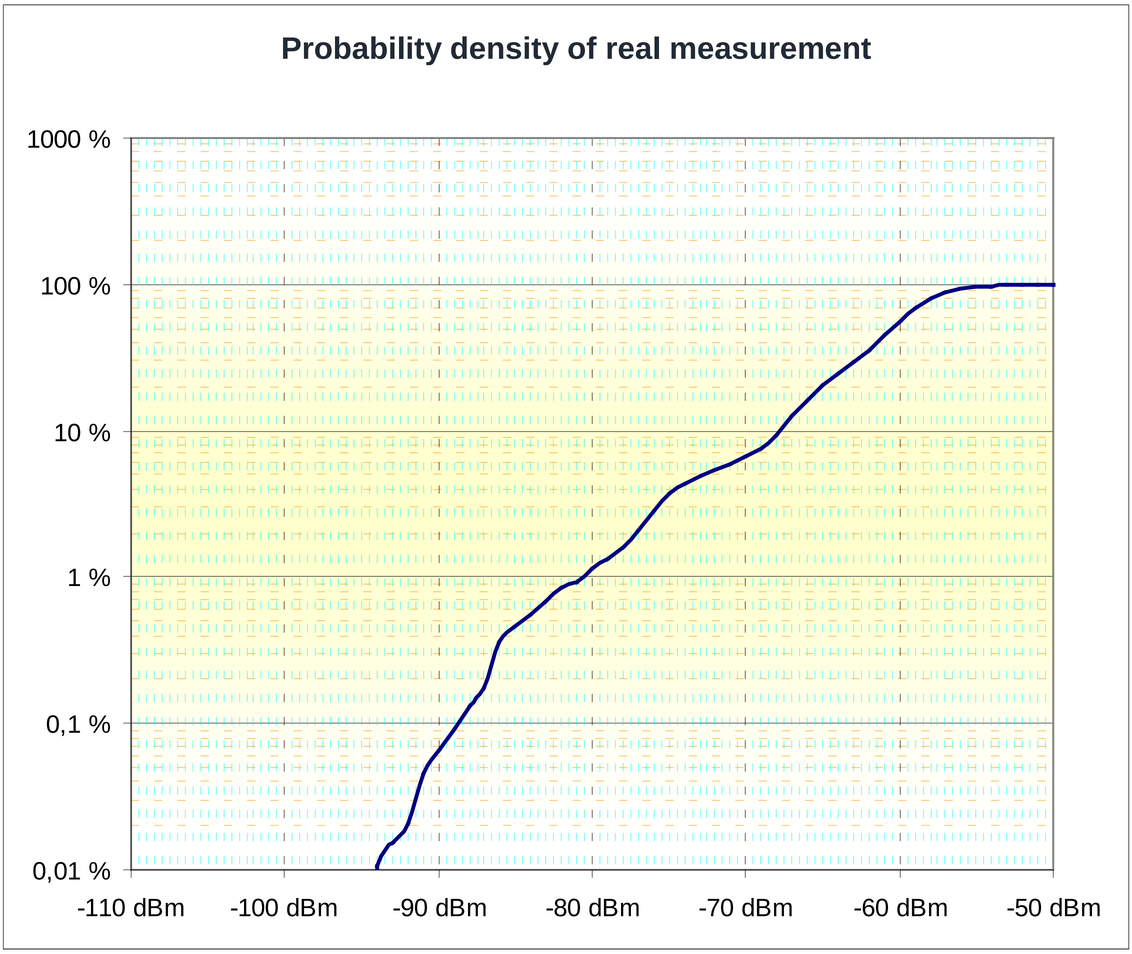


Figure 115: Example of a real of probability level density

It states that e.g. 1% of all received levels quantified were below -80 dBm.

Previous experience shows that the basic progression of the probability density is always the same and is independent of the measurement location in the vehicle. It is described sufficiently in mathematical form

$$P_{A(P)} = 1 - e^{-10^{\frac{1}{10}(P[dBm] - P_{mean}[dBm] - 1.59\,dB}}$$

whereby $P_{mean=} \frac{1}{n}\sum_{m=1}^{m=n} measured\_value\_m$

$$P_{Mittelwert} = \frac{1}{n} \cdot \sum_{m=1}^{m=n} Messwert\_m$$

P_{mean} value represents the averaged received level across all "dBms" (this does not include the mean physical power. This type of "averaging" has different reasons that will not be discussed in further detail here).

The probability density for P_{mean} value = -61.5 dBm:

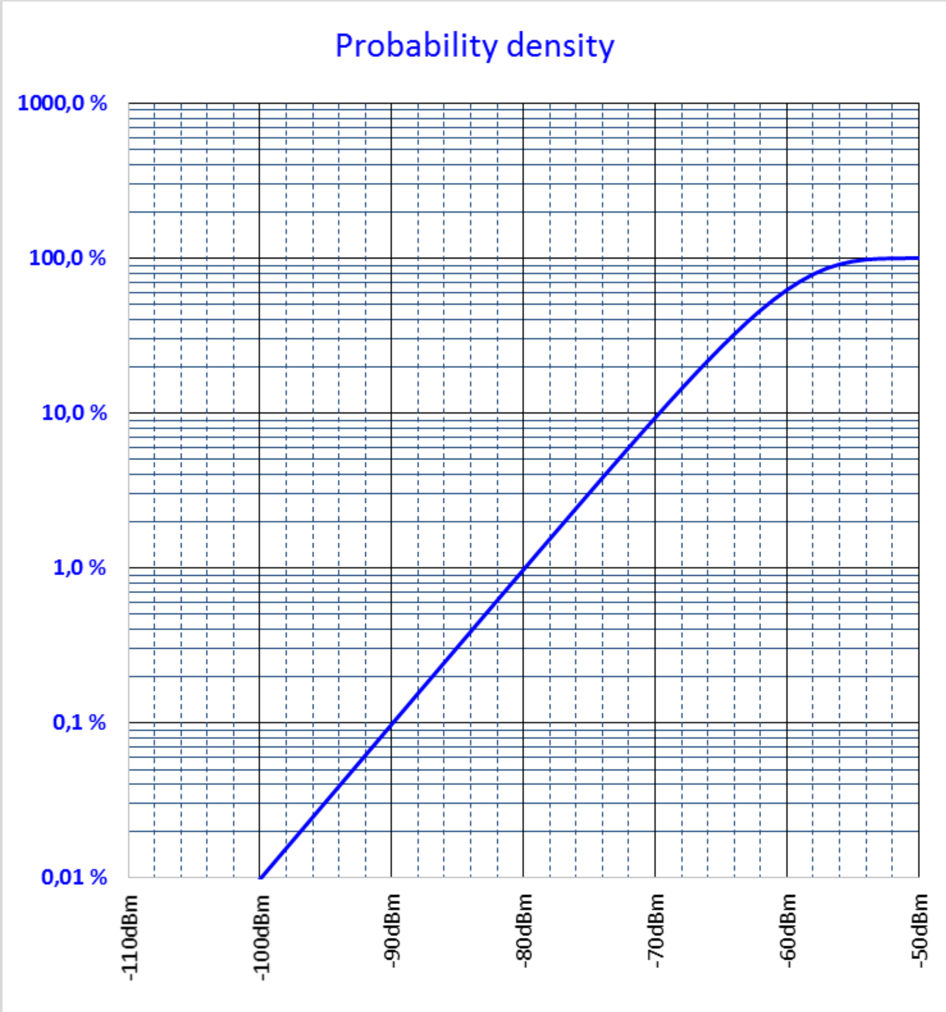


Figure 116: Example of a calculated of probability level density

Due to the good conformity with the prevailing circumstances, the following assumes the above relationship for the probability density.

12.3.1 Example: Key (e.g. -20 dBm) and interferer (e.g. -36 dBm)

As discussed in the previous chapter, the key can assume almost any conceivable position or location in the vehicle. The same must also be assumed for a cellular phone, however.

The key and cellular phone therefore have the same progressional curve for the probability density function.

Only the absolute values differ.

The situation is depicted in the following figure:

- The cellular phone and key are located in the same place in the vehicle. E.g. the key and cellular phone are carried by the vehicle user, whereby both components do not necessarily need to be in the same pocket. It is sufficient if both devices are located in the direct vicinity of the individual (e.g. key in right pants pocket and cellular phone in left pants pocket);
- Spurious emissions of the mobile unit include
  -36 dBm/100 kHz e.i.r.p
  and would exist in the usable band of the vehicle receiver (433.92 MHz ≤ 165 kHz) at the designated level;

- It is also assumed that the spurious emissions can be compared to white noise, which leads to a necessary noise level signal for the useful signal receiver (vehicle) of
  S/N =+13 dB;
- The key itself has a transmission power of
  -20 dBm e.i.r.p.

The probability density of both devices is included in the following figure

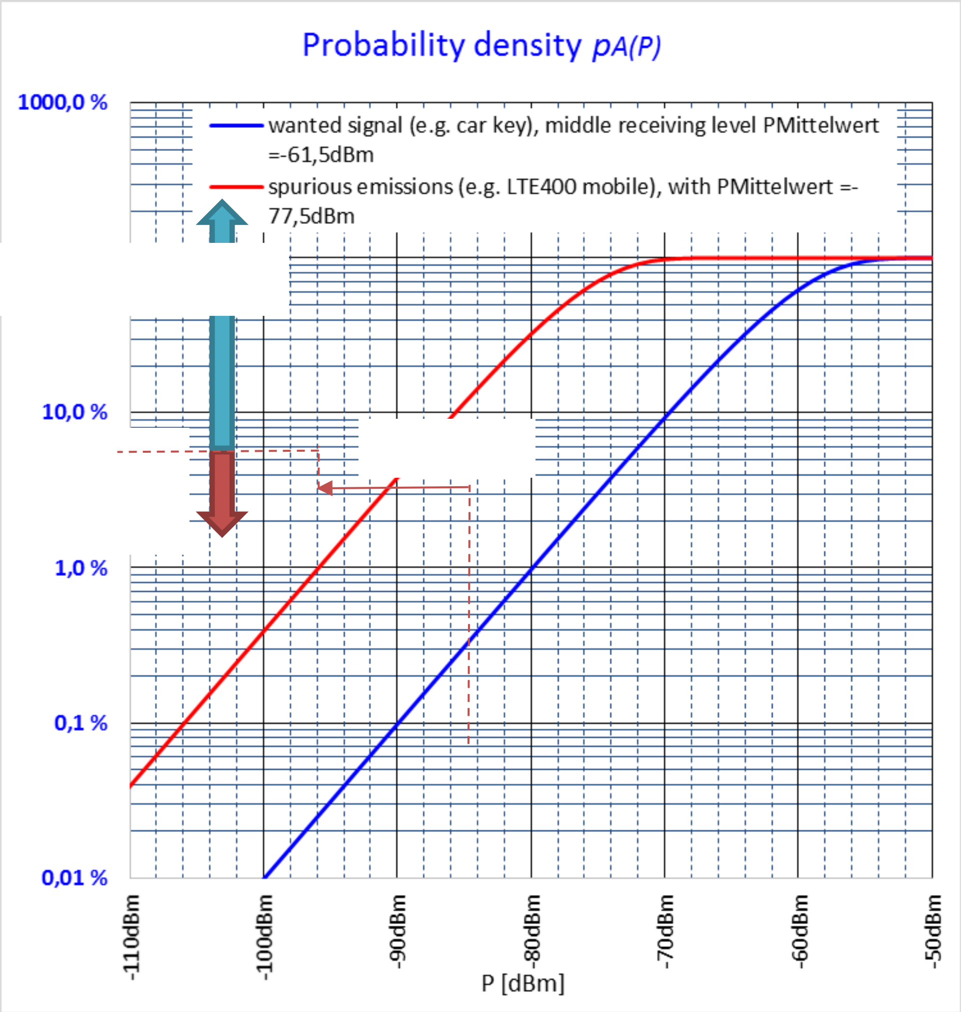


Figure 117: Example of Probabiltiy density for key (-20 dBm) and LTE mobile (-36 dBm@100 kHz spurious emission), while Mobile station (MS) and key are located in the same area

As the key and cellular phone do not have a defined position with respect to each other and are accepted at random, the key and cellular phone levels received by the vehicle antennas are also distributed at random.

What can be derived from Figure 117 above:

Let us assume that the key generates a level of -80 dBm at the vehicle antenna. The vehicle receiver can only successfully receive this signal if

- Its sensitivity is sufficient (typically approx. -105 dBm);
- The minimum required distance between the useful signal and interference signal (here: 13 dB) is fulfilled. (see red arrow at top).

If one now carries out a projection with respect to the probability density for the cellular phone (green line from tip of arrow to red curve), there is a probability of approx. 1.3%. I.e. 1.3% of all base noises from the cellular phone are sufficiently low and do not cause any interference. However, all remaining levels cause a failure consistent with 100% - 1.3% = 98.7%

12.3.2 Consideration of density distribution

A quantitative statement, however, can only be made if one also takes into account the density distribution of the respective received level. The previous example only uses a single received level. The frequency with which this takes place is therefore not yet known.

This gap can be closed by leveraging the density distribution. Afterwards (bottom graphic, in reference to 1 dB), the frequency with which the key signal is received at a level of -80 dBm (-79.5 dBm to -80.5 dBm) is approx. 0.15%; by contrast, approx. 8% of all received levels lie within the range of -59.5 dBm to -60.5 dBm.

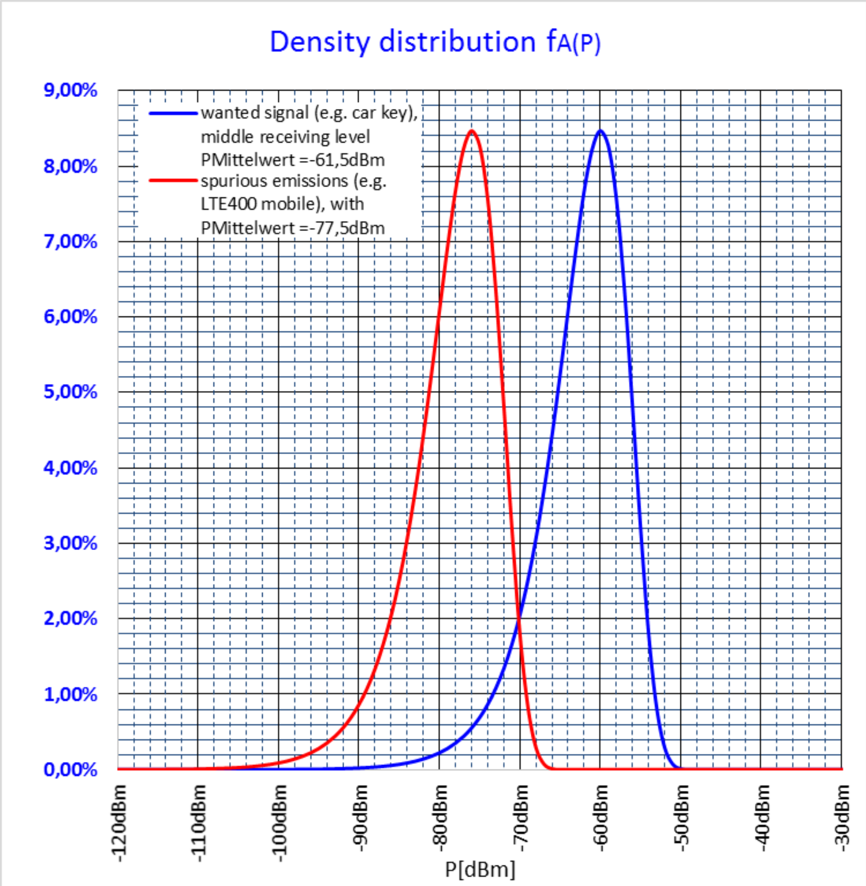


Figure 118: Example of received level density for key (-20 dBm) and LTE mobile (-36 dBm@100 kHz spurious emission), while MS and key are located in the same area

Refer to the red plotted line for the circumstances surrounding the interference signal.

The relational circumstances for the density distribution are as follows:

$$f_{A(P)} = \frac{\ln(10) \cdot 10^{\frac{1}{10} \cdot \left(P_{[dBm]} - P_{Mittelwert\ [dBm]} - 1{,}59 dB\right)}}{10} \cdot e^{-10^{\frac{1}{10} \cdot \left(P_{[dBm]} - P_{Mittelwert\ [dBm]} - 1{,}59 dB\right)}}$$

If one also takes into account the frequency/density distribution, this gives rise to a relationship that can be used to estimate the failure probability.

12.4 FAILURE PROBABILITIES (= SHARE OF ATTEMPTS DURING WHICH AN ENGINE START IS NOT POSSIBLE)

The Keyless-Go system is also involved in an engine start. If the radio signal path between the key and vehicle is compromised due to interference, the engine cannot be started.

The following includes a couple of examples.

12.4.1 Worst case (minimum permissible useful signal, maximum permissible interference signal)

Further assumption: The key and cellular phone are in almost the exact same location (e.g. the driver is carrying the key and cellular phone on his person). As such, it does not make a difference whether the cellular phone is in the left pants pocket and the key in the right pocket, or the devices are stored in similar locations (e.g. chest pocket).

Table 104: Calculation with Worst-case levels (minimum permissible useful signal, maximum permissible interference signal)

	Key	e.i.r.p. transmission power	-22.00 dBm
	LTE	e.i.r.p. interference power (@ 100 kHz*))	-36.00 dBm
	*) The receiver IF bandwidth is 165 kHz, which leads to a 10xlog (165 kHz/100 kHz) = 2.17 dB higher interference entry (-33.83 dBm). The system-determining bandwidth, however, is the demodulation bandwidth, which is lower than the IF bandwidth. As such, the value for 100 kHz represents a good estimate.		
	Key	Mean path attenuation	35.00 dB
	LTE	Mean path attenuation	35.00 dB
		Gain, receiving antenna	-5.00 dBi
Key	Useful signal	Mean reception performance	-62.00 dBm
LTE	Interference signal	Mean reception performance	-76.00 dBm
Resulting failure probability for receiver sensitivity of -108.00 dBm			
			44.269%

12.4.2 Typical useful signal, maximum permissible interference signal

Table 105: Calculation for typical useful signal, maximum permissible interference signal

	Key	e.i.r.p. transmission power	-20.00 dBm
	LTE	e.i.r.p. interference power (@ 100 kHz)	-36.00 dBm
	*) The receiver IF bandwidth is 165 kHz, which leads to a 10xlog (165 kHz/100 kHz) = 2.17 dB higher interference entry (-33.83 dBm). The system-determining bandwidth, however, is the demodulation bandwidth, which is lower than the IF bandwidth. As such, the value for 100 kHz represents a		

	Key	e.i.r.p. transmission power			-20.00 dBm
	good estimate.				
	Key	Mean path attenuation			35.00 dB
	LTE	Mean path attenuation			35.00 dB
		Gain, receiving antenna			-5.00 dBi
Key	Useful signal	Mean reception performance			-60.00 dBm
LTE	Interference signal	Mean reception performance			-76.00 dBm
Resulting failure probability for receiver sensitivity of -108.00 dBm					
					33.386%

12.4.3 Useful signal best case, maximum permissible interference signal

Table 106: Calculation for useful signal best case, maximum permissible interference signal

	Key	e.i.r.p. transmission power			-15.00 dBm
	LTE	e.i.r.p. interference power (@ 100 kHz*))			-36.00 dBm
	*) The receiver IF bandwidth is 165 kHz, which leads to a 10xlog (165 kHz/100 kHz) = 2.17 dB higher interference entry (-33.83 dBm). The system-determining bandwidth, however, is the demodulation bandwidth, which is lower than the IF bandwidth. As such, the value for 100 kHz represents a good estimate.				
	Key	Mean path attenuation			35.00 dB
	LTE	Mean path attenuation			35.00 dB
		Gain, receiving antenna			-5.00 dBi
Key	Useful signal	Mean reception performance			-55.00 dBm
LTE	Interference signal	Mean reception performance			-76.00 dBm
Resulting failure probability for receiver sensitivity of -108.00 dBm					
					13.681%

12.4.4 Typical useful signal, interference signal 10 dB below limit

Table 107: Calculation for typical useful signal, interference signal 10 dB below limit

	Key	e.i.r.p. transmission power			-20.00 dBm
	LTE	e.i.r.p. interference power (@ 100 kHz*))			-46.00 dBm
	*) The receiver IF bandwidth is 165 kHz, which leads to a 10xlog (165 kHz/100 kHz) = 2.17 dB higher interference entry (-33.83 dBm). The system-determining bandwidth, however, is the demodulation bandwidth, which is lower than the IF bandwidth. As such, the value for 100 kHz represents a good estimate.				
	Key	Mean path attenuation			35.00 dB
	LTE	Mean path attenuation			35.00 dB
		Gain, receiving antenna			-5.00 dBi
Key	Useful signal	Mean reception performance			-60.00 dBm
LTE	Interference signal	Mean reception performance			-86.00 dBm
Resulting failure probability for receiver sensitivity of -108.00 dBm					
					4.773%

12.4.5 Typical useful signal, maximum permissible interference signal

Unlike the previous assumptions, here the LTE device is NOT in the immediate vicinity of the key, but is e.g. on the rear seat and therefore has up to 10 dB lower path attenuation:

Key: Driver's seat area

LTE: Rear seat bench area (Receiving antenna: rear window)

Table 108: Calculation for typical useful signal, maximum permissible interference signal

	Key	e.i.r.p. transmission power			-20.00 dBm
	LTE	e.i.r.p. interference power (@ 100 kHz*))			-36.00 dBm
	*) The receiver IF bandwidth is 165 kHz, which leads to a 10xlog (165 kHz/100 kHz) = 2.17 dB higher interference entry (-33.83 dBm). The system-determining bandwidth, however, is the demodulation bandwidth, which is lower than the IF bandwidth. As such, the value for 100 kHz represents a good estimate.				
	Key	Mean path attenuation			35.00 dB
	LTE	Mean path attenuation			25.00 dB
		Gain, receiving antenna			-5.00 dBi
Key	Useful signal	Mean reception performance			-60.00 dBm

	Key	e.i.r.p. transmission power	-20.00 dBm
LTE	Interference signal	Mean reception performance	-66.00 dBm
Resulting failure probability for receiver sensitivity of -108.00 dBm			
			83.366%

12.4.6 Typical useful signal, spurious emission interference signal: -96 dBm

Same scenario as in the previous chapter; only the permissible spurious emissions are reduced from -36 dBm @ 100 kHz to -96 dBm @ 100 kHz.

Key: Driver's seat area

LTE: Rear seat bench area (Receiving antenna: rear window)

Table 109: Calculation for typical useful signal, spurious emission interference signal: -96 dBm

	Key	e.i.r.p. transmission power	-20.00 dBm
	LTE	e.i.r.p. interference power (@ 100 kHz)	-96.00 dBm
	*) The receiver IF bandwidth is 165 kHz, which leads to a 10xlog (165 kHz/100 kHz) = 2.17 dB higher interference entry (-33.83 dBm). The system-determining bandwidth, however, is the demodulation bandwidth, which is lower than the IF bandwidth. As such, the value for 100 kHz represents a good estimate.		
	Key	Mean path attenuation	35.00 dB
	LTE	Mean path attenuation	25.00 dB
		Gain, receiving antenna	-5.00 dBi
Key	Useful signal	Mean reception performance	-60.00 dBm
LTE	Interference signal	Mean reception performance	-126.00 dBm
Resulting failure probability for receiver sensitivity of -108.00 dBm			
			0.001%

13 CONCLUSION

13.1 LTE IMPACT ON NARROWBAND PMR

It should be noted that narrowband PMR includes analogue, DMR and TETRA systems.

Simulations of interference from LTE transmitters into narrowband PMR receivers in adjacent frequency spectrum show that the probabilities of interference based on Out-of-Band Emissions (OOBE) and blocking for low to medium Base station (BS) and Mobile station (MS) densities are generally on the average 1% or less, although unwanted emission improvement compared to the 3GPP Spectrum Emission Mask at the BS may be required to keep the interference from the LTE BS into the PMR MS at these low levels. However, the interference probability calculations are performed for downlink limited systems; results may differ for uplink limited systems, which may tolerate a noise rise in MS receivers up to the level of the DL/UL imbalance. Please also note that other techniques needed to protect the LTE400 BS own reception band (such as duplex filtering) help to provide necessary attenuation of Out-of-Band emissions of the LTE BS into the TETRA MS reception band. Furthermore, the interference probability averaged over the coverage area of the narrowband BS decreases, if the LTE cell size increases. The probability of interference is highest closest to the LTE BS. Out of Band Emission improvement may not be needed depending on the acceptable level of degradation over the coverage area.

The interference probabilities for the LTE BS impact on PMR MS are lower in comparison to the interference probabilities simulated in ECC Report 240 for the PPDR-LTE BS impact on the PMR MS. Even lower interference probabilities are expected if the bursty nature of M2M traffic will be included in the calculations.

Another interference effect to be taken into account is the potential impact of Intermodulation Distortion (IMD) in PMR receivers caused by neighbouring broadband signals. This is dependent on the frequency offset of the LTE carrier from the victim PMR receiver, the received power and the intermodulation performance of the victim PMR receiver at that frequency offset. The assessment of outage probability due to intermodulation by simulations appeared to be far from straightforward. No conclusion on the intermodulation effect from broadband interferers into narrow band victims could be reached.

13.2 LPWAN COMPATIBILITY WITH TETRA

The results of the Monte Carlo simulations carried out show that TETRA and Low Power Wide Area Network (LPWAN) systems can cohabitate without any major difficulty in the band 410-430 MHz, if the following mitigation techniques are implemented:

- A guard band of 200 kHz between the TETRA base station (BS) and the LPWAN end device (ED). This guard band is needed to minimise the interference from TETRA BS transmitter to LPWAN ED receiver.
- A minimum separation distance of 90 m (64 dB minimum coupling loss) between TETRA BS and LPWAN BS. This minimum separation distance is needed to minimise the interference from TETRA BS transmitter to LPWAN BS receiver and can easily be achieved with on site configuration when deploying LPWAN networks.

It should be observed that based on the assumptions of the analysis, the TETRA BS e.i.r.p. is 49 dBm, which is almost 15 dB more that the e.i.r.p. of the LPWAN BS. That could justify why the impact of the TETRA BS into the LPWAN systems is greater than the one in the reverse way. Given that many deployed PMR systems operate with an e.i.r.p. 40 dBm, it could be expected that real life operation of these two systems leads to even better compatibility than the results presented in this analysis.

In the case of co-channel situation between TETRA and LPWAN systems, the minimum separation distance between base stations is more than 100 km.

The co-channel operation in the same area is not possible between TETRA and LPWAN systems.

13.3 LPWAN COMPATIBILITY WITH RLOC

With the RLOC frequency set to 430 MHz and the LPWAN system using the uplink frequency of 413.7375 MHz and downlink frequency of 423.7375 MHz with a 125 kHz channel bandwidth, the minimum separation distances needed to ensure the protection of RLOC are presented in Table below.

Table 110: Separation Distance between Radars and LPWAN system (km)

Separation Distance between Radars and LPWAN system (km)		Due to blocking (km)	Due to desensitisation in co-channel (km)	Due to desensitisation in adjacent channel (km)
Airborne Radar	LPWAN ED	0.04	1374	0.015
	LPWAN BS	0.015	522	0.0025
Ground Radar	LPWAN ED	0.14	9730	0.110
	LPWAN BS	0.66	46560	0.232

The results of the compatibility studies carried out show that the compatibility between LPWAN system and airborne radar is possible in the case of adjacent channel scenario with a minimum guard band of 0.5 MHz from edges. The minimum separation distances are then:

- 40 m between the LPWAN End Devices and Airborne;
- 15 m between the LPWAN Base Station and Airborne.

The compatibility between LPWAN system and Ground radar is possible in the case of adjacent channel scenario with a minimum guard band of 0.5 MHz from edges. The minimum separation distance is then:

- 140 m between the LPWAN End Devices and ground radar;
- 660 m between the LPWAN Base Station and ground radar.

For the co-channel cases there are no possibility for compatibility between LPWAN system and airborne radar or LPWAN system and ground radar.

13.4 LPWAN COMPATIBILITY WITH RAS

The compatibility between LPWAN system and the Radio astronomy service concludes that:

- For a frequency separation between the LPWAN base station and the RAS of 13.7375 MHz (edge to edge), the MCL calculation provides a required minimum path loss equal to 97.51 dB;
- Using the ITU-R propagation model P.452-16, the calculated separation distance is 4.4 km;
- For a frequency separation between the LPWAN end device and the RAS of 3.7375 (edge to edge), the MCL calculation provides a required minimum path loss equal to 101.91 dB. Using the ITU-R propagation model P.452-16, the calculated separation distance is 3.05 km.

13.5 LPWAN COMPATIBILITY WITH LTE

This section summarises the compatibility between LTE and LPWAN systems in the 410-430MHz band.

All the initial configurations of LTE systems are based on figures in the corresponding ETSI standards TS 136 101 and TS 136 104 and the LPWAN system parameters stated in this report. LTE parameters were considered as invariant in the simulations, except when considering LTE BS ACLR in adjacent channel. BS ACLR was based on the measured LTE signal which is 20 dB better than that derived from the transmitter mask in the ETSI standard [13]. It should be noted that the measured ACLR in the first adjacent channel is expected to be lower than the ACLR in adjacent channels further away from the BS centre frequency. According to the ETSI standard for LTE systems [13], there are minimum requirements for the protection of own reception which lead to an ACLR higher than 100 dB/3MHz, that will provide a lower level of unwanted emissions in the LTE BS uplink reception band and its vicinity compared to the level of unwanted emissions resulting from the measured ACLR value used in the analysis.

Amongst the simulated interference scenarios, in three cases it was necessary to improve the ACLR and the Adjacent Channel Selectivity (ACS) of the LPWAN system to ensure compatibility between LTE and LPWAN systems:

- LPWAN BS impact on LTE BS:
  - With the initial LPWAN base station transmitter ACLR and the LTE base station receiver selectivity defined in ETSI standard [13], the LTE bit rate loss is higher than 5%. It is necessary to improve the LPWAN base station transmitter ACLR by 30 dB to reduce the bit rate loss below 5% in the adjacent band scenario. Compatibility is not achieved in the co-channel scenario.
- LTE BS impact on LPWAN BS:
  - With the initial LTE base station transmitter ACLR of 45 dB (which is applicable in the adjacent channel) and the LPWAN base station receiver selectivity as derived from transmitters masks defined in ETSI standard [13], the probability of interference is higher than 10%. Based on the measurements, it can be assumed that the LTE base station ACLR is at least 20 dB better than the value defined in ETSI standards [13], therefore the compatibility is ensured with an improvement of the LPWAN receiver ACS by 30 dB (Probability of Interference < 10 %). Due to the protection of LTE own reception according to the minimum requirements in the ETSI standards, it is expected that the compatibility between the two systems is much better than the results presented in this analysis when the LPWAN operates in the LTE uplink band and probably in the case of operation close to this LTE uplink band. Compatibility is not achieved in co-channel scenario.
- LTE BS impact on LPWAN ED:
  - It may be needed to improve the LTE base station ACLR of 45 dB by several dBs to ensure the compatibility in the adjacent scenario. Based on the measurements, it can be assumed that the LTE base station ACLR is at least 20 dB better than the value defined in ETSI standard [13] so compatibility is expected.

Concerning the LPWAN End Device, compatibility is achieved in adjacent band scenarios. Compatibility is not achieved in co-channel scenario.

The results in this analysis assume an activity factor of 100% of the LPWAN BS and of LTE BS. In practice, the activity factor of LPWAN BS and LTE BS may be lower. That may reduce the potential impact of each system on the other, thus improving the compatibility between the two systems.

13.6 LTE IMPACT ON DTT ABOVE 470 MHZ

The compatibility studies are carried out in this report for LTE based PMR systems in the 400 MHz band with various base station (BS) e.i.r.p. in the range of 48-62 dBm and with DTT receiver ACS of 61 dB. The analyses concluded that an ACLR of 67 dB/8MHz would be required to minimise the interference from LTE BS to DTT reception, irrespective of the bandwidth and the activity factor as long as the LTE BS e.i.r.p. is below 60 dBm. For a BS e.i.r.p. above 60 dBm, the ACLR needs to be improved in such a way that the BS OOBE do not exceed the value of -7 dBm/8MHz., Simulations were conducted with LTE operating within 3GPP Band 31, while in several European countries, 3GPP Band 72 may be used, which offers a higher guard band with regard to DTT systems above 470 MHz.

It should be noted that all BS in the modelled LTE network may not operate at the same time with full buffer packet traffic. Therefore, although the optimal ACLR for LTE BS remains the same, when there is intermediate protection for DTT service, the requirement of LTE BS ACLR could be relaxed (e.g. -4 dBm/8MHz corresponding to an ACLR of 60 dB/8MHz).

These requirements for LTE PMR base stations are summarised in the table below.

Table 111: LTE 400 Base Station e.i.r.p. and OOBE levels for protection of DTT above 470 MHz Frequency range

	Condition on Base station in-block e.i.r.p, P (dBm/cell)	Maximum mean OOBE e.i.r.p (dBm/cell)	Measurement bandwidth
For DTT frequencies above 470 MHz where broadcasting is protected (NOTE 1)	P ≥ 60	-7	8 MHz
	P < 60	(P – 67)	8 MHz
For DTT frequencies where broadcasting is subject to an intermediate level of protection or when mitigation techniques are used (NOTE 2)	P ≥ 56	-4	8 MHz
	P < 56	(P – 60)	8 MHz

NOTE 1: Based on these results, it can be concluded that the limits defined for the base stations of LTE based BB-PPDR in ECC Decision(16)02, should apply to the base stations of LTE based PMR/PAMR as well.

NOTE 2: At a national level based on the type of mobile network deployment the OOBE limits of BS might be relaxed (See ANNEX 9 for a list of possible mitigation techniques/ measures).

At a national level, the out-of-band emissions limit might be relaxed. For example, with a sparse network deployment, using high remote sites, such as those used for DTT, the probability of interference to DTT reception is significantly reduced. Such a deployment has been successfully implemented in Scandinavian countries. Also, the requirement on the ACLR of the LTE PMR BS can be relaxed when the victim DTT receiver is located close to the DTT transmitter so that the received DTT signal is strong enough to mitigate the interferer. Further mitigation measures, as described in Annex 9 may allow solving possible remaining interference, on a case by case basis.

Additionally, based on the results presented in this Report, it can be concluded that LTE eMTC and NB-IoT BS (including in-band, guard band and standalone NB-IoT) provide a better context of compatibility with DTT than typical LTE BS.

Based on the results obtained for the user equipment (UE), it can be concluded that the limits defined for the UE of LTE based BB-PPDR in ECC Decision(16)02, should apply to the UE of LTE based PMR PAMR. This requirement for the LTE PMR UE is summarised in the table below:

Table 112: LTE UE OOBE level for protection of DTT above 470 MHz

Frequency range	User equipment maximum mean OOBE	Measurement bandwidth
For DTT frequencies above 470 MHz where broadcasting is protected	- 42 dBm	8 MHz

13.7 LTE IMPACT ON RADARS

ECC Report 240 demonstrated that LTE based BB-PPDR systems operating in the band 420-430 MHz could cause severe desensitisation of radars in the co-channel case. Calculations lead to large exclusion zones based on free space propagation loss and statistic propagation model (EPM73), therefore further studies were conducted based on additional assumptions.

The new studies focused on the impact of LTE BS (downlink) on radar systems and investigated several propagation models and scenarios for co-channel (420-430 MHz) and adjacent channel (430-440 MHz) operation of the two systems. The effect of the LTE UE (uplink) on the radar system was already addressed in the ECC Report 240 with 37 dBm e.i.r.p. of UE.

To avoid radar desensitisation operated in 430-440 MHz (-114.9 dBm/MHz) based on the present studies, the proposed technical solution for operating LTE in the 410-430 MHz frequency range is to respect both a guard band of 2.5 MHz from the upper edge of LTE BS channel to 430 MHz and 40 dB of OOBE reduction from the standard with LTE BS duplexer filtering. Assuming the above mentioned guard band of minimum 2.5 MHz, a possible LTE channel arrangement could be entirely placed in the tuning range of 410-417.5/420-427.5 MHz applying 100 kHz channel spacing.

The required separation distance depends on the used propagation models (calculating with free space propagation and smooth Earth, or with the Earth curvature, diffraction, reflection or with tuned models using real terrain data).

For ground radars, the required separation distance is around 120 km in the co-channel scenario and less than 40 km in the adjacent channel scenario over smooth Earth (EPM73, Rec. ITU-R P.526-13). Applying digital terrain based propagation models (General 450 and MYRIAD), the minimum required separation distance could be varied from 1.5 to 28 km in the adjacent channel scenario which can be further reduced by using proper mitigation techniques and a well-designed LTE network (calculating with LTE BS antenna downtilting, LTE BS power reduction, additional LTE BS duplexer filtering, etc.).

For airborne radars, the required separation distance remains more than 400 km required in the co-channel scenario if no particular mitigation technique is applied. Co-existence in the adjacent channel scenario for airborne radars can be achieved with the appropriate filtering and frequency separation which however implies that airborne radars are limited to operate above 430 MHz even though the radar tuning range is 420-450 MHz. The coexistence of LTE in the frequency band 410-430 MHz and radars operated on a secondary basis in the frequency band 420-430 MHz cannot be ensured only by technical conditions. It has to be noted that some countries have already concluded multilateral frequency co-ordination agreements for LTE usage without having taken into account the secondary radiolocation service.

13.8 LTE IMPACT ON RADIO ASTRONOMY

Two studies using different statistical calculation methods were used for evaluation of interference from LTE based BB-PPDR systems operating in the band 410-430 MHz into radio astronomy stations in the band 406.1-410 MHz. One study was done by using SEAMCAT and the propagation model described in Recommendations ITU-R P.1546-5 [10] and ITU-R P.452-16 [33] with a different network layout when aggregated effect of BSs and UEs were taken into account; another one - used Matrix Laboratory software (MATLAB) program and the propagation model described in Recommendation ITU-R P.452-16.

Generic compatibility calculations for LTE systems in the band 410-430 MHz and radio astronomy operating in the band 406.1-410 MHz showed that compatibility may be achievable by implementing emission-free zones around RAS stations.

Analysis by using SEAMCAT showed that for an LTE PPDR network completely surrounding a RAS station, the exclusion zone extended up to 241 km with Recommendation ITU-R P.1546-5 and 362 km with Recommendation ITU-R P.452-16 around RAS when no guard band was used. The exclusion zone extended up to 117 km with Recommendation ITU-R P.1546-5 and 261 km with Recommendation ITU-R P.452-16 when 2.5 MHz guard band was used. Separation distances became smaller when the LTE network's layout comprises a part of the ring placed on one side of RAS. They shrank down to 94 km with Recommendation ITU-R P.1546-5 and 246 km with Recommendation ITU-R P.452-16 when no guard band was used between systems. They shrank to 18 km with Recommendation ITU-R P.1546-5 and 127 km with Recommendation ITU-R P.452-16 when 2.5 MHz guard band was used. Such a case could be met when coordination of different systems between two countries occurs.

There is a difference between results for different propagation models Recommendation ITU-R P.1546-5 and Recommendation ITU-R P.452-16. Protection of investigated services could be ensured by applying distances given by using Rec. ITU-R P.1546; for a more precise exclusion zone Rec. ITU-R P.452 might be applied with real terrain data.

Analysis by using MATLAB with Recommendation ITU-R P.452-16 for the outdoor UE, considering a 1 MHz guard band, the separation distances for single emitter and aggregate cases become 78 km and 326 km, respectively. For indoor usage and additional wall attenuation of 11 dB the separation distances for single emitter and aggregate cases are reduced to 34 km and 190 km, respectively. The separation distances decrease with larger guard bands; for example, with a guard band of 5 MHz the separation distances for single emitter and aggregate cases of outdoor UE become 41 km and 261 km, respectively.

13.9 LTE IMPACT ON FIXED SERVICE

According to the worst-case estimation (assuming free space propagation between the stations and both antennas are pointing towards each other) in co-channel frequency range, the sharing will not be possible between LTE and the FS. In adjacent frequency ranges, the compatibility is limited the remaining scenarios and would require protection distances of about 30 km.

A more realistic estimation implies the propagation model described in Recommendation ITU-R P.452-16 between the LTE BS and the FS station. Between the LTE UE and the FS station the extended HATA propagation model is used. If more realistic investigation options are used, in co-channel frequency range, the sharing will be possible between LTE BS and the FS if protection distances of about 85 km are kept. In adjacent frequency ranges, the compatibility can be expected, if protection distances of about 35 km are respected. Operations at smaller distances are possible but require coordination and/or lower OoBE level for the LTE station within the channel used by fixed service.

LTE UE satisfies sharing requirements for operation distances larger than 4 km to the FS station. If used in an adjacent frequency range, no interference for operational distances larger than 0.5 km is expected LTE impact on PMR links in audio-visual production

13.10 LTE IMPACT ON PMR LINKS IN AUDIO-VISUAL PRODUCTION

As a result from ECC Report 240, co-existence, operating within these bands, is possible due to the additional filtering required to fulfil the 3GPP protection of own UL minimum requirement (UE) duplexers to limit the interference at an acceptable level. Indeed such duplexers are needed to ensure both fulfilment of the 3GPP minimum requirements and correct performance of the LTE400 system itself.

Two new scenarios (TDD PMSE and 100 m co-location) based on those considered in ECC Report 240, relating to the impact of the LTE BS on the PMSE BS (receiving in 453-455 MHz), have been studied:

- Considering the general spurious emissions limits given in 3GPP TS 36.104 [14], coexistence is unlikely to be reached due to the large separation distances required. The level given in ECC/DEC/(06)02 [45] (e.i.r.p. limit of -43 dBm/100 kHz) is not sufficient. Coexistence is expected if the BS spurious emissions meet the minimum requirements of -96 dBm/100kHz emissions in the band 450-455 MHz (Annex 2 in 3GPP TS 36.104 [14]) except if the base stations are located within 100 m where the interference become significant.
- Considering scenarios differing from those considered in ECC Report 240, for example, the TDD case or MS transmitting in 455-460 MHz, the achieved separation distances are larger, and the risk of interference is quite high, in particular when the PMSE BS is located nearby the LTE BS and receiving in the first megahertzs adjacent to the LTE band. A mixture of TDD PMSE and LTE400 should be avoided.

Based on MCL calculations, the separation distance between LTE UE and PMSE MS is of the order of 10 m, leading to a risk of interference if they are operated in the same location.

Similar conclusions apply for the lower band, 410-430 MHz.

13.11 LTE IMPACT ON PAGING

The results of SEAMCAT simulation considering the impact of LTE BS on paging receiver indicate that the level of interference strongly depends on the LTE cell radius. It is also seen that a decrease of the level of unwanted emissions by additional filtering or any other means improves the compatibility. Blocking appears however to be a significant effect. This effect is not specific to LTE; any system with the same in-band transmitter levels will cause the same level of outage due to the poor ACS of the Paging Receiver.

Outage due to interference of blocking may be reduced by repeating the paging messages, which is a standard mechanism in paging systems. The simulations considered an offset of 970 kHz and 3 MHz, if the offset between the paging frequency and the edge of the LTE system is smaller, then, the probability of interference will be higher. With an additional reduction of the LTE OOBE by 25 dB, no interference is expected. No sensitivity study has been conducted related to 25 dB value.

Additional simulations may be needed to consider the impact of 5 MHz and 1.4 MHz systems and the impact of the MS.

13.12 LTE IMPACT ON SRD SYSTEMS

Studies show that there are compatibility issues in case automotive SRD systems and LTE UEs are used in close proximity (< 1 m).

ANNEX 1: TECHNICAL PARAMETERS

A1.1 LTE IN THE 400 MHZ BAND

The following Table 113 and Table 114 provide technical information regarding Long-term Evolution (LTE) user equipment and base stations. Those values are derived from existing 3GPP LTE frequency bands leveraging the recent introduction of Band 31 (452.5-457.5 / 462.5-467.5 MHz). Reference documents are:

- 3GPP TS 36.101 v12.5.0 (2014-09) [12]; 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (Release 12);
- 3GPP TS 36.104 v12.5.0 (2014-09) [13]; 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception (Release 12)

For the LTE BS and UE parameters, see section 2.4.

Table 113: LTE UE emission limits (From Table 6.6.2.1.1-1 in TS 36.101 [12])

Delta f_{OOB} (MHz)	Channel width			Measurement bandwidth
	1.4 MHz	3 MHz	5 MHz	
± 0-1	-10 dBm	-13 dBm	-15 dBm	30 kHz
± 1-2.5	-10 dBm	-10 dBm	-10 dBm	1 MHz
± 2.5-2.8	-25 dBm	-10 dBm	-10 dBm	1 MHz
± 2.8-5		-10 dBm	-10 dBm	1 MHz
± 5-6		-25 dBm	-13 dBm	1 MHz
± 6-10			-25 dBm	1 MHz

Table 114: LTE UE (3 MHz) emission limits when transmission is limited to 3 or 5 RBs

Delta f_{OOB} (MHz)	3 RB	Delta f_{OOB} (MHz)	5 RB	Measurement bandwidth
± 0 - 0.2	-13 dBm	± 0 - 0.333	-13 dBm	30 kHz
± 0.2 – 1	-10 dBm	± 0.333 – 1.666	-10 dBm	1 MHz
±1 - 1.2	-25 dBm	± 1.666 – 2	-25 dBm	1 MHz

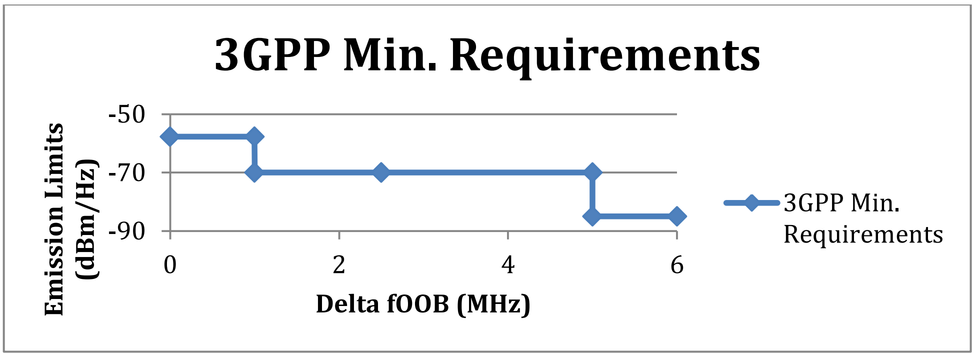


Figure 119: 3GPP minimum requirements

Table 115: LTE UE spurious emissions limits (From Table 6.6.3.1-2 in TS 36.101 [12])

Frequency range outside the out-of-band domain	Maximum level	Measurement bandwidth
9 kHz ≤ f < 150 kHz	- 36 dBm	1 kHz
150 kHz ≤ f < 30 MHz	- 36 dBm	10 kHz
30 MHz ≤ f < 1000 MHz	- 36 dBm	100 kHz
1 GHz ≤ f < 12.75 GHz	- 30 dBm	1 MHz

Table 116: LTE UE Spurious emissions limits for protection of own UE receiver for 3GPP Band 31 (From Table 6.6.3.2-1 in TS 36.101 [12])

E-UTRA Band	Spurious emission						
	Protected band	Frequency range (MHz)			Maximum Level (dBm)	MBW (MHz)	Note
31	E-UTRA Band 1, 5, 7, 8, 20, 22, 26, 27, 28, 31, 32, 33, 34, 38, 40, 42, 43	F_{DL_low}	-	F_{DL_high}	-50	1	
	E-UTRA Band 3	F_{DL_low}	-	F_{DL_high}	-50	1	2

Note: Band 31 UL emissions towards Band 31 own Rx is -50dBm/MHz. The same requirement applies for UE UL emissions to protect own Rx

Table 117: LTE UE receiver blocking values
(From Tables 7.3.1-1, 7.6.1.1-1 and 7.6.1.1-2 in TS 36.101 [12])

	Channel width		
	1.4 MHz	3 MHz	5 MHz
P_{wanted}	-93 dBm	-89.7 dBm	-87.5 dBm

$P_{unwanted}$	-56 dBm	-56 dBm	-56 dBm
Blocking capability	37 dB	33.7 dB	31.5 dB

Table 118: LTE BS emission limits
(From Tables 6.6.3.2.1-1, 6.6.3.2.1-2 and 6.6.3.2.1-3 in TS 36.104 [13])

Channel width	Delta F_c (MHz)	OOB emissions	Measurement bandwidth
1.4 MHz	0.7 to 2.1	-1 dBm -10/1.4 * (Delta F_c – 0.7) dB	100 kHz
	2.1 to 3.5	-11 dBm	100 kHz
	3.5 to 9.95	-16 dBm	100 kHz
3 MHz	1.5 to 4.5	-5 dBm -10/3* (Delta F_c – 1.5) dB	100 kHz
	4.5 to 7.5	-15 dBm	100 kHz
	7.5 to 9.995	-16 dBm	100 kHz
5 MHz	2.5 to 7.5	-7 dBm -7/5* (Delta F_c – 2.5) dB	100 kHz
	7.5 to 9.95	-14 dBm	100 kHz

Table 119: LTE BS spurious emissions limits
(From Table 6.6.4.1.2.1-1. in TS 36.104 [13])

Frequency range outside the out-of-band domain	Maximum level	Measurement bandwidth
9 kHz ≤ f < 150 kHz	- 36 dBm	1 kHz
150 kHz ≤ f < 30 MHz	- 36 dBm	10 kHz
30 MHz ≤ f < 1000 MHz	- 36 dBm	100 kHz
1 GHz ≤ f < 12.75 GHz	- 30 dBm	1 MHz

Table 120: LTE BS Spurious emissions limits for protection of own BS receiver
(From Table 6.6.4.2-1 in TS 36.104 [13])

	Frequency range	Maximum level	Measurement bandwidth	Note
Wide Area BS	F_{UL_low} – F_{UL_high}	-96 dBm	100 kHz	

Table 121: LTE BS blocking values
(From Tables 7.2.1-1 and 7.6.1.1-1. in TS 36.104 [13])

	Channel width		
	1.4 MHz	3 MHz	5 MHz
P_{wanted}	-100.8 dBm	-97 dBm	-95.5 dBm

$P_{unwanted}$	-15 dBm	-15 dBm	-15 dBm
Blocking Capability	85.8 dB	82 dB	80.5 dB

A1.2 LTE NB-IOT

Table 122: Transmission bandwidth (3GPP TS 36.104 Table 5.6-3)

NB-IoT	Standalone
Channel bandwidth (BW) Channel (kHz)	200

Table 123: Foffset for NB-IoT standalone operation (3GPP TS 36.104 Table 5.6-3A)

Lowest or Highest Carrier	Foffset
Standalone NB-IoT	200 kHz

Table 124: Standalone NB-IoT BS unwanted emission limits (3GPP TS 36.104 Table 6.6.3.2E-1)

Frequency offset of measurement filter -3dB point, Δf	Frequency offset of measurement filter centre frequency, f_offset	Minimum requirement (Note 1, 2, 3, 4, 5)	Measurement bandwidth (Note 8)
0 MHz ≤ Δf < 0.05 MHz	0.015 MHz ≤ f_offset < 0.065 MHz	$Max(5dBm - 60 \cdot \left(\frac{f_{offset}}{MHz} - 0.015\right)dB + XdB, -14dBm)$	30 kHz
0.05 MHz ≤ Δf < 0.15 MHz	0.065 MHz ≤ f_offset < 0.165 MHz	$Max(2dBm - 160 \cdot \left(\frac{f_{offset}}{MHz} - 0.065\right)dB + XdB, -14dBm)$	30 kHz
0.15 MHz ≤ Δf < 0.2 MHz	0.165 MHz ≤ f_offset < 0.215 MHz	-14 dBm	30 kHz
0.2 MHz ≤ Δf < 1 MHz	0.215 MHz ≤ f_offset < 1.015 MHz	$-14dBm - 15 \cdot \left(\frac{f\_offset}{MHz} - 0.215\right)dB$	30 kHz
(Note 9)	1.015 MHz ≤ f_offset < 1.5 MHz	-26 dBm	30 kHz
1 MHz ≤ Δf ≤ min(Δfmax, 10 MHz)	1.5 MHz ≤ f_offset < min(f_offsetmax, 10.5 MHz)	-13 dBm	1 MHz
10 MHz ≤ Δf ≤ Δfmax	10.5 MHz ≤ f_offset < f_offsetmax	-15 dBm (Note 10)	1 MHz

NOTE 1: The limits in this table only apply for operation with a NB-IoT carrier adjacent to the Base Station RF Bandwidth edge.

NOTE 2: For a BS supporting non-contiguous spectrum operation within any operating band the minimum requirement within sub-block gaps is calculated as a cumulative sum of contributions from adjacent sub blocks on each side of the sub block gap.

NOTE 3: For a BS supporting multi-band operation with Inter RF Bandwidth gap < 20MHz the minimum requirement within the Inter RF Bandwidth gaps is calculated as a cumulative sum of contributions from adjacent sub-blocks or RF Bandwidth on each side of the Inter RF Bandwidth gap.]

NOTE 4: In case the carrier adjacent to the RF bandwidth edge is a NB-IoT carrier, the value of X = PNB-IoT carrier – 43, where PNB-IoT carrier is the power level of the NB-IoT carrier adjacent to the RF bandwidth edge. In other cases, X = 0.
NOTE 5: For BS that only support E-UTRA and NB-IoT multi-carrier operation, the requirements in this table do not apply to an E-UTRA BS from Release 8, which is upgraded to support E-UTRA and NB-IoT multi-carrier operation, where the upgrade does not affect existing RF parts of the radio unit related to the requirements in this table. In this case, the requirements in subclauses 6.6.3.1 and 6.6.3.2 shall apply. TETRA

The ETSI standard EN ETSI 300 392-2 [16] has been used to obtain most of the TETRA system parameters. This standard is titled 'Radio Equipment and Systems (RES); Trans-European Trunked Radio (TETRA); Voice plus Data (V+D); Part 2: Air Interface (AI)'. Those parameters which cannot be obtained from the standard are assumed values believed to accurately model operational TETRA systems. Following Tables list all of the parameters required by the Monte Carlo simulation to model a TETRA system.

Table 125: System parameters for TETRA

Parameters	Mobile Station	Base Station
Channel spacing	25 kHz	25 kHz
Transmit Power	30, 35 or 40 dBm	40 dBm
Receiver Bandwidth	18 kHz	18 kHz
Antenna Height	1.5 m	30 m
Antenna gain	0 dBi	9 dBi
Receiver Sensitivity	-103 dBm	-106 dBm
Receiver Protection Ratio	19 dB	19 dB
TDMA Users / Carrier	4	4
Power Control Characteristic	5 dB steps to a minimum of 15 dBm	Not used

Table 126: Unwanted emissions for the TETRA System (measurement bandwidth of 18 kHz)

Frequency Offset	30 dBm Mobile Station	35 dBm Mobile Station	40 dBm Mobile Station	40 dBm Base Station
25 kHz	- 30 dBm	- 25 dBm	- 20 dBm	- 20 dBm
50 kHz	- 36 dBm	- 35 dBm	- 30 dBm	- 30 dBm
75 kHz	- 36 dBm	- 35 dBm	- 30 dBm	- 30 dBm
100 - 250 kHz	- 45 dBm	- 43 dBm	- 40 dBm	- 40 dBm
250-500 kHz	- 50 dBm	- 48 dBm	- 45 dBm	- 45 dBm
500 kHz-frb	- 50 dBm	- 50 dBm	- 50 dBm	- 50 dBm
Greater than frb	- 70 dBm	- 65 dBm	- 60 dBm	- 60 dBm
At frequency offsets less than 100 kHz no limit tighter than - 36 dBm shall apply At frequency offsets equal to and greater than 100 kHz no limit tighter than - 70 dBm shall apply				

Table 127: Receiver blocking values for the TETRA System

Frequency Offset	30, 35, 40 dBm Mobile Station	40 dBm Base Station
50-100 kHz	-40 dBm	-40 dBm

100-200 kHz	-35 dBm	-35 dBm
200-500 kHz	-30 dBm	-30 dBm
> 500 kHz	-25 dBm	-25 dBm

A1.3 TETRAPOL

Tetrapol parameters have been obtained from the Tetrapol's publicly available specification and are reflecting ETSI EN 300-113 [20] related radio systems.

Table 128: System parameters for Tetrapol

Parameters	Mobile Station	Base Station
Channel spacing	10 or 12.5 kHz	10 or 12.5 kHz
Transmit Power	33 dBm	38 dBm
Receiver Bandwidth	8 kHz	8 kHz
Antenna Height	1.5 m	30 m
Antenna gain	0 dBi	9 dBi
Receiver Sensitivity	-111 dBm	-113 dBm
Receiver Protection Ratio	15 dB	15 dB
TDMA Users / Carrier	4	4
Power Control Characteristic	2 dB steps to a minimum of 21 dBm	Not used

Table 129: Receiver blocking for the Tetrapol system (Mobile station (MS) and BS)

Frequency Offset	Blocking
13.5-25 kHz	-65 dBm
25-40 kHz	-55 dBm
40-100 kHz	-50 dBm
100-150 kHz	-40 dBm
150 – 500 kHz	-35 dBm
> 500 kHz	-25 dBm

Table 130: Unwanted emissions (dBm) for the Tetrapol system (in 8 kHz bandwidth)

Frequency Offset	Mobile Station	Base Station
8.5 - 21 kHz	Max (p-60,-36)	Max (p-60,-36)
21-25 kHz	Max (p-70,-36)	Max (p-70,-36)
25-40 kHz	p – 70	p - 70
40-100 kHz	p – 75	p – 75

100-150 kHz	p – 85	p – 85
150-500 kHz	p – 90	p – 95
Greater than 500 kHz	p – 100	p – 105
In the corresponding receiving band	-80	-100

(1): where p represents the transmission power expressed in dBm.

A1.4 ANALOGUE FM PMR

A1.4.1 25 kHz Analogue FM PMR

The ETSI standards ETSI EN 300 086 [19] and ETSI EN 300 113 [20] have been used to obtain information regarding 25 kHz Analogue Frequency Modulation (FM) system parameters. Other parameters are assumed values believed to accurately model operational FM systems. Following Tables list all of the parameters required by the Monte Carlo simulation to model a 25 kHz FM system.

Table 131: Parameters for the 25 kHz Analogue FM PMR

Parameter	Mobile Station	Base Station
Channel Spacing	25 kHz	25 kHz
Transmit Power	37 dBm	44 dBm
Receiver Bandwidth	15 kHz	15 kHz
Antenna Height	1.5 m	30 m
Antenna gain	0 dBi	9 dBi
Transmitting Interferer Density Range	Variable	Variable
Receiver Sensitivity	-107 dBm / -117 dBm (1)	-110 dBm / -120 dBm (1)
Receiver Protection Ratio	17 dB	17 dB
Power Control Characteristic	Not used	Not used

(1): The first values were taken from ECC Report 099 [14]; the second ones were in this Report following guidance received from ETSI ERM.

Table 132: Unwanted emissions for the 25 kHz Analogue FM PMR (measurement bandwidth of 18 kHz)

Frequency Offset	Mobile Station	Base Station
25 kHz	- 33 dBm	- 26 dBm
100 - 250 kHz	- 53 dBm	- 46 dBm
250 - 500 kHz	- 60 dBm	- 53 dBm
500 kHz - 1 MHz	- 64 dBm	- 57 dBm
1 MHz - 10 MHz	- 69 dBm	- 62 dBm
> 10 MHz	- 71 dBm	- 64 dBm

Linear interpolation (in dB) is used between 25 kHz and 100 kHz

Table 133: Receiver blocking values for the 25 kHz Analogue FM PMR

Frequency Offset	Mobile Station	Base Station
Any frequency	- 23 dBm	- 23 dBm

A1.4.2 **20 kHz Analogue FM PMR**

The ETSI standards ETSI EN 300 086 [19] and ETSI EN 300 113 [20] have been used to obtain information regarding 20 kHz FM system parameters. Other parameters are assumed values believed to accurately model operational FM systems.

Table 134: Parameters for the 20 kHz Analogue FM PMR

Parameter	Mobile Station	Base Station
Channel Spacing	20 kHz	20 kHz
Transmit Power	37 dBm	44 dBm
Receiver Bandwidth	12 kHz	12 kHz
Antenna Height	1.5 m	30 m
Antenna gain	0 dBi	9 dBi
Transmitting Interferer Density Range	Variable	Variable
Receiver Sensitivity	- 107 dBm	- 110 dBm
Receiver Protection Ratio	17 dB	17 dB
Power Control Characteristic	Not used	Not used

Table 135: Unwanted emissions for the 20 kHz Analogue FM PMR (measurement bandwidth of 12 kHz)

Frequency Offset	Mobile Station	Base Station
20 kHz	- 33 dBm	- 26 dBm
100 - 250 kHz	- 53 dBm	- 46 dBm
250 - 500 kHz	- 60 dBm	- 53 dBm
500 kHz - 1 MHz	- 64 dBm	- 57 dBm
1 MHz - 10 MHz	- 69 dBm	- 62 dBm
> 10 MHz	- 71 dBm	- 64 dBm

Linear interpolation (in dB) is used between 20 kHz and 100 kHz

Table 136: Receiver blocking values for the 20 kHz Analogue FM PMR

Frequency Offset	Mobile Station	Base Station
Any frequency	- 23 dBm	- 23 dBm

A1.4.3 **12.5 kHz Analogue FM PMR**

The ETSI standards ETSI EN 300 086 and ETSI EN 300 113 have been used to obtain information regarding 12.5 kHz FM system parameters. Other parameters are assumed values believed to accurately model operational FM systems. Following Tables list all of the parameters required by the Monte Carlo simulation to model a 12.5 kHz FM system.

Table 137: Parameters for the 12.5 kHz Analogue FM PMR

Parameter	Mobile Station	Base Station
Channel Spacing	12.5 kHz	12.5 kHz
Transmit Power	37 dBm	44 dBm
Receiver Bandwidth	8 kHz	8 kHz
Antenna Height	1.5 m	30 m
Antenna gain	0 dBi	9 dBi
Transmitting Interferer Density Range	Variable	Variable
Receiver Sensitivity	-107 dBm*	-110 dBm*
Receiver Protection Ratio	21 dB	21 dB
Power Control Characteristic	Not used	Not used

*those numbers for receiver sensitivity were taken from ECC Report 099 [14] and have been modified for the purpose of this Report to -117 dBm for MS and -120 dBm for BS

Table 138: Unwanted emissions for the 12.5 kHz Analogue FM PMR (measurement bandwidth of 8 kHz)

Frequency Offset	Mobile Station	Base Station
12.5 kHz	- 23 dBm	- 16 dBm
100-250 kHz	- 43 dBm	- 36 dBm
250-500 kHz	- 60 dBm	- 53 dBm
500 kHz - 1 MHz	- 64 dBm	- 57 dBm
1 MHz-10 MHz	- 69 dBm	- 62 dBm
> 10 MHz	- 71 dBm	- 64 dBm

Linear interpolation (in dB) is used between 12.5 kHz and 100 kHz

Table 139: Receiver blocking values for the 12.5 kHz Analogue FM PMR

Frequency Offset	Mobile Station	Base Station
Any frequency	- 23 dBm	- 23 dBm

A1.5 CODE DIVISION MULTIPLE ACCESS (CDMA)-PUBLIC ACCESS MOBILE RADIO (PAMR)

Table 140: System parameters for the CDMA-PAMR systems

Parameters	Mobile Station	Base Station
Channel spacing	1250 kHz	1250 kHz
Transmit Power	23 dBm	42 dBm
Receiver Bandwidth	1250 kHz	1250 kHz
Antenna Height	1.5 m	30 m
Antenna gain	0 dBi	15 dBi (1)
Receiver Sensitivity	-121 dBm	-126 dBm
Interference introduced by own CDMA transmitters over thermal noise	5 to 15 dB 12 dB maximum at the cell edge of the regular cell	3 to 6 dB 3 dB at medium loaded cell
Power Control Characteristic	Used at SEAMCAT simulation	No Power Control on DL

Kathrein product datasheet (741 516) used to create SEAMCAT antenna patterns

Table 141: Receiver blocking values for the CDMA-PAMR systems

Frequency Offset	Mobile Station	Base Station
Greater than 900 kHz	-30 dBm	-21 dBm

Table 142: Unwanted emissions for the CDMA-PAMR systems

Frequency Offset	Mobile Station	Base Station	Measurement bandwidth
0.75 MHz	p	p – 45	1.25 MHz
0.885 MHz	p – 47	p – 60	30 kHz
1.98 MHz	p – 67	p – 65	30 kHz
4 MHz	p – 82	p – 75	30 kHz
6 MHz	p – 74	p – 76	100 kHz
12 MHz	p – 74	p – 85	100 kHz

(1): where p represents the transmission power expressed in dBm.

A1.6 DTT

A1.6.1 DTT Transmissions

A1.6.1.1 *Reference broadcast transmitter configurations*

Reference broadcast transmitter configurations in Table 143 are provided that are representative of actual deployments.

Low power DTT antenna

For compatibility calculations a directional low power DTT antenna based on a cardioid should be used. The attenuation (Aϑ) of the cardioid's horizontal pattern with azimuth angle (ϑ) is given by

$$A_{\vartheta} = 20Log_{10}(2B - B^2)\ \text{dB}$$

where:

$$B = \frac{1 + k + Cos(\vartheta)}{2 + k}$$

where:

- ϑ = Azimuth angle
- k = 0.4187 for 10 dB pattern minima

The resulting pattern is shown in the figure below.

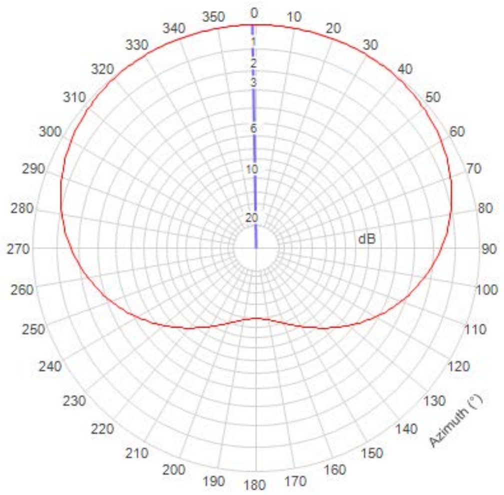


Figure 120: Low power DTT

Table 143: DTT transmitter characteristics

Parameter		Value		
Transmitter Class		High Power	Medium Power	Low Power
ERP		200 kW	5 kW	250 W
Effective antenna height		300 m	150 m	75 m
Antenna height a.g.l.		200 m	75 m	30 m
Antenna pattern	horizontal	Omnidirectional	Omnidirectional	Directional (see Figure above)
	vertical	based on 24λ aperture with 1° beam tilt	based on 16λ aperture with 1.6° beam tilt	based on 4λ aperture with 3° beam tilt

A1.6.1.2 *Antenna Height*

Where no terrain information is available when propagation predictions are being made, the height h1 (m) of the antenna above ground is calculated according to path length, d (km), as follows:

$h_1 = h_a$ (m), for d ≤ 3 km

$h_1 = h_a + (h_{eff} - h_a)(d-3)/12$ (m), for 3 km < d < 15 km

where:

- h_a is the antenna height above ground level;
- H_{eff} is the effective antenna height.

A1.6.1.3 *Vertical radiation patterns*

The field strength in the vicinity of the broadcast transmitting station is a function of the vertical radiation pattern of the transmitting antenna. The equation below is an approximation to be used for sharing studies.

$$E(\theta) = abs\left(\frac{Sin\Psi}{\Psi}\right)$$

where:

$\psi = \pi A sin(\theta - \beta)$;

- and
- A = the antenna vertical aperture in wavelengths;
- β = the beam tilt below the horizontal.

To allow for null fill the value of E(θ) should not go below the value shown in Table 144.

Table 144: Null fill values to be applied to vertical radiation patterns

	Limit on E(θ)
First null	0.15
Second null	0.1

For the third null and at all angles of θ beyond the third null the value of E(θ) should not fall below 0.05, see Figure 121.

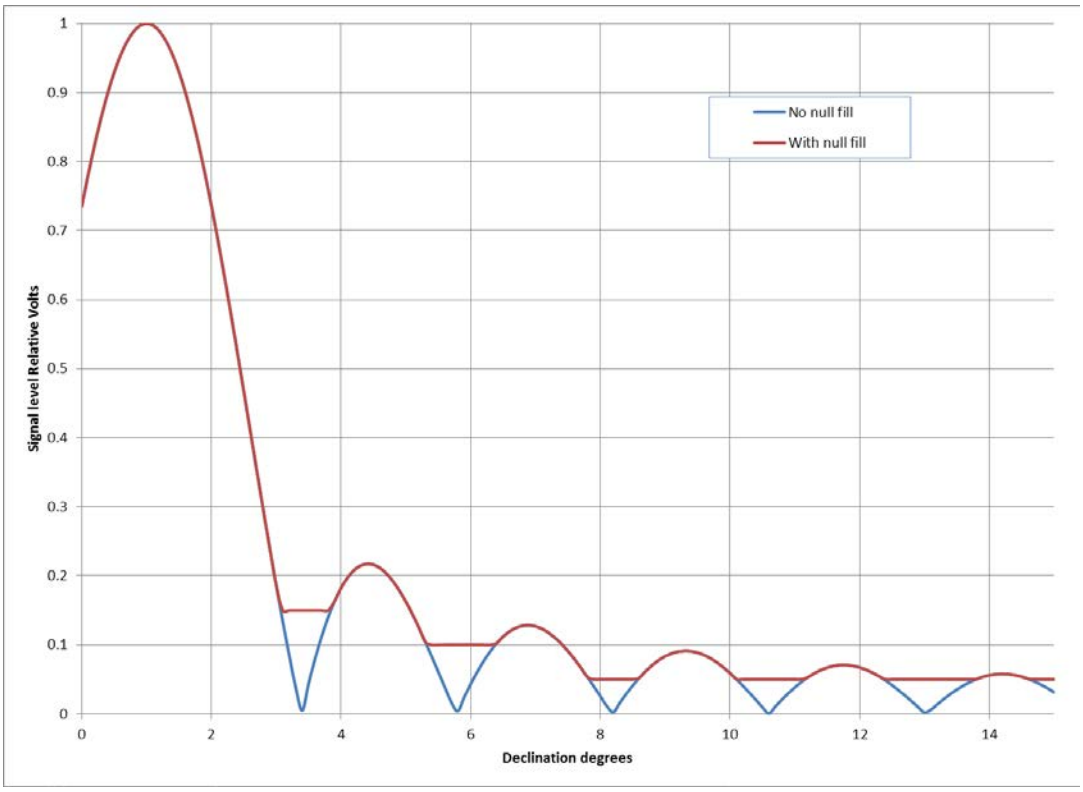


Figure 121: Vertical pattern of a high power DTT transmitter

A1.6.1.4 *DVB Mask*

Out-of-band emission (OOBE) limits of DTT transmitters to use in compatibility studies are based on ETSI EN 302 296[18].

A1.6.1.5 *Out-of-band emissions limits*

Out-of-band emissions (OOBE) limits are given as mean power level measured at the antenna port in a 3 kHz bandwidth for the non-critical (Table 145 & Figure 122) and critical (Table 146 & Figure 122). It should be noted that these are the same as the GE06 masks but referenced to a 3 kHz not 4 kHz measurement bandwidth and they extend to ± 20 MHz not ± 12 MHz.

Table 145: OOBE limits for DVB-T/T2 transmitter non-critical

Classification	8 MHz Channel, frequency difference from the centre frequency (MHz)	Relative level (dBc/3kHz)
Non-critical cases	±3.9	-34
	±4.2	-74

[e] Draft ETSI EN 302 296v1 (2016), ‘Electromagnetic compatibility and Radio spectrum Matters (ERM); Transmitting equipment for the digital television broadcast service, Terrestrial (DVB-T and DVB-T2); Harmonised EN covering the essential requirements of article 3.2 of the Directive 2014/53/EU’

Classification	8 MHz Channel, frequency difference from the centre frequency (MHz)	Relative level (dBc/3kHz)
	±6	-86
	±12	-111
	±20	-111

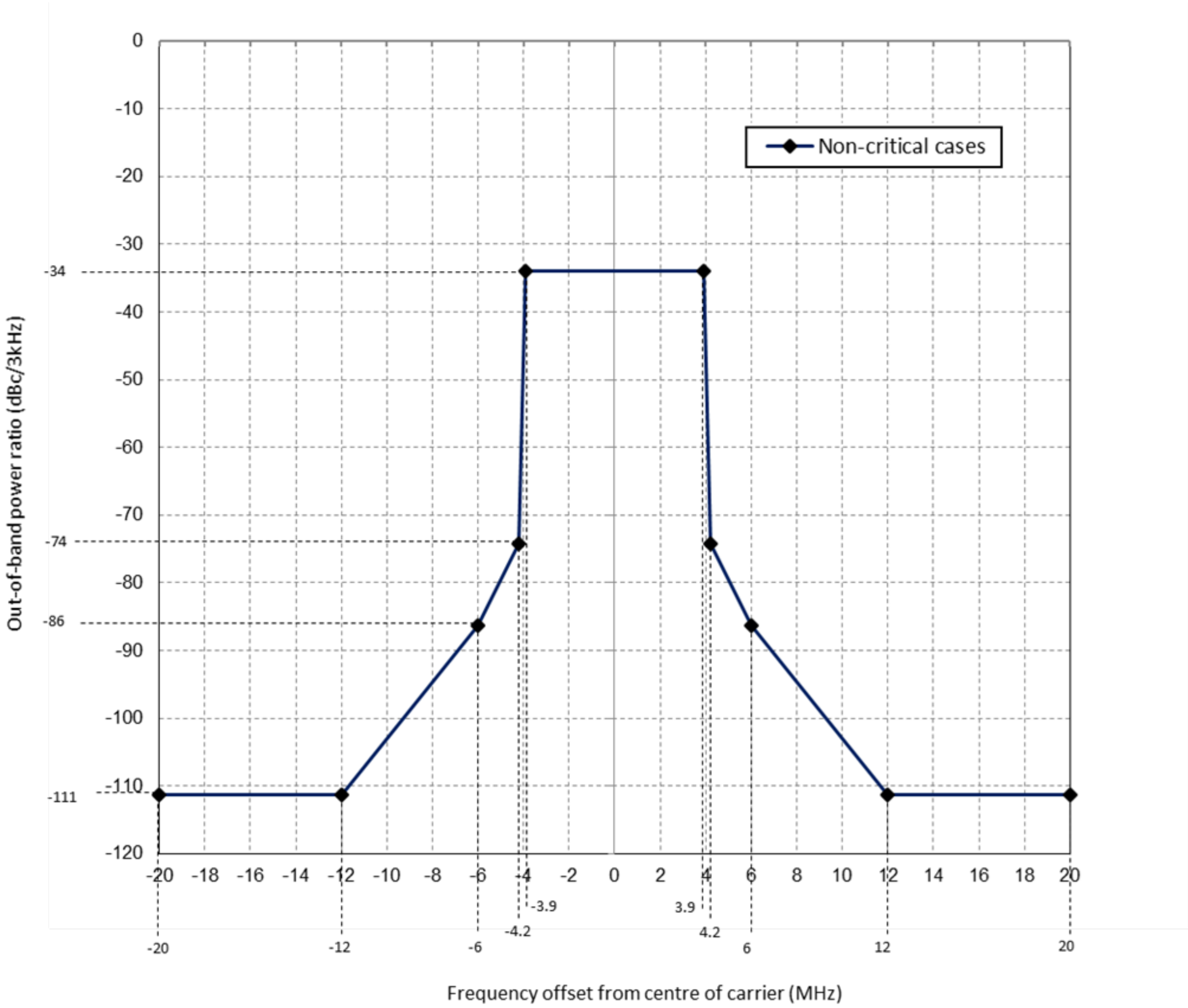


Figure 122: Non-critical OOBE limits for DVB-T/T2 transmitters 8 MHz channels

Table 146: OOBE limits for DVB-T/T2 transmitter critical

Classification according to the frequency assignment	8 MHz Channel, frequency difference from the centre frequency (MHz)	Relative level (dBc/3kHz)
Critical cases	±3.9	-34
	±4.2	-84
	±6	-96
	±12	-121
	±20	-121

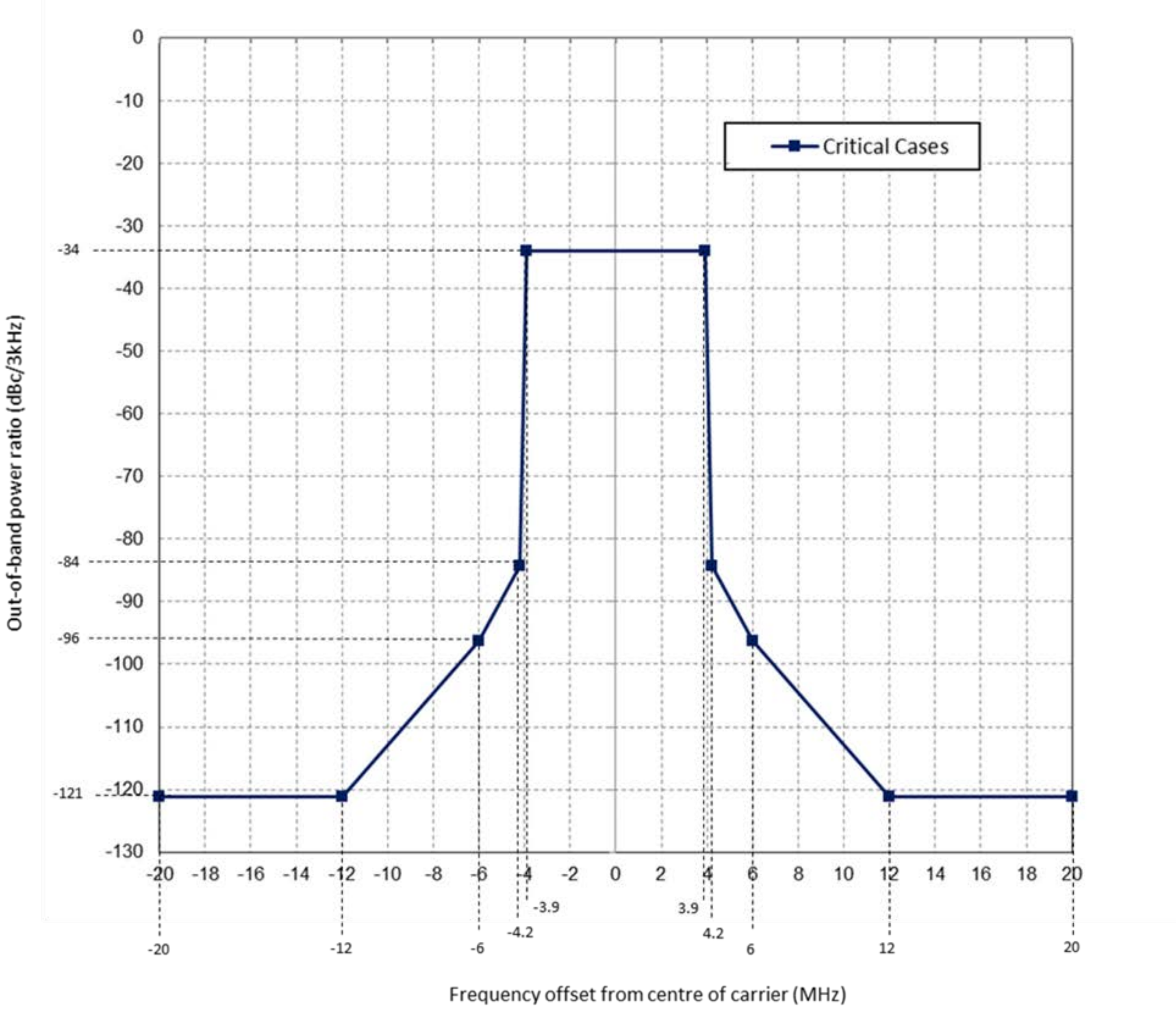


Figure 123: Critical OOBE limits for DVB-T/T2 transmitters 8 MHz channels

A1.6.2 **Fixed reception**

The reference receiving antenna height considered to be representative for fixed reception is 10 m above ground level.

A1.6.2.1 *Fixed antenna pattern*

Standard radiation patterns for receiving antennas for Bands IV and V (see Figure 124), are given in Recommendation ITU-R BT.419.

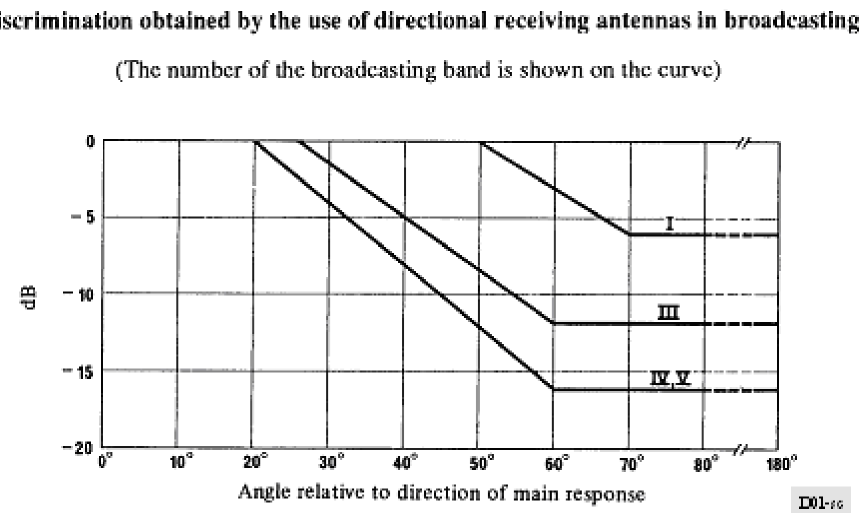


Figure 124: Discrimination obtained by the use of directional receiving antennas in broadcasting

A1.6.2.2 *Antenna gain*

The antenna gain values (relative to a half-wave dipole) to be used are given in Table 147.

Table 147: Antenna gain (relative to a half-wave dipole)

Frequency (MHz)	470
Antenna gain (dBd)	10

A1.6.2.3 *Feeder loss*

The feeder-loss values to be used are given in Table 148.

Table 148: Feeder loss

Frequency (MHz)	470
Feeder loss (dB)	3

A1.6.2.4 *Location probability for fixed reception*

For fixed reception, a location probability of 95% shall be used.

A1.6.2.5 *Polarisation discrimination for fixed reception*

It is possible to take advantage of polarisation discrimination for fixed reception. However, in the case of orthogonal polarisation, the combined discrimination provided by directivity and orthogonality cannot be calculated by adding together the separate discrimination values. A combined discrimination value of 16 dB shall be applied for all angles of azimuth in Bands IV and V.

A1.6.3 **Portable reception**

The reference receiving antenna height considered to be representative for portable reception is 1.5 m above ground level.

A1.6.3.1 *Building entry loss*

Table 149 contains the mean values for building entry loss and the corresponding standard deviation at UHF derived from table 14 in Recommendation ITU-R 1812.

Table 149: Building entry loss 470 MHz

Building entry loss	Standard deviation
10.4 dB	5 dB

A1.6.3.2 *Antenna gain for portable reception*

Recommendation ITU-R BT.1368-12 gives in its Annex 5, § 4.1, information on antennas for portable reception. For portable reception, an omnidirectional antenna shall be applied. The antenna gain (relative to a half-wave dipole) is as given in Table 150.

Table 150: Antenna gain (dBd) for portable reception

Band	Gain (dBd)
Band IV	0
Band V	0

A1.6.3.3 *Location probability for portable reception*

For portable indoor and outdoor reception of DTT, a location probability of 95% shall be used.

A1.6.3.4 *Polarisation discrimination for portable reception*

Polarisation discrimination shall not be taken into account in frequency planning for portable reception.

A1.6.4 System parameters and protection requirements related to DVB-T

A1.6.4.1 *General parameters*

Table 151: General DVB-T Parameters

Parameter	Units	Fixed reception Portable reception (outdoor/Mobile or indoor)
Signal bandwidth	MHz	7.60
Thermal noise density (kT_0)	dBm/Hz	-173.98
Receiver noise figure	dB	7

The studies should consider two reception modes, one mode for fixed reception and one mode for portable reception.

A1.6.4.2 *Carrier-to-noise ratio*

Table 152: Carrier-to-noise ratio [21]

Fixed reception	Portable reception
21 dB	19 dB

A1.6.4.3 *Minimum received power at 470 MHz*

Table 153: Minimum receive power at 470 MHz at receiver input

Fixed reception	Portable reception
-77.1 dBm	-79.1 dBm

A1.6.5 System parameters and protection requirements related to DVB-T2

A1.6.5.1 *General parameters*

Table 154: General DVB-T2 Parameters

Parameter	Units	Fixed reception Portable reception (outdoor/ indoor)
Signal bandwidth	MHz	7.77
Thermal noise density (kT_0)	dBm/Hz	–173.98
Receiver noise figure	dB	6

The studies should consider two reception modes, one mode for fixed reception and one mode for portable reception.

A1.6.5.2 *Carrier-to-noise ratio*

Table 155: Carrier-to-noise ratio

Fixed reception	Portable reception
21 dB	19 dB

A1.6.5.3 *Minimum receive power at 470 MHz*

Table 156: Minimum receive power at 470 MHz at receiver input

Fixed reception	Portable outdoor reception
-78.1 dBm	-80.1 dBm

A1.6.6 **DTT ACS values**

For more details on the ACS values see ECC Report 240 Annex 1.7.

Table 157: DTT ACS

DTT receiver ACS	
Guard band (MHz)	Value (dB)
2.5	59.5
12.5	69.5

A1.7 FIXED SERVICE

In Germany, approximately 500 fixed service (FS) narrowband applications are used e.g. by utility companies. These applications are not covered by the harmonized standard ETSI EN 302 217-2-2 [24] and might be considered as specific. The technical parameters of the point-to-point-service applications in the 400 MHz frequency range are the following:

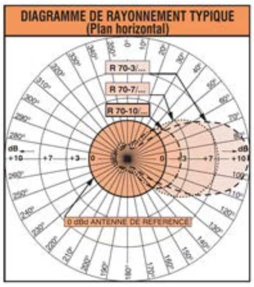
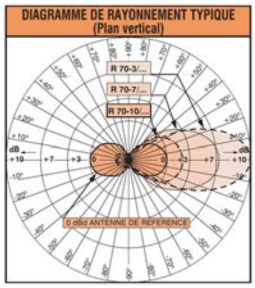
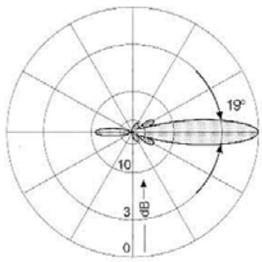
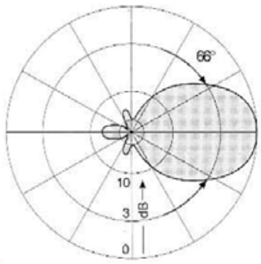
Table 158: FS common usage characteristics at 410-430 MHz

Common FS characteristics in the 400 MHz frequency range	
Lower half band	410.000-410.800 MHz
Upper half band	420.000-420.800 MHz
Duplex spacing	10 MHz
Channel spacing	20 kHz
Number of channels	40
Polarisation	horizontal or vertical

Common FS characteristics in the 400 MHz frequency range	
Link modes	duplex or simplex
e.i.r.p. (max)	0.03 kW (15 dBW)
Designation of emissions	D7W, F7W, G7W
Related standards	EN 300 113-2, EN 301 753, EN 300 086-2, EN 301 489-1
Radio interface specification	SSB FE-OE 024
Remark	These systems have to provide Adjacent channel co-polarized (ACCP) capability. Applications are not intended for large networks.

Two antenna specifications were agreed to be representative examples of the antennas used for fixed service applications in this frequency range.

Table 159: FS sample antenna characteristics at 410-430 MHz

Manufacturer & product	built principle	frequency range (MHz)	gain (dBi)	antenna pattern horizontal	antenna pattern vertical
PROCOM France S.A.R.L. R 70-3/…	2 elements Yagi	380-430	5 dBi		
KATHREIN K733421 and K733427	directional antenna half power beamwidth 19°	400-470	13.5 dBd		

As the relevant HN EN 302 217-2-2 (04/2014) [24] does not contain any equipment specification in this frequency range, the following generic data were derived from specific systems in use and drawn from the German national licensing database. A protection ratio of (N+I)/N = 1 dB equal to an I/N = -5.87 dB is assumed. The parameter “T” represents the receiver threshold and is very common in protection considerations of the FS. It is basically the same as the sensitivity and describes the lowest possible signal level which can be processed by the receiver.

Table 160: FS generic equipment characteristics at 410-430 MHz

Frequency lowest (GHz)	frequency highest (GHz)	BW (MHz)	transfer rate (kBit/s)	designation of emission	modulation	C/N (dB)	T/I (dB)	N (dBm)	T (dBm)
0.410	0.421	0.020	20	20K0F3E	2-PSK	10.5	17.4	-158.4	-146.9

The following Table 161 specifies the both the spectral transmission mask and the receiver selectivity which can be used as information on the blocking performance of the receiver.

Table 161: FS Tx spectrum and Rx selectivity of equipment for 410-430 MHz

Frequency offset (MHz)	Relative PSD (dB)
-0.05	-40
-0.013	-40
-0.01	0
0	0
0.01	0
0.013	-40
0.05	-40

Table 162: Further technical information on the fixed link applications in the 400 MHz frequency range

	Gain (dB)	Hop length (km)	Antenna height (m)	Polarisation	Number of links
Maximum	15.7	157.9	226	V	706
Minimum	1.5	0.53	1	V [%]	88.7
Average	11.1	14.0	26.3	H	90
Standard deviation	3.6	13.8	20.0	H [%]	11.3

A1.8 PAGING SYSTEM

Radio paging services are listed over the whole frequency range from 450-470 MHz in the EFIS. These applications are usually narrowband (20 and 25 kHz), wide area, simplex[19], point-to-point or point-to-multipoint (see EN 300 224 V2.1.1 and ETSI TR 103 102). They use a 2-FSK modulation and provide a throughput of 512 baud or 1200 baud. The receivers are tuned to a dedicated receive frequency which cannot be changed after put into operation. An essential feature of the paging receivers is their very low power consumption implying not to offer a transmission function.

Table 163: Paging Transmitter

Parameter	Limit / Level	
Maximum transmitted power	100 W ERP (50 dBm)	
Bandwidth	20 / 25 kHz	
Carrier frequency	430 MHz-470 MHz	Germany

[19] the paging BS is a transmitter only

Parameter	Limit / Level	
	(Tuning range)	465.96-465.98 MHz 466.0625-466.0875 MHz 466.22-466.24 MHz 448.4125-448.4375 MHz 448.4625-448.4875 MHz 15. France 16. 466.0375-466.0625 MHz 466.0625-466.0875 MHz 466.1625-466.1875 MHz 466.19375-466.21875 MHz
Frequency reuse	None	
Modulation	2FSK	
Data rate	512 Baud / 1200 Baud	
Duty cycle	Up to 100 %	
Base station height	30-100 m	
Antenna pattern and gain / downtilt angle	omnidirectional / 0 dBi / no downtilt	
Network topology (for simulations only)	hexagonal	
Typical “base station coverage radius	6 km (urban) / 18 km (rural)	
Adjacent channel power ratio (ACPR)	≤ 70 dBc	
Intermodulation suppression	> 70 dB	
Spurious emissions	-36 dBm/25 kHz	

Table 164: Paging Receiver

Parameter	Value
Typical Sensitivity	20 dBµV/m (-110dBm)
Co-channel rejection (CSs: 20 kHz, 25 kHz)	-8...0 dB
Co-channel rejection (CSs: 10 kHz, 12.5 kHz)	-12...0 dB
ACS, PS , normal conditions (CSs: 20 kHz, 25 kHz)	>60 dB
Blocking immunity, PS	≥60 dB
Intermodulation immunity, PS	≥50 dB
Spurious emissions, PS, 100 kHz...1 GHz	≤2 nW (-57 dBm)
Spurious emissions, PS, 1 GHz...4 GHz	≤20 nW (-47 dBm)

The additional path loss for indoor use is 10 dB. Indoor use will reflect the usage inside buildings in rooms with windows at the ground floor and above.

A1.9 AUTOMOTIVE SRD SYSTEMS

A1.9.1 Remote Keyless Entry Systems

A1.9.1.1 *Contemporary RKS*

Table 165: System parameters for locking systems

Parameters	locking systems (Keyless-Go or Remote Keyless Entry)
Centre frequency	433.92 MHz
Channel spacing	450 kHz
Transmit Power[20]	< -15 dBm e.i.r.p. (key); <+10dBm e.i.r.p. (car)
Receiver Bandwidth	165 kHz
Antenna gain	-20 dBi (key) -5 dBi (car)
Antenna pattern	no specific direction (for simulations: Omnidirectional)
Receiver Sensitivity	-108 dBm
Minimum Signal to Noise ration[21]	13 dB
Modulation	Frequency Shift Keying (FSK)
Modulation: Frequency deviation	±10 kHz
Modulation: Data rate	10 kBaud
duty cycle	<1%
Tx_{on}	<250 ms
Tx_{off}	>25 ms
longest transmission period (worst case)	60 s
Mitigation	manual triggered duty cycle Similar to DAA (keyless-go): The following behaviour is every time active: After each 50 ms, all used channel will be checked. That channel with the lowest occupancy is stored to memory. If keyless-go is triggered (e.g. a person touch the door handle), the communication starts immediately with stored channel. Note: Keyless-go has not enough time to make a channel check before each communication. This is the background for above described behaviour.

[20] Includes the antenna gain

[21] Relationship between wanted signal to white noise.

Table 166: Receiver blocking in car

Frequency Offset	Blocking
≥ 150 kHz	≥ 30 dB
≥ 225 kHz	≥ 40 dB
≥ 450 kHz	≥ 45 dB
≥ 800 kHz	≥ 50 dB
≥ 1500 kHz	≥ 60 dB
≥ 2500 kHz	≥ 70 dB
≥ 5000 kHz	≥ 80 dB
≥ 10000 kHz	≥ 95 dB
at image frequency	≥ 40 dB

Table 167: Receiver blocking in key

Frequency Offset	Blocking
≥ 150 kHz	≥ 30 dB
≥ 225 kHz	≥ 40 dB
≥ 450 kHz	≥ 45 dB
≥ 800 kHz	≥ 50 dB
≥ 1500 kHz	≥ 50 dB
≥ 2500 kHz	≥ 55 dB
≥ 5000 kHz	≥ 65 dB
≥ 10000 kHz	≥ 75 dB
at image frequency	≥ 40 dB

A1.9.1.2 *Legacy RKS*

Table 168: System parameters for locking systems

Parameters	“old” locking systems remote keyless entry
Centre frequency	433.92 MHz
Channel spacing	no

Parameters	"old" locking systems remote keyless entry
Transmit Power[22]	< -15 dBm e.i.r.p. (key); <+10 dBm e.i.r.p. (car)
Receiver Bandwidth	600 kHz (remote keyless entry) 150 kHz (keyless-go)
Antenna gain	-20 dBi (key) -5 dBi (car)
Antenna pattern	no specific direction (for simulations: Omnidirectional)
Receiver Sensitivity	-99 dBm
Minimum Signal to Noise ration[23]	13 dB
Modulation	Frequency Shift Keying (FSK)
Modulation: Frequency deviation	±15....±32 kHz
Modulation: Data rate	10 kBaud (keyless-go) 1 kBaud (remote keyless entry)
duty cycle	<1%
Tx_{on}	<250 ms
Tx_{off}	>20 ms
longest transmission period (worst case)	60 s
Mitigation	manual triggered duty cycle

Table 169: Receiver blocking

ECE										
frequency range							Blocking			
0.001	MHz	<	...	≤	0.135	MHz	≥75	dB	(tbd.)	
0.135	MHz	<	...	≤	80	MHz	≥70	dB	(tbd.)	
80	MHz	<	...	≤	370	MHz	≥70	dB	(tbd.)	
370	MHz	<	...	≤	428	MHz	≥80	dB	(tbd.)	
428	MHz	<	...	≤	428	MHz	≥50	dB	(tbd.)	
428	MHz	<	...	≤	433.52	MHz	≥-10.87	*fMHz+(	4702	)

22 Includes the antenna gain

23 Relationship between wanted signal to white noise.

ECE										
433.52	MHz	<	...	≤	434.42	MHz	≥-10	dB	(tbd.)	
434.42	MHz	<	...	≤	441.5	MHz	≥12.712	*fMHz+(	-5532	)
441.5	MHz	<	...	≤	500	MHz	≥80	dB	(tbd.)	
500	MHz	<	...	≤	1500	MHz	≥70	dB	(tbd.)	
							f in MHz			

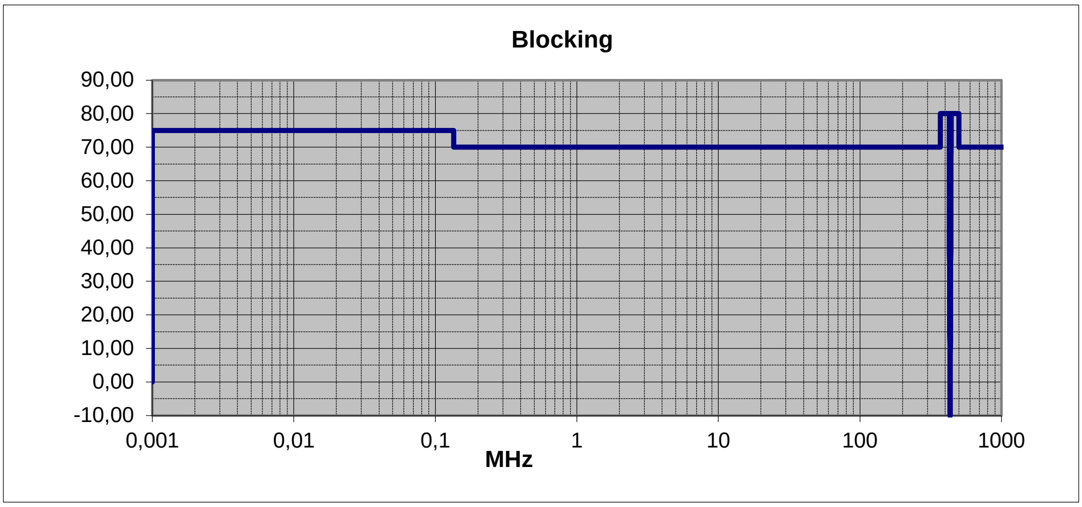


Figure 125: Receiver blocking

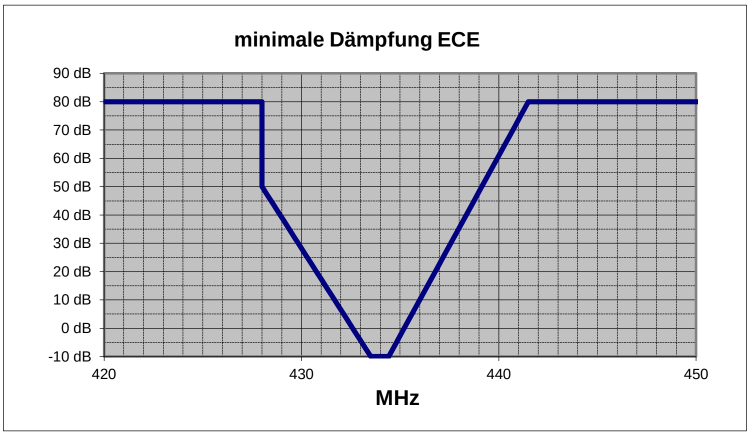


Figure 126: Receiver filter around 433.92 MHz

A1.9.2 Tire Pressure Monitoring Systems

Table 170: Transmitter Hardware

Tx	Gamma - Gen 4 WAL 2 Tyre Pressure Sensor
Centre frequency	433.92 MHz
Transmit Power	7 dBm

Tx	Gamma - Gen 4 WAL 2 Tyre Pressure Sensor
Antenna gain	-21.5 dBi
Antenna pattern	See polar plots below:
Minimum Signal to Noise ratio	
Modulation	AM OOK
Modulation: Frequency deviation:	
Modulation: Data rate:	4.096 kHz ±5%
duty cycle	< 1.0%
Tx_{on}	16.85 ms ±5% (Mode dependent)
Tx_{off}	12 s (Mode dependent)
longest transmission period (worst case)	16.85 ms ±5% (Mode dependent)
Mitigation	Low duty cycle Pseudo-random transmission structure

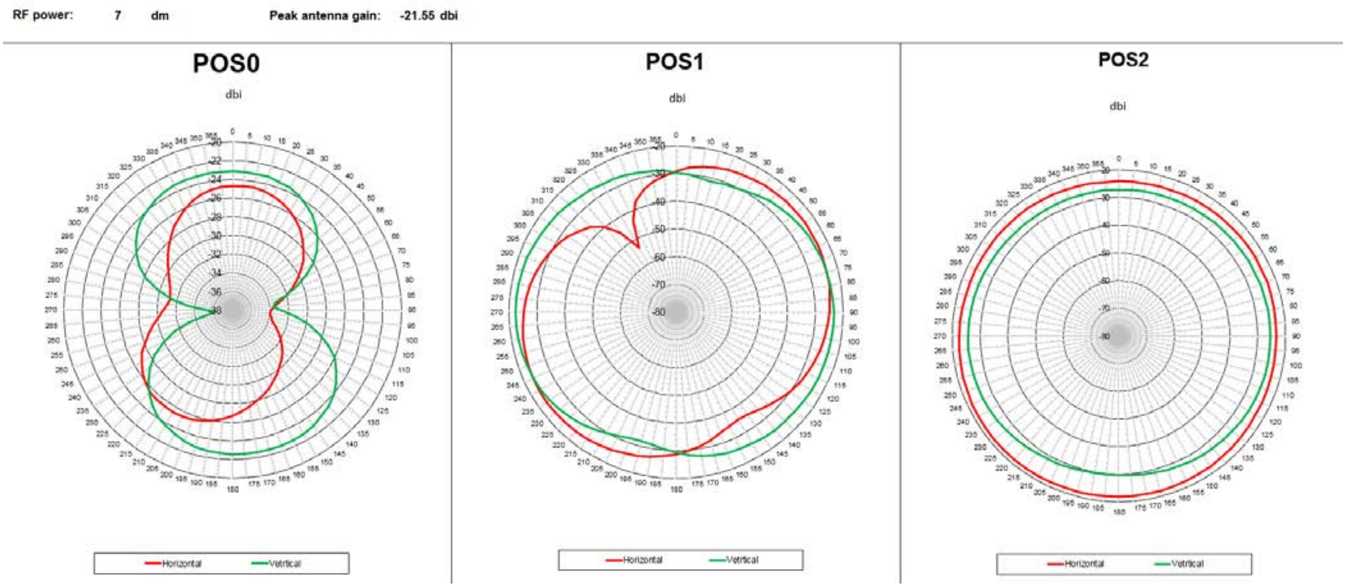


Figure 127: Antenna patterns

Table 171: Transmitter Hardware

Tx	Delta - Gen6 PAL Sensor
Centre frequency:	433.92 MHz
Transmit Power:	8.4 dBm
Antenna gain:	-26.8 dBi
Antenna pattern:	See polar plots below:

Tx	Delta - Gen6 PAL Sensor
Minimum Signal to Noise ratio:	
Modulation:	Frequency Shift Keying (FSK)
Modulation: Frequency deviation:	Min 40 kHz; Typ 60 kHz; Max 80 kHz
Modulation: Data rate:	19.2 kbps
duty cycle:	< 1.0%
Tx_{on}:	25+5.57+5.57+5.57 ms = 41.71 ms (Mode dependant worst case)
Tx_{off}:	30 s (Mode dependant)
longest transmission period (worst case):	41.71 ms (Mode dependant)
Mitigation:	Low duty cycle Pseudo-random transmission structure

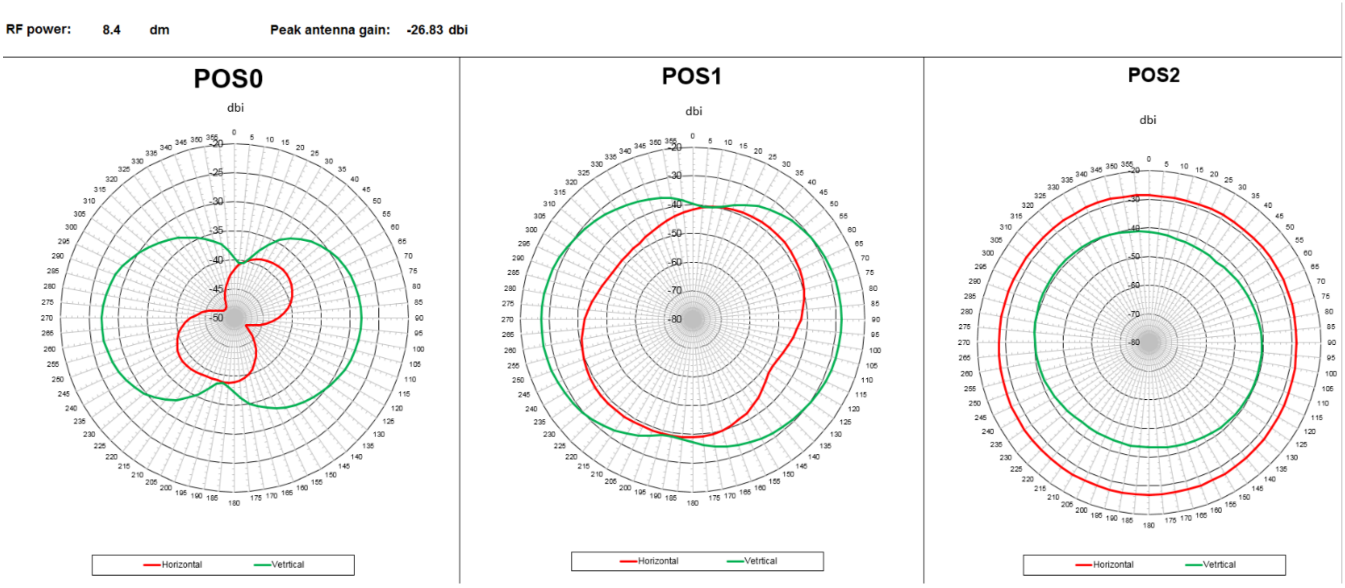


Figure 128: Antenna patterns

Table 172: Receiver Hardware

Rx	CORAX3
Centre frequency:	433.92 MHz
Receiver Bandwidth:	
Antenna gain:	
Antenna pattern:	no specific direction (for simulations: Omnidirectional)
Receiver Sensitivity:	Min -71 dBm
Minimum Signal to Noise ratio:	33% Frame Error Rate (FER)

Rx	CORAX3
Modulation:	AM OOK
Mitigation:	SAW Filter (TDK B3743) to reject sidebands Omnidirectional antenna design

Table 173: Receiver Hardware

Rx	MFR
Centre frequency:	433.92 MHz
Receiver Bandwidth:	360 kHz
Antenna gain:	
Antenna pattern:	no specific direction (for simulations: Omnidirectional)
Receiver Sensitivity:	Min -77 dBm
Minimum Signal to Noise ratio:	33% Frame Error Rate (FER)
Modulation:	Frequency Shift Keying (FSK)
Mitigation:	SAW Filter (TDK B3743) to reject sidebands Omnidirectional antenna design

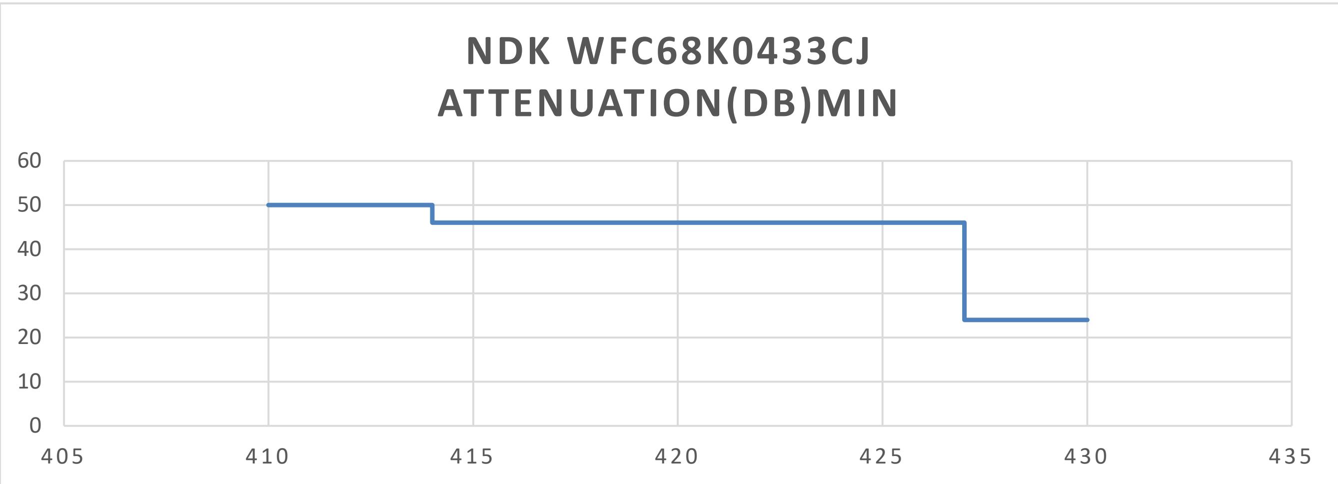


Figure 129: Receiver filter minimum attenuation

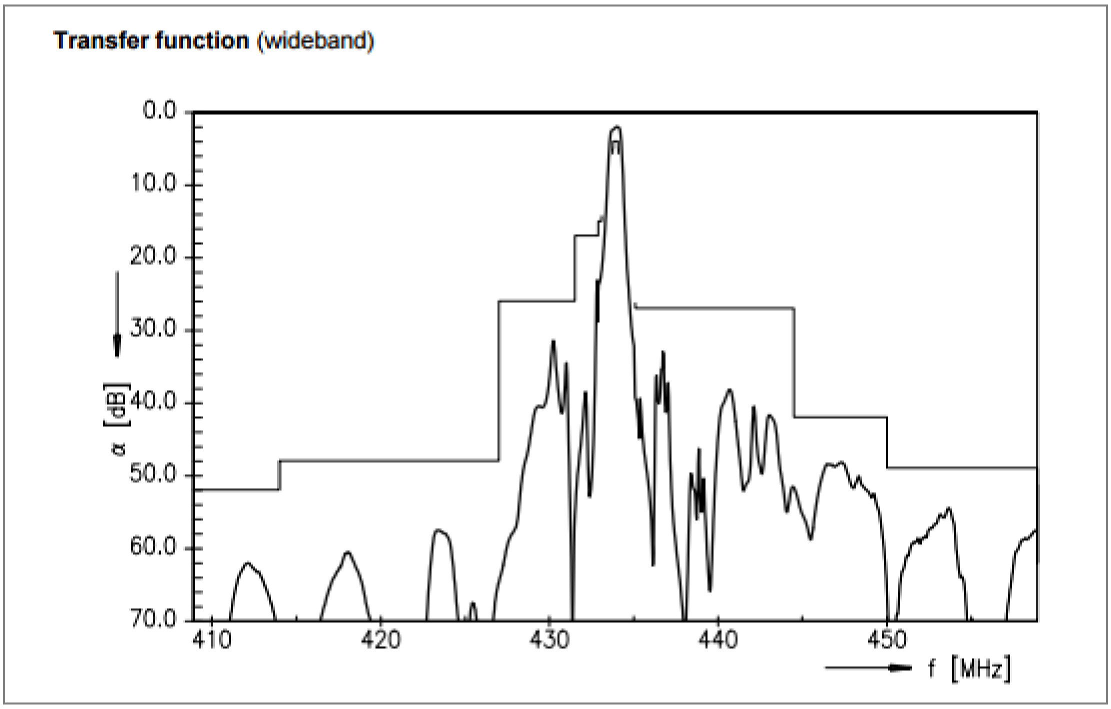


Figure 130: Receiver filter characteristics

TDK

SAW Components B3743

SAW filter 433.92 MHz

Data sheet SMD

Characteristics

Temperature range for specification: T = –45 °C to +95 °C
Terminating source impedance: Z_S = 50 Ω and matching network
Terminating load impedance: Z_L = 50 Ω and matching network

		min.	typ. @ 25 °C	max.	
Center frequency	f_C	—	433.92	—	MHz
Minimum insertion attenuation	α_{min}				
incl. loss in matching elements (Q_L = 47)		—	1.9	2.6	dB
excl. loss in matching elements		—	1.5	2.2	dB
Pass band (relative to α_{min})					
433.77 ... 434.07 MHz		—	0.5	2.0	dB
433.75 ... 434.09 MHz		—	0.8	3.0	dB
Relative attenuation (relative to α_{min})	α_{rel}				
10.00 ... 380.00 MHz		55	60	—	dB
380.00 ... 414.00 MHz		50	56	—	dB
414.00 ... 427.00 MHz		46	52	—	dB
427.00 ... 431.52 MHz		24	29	—	dB
431.52 ... 432.90 MHz		15	20	—	dB
432.90 ... 433.10 MHz		13	20	—	dB
435.10 ... 444.50 MHz		25	30	—	dB
444.50 ... 450.00 MHz		40	45	—	dB
450.00 ... 810.00 MHz		47	52	—	dB
810.00 ... 1500.00 MHz		60	65	—	dB
1500.00 ... 2500.00 MHz		50	55	—	dB
Impedance for pass band matching[1)]					
Input: $Z_{IN} = R_{IN} \parallel C_{IN}$		—	350 ‖ 2.2	—	Ω ‖ pF
Output: $Z_{OUT} = R_{OUT} \parallel C_{OUT}$		—	350 ‖ 2.2	—	Ω ‖ pF

1) Impedance for passband matching bases on an ideal, perfect matching of the SAW filter to source- and to load impedance (here 50 Ohm). After removal of the SAW filter the input impedance of the input and output matching network is calculated. The conjugate complex value of these characteristic impedances are the input and output impedances for flat passband. For more details we refer to EPCOS application note #4.

Figure 131: SAW filter characteristics

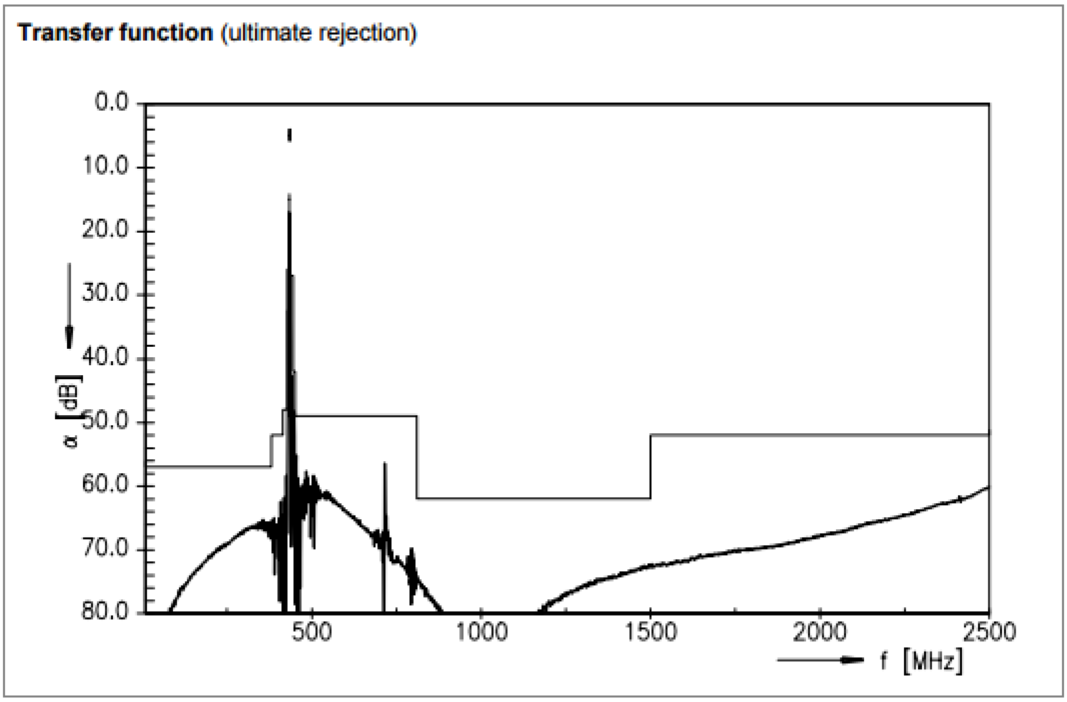


Figure 132: Receiver filter characteristics

ANNEX 2: LTE BS ACTIVITY FACTOR AND IMPACT ON DTT

A2.1 GENERAL CONSIDERATION

In LTE compatibility studies it has been normal practice to base interference assessments on a full buffer traffic model. Report ITU-R M.2241 mentions that this is not the case in deployed OFDM networks because transmitting 100% of the frequency resource blocks 100% of the time leads to saturation of the cell and service failure for many of the users. In real deployed LTE systems, base stations transmit using only part of the available resource blocks most of the time and Report ITU-R M.2292 [6] suggests 50% LTE BS average activity factor (average being for a busy hour). As indicated in ITU-R Reports M.2292 and M.2241 the base station power to use depends on the case being studied.

A2.2 REAL-LIFE MEASUREMENT OF THE LTE BS ACTIVITY FACTOR

Measurements were carried out in France, the UK and in Denmark showing that, during the period of the measurements, these LTE base stations regularly transmitted at maximum power, for short periods of time, using all resource blocks.

Examples of LTE BS transmissions are shown in Figure 133 to Figure 138 (800 LTE BS in France), Figure 139 to Figure 142 (800 MHz LTE BS in the UK) and Figure 144 (450 LTE BS in Denmark). Each measurement point was carefully chosen with the aim to measure only the emissions coming from a targeted single base station/sector, in order to minimise the emissions coming from other base stations (BS) or sectors. However, it should be noted that the cell ID identifying the individual base stations was not recorded during the measurements. The cell ID would identify the measured base station/sector, however the measurement method and power level received indicate that the signal is from the base station that the directional antenna was being pointed at; other base stations/sector would be displayed at a lower level.

These measurements show that, during the period of the measurements, the measured individual LTE BS regularly transmitted using all resource blocks, however no general conclusions can be drawn from the measurements in this annex about **network** LTE activity factor.

A2.2.1 **Measurements in France (urban area):**

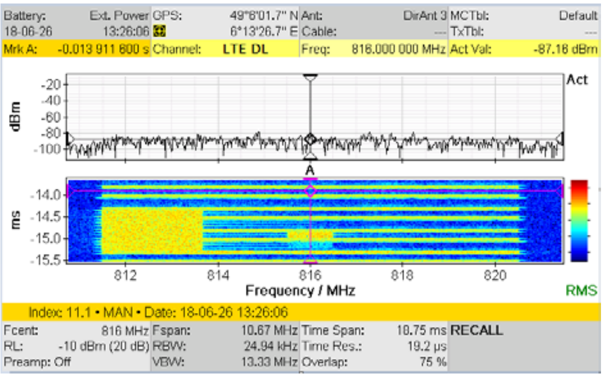


Figure 133: Slice showing standby mode of LTE BS

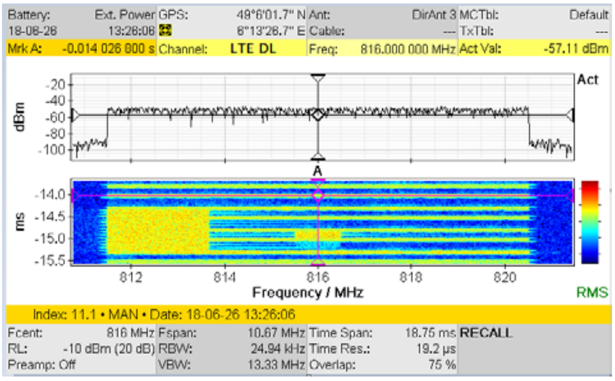


Figure 134: Slice showing LTE reference signal

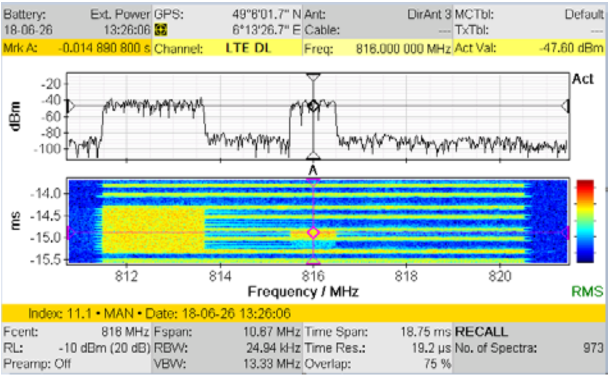


Figure 135: Slice through LTE signal showing partial RB allocation

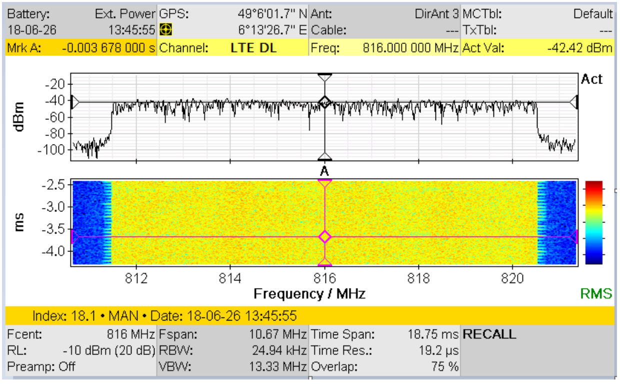


Figure 136: Slice through LTE signal showing full RB allocation (BS transmitting at full power)

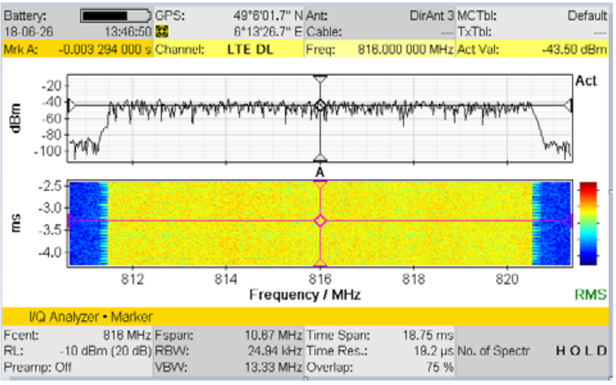


Figure 137: Slice through LTE signal showing full RB allocation (BS transmitting at full power)

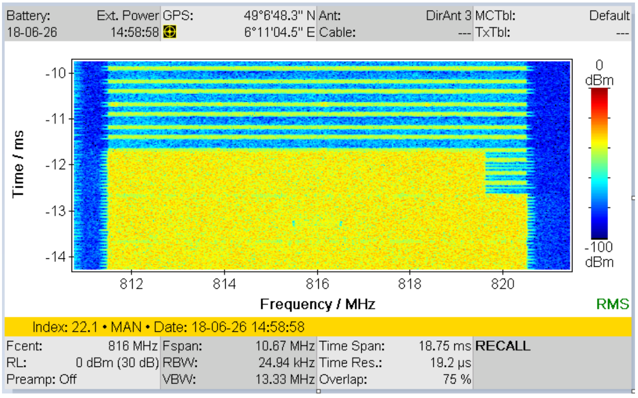


Figure 138: LTE signal showing the change of LTE BS state from low into high activity

A2.2.2 **Measurements in the UK (rural / suburban area):**

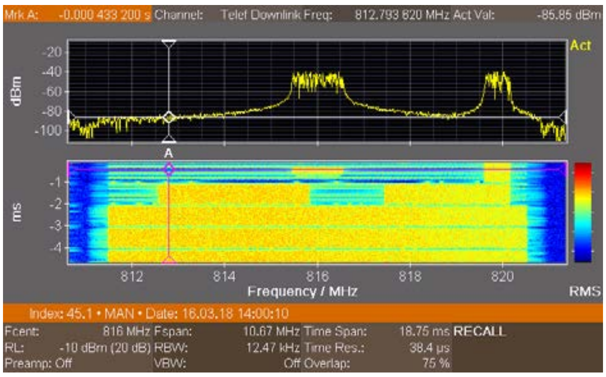


Figure 139: Slice through LTE signal showing control channel and 3RB

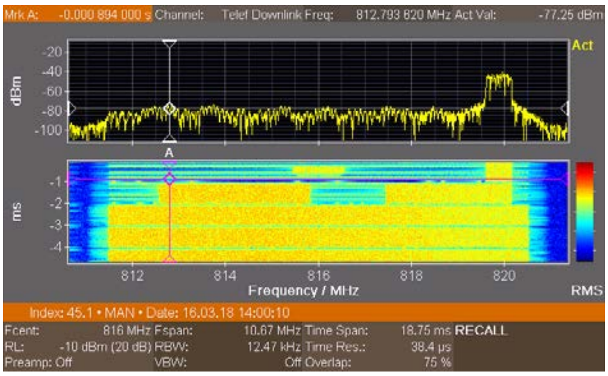


Figure 140: Slice through LTE signal showing 3RB allocation

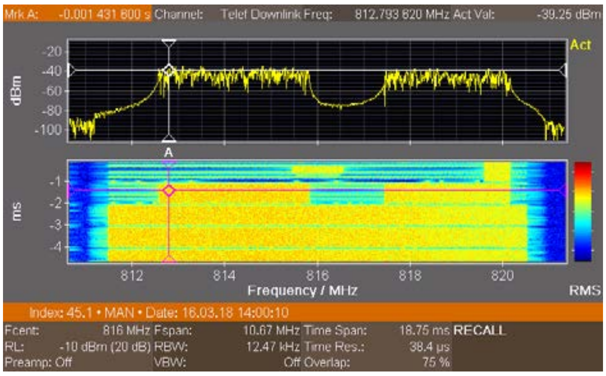


Figure 141: Slice through LTE signal showing partial RB allocation

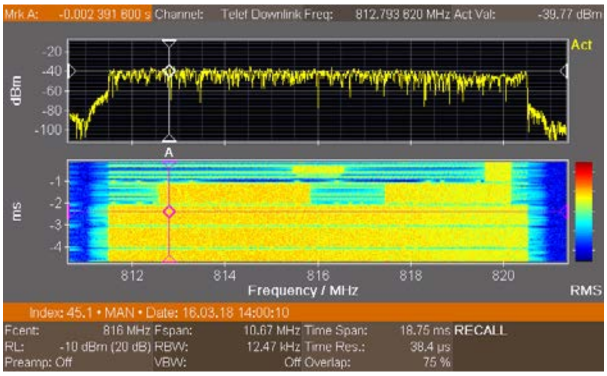


Figure 142: Slice through LTE signal full RB allocation (BS transmitting at full power)

The distribution of resource block usage for the measurements taken in the UK, Figure 143, indicates that this scheduler is set to distribute the maximum amount of resource blocks in as short a time as possible.. In line with the observations made at the time of the measurements, data traffic was heavier at 14:00 than 19:00 which resulted in a higher percentage of frames (measurement samples) that used all resource blocks.

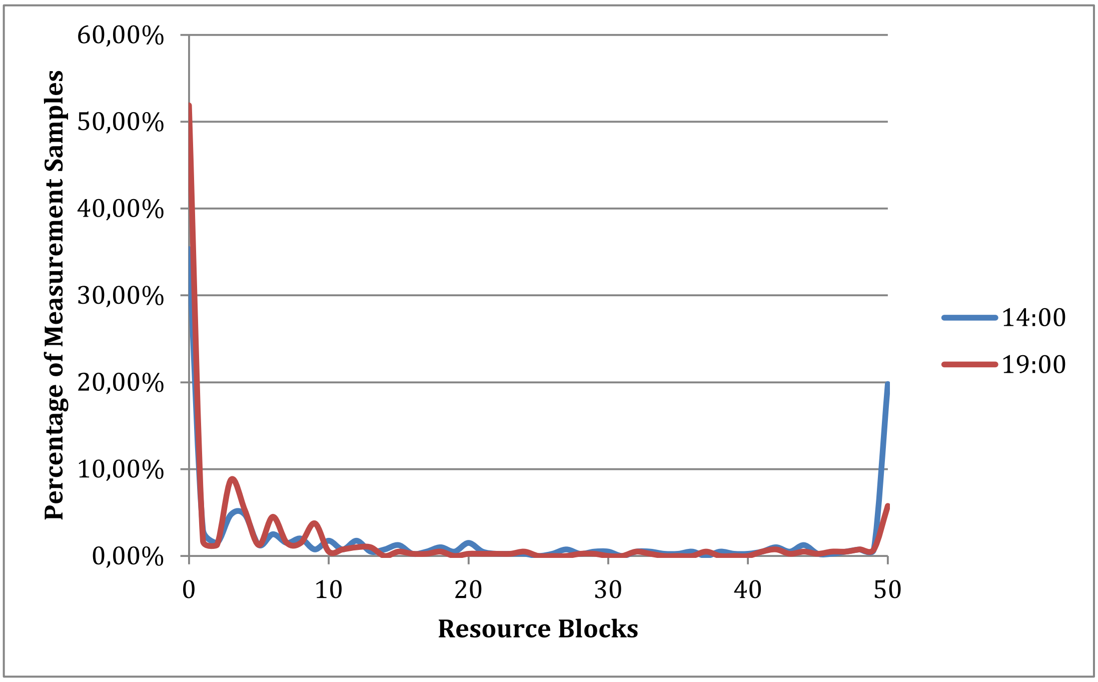


Figure 143: Resource Block usage measured at two times for a UK base station

A2.2.3 Measurements in Denmark (urban/industrial area)

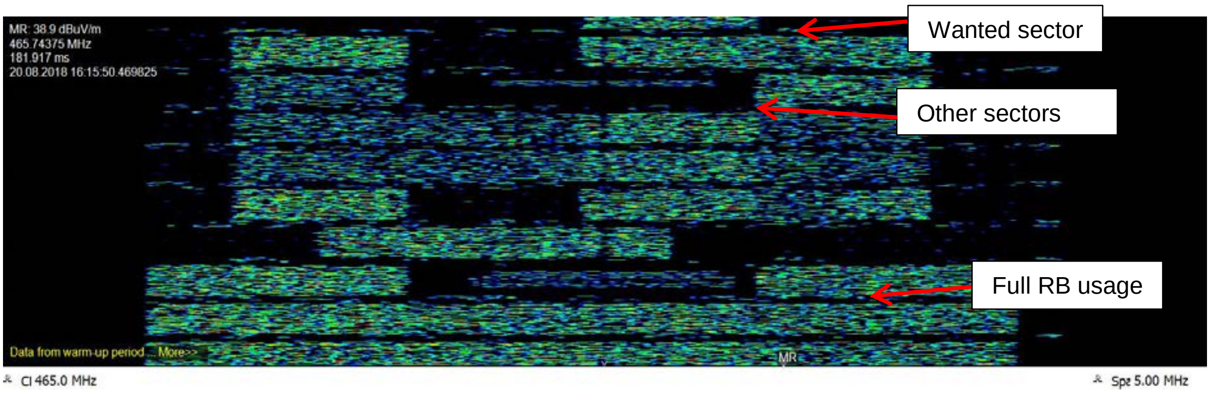


Figure 144: Spectrogram showing a snap shot (9ms) of 450 MHz LTE Base Station activity

Note: The measured base station was located in Copenhagen, Denmark. Limitations on access to spectrum mean that the top two resource blocks are suppressed (never used)

A2.3 IMPACT ON DTT

For DTT, peaks in interfering power are important. Therefore for determining interference, the use of LTE BS activity factor and average power are not relevant to this study. During the period of the measurements, these individual LTE base stations regularly transmitted at full (maximum) power using all available resource blocks. Each of these transmissions only lasted a limited number of milliseconds. Studies have shown that interference lasting only 1 millisecond can cause interruption to the DTT service for up to 1 second. Therefore, as within a one hour time window, which is the period used to assess DTT quality of service, an LTE BS will transmit many times using maximum power, calculations must be based on the maximum power of the LTE BS and not an average power.

ANNEX 3: INTERMODULATION DISTORTION IN TETRA MOBILE STATION (MS) RECEIVERS

A3.1 NON-LINEAR MODEL OF THE RECEIVER

In order to model the victim receiver's behaviour in the presence of blockers, spurious and interferers, whether wideband or narrowband, certain assumptions about its nonlinearity, selectivity and dynamic range have to be made. An obvious way is to derive the receiver's characteristics from the standards the victim receiver has to comply to. This typically contains: blocking test, intermodulation rejection test, spurious response rejection test and nominal error rate (NER) test, whereby this receiver must be compliant to all 4 specifications testing receiver nonlinearity. It is therefore not sufficient if the receiver model and thus the parameterisation of IM plugin are derived from one test alone.

However, the standards represent minimum performance requirements for all defined standard test, and a practical receiver may exceed this performance, for example so that the manufacturer has confidence that deployed equipment can meet the requirements of the standard when manufacturing production tolerances are taken into account Practical designs typically reflect much higher performance, which accounts the fact that equipment vendors want to give their customers a good experience also in challenging signal scenarios

Some considerations:

- The standard reflects a test with a single blocker whereas in practical usage scenarios there might be multiple ones.
- The standard specifies two interferers, which are placed at certain frequency offsets so that the intermodulation product falls exactly together with the weak wanted signal. In practice however there might be a multitude of interferers and thus more mixing products. As the standard assumes a narrowband environment, it is assumed that intermodulation products will arise within a victim receiver, however there is a high probability that the products will not arise on the wanted frequency of the victim receiver. This is not the case where the interferer is a broadband transmitter, as products will arise.
- The intermodulation response rejection test assumes that the receiver can be modelled simply by unwanted signals of particular level, from which an IP3 value could be extrapolated. However this is only possible under an unrealistic assumption that intermodulation response is independent of the occupied bandwidth. The following figure shows the difference of the signal scenarios in the narrowband case as defined in TETRA Standard and the wideband scenario under study.

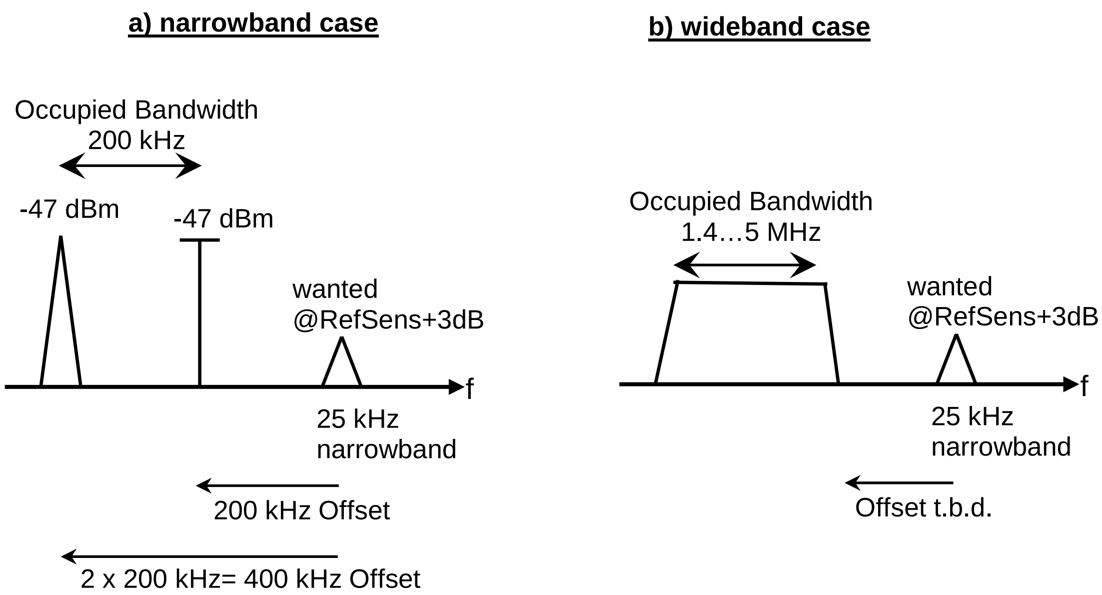


Figure 145: Signal scenario containing narrowband versus wideband interferer with intermodulation response test

- The occupied bandwidth of 200 kHz with the narrowband case is much less compared to the wideband case, where it is 1.4 - 5 MHz. Furthermore, the offset of the interferer to the wanted narrowband signal is 400 kHz in the narrowband case and in the order of several MHz in the wideband case. Because of these two reasons nonlinearity behaviour assessed with the narrowband case cannot simply be extrapolated to the wideband case.
- This fact has a major consequence for modelling the non-linearity of the receiver.
- A Taylor series expansion for non-linearity modelling is insufficient if the system is memory contained (Non-Linear Time Variant - NLTV system). However, for wider occupied bandwidth and larger offset, memory effects become more and more significant and can no longer be neglected.
- In the wide occupied bandwidth case the receiver intermodulation distortion depends on wideband performance of all elements of the receiver, such as amplifiers, mixers, switching components, filters, and digital components. From circuit analysis of mobiles in the field it was found that high order reactive networks are used with input filter, interstage filter and IF filter. These all contain memory, which compels using Volterra series expansion for non-linearity modelling. However, Volterra series modelling is more complex than Taylor series modelling and the three dimensional non-linear transfer function of the non-linear receiver system is difficult to extract. In order to still account for the memory effects, the concept of "Effective IIP3" has to be implemented. The Effective IIP3 takes into account the additional effects introduced by memory, wideband behaviour and dispersive impedance terminations in all zones. Therefore, it deviates from an IIP3 that would be extracted from the standard IM performance test in a narrowband regime.
- The standard assumes there is only one narrowband network on air, where one operator has full control over the planning of radio resources within its spectrum license. However in practice there might be multiple network operators co-located like e.g. at an airport, where one operator has no control over the radio resource planning of the others The standard assumes that the victim receiver is only hurt by signals of identical type than the receiver is tailored to receive. This is typically not the case. E.g. at 400 MHz range strong blockers arise by broadcast stations operating at several 100 kW.
- The spurious response rejection test only allows for 5% exceptions. This leads to designs using high intermediate frequencies or direct conversion, and wideband receiver front end designs with little or no attenuation of frequencies within of the wanted receiver frequency.

A spurious response rejection test considers a wanted signal 3dB above the static reference sensitivity level which is for TETRA -112dBm+3dB=-109 dBm in the presence of sine tone at any offsets limited by the switching range, the local oscillator frequency and the sum of the all intermediate frequencies. In the TETRA standard the sine tone at a level of -45 dBm is applied.

Looking at an example for a spurious table of a mixer, e.g. Figure 146 the spurious response at the frequency defined by the relationship 2 x local oscillator frequency 2 x tone frequency is attenuated by 62 dB.

MxN Spurious Outputs

	nLO				
mRF	0	1	2	3	4
0	xx	-11	-6	5	19
1	7	0	37	27	38
2	53	64	62	46	72
3	83	>85	>85	>85	>85
4	>85	>85	>85	>85	>85

Figure 146: Mixer spurious table (rejections given in [dB])

The noise floor of the receiver can be approximated roughly by -125 dBm, considering 18 kHz effective RX bandwidth and the receiver Noise figure (NF) of 6 dB.

So a -45 dBm signal would have to be attenuated by 80 dB to bring it down to noise level. But spurious rejection is only 62 dB, hence an additional selectivity of 18 dB is required to overcome the spurious problem for this spur.

Depending on the choice of the IF frequency, the spurious will appear at a certain offset from the wanted signal within tuning range of the RX. Nevertheless this implies that at a certain offset selectivity must be implemented in order to attenuate the input signal at this offset by a value in the order of 18 dB.

Blocking performance test can be used to derive a selectivity function

From the analysis of the blocking specs of TETRA MS the following selectivity function can be assumed

Offset	Selectivity
50…100 kHz	0 dB
100…200 kHz	-5 dB
200…500 kHz	-10 dB
>500 kHz	-15 dB

Table 174: Selectivity derived from TETRA blocking specification

However, in some analysed receiver designs preselectors providing this selectivity do not exist. The blocking response in a historical receiver would almost certainly be due to overload of the early stages in the receiver, the front end amplifier and the mixer. In a modern receiver blocking can be a combination of overload of these stages, overload in the IF (both analogue and digital) but also can be a factor of the spurious emissions and noise generated in the receiver local oscillator synthesizer. Close to carrier noise and spurious outputs from a synthesizer will mix with unwanted signals close to the wanted frequency to produce the intermediate frequency, which will desensitise reception of the wanted signal, and these can be a reason for a blocking response which is worse close to the wanted signal.

Blocking specifications can allow some frequency dependence, for example allowing a lower blocking signal level close to the wanted signal level. These allow the manufacturer to apply different techniques, such as analogue roofing filters in the receiver design without the need for so stringent performance in digital filtering following the roofing filter, and also reduce the effects of the local oscillator synthesizer spurious and noise performance on the measurement.

Receiver selectivity in the front end can improve blocking performance. However due to variations of the manufacturing process and the desire to avoid alignment during the manufacturing of the receiver, there is usually little selectivity in the mobile receiver which effects the performance at the frequency offsets where blocking is measured. This clearly shows that non-linear effects in the receiver are interdependent and therefore all performance tests must be taken into account in elimination of the non-linear effects.

In the case of modern receivers linearity is much higher than defined by the narrowband Intermodulation (IM) test and therefore the blocking test can be passed without any implementation of this selectivity. Therefore, the application of lower bound of IIP3 in accordance to the narrowband intermodulation test requires using the selectivity as derived from the blocking test.

Analysis of existing mobile designs

A study of mobiles that are in the field for more than 10 years, coming from 4 different suppliers have been carried out. The addressed questions during analysis were:

- What Cascaded IIP3 figures are typical in the field for MS older than 10 years?
- What Noise Figures are typical in the field for MS older than 10 years?
- Are tunable preselectors in use?
- Is tunable preselection only done on input filter or also on interstage filter?
- What dominates non-linearity: the mixer or the LNA?

The Cascaded IIP3 is computed according to the following theory. The IIP3 of a system that contains multiple nonlinear stages can be computed by the following formula:

$$\frac{1}{IIP3_{cascaded}} = \frac{1}{IIP3_1} + \frac{G1}{IIP3_2} \qquad \text{eq. 1}$$

This formula assumes nonlinear stages placed in series without any selectivity or dispersive termination in their harmonic zones. If there is selectivity in front of the first stage and in between the first and second stage, the Cascaded IIP3 will be higher. This is a further reason why the concept of Effective IIP3 and Effective Selectivity was introduced.

The derivation of Cascaded IIP3 figures is based on nominal system design figures found in detailed service manuals. For computation of cascaded IIP3, nominal IIP3 figures for LNA and mixer and nominal losses by filters, transmission lines and attenuator pads were taken into account.

Nominal figures reflect average performance. In some cases, depending on temperature, battery level and component tolerances, a spread of the IIP3 in the order of +/- 2 dB is observed.

However, the approach to compute Cascaded IIP3 from system design serves as a lower bound on mobiles in the field, as the Cascaded IIP3 formula ignores memory effects due to dispersive elements in the receiver design which usually contribute to a higher linearity for a larger occupied bandwidth. The reason for that are IM products in other harmonic zones than zone 1 which are filtered out in every design. Therefore the approach followed is a pessimistic approach. IIP3 figures in reality will be better (higher) than those derived from cascading the IIP3.

It was found that mobiles in the field for more than 10 years offer IIP3 values that are much higher than -9.5 dBm derived from intermodulation response alone. Indeed values of +2.7 dBm and the implementation of preselectors (which is not taken into account for this effective IIP3 figure) are found.

Thanks to advancements in microelectronics over the last decades, high IIP3 values are not problematic to implement. LNA IIP3 Values of up to +17 dBm are offered at low current. Even with mixers high IIP3 values, e.g. up to +17 dBm, are widely available.

As derived from the GSM400 MS specification an IIP3 of +8 dBm can be considered an upper bound.

The Cascaded IIP3 formula used during analysis of existing MS assumes no selectivity at the input and between the LNA and the mixer stage. It only considers the losses and gains in front of each stage. However during analysis, mobiles with tuneable preselector filter and tuneable interstage filters were found. At least there is always a passband filter for zone 1 at input and interstage. This proves that the Cascaded IIP3 computation on studied MS is a further lower bound on mobiles in the field. Effective IIP3 is thus higher thanks to selectivity. The Cascaded IIP3 formula assumes that impedance is constant along the frequency axis and all zones are terminated equally and in non-dispersive manner. This is not the case with the studied MS. Shorts or reactive terminations in other harmonic zones improve linearity, which is a further indication that real Effective IIP3 is higher than derived by Cascaded IIP3 formula.

- Electronic tuning can be added in a receiver, but the electronic tuning components themselves introduce non-linearity but may contribute to memory effects.
- Receiver performance can be improved by adding automatic gain control to reduce the receiver gain at strong signal levels. Unfortunately, this does not help in the cases where the wanted signal is weak and the interferer is strong.

The consequence of above findings is that the non-linear receiver model cannot be derived from only one performance test as defined the standard. The modelling can be done by a simplified Taylor Series Expansion Model with non-linear parameter Effective IIP3 and Effective Selectivity which reflect also other performance tests as well as ongoing technical progress in microelectronics.

An analysis of all four standard specifications and a study of mobile stations which are older than 10 years provides an effective IIP3 figure of approximately +3.5 dBm. This value is much higher as derived from a single standard performance test. A next step to further prove this value could be the conduction of a measurement campaign and test mobiles’ intermodulation response to wideband signals.

A3.2 TRADE-OFF BETWEEN SELECTIVITY AND LINEARITY IN RECEIVER DESIGN

In order to increase robustness of receivers to challenging signal scenarios, one can either go for highest analogue selectivity by very narrow tuneable preselectors as the first stage in receiver or by very high IP3 active devices. In practice typically a combination of both strategies is implemented because of the following reasons.

Very high selectivity through tuneable preselectors can solve nearly all unforeseeable blocking, spurious and intermodulation problems, however it would imply very high Q filters, which are bulky and costly. Typically, the Q factor is limited, and thus high selectivity would come along with additional losses in front of first active device (LNA), which increases Noise Figure and this would degrade sensitivity. Also there is typically a trade-off between Q factor, thus selectivity and tuneability.

Very high linearity by extremely high IP3 factors solves all intermodulation problems; however, it typically comes along with high power consumption and costly devices. In literature GaN (Gallium Nitride) LNAs with superior Noise figure of 0.5 dB and IIP3 of +42 dBm have been reported by e.g. Northrop Grumman [52], FBH research institute in Berlin [53] and Fraunhofer IAF in Freiburg.

A receiver designer therefore balances out both strategies by implementing moderate selectivity in a tuneable analogue preselector by using resonators with moderate Q factors and by using active devices with moderate IIP3.

GaAs HBT (Gallium Arsenide hetero bipolar transistor) technology is selected for LNAs and Mixers to obtain IIP3 values in the range of +6…+18 dBm [55] [56].

In conclusion this means that for any compatibility studies realistic assumptions about victim receivers present in the field should be made. Given above realistic IIP3 ranges between +6…+18 dBm for the active devices, a pragmatic assumption of +3.5 dBm is assumed for below studies to account for multiple non-linear effects adding up. The LNA's and mixer's IP3 for instance do combine. The value of IIP3 = +3.5 dBm was inspired by a typical TETRA handheld device [54] [55] [56].

These receivers in the field comply with good receiver design practice and state of the art in receiver design and not just with minimum performance requirements. Higher selectivity and higher linearity, than what can be derived indirectly from TETRA specifications, typically is a consequence of spurious response problems with mixers. The exception rule of 5% is not sufficient to cope with all these spurious response problems. In conclusion this means that the demand for tuneable preselectors is mainly a consequence of the typical performance limitations in mixers.

Deriving linearity metric like IP3 from TETRA receiver specifications neglects the fact that in real receivers there is a multitude off LO, reference and digital clock signals, which the TETRA standard does not consider. Therefore linearity metrics have to be obtained from state of the art receivers and not in an indirect way from TETRA receiver specs.

A3.3 MODELLING OF INTERMODULATION DISTORTION LEVEL WITH MATLAB

In order to characterise the in-band interference due to intermodulation of LTE signal in TETRA receiver the nonlinearity of the receiver has been concentrated in accordance to the Taylor Series Expansion Model into a zero dB gain non-linear block preceding the TETRA receiver.

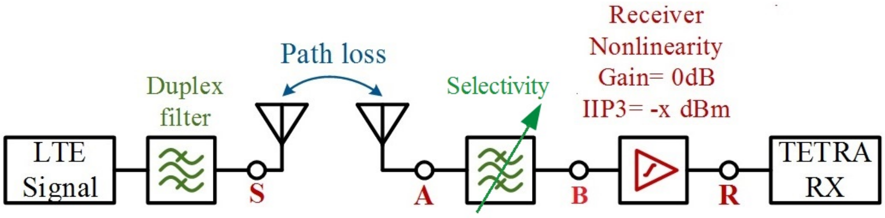


Figure 147: System model concentrating on the non-linearity of the TETRA receiver

The out-of-band emission (OOBE) of the LTE signal source has been removed by a brick-wall duplex filter. Thus, the Third order intermodulation can be observed alone. Various values for input referred Third order intercept of IIP3 have been considered below (-9.5 / -5 / +3.5 dBm).

For the receiver analysis eq. (1) is reduced to the linear and cubic term, v_out (t)=a_1·v_in (t)+a_3·v_in^3 (t). As the gain of the non-linear block is one the coefficient a_1=1. The coefficient a_3 is given by

a_3=-2/3·a_1/(R_s·IIP3)

RS=1 Ohm was chosen for the sake of simplicity in the MATLAB model. This assumption has no impact on the further considerations as all power levels are calculated in this 1 Ohm system.

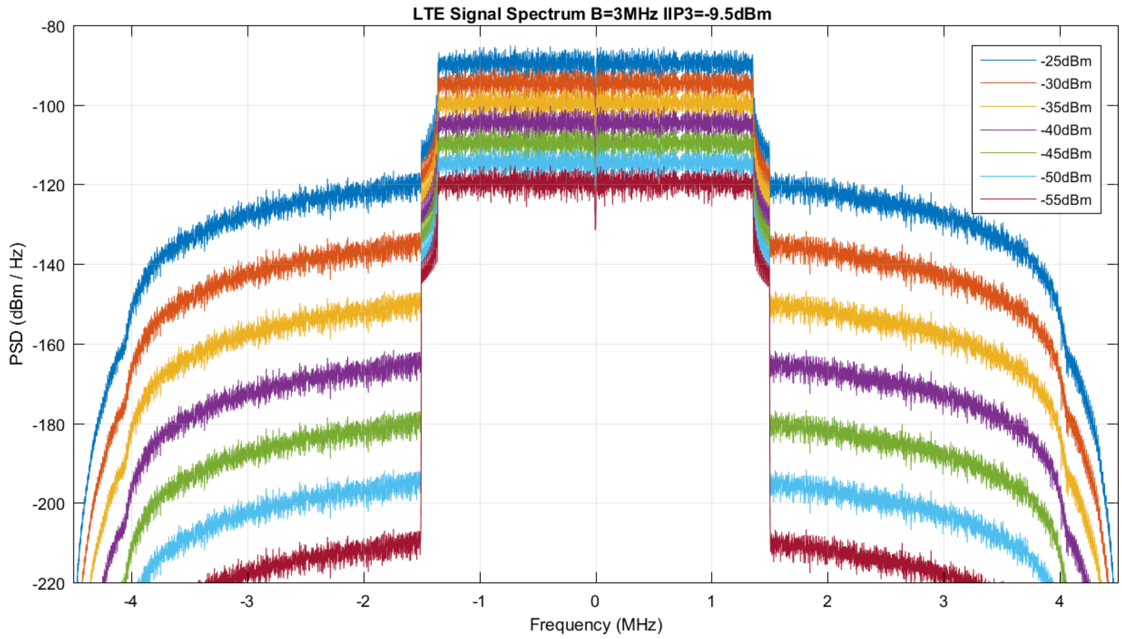
The spectrum at point R has been simulated using MATLAB as shown in Figure above, where the power of the interfering LTE at point B has been varied in 10 dB steps.

A3.3.1 **LTE Signal generation**

The MATLAB LTE signal function (tm = lteTestModel[tmn,bw]) returns the E-UTRA test model (E-TM) configuration structure for given a test model number and bandwidth. The output structure, tm, contains the configuration parameters required to generate a given downlink E-TM waveform using the generator tool, lteTestModelTool. The field names and default values align with those defined in TS 36.141, Section 6.1.

The PDSCH is a substructure relating to the physical channel configuration and contains the fields NLayers, TxScheme, and Modulation.

A3.3.2 **Simulation Results**



In RBW=1 kHz

Figure 148 the power spectral density at port R for a 3 MHz wide LTE channel for different input powers up to -25 dBm at port B (IIP = -9.5 dBm) is presented. An increase of 10 dB signal power at port R leads to a 30 dB decrease of the adjacent channel power ratio (ACPR) caused by Third order intermodulation. The nonlinearity is operating under small signal conditions up to at least -25 dBm.

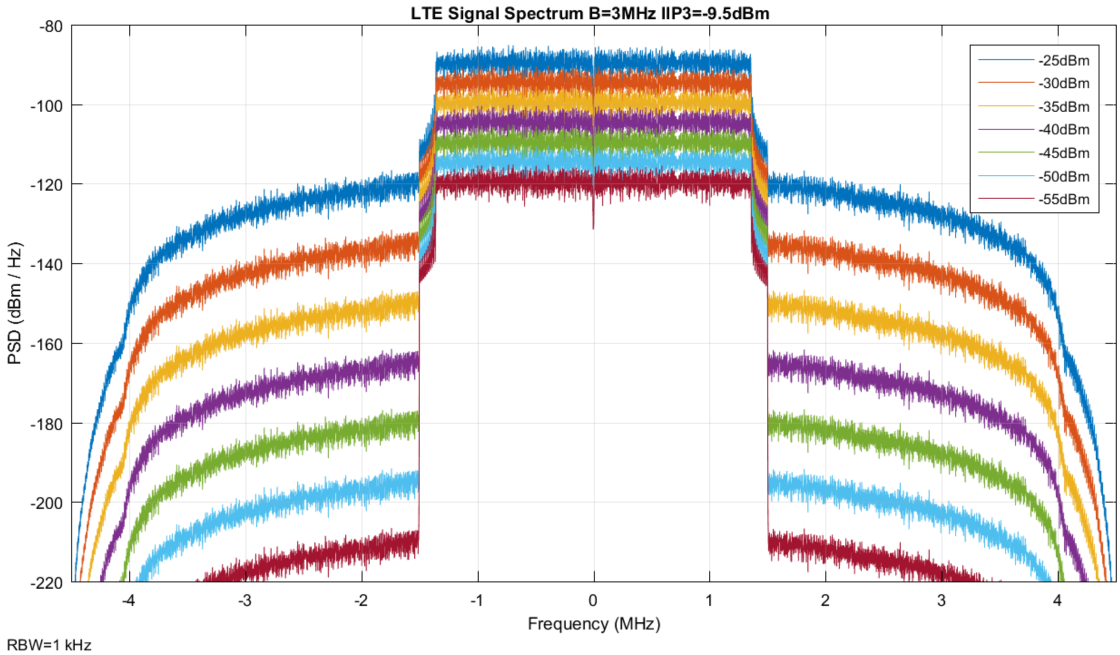


Figure 148: Power spectral density for 3 MHz channel width at port R for different input powers at port B (IIP3 = -9.5 dBm) without selectivity

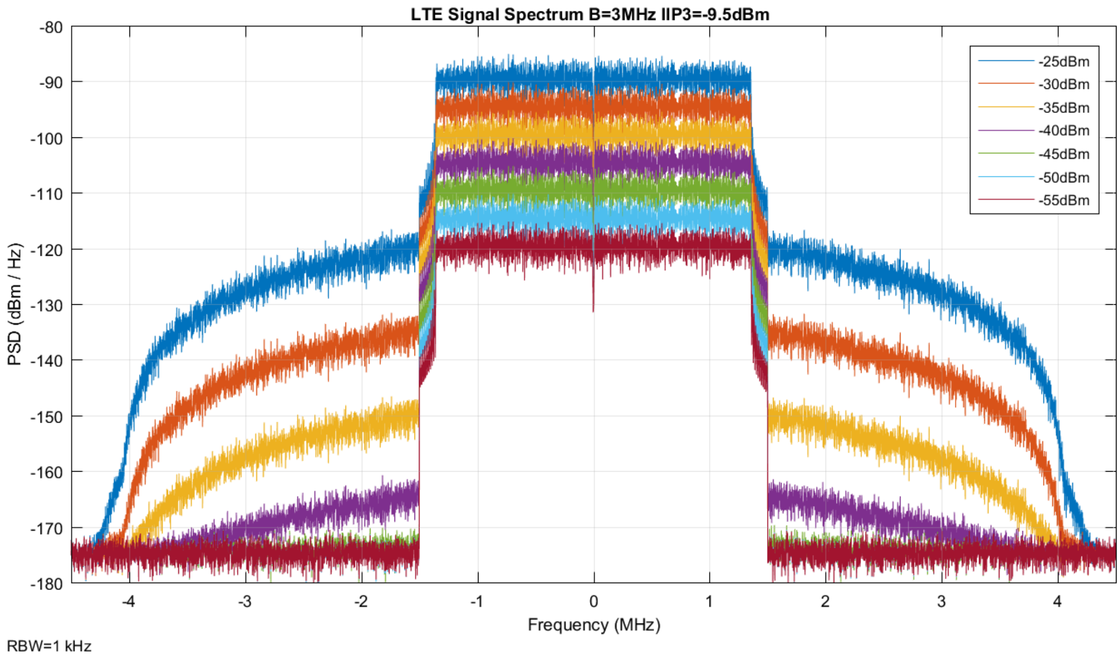


Figure 149: Power spectral density for 3 MHz channel width at port R for different input powers at port B including the thermal noise floor -174 dBm/Hz (IIP3 = -9.5 dBm)

In the above Figure 149 the thermal noise floor at the antenna of the TETRA receiver is included. For the LTE signal power of -45 dBm the Third Order Intermodulation (IM3) component has almost the same power spectral density as the noise floor. Thus only LTE signals -45 dBm and above are considered in the further discussion. Considering a typical noise figure of 5 dB of the receiver, even signals up to -40 dBm are irrelevant.

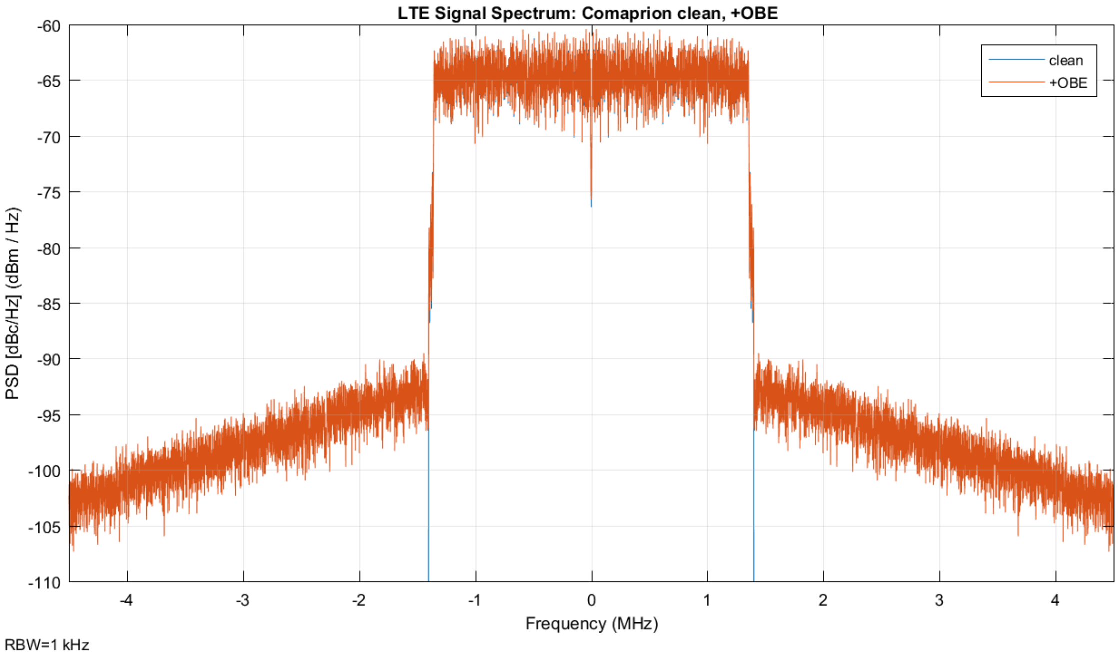


Figure 150: Power spectral density of the LTE signal for 3 MHz channel width at port S with OOBE according to section 6.6.3.1 of 3GPP TS 36.104.)

For a wide area BS the operating band unwanted emission limits are specified in 6.6.3.1 of 3GPP TS 36.104 table 6.6.3.1-2. The LTE BS hat an output power of 38 dBm. The unwanted emissions are given as absolute power in 100 kHz bandwidth. The -5 dBm OOBE power close to the channel edge translates into (-5 dBm - 38 dBm) = -43 dBc at the BS antenna. Figure 151 shows the power spectral density of the LTE signal for 3 MHz channel width at port S noise shaped to LTE OOBE requirements, which is used as input for the TETRA receiver in the further discussion.

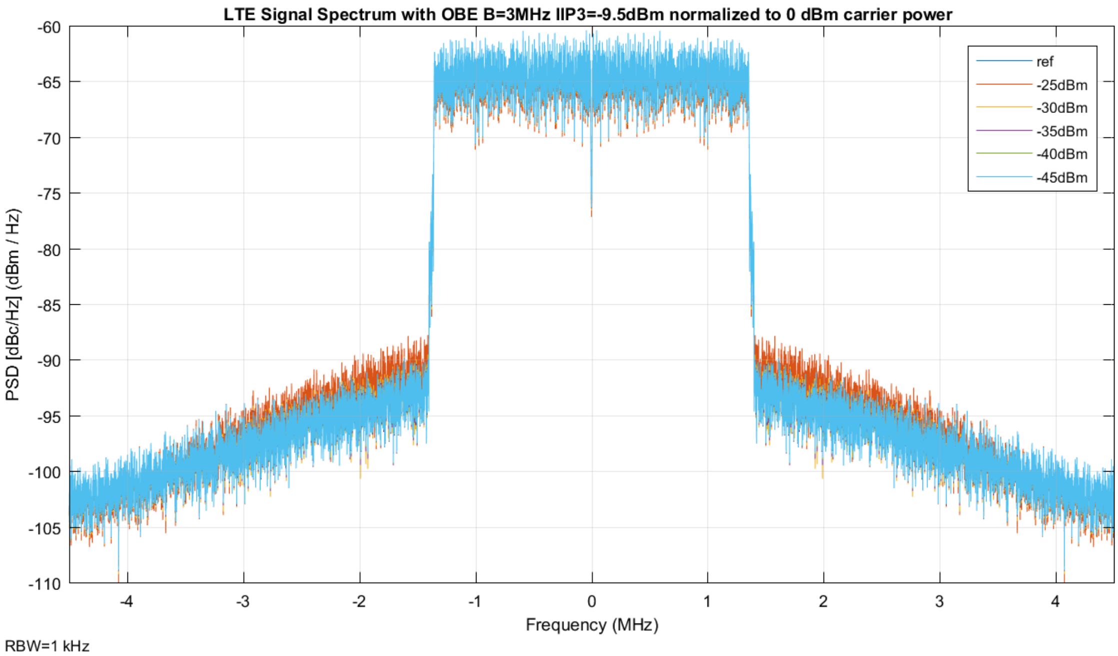


Figure 151: Power spectral density at port R generated by the nonlinearity of the TETRA receiver for an input signal including OOBE (see Figure 150)

The relative power of the OOBE at 2 MHz offset from the central frequency within the 20 kHz bandwidth of the TETRA RX versus the LTE signal power is given in Figure 152.

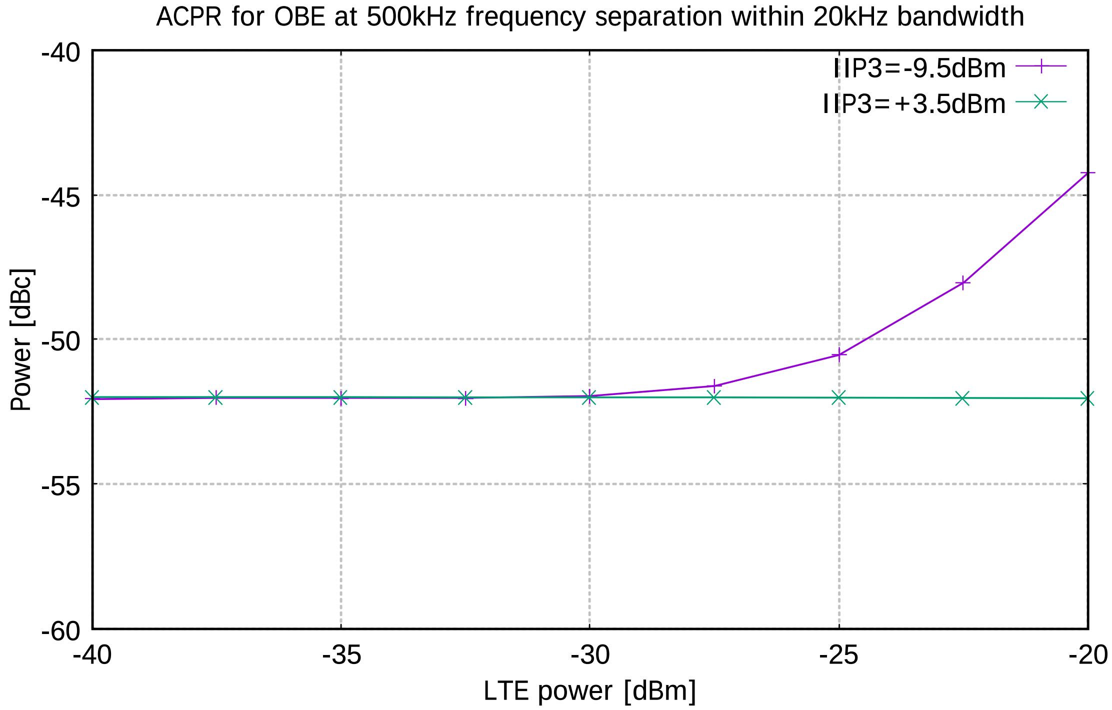


Figure 152: ACPR at 2 MHz offset within the 20 kHz bandwidth of the TETRA RX versus the LTE signal power

For an IIP3 of -9.5 dBm the influence of the Third Order Intermodulation (IM3) on the ACPR can be neglected up to -30 dBm LTE signal power. At the TETRA blocking level of -25 dBm the ACPR is increased by about 2 dB which means that the IM3 component is still lower than the power of the OOBE.

As discussed above a widely tuneable TETRA receiver using an IF of approx. 100 MHz using a tuned pre-selection filter requires linearity, which is significantly higher than the requirement of the TETRA standard to overcome spurious problems. As a result a state of the art TETRA receiver has an IIP3 of +3.5 dBm. Therefore, the IM3 components are reduced by another 26 dB, which yields the constant ACPR in Figure 152.

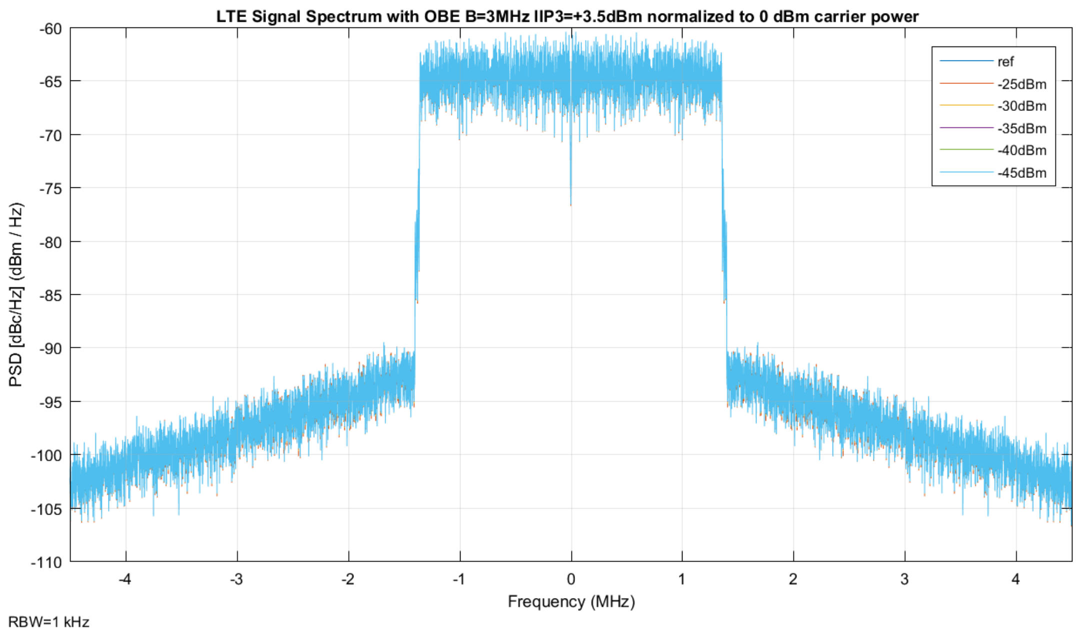
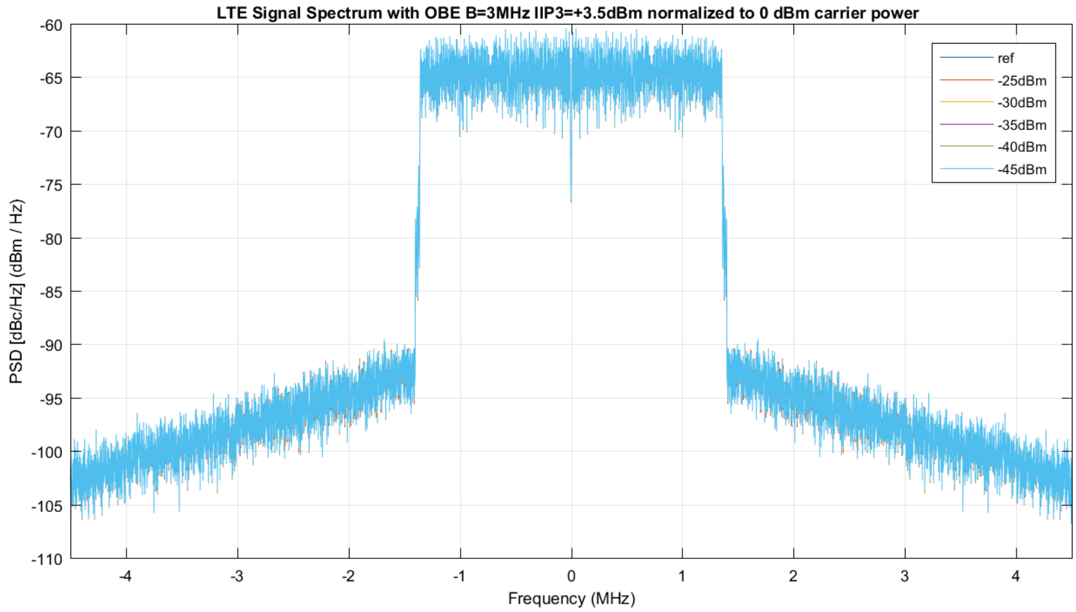


Figure 153: Power spectral density at port R generated by the nonlinearity of the TETRA receiver (IIP3=+3.5dBm) for an input signal including OOBE (see Figure 150)



In RBW=1 kHz

Figure 153 the curves for the different input power levels are laying on top each other as indicated by the flat green line in Figure 152. This leads to the conclusion: For a state of the art TETRA MS with high linearity the interoperability is dominated by the direct OOBE of the LTE base station. Therefore, there is no need to include the RX nonlinearity effects in the SEAMCAT simulations.

The LTE OOBE may cause a limitation to the overall system performance. Additional selectivity in the LTE base station may be used to reduce the OOBE at 500 kHz from the LTE channel edge. In the following discussion an additional duplex filtering is used, which attenuates the LTE OOBE by 25 dB starting at 500 kHz offset from the LTE channel edge (1.9 MHz offset from the centre frequency) as shown in Figure 154.

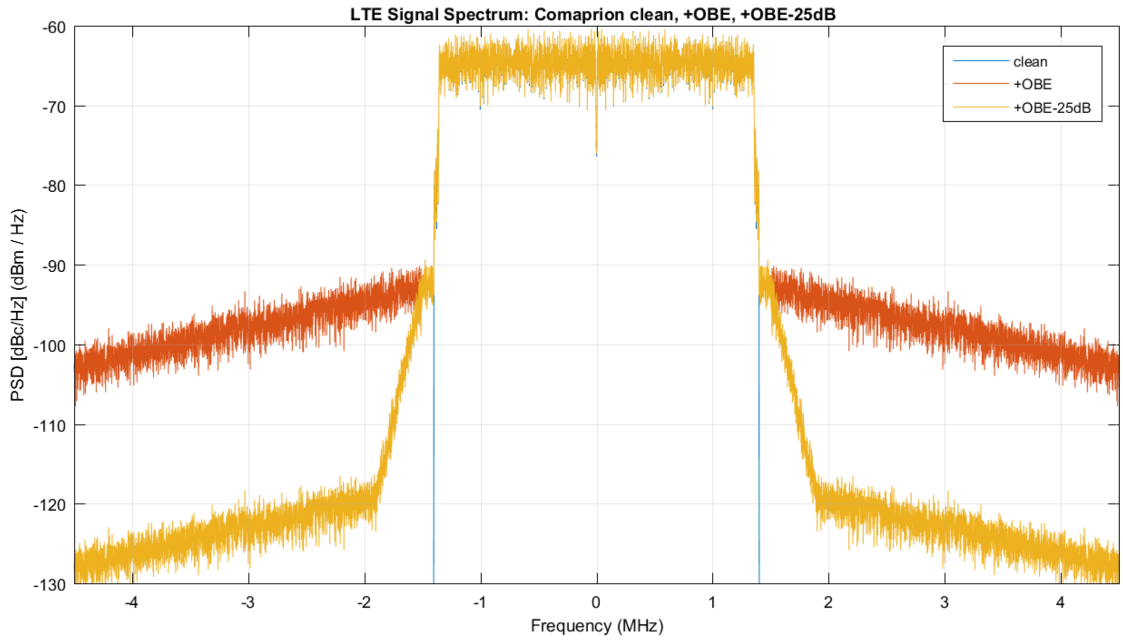


Figure 154: Power spectral density of the LTE signal for 3 MHz channel width at port S with OBE attenuated by 25 dB starting at 400 kHz offset from the channel edge. (-78 dBc at 3.05 MHz offset within 100 kHz bandwidth)

By attenuating the Out-of-Band Emissions (OOBE)by 25 dB the Third Order Intermodulation (IM3) components generated by the nonlinearity of the TETRA RX become dominant. In Figure 155 this is shown for an IIP3 of -9.5 dBm, which is the absolute minimum requirement for an TETRA RX.

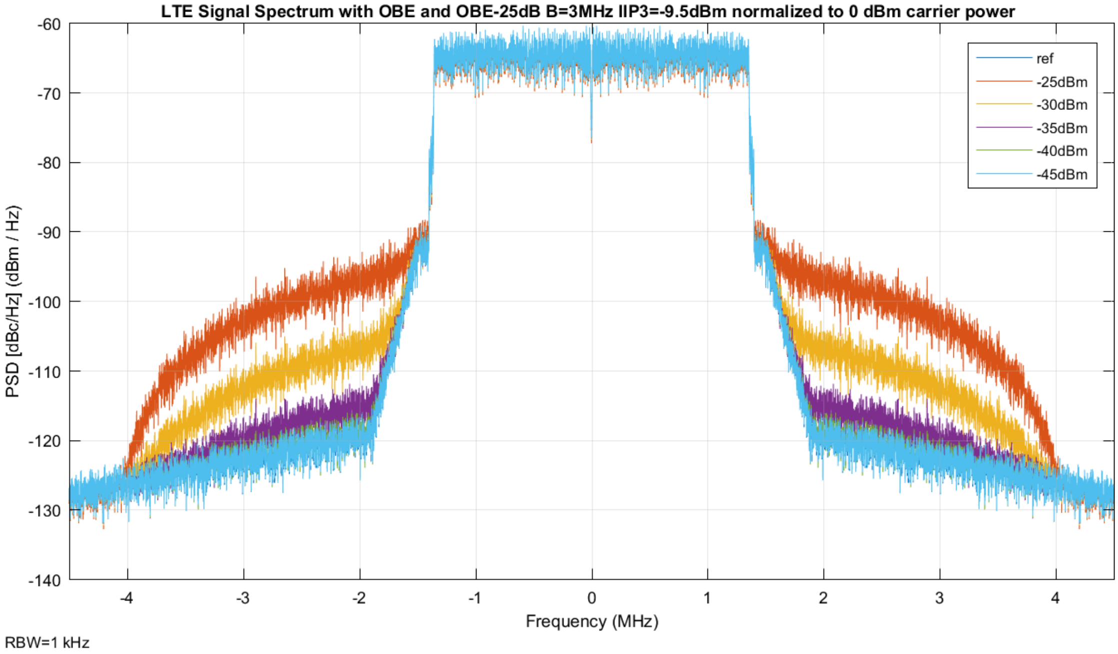


Figure 155: Power spectral density at port R generated by the nonlinearity (IIP3=-9.5dBm) of the TETRA receiver for an input signal including OOBE attenuated by 25 dB (see Figure 154)

For a state of the art TETRA receiver IIP3 of +3.5 dB IM3 components are reduced significantly as shown in Figure 156.

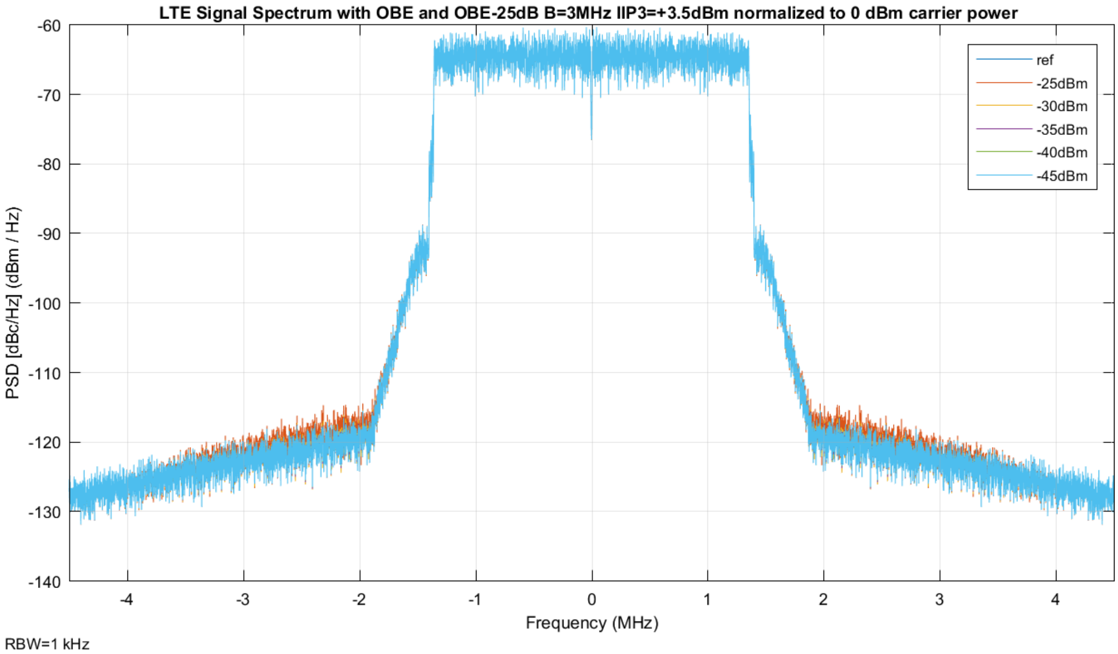


Figure 156: Power spectral density at port R generated by the nonlinearity (IIP3 = 3.5 dBm) of the TETRA receiver for an input signal including OOBE attenuated by 25 dB (see Figure 154)

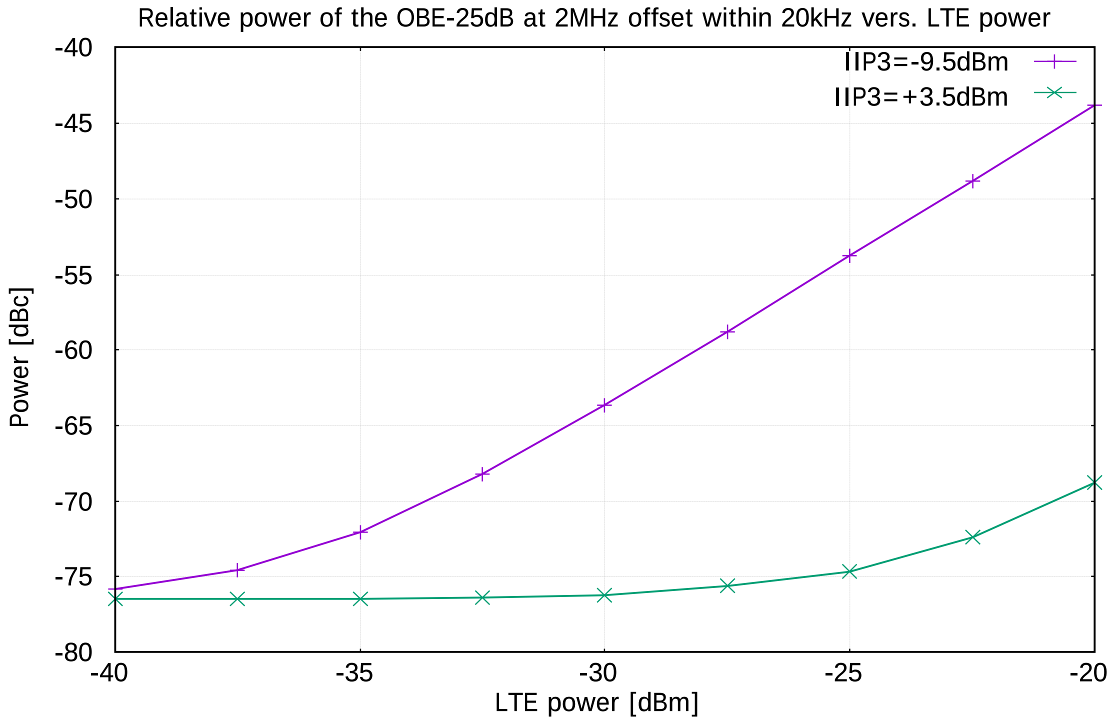


Figure 157: ACPR at 500 kHz offset from the LTE channel edge (2 MHz offset from the central frequency) within the 20 kHz bandwidth of the TETRA RX as a function of the LTE signal power, where the OOBE is attenuated by 25 dB

In a state of the art TETRA RX the ACPR is not affected by the Third Order Intermodulation (IM3) up to a LTE power of -30 dBm. A degradation of about 2 dB occurs at the TETRA blocking level. The direct OOBE are dominating the adjacent co-channel power in this case as well. For the interoperability scenario discussed here the burden can be distributed to both systems. The LTE base station has to provide the increased duplexer selectivity, whereas the TETRA mobile has to provide an increased state of the art input intercept point.

Table 175: ACPR at 500 kHz offset within the 20 kHz bandwidth of the TETRA RX versus the LTE signal power

MATLAB Simulation	ACPR at 500 kHz offset in 20kHz bandwidth			
LTE Power	for LTE OOBE		for LTE OOBE -25 dB	
	IIP3=-9.5 dBm	IIP3=+3.5 dBm	IIP3=-9.5 dBm	IIP3=+3.5 dBm
-200.0 dBm	-51.3 dBc	-50.8 dBc	-76.5 dBc	-76.5 dBc
-40.0 dBm	-51.4 dBc	-50.8 dBc	-75.8 dBc	-76.5 dBc
-37.5 dBm	-51.4 dBc	-50.8 dBc	-74.6 dBc	-76.5 dBc
-35.0 dBm	-51.4 dBc	-50.8 dBc	-72.0 dBc	-76.4 dBc
-32.5 dBm	-51.4 dBc	-50.8 dBc	-68.2 dBc	-76.4 dBc
-30.0 dBm	-51.4 dBc	-50.8 dBc	-63.6 dBc	-76.2 dBc
-27.5 dBm	-51.1 dBc	-50.8 dBc	-58.8 dBc	-75.6 dBc
-25.0 dBm	-50.1 dBc	-50.8 dBc	-53.8 dBc	-74.6 dBc
-22.5 dBm	-47.6 dBc	-50.8 dBc	-48.8 dBc	-72.3 dBc
-20.0 dBm	-43.6 dBc	-50.8 dBc	-43.8 dBc	-68.8 dBc

A3.4 SUMMARY OF THE INTERMODULATION DISTORTION (IMD) IN TETRA RECEIVERS

The minimum performance requirement regarding intermodulation distortion in standards of narrowband equipment is defined using signals with relatively small frequency offsets (e.g. for TETRA at offsets of 200 kHz and 400 kHz).. It means that the intermodulation response rejection performance is neither defined for wideband signals nor for higher frequency offsets. Therefore, it is necessary to make further considerations: regarding the adjacent co-channel power originating from the broadband signal within the non-linear TETRA receiver and assess the receiver non-linearity and selectivity based on all four performance tests and upon good receiver design practice.

The conclusions of these considerations can be summarised in the following way:

- The power of an LTE signal at various locations of the TETRA receiver is typically less than -30 dBm;
- Good receiver design practice goes for a combination of moderate analogue selectivity and moderately higher linearity than indirectly implied by TETRA standard;
- Non-linearity problems are dominated by spurs, thus higher order Intermodulation (IM) products in the mixers. A multitude of frequencies is present in receivers. The design of preselector selectivity is dominated by spurious requirements;
- Analogue selectivity by a tuneable preselector is the main scheme to overcome spurious response problems
- In case of a limited selectivity of pre-filters higher receiver linearity is required in order to cope with large blocking signals and spurious;
- State of the art TETRA mobiles show an IIP3 of +3.5 dBm;
- The IIP3 of -9.5dBm derived from the TETRA specification at small frequency offsets is not sufficient for TETRA mobile stations with large tuning bandwidth;
- Interoperability with other services in the range from 350 to 500 MHz is requiring a much higher linearity anyway;
- For an OOBE complaint with the LTE spectral mask the ACPR is not influenced by the TETRA receiver nonlinearity (IIP3 = -9.5 dBm) up to a LTE power of -30 dBm;
- Additional filtering may reduce the OOBE by e.g. 25 dB:
  - For an IIP3 = -9.5 dBm the Third Order Intermodulation (IM3) is larger than the direct OOBE;
  - At PLTE = -30 dBm there is still an improvement of 10 dB;.
  - For an IIP3 = +3.5 dBm the IM3 does not degrade the ACPR up to TETRA blocking level (PLTE = -25 dBm).

The direct LTE-OOBE attenuated by duplex selectivity are dominating the ACPR for more than 10 years old TETRA receivers.

ANNEX 4: INTERFERENCE FROM LTEBS IN THE 400 MHZ BAND TO PMR NARROWBAND MOBILE STATION (MS)

The intermodulation simulations done in this Annex do not meet all conditions for proper intermodulation simulation. As a consequence the results of these simulations should be considered very cautiously.

A4.1 INTRODUCTION

Results from simulation of the interference from LTE base station (ILT) in the 400 MHz band to narrowband TETRA mobile receiver (VLR) due to OOBE, blocking and intermodulation of the LTE signal in the VLR are presented.

The simulation shows that additional attenuation of the LTE 400 base station OOBE is required.

The results also show that the intermodulation effect increases the outage considerably. Both in general and more severe near the LTE base station.

The following versions of the SEAMCAT sws are used:

- SEAMCAT version used: 5.1.1 rev 4031 – build time 04.05.2017-14:30;
- SEAMCAT EPPforIM3 plugin supplied STG in June 2017.

A4.2 NARROWBAND RADIO SYSTEM

As an example of a narrowband radio system a TETRA Downlink Base station to Mobile Station is used. The SEAMCAT parameters for the TETRA radio system is equivalent to what is used in the TETRA Downlink Base Station to Mobile used in the ECC Report 240.

Table 176: Receiver Parameters for TETRA Downlink (BS to MS)

Receiver TETRA Downlink (BS to MS)	Value
Antenna height	1.5 m (Constant)
Antenna Peak Gain	0 dBi
Noise Floor	-122 dBm
Blocking Mode / Mask	USER_DEFINED, Ref. [1]
Intermodulation rejection mode	Relative attenuation
Sensitivity (Dynamic)	-103 dBm
Reception Bandwidth	18.0 kHz
Outage criterion C/(I+N)	19 dB

The used outage criterion is based on TETRA C/Ic performance parameter defined for co-channel interference whereby the power for wanted signal is assumed to be -85 dBm and the interfering signal is assumed to be a continuous TETRA random signal of the same modulation and of the same propagation condition as the wanted signal but as an independent fading realization. For C/Ic = 19 dB performance parameter in terms of permissible MER and BER for some logical channels are defined in the standard. The TETRA standard does not state that for lower C/Ic values outage takes place. Furthermore, the assumption of both signals are narrow band TETRA signals both impacted by fading phenomena which require margins for C/Ic to ensure demodulation of logical channels.

The requirement for C/N needed for the demodulation of TETRA signals within the MS receivers is 10 dB which can be derived from the static sensitivity of -112 dBm and the noise floor of -122 dBm. With the scenario of LTE BS transmission aside of narrowband PMR receive channel, it has to be considered that the intermodulation noise is more spectrally white and Gaussian distributed due to wideband nature of interferer and its associated Intermodulation (IM) products. IM products falling into the PMR's receiver bandwidth reflect a superposition of a multitude of mixing products, thereby approaching the central limit theorem, which states that the more signals are superimposed the combined signal will approach white Gaussian noise. This is also true in light that thermal noise and intermodulation noise add up as the outage happens mainly at the edge of narrowband PMR cell.

The PMR receiver now is more robust against white Gaussian noise interference than to structured narrowband fading PMR interferers. Therefore, the assumed outage criterion is too pessimistic for an IM scenario.

Table 177: Transmitter Parameters for TETRA Downlink (BS to MS)

Transmitter TETRA Downlink (BS to MS)	Value
Antenna height	30 m (Constant)
Antenna Peak Gain	9 dBi
Power	40 dBm

Table 178: Path Parameters for TETRA Downlink (BS to MS)

Path TETRA Downlink (BS to MS)	Value
Path azimuth	Uniform 0-360º
Path distance factor 1	Uniform polar distance 1.0
Coverage Radius 2	4.4 km
Local Environment	100% Outdoor
Propagation Model	Extended Hata
Variations	Yes
General environment	Urban
Propagation environment	Above roof

Note 1: Path distance factor selected to get uniform area distribution
Note 2: Coverage radius selected to get 5% area coverage

TETRA MS blocking is measured with a wanted static signal at -109 dBm and a static blocking signal as shown in the Table below. It is assumed the same absolute specification apply for dynamic propagation with the dynamic reference sensitivity and dynamic Es/No. The SEAMCAT blocking mask in Table 179 below in MODE_SENSITIVITY has been used in the simulation. In general the blocking has little influence on the interference.

Table 179: TETRA MS blocking

TETRA MS blocking		
Offset [kHz]	Interferer [dBm]	Blocking mask in MODE_SENSITIVITY
0-9		-1191
12.5-50	-60 (adj. chan.spec)	-60
50-100	-40	-40
-35	-35	-35
200-500	-30	-30
>500	-25	-25

Note 1: From formula in [26] Annex A8.7a.

Blocking characteristic implies selectivity in the receiver. Since the IMR3 is derived for signals at 200 and 400 kHz offset, in average a 10 dB attenuation could be assumed for IM modelling caused by broadband signals. This selectivity is not assumed in this study.

A4.3 LTE RADIO SYSTEM

The PMR systems by LTE in the 400 MHz band studied is a cell grid system with the following parameters:

Table 180: General Settings for the LTE BS PMR system in the 400 MHz band

LTE BS PMR system in the 400 MHz band	Value
Max RBs per BS	15
Number of RBS per MS	15
Handover margin	3 dB
Minimum coupling loss	70.0 dB
System bandwidth	3.0 MHz
Receiver noise figure	5.0 dB
Bandwidth of a RB	180.0 kHz
Bitrate mapping	USER_DEFINED
Local Environment	100% Outdoor
Emission mask1	USER_DEFINED
BS max. transmit power	41 dBm
OFDMA capacity	40
Propagation Model	Extended Hata w. variations
General environment	Urban
Propagation environment	Above roof

Note 1: Derived from 3GPP TS 36.104, Table 6.6.3.2.1-3. Assumes Tx power = 46dBm

Figure 158 below shows the emission mask. For the given frequency offset of 0.25 up to 2 MHz the unwanted emissions come from the slanted slope.

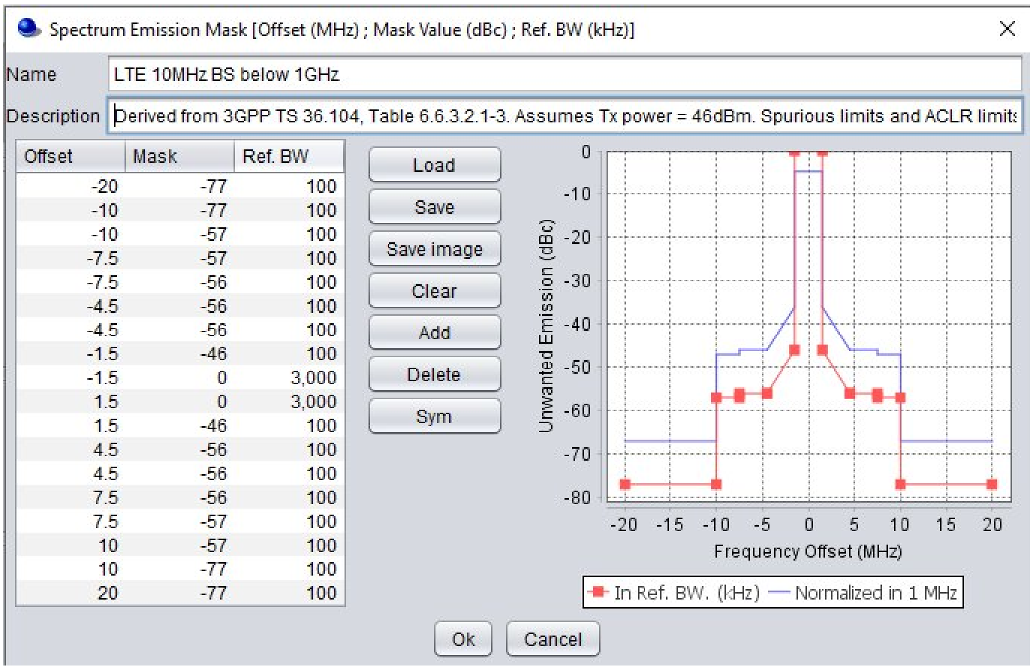


Figure 158: Emission mask for the LTE system in the 400 MHz band

Table 181: General Settings for the LTE BS PMR system in the 400 MHz band

LTE BS system positioning	Value
Cell layout	2-tiers, Tri-sector (3GPP)
Cell radius	0.87 km
System Layout - reference cell selection	Center of “infinite” network
Base Station antenna height	30 m
Antenna tilt	0 deg
Notes	Urban 15 dBi antenna gain −2 dB feeder loss −3 dB antenna discrimination. -3 deg. tilt build in pattern
Antenna Peak gain	10.0 dB
Horizontal, Vertical pattern	Based on ECC Report 240[1]

A4.4 SCENARIO

The frequency of the TETRA BS transmitter is varied so the offset from the centre frequency to the upper edge frequency of the LTE transmitter take the values 0.25, 0.5, 1.0 and 2.0 MHz.

For each offset the simulation are run with the emission mask shown in Figure 158 corresponding to that no duplexer is used on the LTE transmitter. The simulation is also run with emissions masks where the mask attenuation for offsets higher than half the LTE bandwidth are reduced with 10, 15, 20, 25, 30 dB to simulate the usage of a duplexer with increased attenuation of the OOBE from the LTE BS transmitter.

Table 182: Scenario parameters

Scenario parameters	Value
Relative Positioning mode	Correlated
Reference component	Interfering BS ref.cell
Position relative to	VLT
Delta X	1.305 km
Delta Y	0.87 km
Propagation mode	Extended Hata w. variations
General environment	Urban
Propagation environment	Above roof

This gives a scenario outline illustrated in Figure 158. The author intention was to place the TETRA base station in the centre between three adjacent LTE base stations. Unfortunately, the Delta Y should then have been 0.75km. This will however not change the general conclusions of the simulations.

Spacing LTE BS at distances of 2.5 km distance is a very Worst-case assumption. In realistic deployments, cell spacing at 400 MHz bands are much larger.

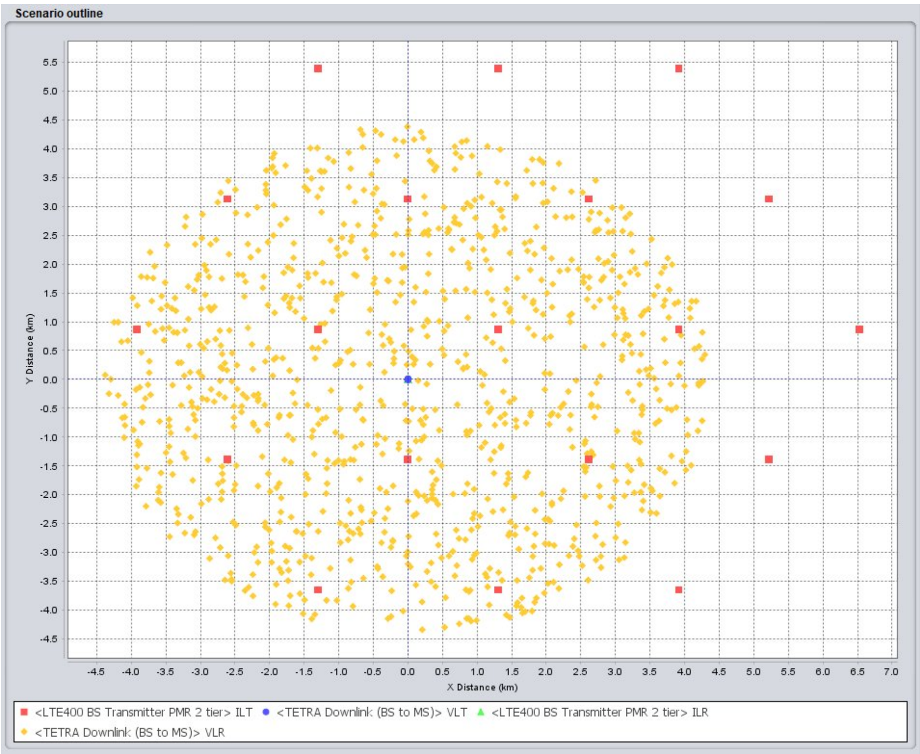


Figure 159: Hypothetical study in which a single Tetra cell is surrounded by a large number of LTE cells

A4.5 INTERMODULATION PLUGIN EPPFORIM3

TETRA intermodulation specification for Mobile station (MS) is defined in clause 6.5.3. in [16]. The wanted signal is 3 dB above static ref. sensitivity level corresponding to -109 dBm. There are two unwanted signals with the level of -47 dBm, corresponding to an intermodulation rejection of 62 dB relative to the wanted signal and 75 dB relative to the created intermodulation products in the receiver. The first unwanted signal is a sine wave signal at 100 kHz offset and the second unwanted signal a TETRA modulated signal at 200 kHz offset. For TETRA static the Es/No is 10 dB and the noise floor is -122 dBm.

The rather simplistic specification assumes two independent static signals. A real-life scenario would include two independent signals with uncorrelated dynamic propagation conditions. In a broadband scenario the two signals which create intermodulation are uncorrelated with regards to modulation information however they will have a high correlated propagation condition with regards to envelope amplitude since the originate from the same LTE BS. The correlation will decrease with increasing offset between the frequencies. Since the intermodulation product will increase with a factor 3 with the amplitude it could be expected that the spread of the amplitude of the intermodulation products could be higher.

The Intermodulation plugin developed by STG for SEAMCAT and introduced in SE7 in [55] is used. This modulation plugin addresses (only) Third order intermodulation generated in a generic victim receiver.

In SEAMCAT simulation normally dynamic propagation conditions are used. It is now assumed that the static intermodulation rejection ratio can be used under dynamic propagation condition when dynamic sensitivities (−103 dBm) and dynamic Es/No (19 dB) applies.

Gain compression of 13dB is used however it has no impact on the results (see also SE7(17)049).

The intermodulation rejection mode is set to “relative in dB”

The unwanted signal levels in the TETRA standard are -47 dBm and they create an interferer with a level of -122 dBm. This gives a rejection of 75 dB. The rejection is set to be constant over the band as the TETRA receiver is assumed wideband without additional selectivity for the relevant 400 MHz band and the IP3 mainly determined by the front end and mixer.

Configuration parameters in the Show Third Order Intermodulation (IM3) tab:

- Protection criterion: C/(N+I)
- Value for protection criterion: 19 dB
- Sensitivity: -103 dBm
- Noise floor: -122 dBm

A4.6 SIMULATION RESULTS

The simulation demand on memory increases significantly as the intermodulation plugin collects vectors. In this scenario with 19 LTE base stations the scatter coordinates are collected (even though they are the same in each event). This limits the number of events to 20,000 on the authors PC/SEAMCAT/Java configuration. With 20,000 events the scatter array of the LTE base stations is 1,140,000 positions.

The simulation results are shown in the Table 183 below.

Table 183: Probability of interference with intermodulation

Results from SEAMCAT EPPforIM3 plugin Show IM3 tab Protection criterion C/(N+I) 19 dB, Sensitivity -103 dBm, noisefloor -122 dBm Freq. & Offset in MHz, Duplex att. In dB, outage in %												
	Unwanted				Blocking				Third Order Intermodulation (IM3)			
Freq.	465.25	465.5	466	467	465.25	465.5	466	467	465.25	465.5	466	467
Offset Dup. att.	0.25	0.5	1	2	0.25	0.5	1	2	0.25	0.5	1	2
0	16.01	14.34	12.47	8.36	0.12	0.08	0.08	0.08	4.84	4.21	4.16	3.38

Results from SEAMCAT EPPforIM3 plugin Show IM3 tab Protection criterion C/(N+I) 19 dB, Sensitivity -103 dBm, noisefloor -122 dBm Freq. & Offset in MHz, Duplex att. In dB, outage in %											
10	5.41	4.67	4.11	2.76	0.09	0.12	0.08	0.17	4.48	4.21	4.08	3.52
15	2.92	2.79	2.26	1.53	0.07	0.12	0.15	0.07	4.38	4.22	3.98	3.65
20	1.7	1.42	1.15	0.78	0.12	0.09	0.06	0.1	4.64	4.36	4.07	3.48
25	0.88	0.87	0.56	0.37	0.06	0.08	0.1	0.07	4.5	4.45	3.95	3.48
30	0.47	0.39	0.23	0.2	0.14	0.08	0.08	0.13	4.36	4.48	4.12	3.58

The Table above confirms what previous input documents have shown that the Out-of-Band Emissions (OOBE) from the LTE base station has to be improved by 25 to 30 dB. It also confirms that blocking is a minor issue. It can be seen that the IM3 is not improved by duplexer attenuation. Outage due to IM3 is reduced as expected when the frequency offset is increased.

The outage as illustrated by SEAMCAT EPPforIM3 plugin is shown in the Figure 160 below for an offset of 250 kHz and with 0 dB duplexer attenuation (left) and with -30 dB attenuation (right).

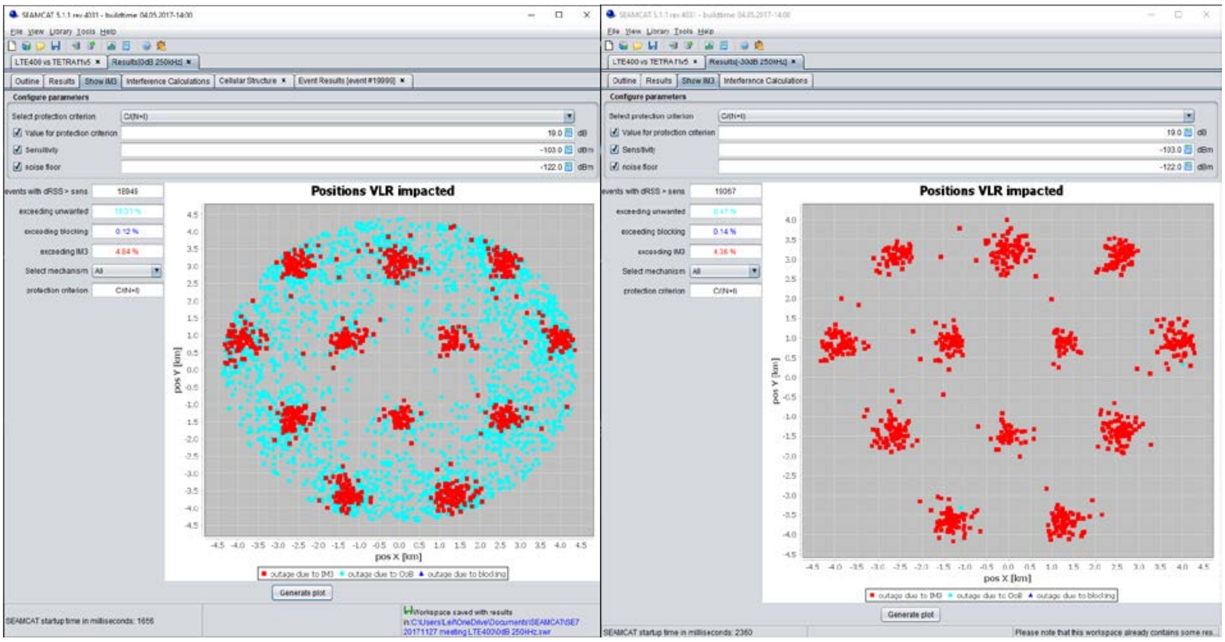


Figure 160: Outage plot for TETRA MS VLR and LTE BS ILT in the 400 MHz band Offset 250 kHz. 0 dB att. (left) -30 dB att. (right)

The above Figure shows that the IM3 outage is concentrated near the LTE BS stations. Two simulations where the VLR coverage radius is changed to 500 m around the LTE base stations located at (1.305 km, 0.87 km) and (2.61 km, -1.39 km) respectively have been done to illustrate the outage near a LTE base station. The scenario outlines are shown in the below Figure 161.

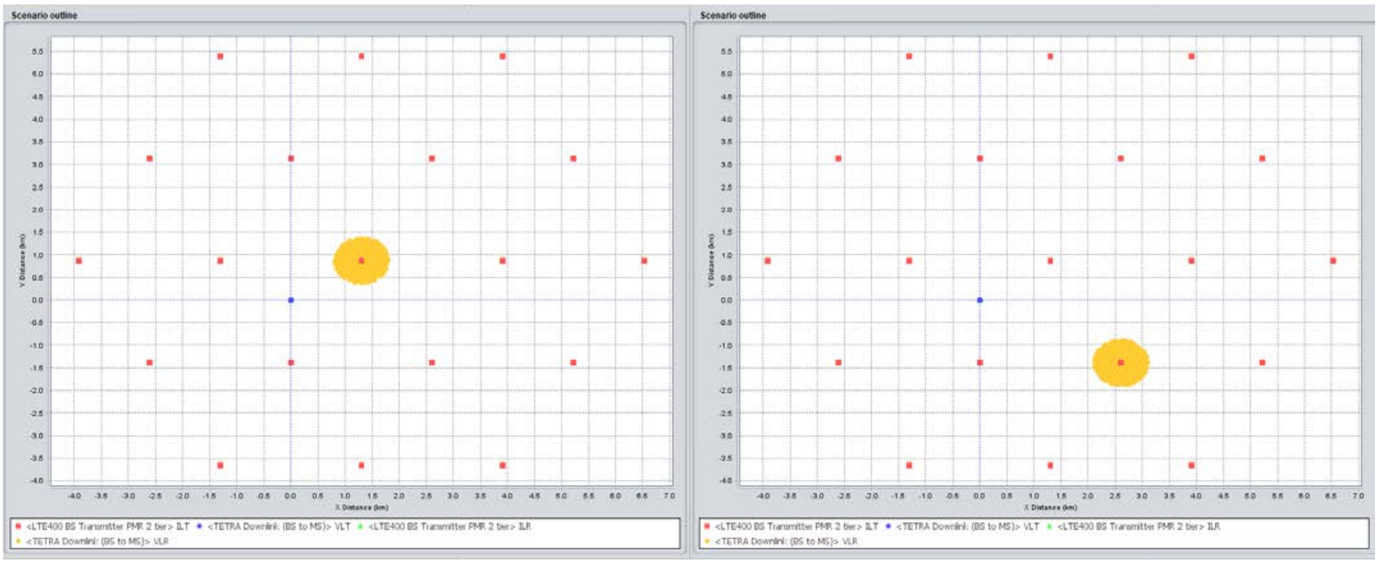


Figure 161: Scenario outlines for within 500 m selected LTE base stations

The frequency offset is 250 kHz and the duplex attenuation is 30 dB.

Table 184: Outage within 500 m of LTE base station

Outage within 500 m of LTE base station		
Delta X	1.307 km	**2.61 km**
Delta Y	0.87 km	-1.39 km
Unwanted OOBE	0.53%	2.4%
Blocking	0.1%	0.54%
IM3	19.32%	26.61%

It can be seen that the outage due to IM3 are considerable in both cases and higher for the LTE base station furthers away from the TETRA base station where the wanted TETRA signal is lower.

A4.7 FURTHER SIMULATIONS FOR LARGER LTE CELLS

The following scenario was developed for the study of cell size dependency on the Intermodulation (IM) distortion risk.

LTE cell radius increased to 3.85 km from 870 m.

The centre LTE BS is randomly positioned within a distance of the LTE cell range from the TETRA BS Tx.

Assign 1RB per LTE UE in order to represent an eMTC scenario. BTS is still transmitting at all available RB (full buffer model). This scenario provides the following results.

Table 185: Probability of interference with intermodulation

Results from SEAMCAT EPPforIM3 plugin Show IM3 tab

LTE eMTC cell radius 3.85 km

Protection criterion C/(N+I) 19dB, Sensitivity -103 dBm, noisefloor -122dBm

Freq. & Offset in MHz, Duplex att. In dB, outage in %

	Unwanted				Blocking				Third Order Intermodulation (IM3)			
Freq.	465.25	465.5	466	467	465.25	465.5	466	467	465.25	465.5	466	467
Offset Dup. att.	0.25	0.5	1	2	0.25	0.5	1	2	0.25	0.5	1	2
0	0.69				0.02				0.16			
10												
15												
20												
25												
30												

The table shows that the probability of interference in this scenario is very low.

A4.8 CONCLUSION

The simulations are performed using the second version of SEAMCAT plug-in, which assumes a linear superposition of multiple narrowband parts of broadband signal with a frequency relationship that might produce IM in the wanted frequency band. Since the model for Intermodulation (IM) distortion is more complex (s. Annex 2) this approach provides conservative results.

The results by SEAMCAT plugin are too pessimistic as they do not reflect spectral thinning, which accounts for factor 1/3 equal to -4.7 dB.

The results from the simulations show:

- An additional duplex attenuation on the LTE base station of at least 25-30 dB is required to reduce the OOBE at the VLR receive frequency.
- The intermodulation effect of the broadband signal in the VLR introduce an unwanted interference outage of 3-5% when the entire TETRA coverage is considered and is considerably higher up to 19-26% outage within a radius of 500 m from a LTE base station.
- Interference probability significantly deceases if LTE cell size increases

ANNEX 5: LTE IMPACT ON NARROWBAND PMR

A5.1 PARAMETERS

- Parameter settings according to ECC Report 240 [1], A1.1 LTE and A1.2 TETRA;
- Calibrating Matrix Laboratory software (MATLAB) simulation tool with SEAMCAT simulation results published in ECC Report 240, chapter 3;
- Extended HATA propagation model defined in SEAMCAT Handbook (ECC Report 252) [26];
- Assumption on the maximum transmit power: LTE BS 46 dBm, LTE UE 37 dBm.

A5.2 INTERFERENCE MODELING IN TETRA

- TETRA: single cell considered (i.e. infinite reuse factor for TETRA, so that co-channel interference vanishes);
- LTE: 1 tier (19 cells), 3-sectors antenna;
  - TETRA cell randomly dropped in the LTE network.

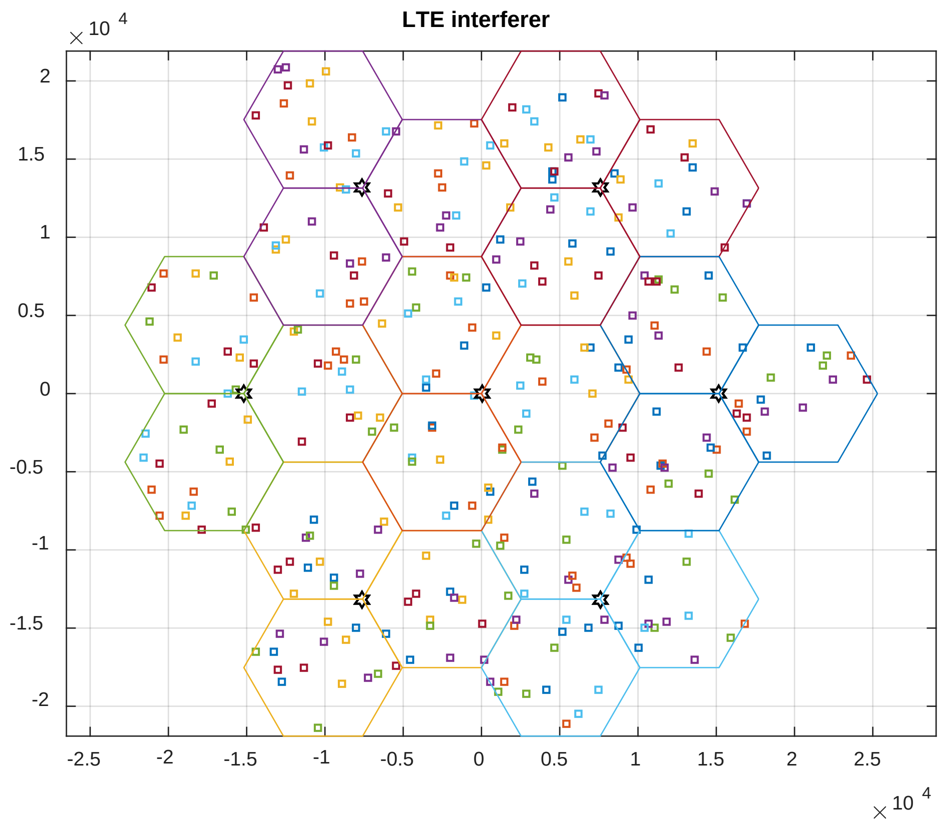


Figure 162: TETRA and LTE cell configurations

A5.2.1 Uplink case

Set UE transmit power to:

$$P_t = P_{\max} \times \min\left\{1, \max\left[R_{\min}, \left(\frac{PL}{PL_{x-ile}}\right)^{\gamma}\right]\right\}$$

where:

- P_t is LTE UE transmit power;
- P_{max} = 37 dBm: maximum UE transmit power;
- P_{min} = -40 dBm: minimum UE transmit power;
- $R_{min} = P_{min} / P_{max;}$
- PL: path loss in dB from UE to its serving BS;
- $PL_{x\text{-}ile}$ = 137 dB: the x-percentile path-loss (including shadowing);
- Y = 1 (0<Y<1) balancing factor.

UL Interference Probability: LTE UE to TETRA BS.

Depending on the “Channel Utilization Factor”, 15 active UEs from the N UEs randomly dropped are scheduled per snapshot.

Only 1 RB of each active UE is loaded.

Power control as explained above.

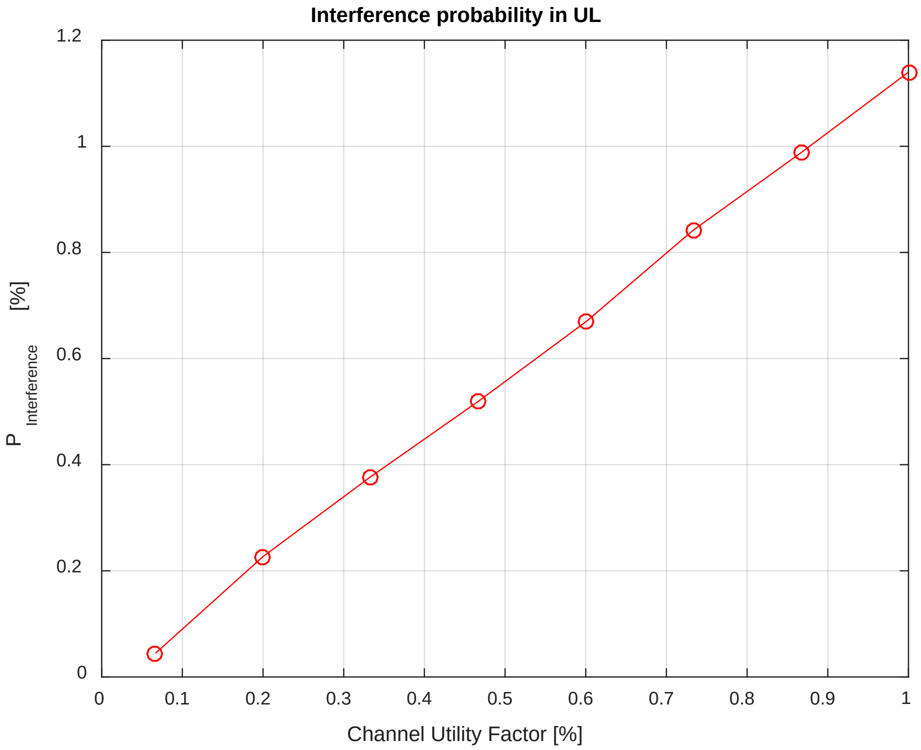


Figure 163: Interference probability in the uplink case

A5.2.2 **Downlink case**

DL Interference Probability: Over all channels

- LTE BS to TETRA MS averaged over all TETRA channels;
- LTE Channel Utilization in DL is modelled as reduction in the BS Tx-power.

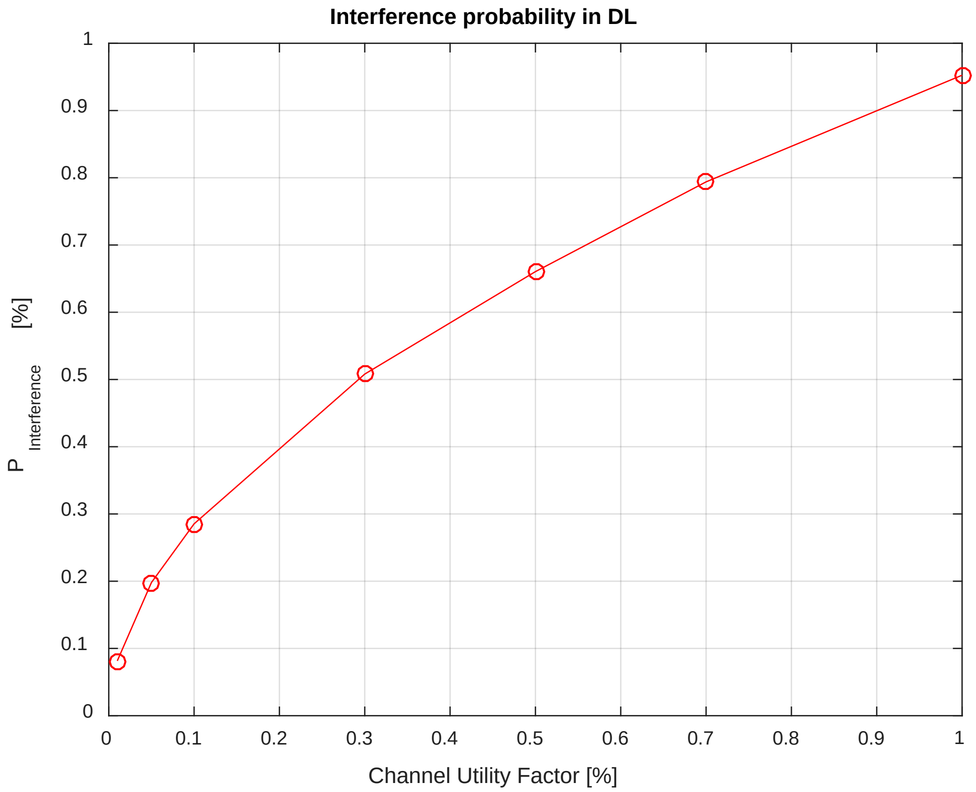


Figure 164: Interference probability in the downlink case

DL Interference Probability: Most adjacent TETRA channels

- Case 1: Averaged over Channels 1 and 2;
- Case 2: Averaged over Channels 1 to 10.

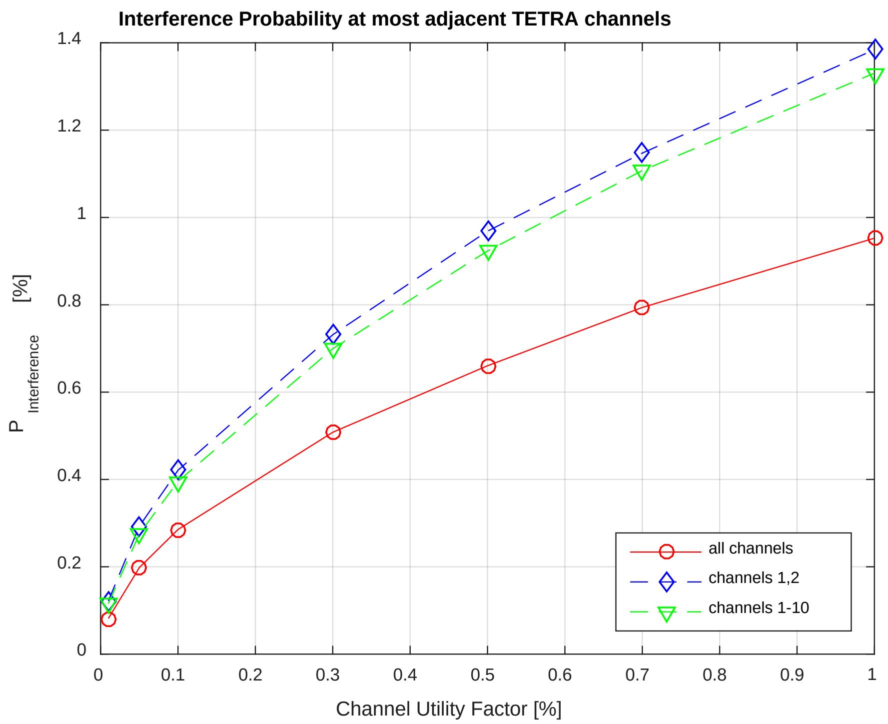


Figure 165: Interference probability at most adjacent TETRA channels

DL Interference Probability: Each single TETRA channel

- Fully loaded LTE system;
- Interference probability for each TETRA channel.

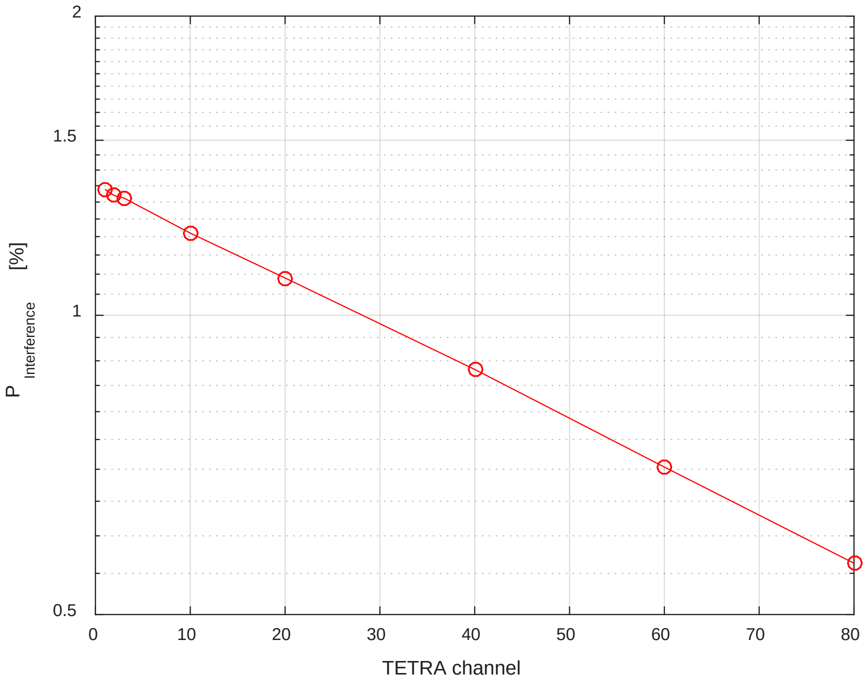


Figure 166: Interference probability at each TETRA channel

Desired Power and Interference in TETRA DL:

- Interferer LTE: 1 tier, 3-sectors antenna;
- Received power at TETRA MS from TETRA BS (desired) = dRSS;
- Interference power from LTE BS to TETRA MS = Interfering Received Signal Strength (iRSS);
- Sensitivity condition (dRSS > -103 dBm).

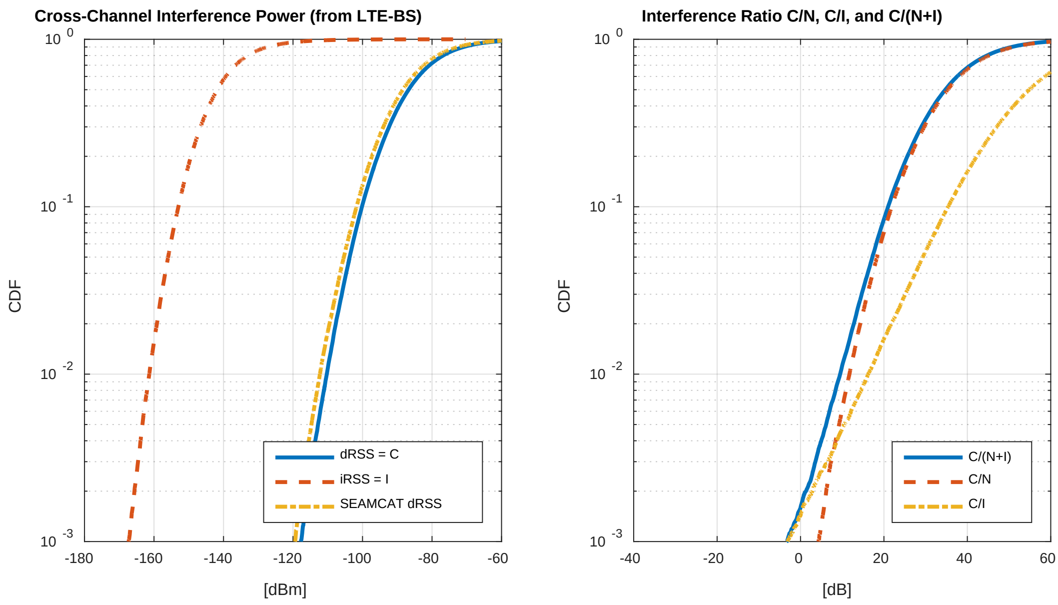


Figure 167: Interference power and ratio distributions

A5.3 DESIRED POWER AND CO-CHANNEL INTERFERENCE IN TETRA

- TETRA: 9 cells per cluster, 1 tier, omnidirectional antenna;
- Received power at TETRA BS from TETRA MS (desired);
- Co-channel interference within TETRA from neighbouring cells using the same frequency.

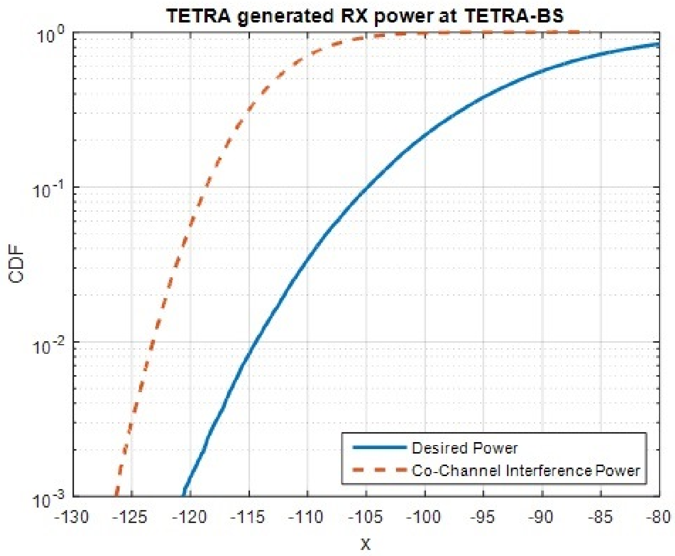


Figure 168: Desired power and co-channel interference power distributions

A5.4 LTE UE TRANSMIT POWER

- LTE: 1 tier, 3-sectors antenna;
- 37 dBm max. transmit power (ECC Report 240);
- Power control, target -100 dBm at BS-Rx.

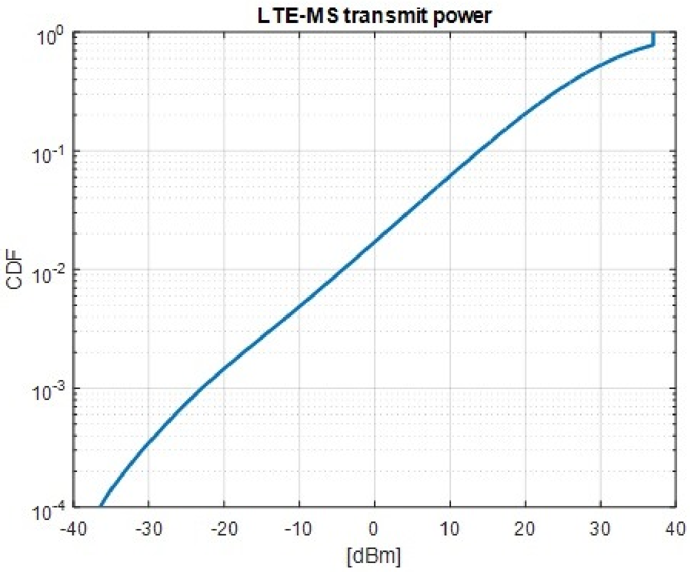


Figure 169: LTE UE transmit power distribution

Statistics:

- Mean value: 27.177 dBm;

- Median value: 29.297 dBm.

A5.5 INTERFERENCE CALCULATION

- Combine TETRA-blocking mask with LTE-emission mask;
- TETRA: 80 positions of blocking mask;
- LTE: 15 PRB (physical resource blocks, each 12 subcarriers).

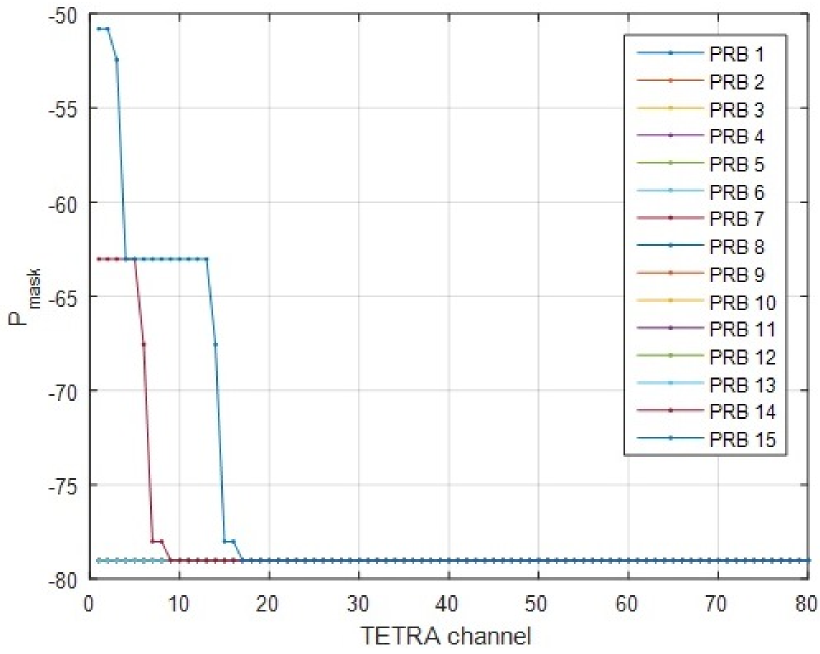


Figure 170: LTE interference power in TETRA channels

A5.6 CONCLUSION

- Only low TETRA channels ≤ 200 kHz affected;
- Only upper LTE-resource blocks 14 and 15 generate essential interference.

A5.7 CHANNEL MODEL: EXTENDED HATA

- Median propagation loss exceeds free space loss;
- High variance of lognormal shadowing;
  - higher distance no guarantee for higher path loss.

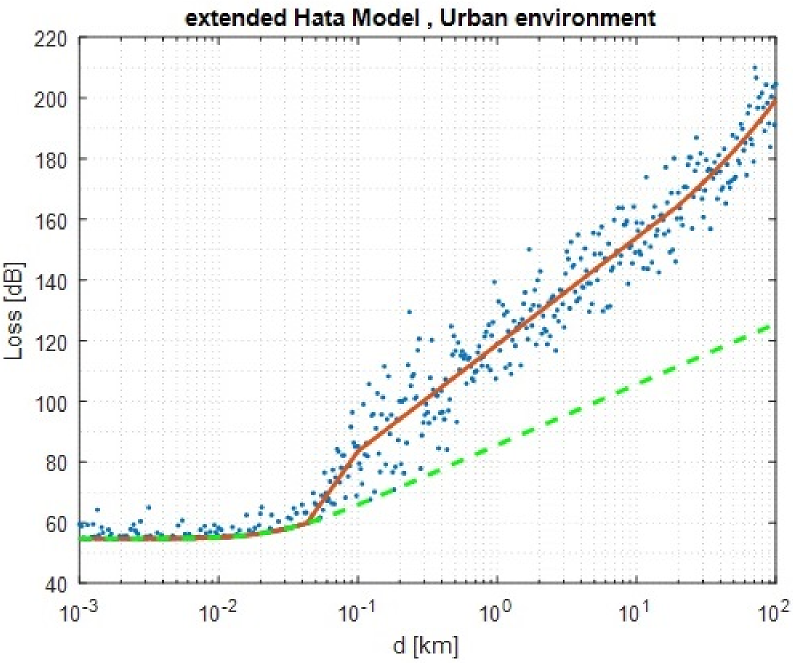


Figure 171: Propagation loss curves

Curves in the figure above:

- Red: median propagation loss, without shadowing;
- Blue: shadowing in HATA;
- Green: free space propagation.

A5.8 INTERFERENCE PROBABILITY CALCULATION

$$PI = 1 - P\ dRSS\ iRSScomp > CI\ dRSS > sens$$

See ECC Report 240 [1]:

- TETRA-BS Sensitivity: -106.0 dBm;
- TETRA-MS Sensitivity: -103.0 dBm;
- Interference criterion: C/I = 19.0 dB (‘receiver detection ratio’) C/(N+I) = 16.0 dB;
- Interference probability is defined as:

with

- dRSS: desired received signal strength;
- Interfering Received Signal Strength (iRSS): unwanted received signal strength;
- iRSScomp: composite interfering received signal strength;
- sens: receiver sensitivity.

A5.9 SCHEDULER EXAMPLE

Example for case with:

- 80% loading (12 of 15 RBs in use during the same time slot)
- Density 100 UEs per km^2
- Scheduling of 3654 UEs into 15 RBs over 305 time slots

Table 186: Mapping of UEs to RB and time slots

	Time Slot															
RB	1	2	3	4	5	6	7	8	9	10		301	302	303	304	305
1	1	16	31	46	61		76	91	106	…			…	3646		
2	2	17	32	47	62	77	92		107	…			…	3432		3647
3	3		18		33	48	63	78	93	…			…		3648	
4		4	19		34	49	64	79	94	…			…	3634	3649	
5		5	20	35	50	65	80	95	110				…		3635	3650
6	6		21			36		51	66				…	3621	3636	3651
7	7	22			37	52	67	82	97				…	3622	3637	
8		8	23	38	53	68	83	98	113				…	3623	3638	
9	9	24	39	54	69	84		99	…				3654			3652
10	10	25		40				55	…				3610	3625	3640	
11	11		26	41	56	71	86	101	…				3611	3626	3641	3653
12	12	27	42	57	72	87	102		…						3642	
13	13	28	0	43	58	73	88		…				3643	3627		
14	14	29	44		59	74	89	104	…					3629	3644	3654
15				15	30	45	60	75	…				3615	3630	3645	

A5.10 SOME INITIAL RESULTS ON INTERFERENCE PROBABILITY

Table 187: Results on Interference Probability

UE/km^2	UE/sector	RB per UE	Load	Slots	P: C/I	P: C/(I+N)	Co-channel interference
0.0274	1	15	100%	1	0.701%	0.527%	40.52%
0.4105	15	1	100%	1	1.195%	0.919%	39.06%
100	3654	1	80%	305	0.580%	0.419%	38.05%
100	3654	1	50%	488	0.363%	0.263%	38.65%
100	3654	1	10%	2436	0.066%	0.054%	38.44%

Layout:

- LTE-layout: 1 tier, 3-sectors. Power control target: -100 dBm at BS-Rx;

- TETRA-layout: 9 cells per cluster, omnidirectional antenna. No power control (could be considered included if required).

A5.11 SIMULATION RELIABILITY CHECK

- Simulations have been performed with 100 000 snapshots;
- Scheduling simulation with 10 UE/km^2.

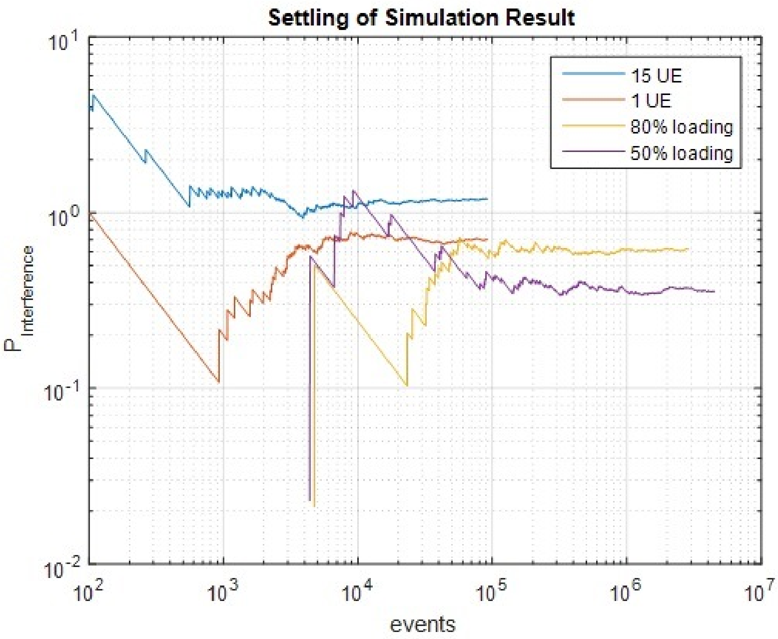


Figure 172: Simulation reliability check

ANNEX 6: LTE IMPACT ON TETRA

The intermodulation simulations done in this Annex do not meet all conditions for proper intermodulation simulation. As a consequence the results of these simulations should be considered very cautiously.

A6.1 DESCRIPTION OF THE METHOD

A tool was constructed to examine the interference effects of a network of LTE cells on the mobile receivers in a single narrowband PMR (PPDR or commercial) cell. The tool operates as described in the following sections.

A service area is defined by a 200x200 pixel grid, providing 40 000 possible simulation locations. Within this area, the coverage area for a narrowband cell is defined to provide 95% area coverage for UHF handheld portable coverage. At each point defined by a pixel within the grid within the narrowband cell, the received signal strength was simulated using the following parameters, derived from TETRA receiver specifications:

Table 188: Narrowband system specifications

Characteristics	Value
Base station Transmitter	
e.i.r.p. (dBm)	46
Antenna height (m)	30
Range (km)	4.2
PMR Receiver:	
NB Rx Antenna gain (dBi)	-6
Equivalent Noise Bandwidth (kHz)	18
Channel Performance Criterion (dB CNR)	19
Receiver Static Sensitivity (dBm)	-112
Rx Co-channel Rejection (CCR) Ratio (dB)	10
Receiver IMR3 Specification (dB)	65
Receiver IMR5 Specification (dB)	75

This gave a range for the narrowband cell of 4.2 km, and using a 6 km pixel grid, 15361 locations for measurement.

The propagation model is the SEAMCAT suburban extended HATA model, as specified in ECC Report 252, Annex 17 [26], which includes variable propagation loss with range, in conjunction with the range dependent standard deviation specified in the same Annex. An omnidirectional transmitter antenna pattern was assumed.

A typical simulation result without interference provides a following coverage result as illustrated in Figure 173 below.

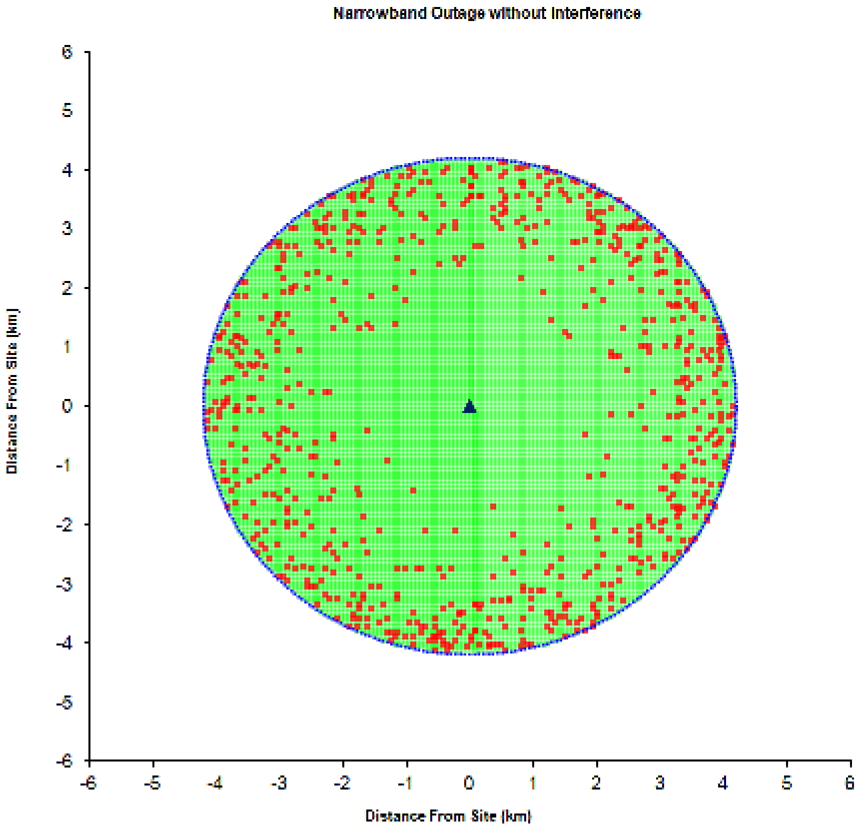


Figure 173: Typical narrowband coverage plot

Within the service area, a network of LTE cells was overlaid at defined positions on the pixel grid. Different positions and different cell radius and cell centre spacing were simulated, using the cell geometry defined in Report ITU-R M.2290-0 [26], as shown in Figure 174 below.

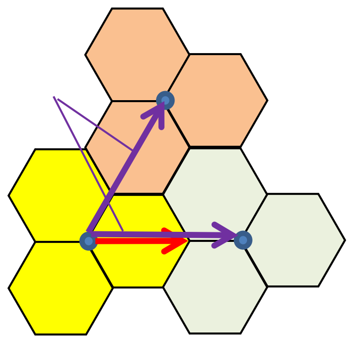
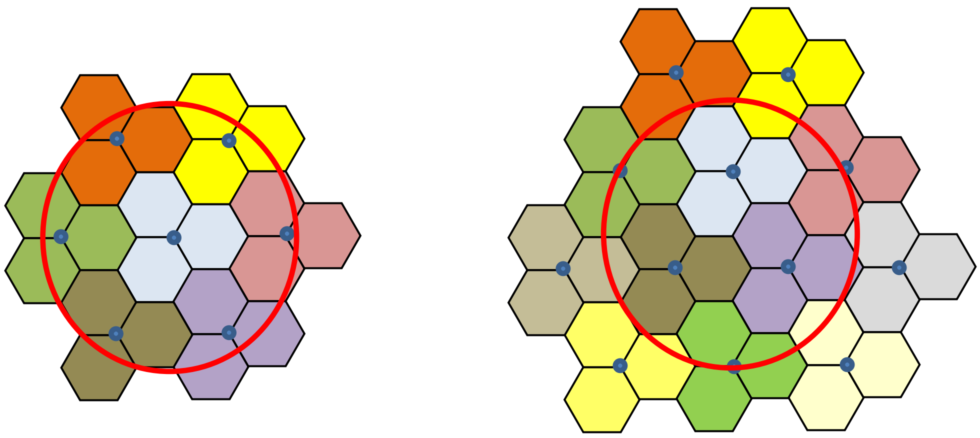


Figure 174: Cell geometry for LTE cell pattern

A cell radius of 2 km, corresponding to a cell centre spacing of 3 km, and a cell radius of 3km corresponding to cell centre spacing of 4.5 km were simulated. The overlay positions chosen were the limiting positions, where in one case one LTE cell site was co-located with the narrowband cell site, and in the other case the closest LTE cell sites were distributed equidistantly around the narrowband cell site – see Figure 175 below. The cell radii were chosen using recommended suburban deployment parameters from Report ITU-R M.2290-0, which recommends typical 2 km cell radius below 1 GHz, and then increasing by 50% recognising the probable lower density of cells in a PPDR or commercial deployment in the 400 MHz band. Figure 175 below illustrates the two overlay patterns.



1. LTE cell coincident with narrowband cell

2. LTE cells equidistant from narrowband cell

Figure 175: LTE overlay patterns on narrowband cell

The LTE transmitter parameters were the following:

Table 189: LTE transmitter parameters

Broadband LTE Inputs	Value
LTE B/W (5 or 3MHz)	5
LTE Tx Power per LTE Carrier (dBm)	43
LTE Antenna Height (m)	30
LTE Antenna System Gain (dBi)	13

Each simulation then derived combined signal strength from the LTE transmitters at each pixel location, also using the SEAMCAT propagation model and range dependent path loss and standard deviations. The antenna pattern was derived from a production 450 MHz panel antenna, using the relative gain figures at the relevant azimuth and elevation offset for each pixel.

Each pixel point within the defined range of the narrowband cell was then checked for coverage in the presence of interference caused by:

- Out-of-band emissions from the LTE transmitters;
- Third and fifth order intermodulation in the narrowband receiver;
- Blocking in the narrowband receiver.

The out-of-band emissions are taken from 3GPP TS 36.104 [13] 'operating band emissions' figures, which apply within 10 MHz of the transmitter frequency.

Third order intermodulation products were derived by calculating an interference spectrum (in dBm/Hz) at a reference level, and calculating the actual interference at the simulated received signal level against that at the reference level.

Blocking effects made use of the narrowband receiver's blocking specification at the relevant offset from the wanted received frequency.

Sets of simulations were then run where the wanted narrowband received frequency was set at offsets from the edge of the LTE transmitter wanted bandwidth of 250 kHz, 500 kHz, 1 MHz and 2 MHz, allowing for a duplexer on the LTE transmitter increasing attenuation of out-of-band emissions by 0 dB (no duplexer), 25 dB and 30 dB. Ten simulations were made of each scenario to combine and average the results.

Note: It may be impractical to obtain as much as 30 dB attenuation at frequencies less than 500 kHz from the edge of the LTE transmitter wanted bandwidth.

Each simulation generated a new estimate of both narrowband and LTE signal strengths at each pixel, and multiple simulations (up to ten) were run at each frequency offset and with both cell patterns to obtain mean results and also the spread of results between simulation runs. Thus as single simulation estimated the coverage or outage for 15 000 points, ten simulations gave 150 000 result points.

Results were then taken to:

- Observe degradation due to interference over the narrowband transmitter's wanted coverage area;
- Observe principle cause of interference (OOBE, intermodulation, blocking);
- Observe degradation of narrowband transmitter's wanted coverage within a certain radius (500 m) of an LTE transmitter site.

The degradation within a radius of an LTE transmitter site is of particular importance where the narrowband system is providing safety critical service, i.e. PPDR, or to a critical national infrastructure (transport, utilities etc.).

An example result is shown in Figure 176 below.

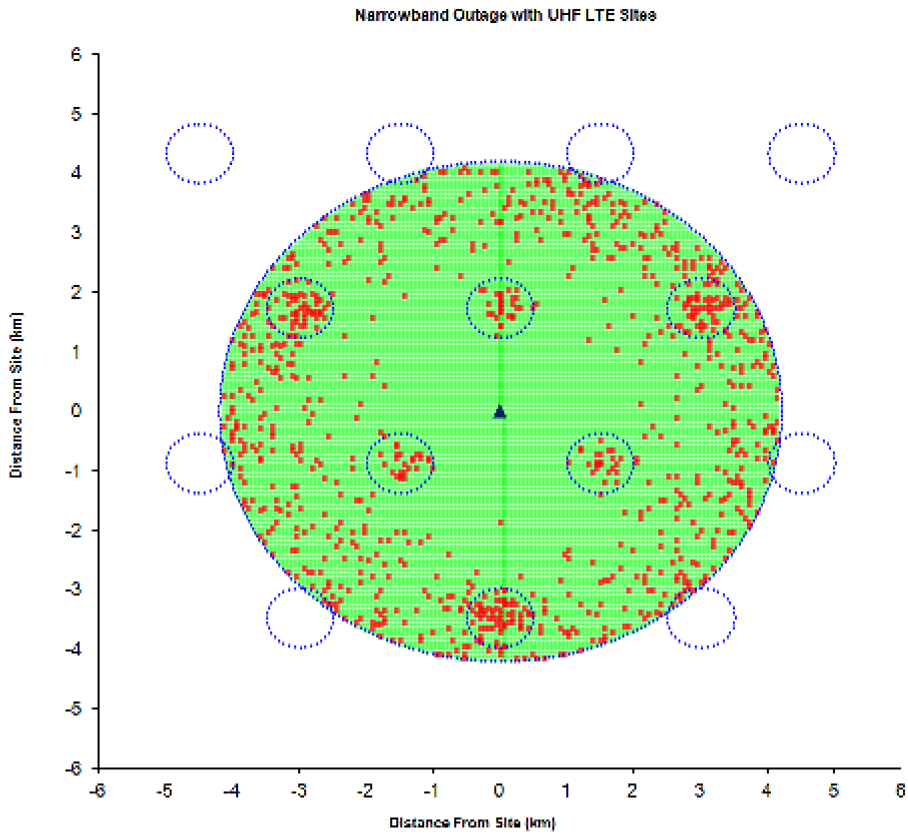


Figure 176: Narrowband coverage with outage caused by LTE interference

In Figure 176, the smaller circles represent a 500 m radius around the interfering LTE transmitters.

Following the simulations of the network patterns, a further study was undertaken to look at the outage within the 500 m radius of an LTE transmitter located anywhere within the narrowband system's coverage area. To do this, the simulation measured the outage within the 500 m radius of a single LTE transmitter site with the transmitter placed at intervals of 0.2 km along a radius from the centre of the narrowband transmitter coverage area (i.e. from its transmitter site) to the edge of the area. Then a 0.2x0.2 km pixel grid was overlaid and each pixel assigned to the closest 0.2 km radius. Thus the number of locations for each interference result at each radius could be used to generate an overall average of the level of interference degradation with a random placement of an LTE transmitter within a narrowband transmitter cell. Ten simulations were run at each radius, using the same models as the previous simulations, and assessing the effect of intermodulation, out-of-band emissions and blocking. A single frequency offset and duplexer attenuation was chosen as a result of the first set of simulations.

A6.2 RESULTS FOR LTE NETWORK PATTERNS

A6.2.1 **3 km cell spacing, network centred on narrowband transmitter**

In this network layout, the LTE cells have 2 km radius, leading to a site spacing of 3 km. A typical result for the simulations is illustrated in Figure 177 below.

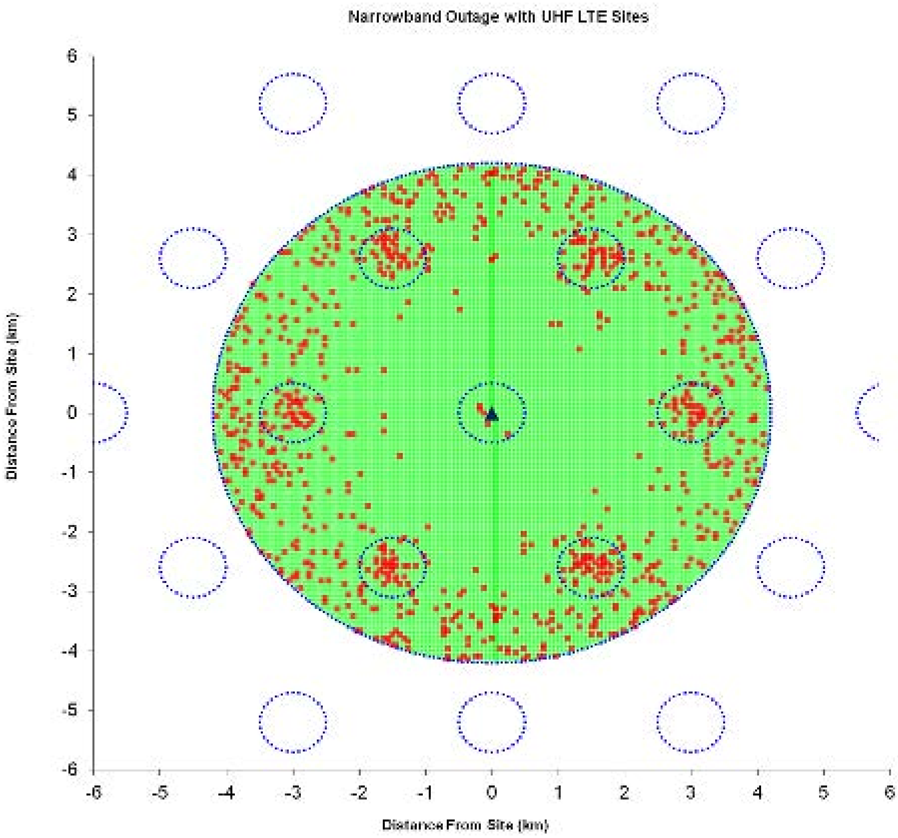


Figure 177: LTE network, 3 km site spacing, centred on narrowband transmitter

Table 190 below shows the outage within the narrowband cell due to the combined interference from the LTE transmitters.

Table 190: Simulation results with 3 km spacing, centred, over narrowband transmitter coverage area

Duplexer attenuation	Total outage				Increase in outage compared to S/N only			
	PMR frequency offset from LTE Bandwidth edge (MHz)				PMR frequency offset from LTE Bandwidth edge (MHz)			
	0.25	0.5	1	2	0.25	0.5	1	2
0 dB	20.78%	20.39%	19.29%		15.99%	15.59%	14.50%	
25 dB	6.31%	6.22%	6.24%		1.52%	1.43%	1.44%	
30 dB	6.16%	6.33%	6.34%	6.11%	1.37%	1.54%	1.55%	1.32%

The 'total outage' column illustrates the outage over the coverage area of the narrowband transmitter from both signal to noise and interference. The 'Increase in outage compared to S/N only' indicates the increase in outage compared to the non-interference case, as the narrowband coverage without interference was 95.21%, giving an outage of 4.79%.

Table 191 below however shows the same figures for outage within 500 m radius of an LTE transmitter.

Table 191: Simulation results with 3 km spacing, centred, within 500 m of LTE transmitter

Duplexer attenuation	Total outage				Increase in outage compared to S/N only			
	PMR frequency offset from LTE Bandwidth edge (MHz)				PMR frequency offset from LTE Bandwidth edge (MHz)			
	0.25	0.5	1	2	0.25	0.5	1	2
0 dB	48.75%	47.8%	45.58%		44.71%	43.97%	41.74%	
25 dB	16.61%	16.06%	16.17%		12.78%	12.22%	12.33%	
30 dB	16.16%	16.45%	15.98%	14.88%	12.33%	12.61%	12.15%	11.04%

'Increase in outage compared with S/N' compares the outage with interference with that without interference; in this case due to the placement of the LTE cells within the coverage area of the narrowband transmitter, the outage without interference averaged across the 500 m radius circles of interest was 3.84%.

A6.2.2 **3 km cell spacing, offset from narrowband transmitter**

In this scenario, the positions of the LTE cells were offset, such that the three closest transmitters were an equidistant distance from the narrowband site. A typical simulation result is shown in Figure 178 below.

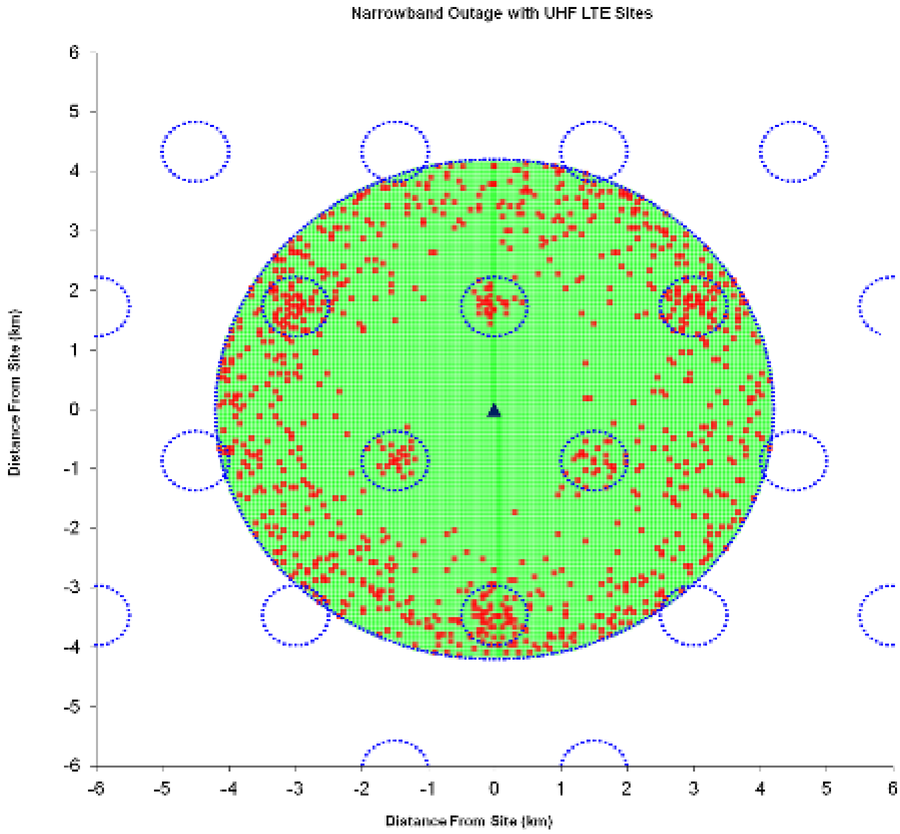


Figure 178: LTE network, 3 km site spacing, offset from narrowband transmitter

Table 192 below shows the outage within the narrowband cell due to the combined interference from the LTE transmitters in this network configuration. The outage in non-interference conditions was 4.79%; the increase above this over the total coverage area of the narrowband transmitter is shown in the right hand columns.

Table 192: Simulation results with 3 km spacing, offset, over narrowband transmitter coverage area

Duplexer attenuation	Total outage				Increase in outage compared to S/N only			
	PMR frequency offset from LTE Bandwidth edge (MHz)				PMR frequency offset from LTE Bandwidth edge (MHz)			
	0.25	0.5	1	2	0.25	0.5	1	2
0 dB	20.67%	19.99%	18.89%		15.88%	15.20%	14.10%	
25 dB	6.26%	6.25%	6.23%		1.47%	1.45%	1.43%	
30 dB	6.05%	6.18%	6.05%	5.80%	1.26%	1.39%	1.26%	1.01%

Table 193 below shows the outage within 500 m of an LTE transmitter in this network configuration. The outage in non-interference conditions was 4.38% averaged over the 500 m radius circles around the LTE transmitters.

Table 193: Simulation results with 3 km spacing, offset, within 500 m of LTE transmitter

Duplexer attenuation	Total outage				Increase in outage compared to S/N only			
	PMR frequency offset from LTE Bandwidth edge (MHz)				PMR frequency offset from LTE Bandwidth edge (MHz)			
	0.25	0.5	1	2	0.25	0.5	1	2
0 dB	48.06%	47.65%	46.00%		43.68%	43.27%	41.62%	
25 dB	16.95%	17.12%	16.56%		12.58%	12.74%	12.18%	
30 dB	15.80%	16.06%	15.87%	14.73%	11.42%	11.68%	11.49%	10.36%

A6.2.3 **4.5 km cell spacing, centred on narrowband transmitter**

In this scenario, the LTE network is centred on the narrowband transmitter, with site spacing increased to 4.5 km (3 km cell radius). A typical simulation result is shown in Figure 179 below.

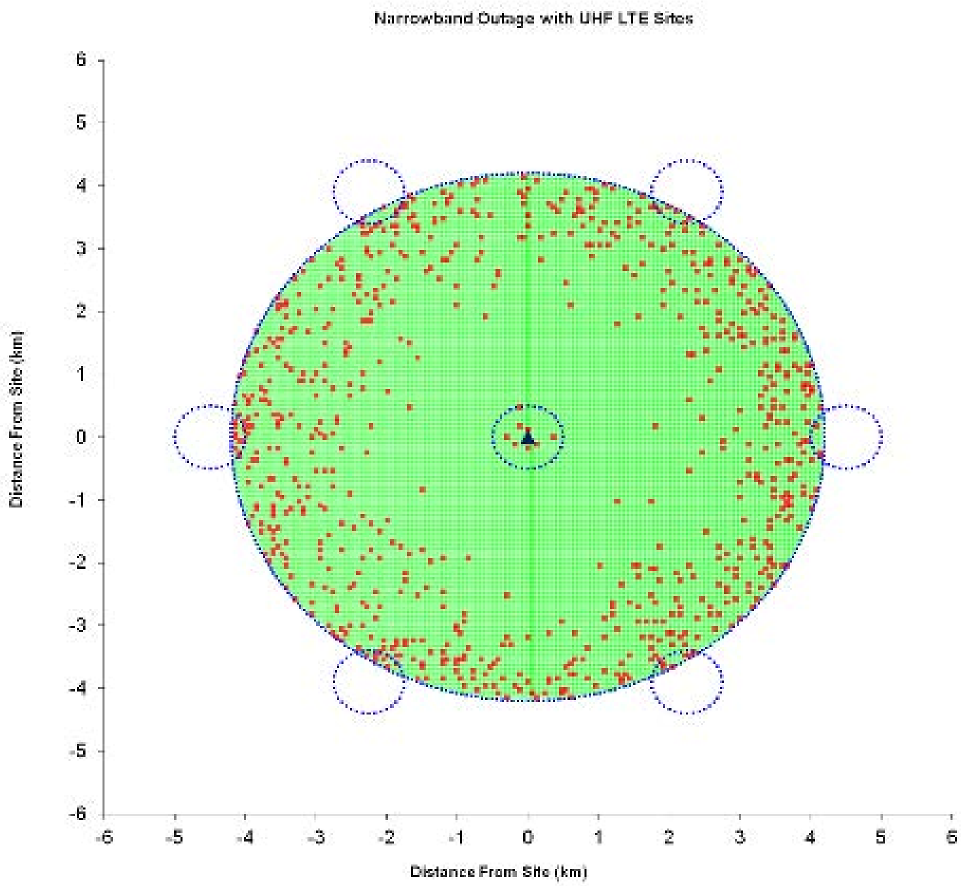


Figure 179: LTE network, 4.5 km site spacing, centred on narrowband transmitter

Table 194 below shows the outage within the narrowband cell due to the combined interference from the LTE transmitters in this network configuration. The outage in non-interference conditions was 4.79%; the increase above this over the total coverage area of the narrowband transmitter is shown in the right hand columns.

Table 194: Simulation results with 4.5 km spacing, centred, over narrowband transmitter coverage area

Duplexer attenuation	Total outage				Increase in outage compared to S/N only			
	PMR frequency offset from LTE BW edge (MHz)				PMR frequency offset from LTE BW edge (MHz)			
	0.25	0.5	1	2	0.25	0.5	1	2
0 dB	11.75%	11.73%	10.88%		6.95%	6.58%	6.09%	
25 dB	4.95%	5.18%	5.10%		0.16%	0.39%	0.30%	
30 dB	4.99%	5.04%	5.00%	5.11%	0.20%	0.25%	0.21%	0.31%

Table 195 below shows the outage within 500 m of an LTE transmitter in this network configuration. The outage in non-interference conditions was 4.38% averaged over the 500 m radius circles around the LTE transmitters.

Table 195: Simulation results with 4.5 km spacing, centred, within 500 m of LTE transmitter

Duplexer attenuation	Total outage				Increase in outage compared to S/N only			
	PMR frequency offset from LTE BW edge (MHz)				PMR frequency offset from LTE BW edge (MHz)			
	0.25	0.5	1	2	0.25	0.5	1	2
0 dB	28.91%	29.75%	27.14%		23.88%	24.71%	22.10%	
25 dB	11.39%	11.80%	11.01%		6.36%	6.76%	5.98%	
30 dB	10.10%	10.25%	10.33%	10.33%	5.07%	5.22%	5.29%	5.29%

A6.2.4 4.5 km cell spacing, offset from narrowband transmitter

In this scenario, the positions of the LTE cells was offset such that the three closest transmitters were an equidistant distance from the narrowband site, with the larger 3 km cell radius providing 4.5 km spacing between LTE transmitters. A typical simulation result is shown in Figure below.

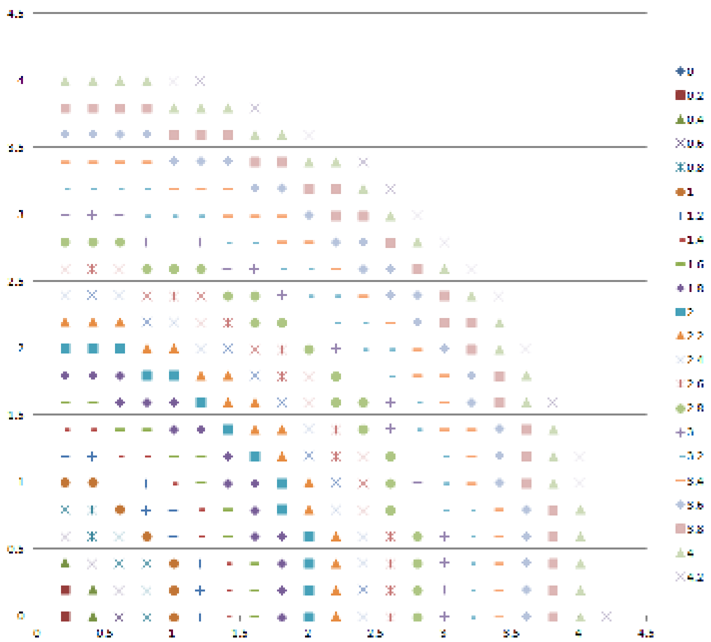


Figure 180: LTE network, 4.5 km site spacing, offset from narrowband transmitter

Table 196 below shows the outage within the narrowband cell due to the combined interference from the LTE transmitters in this network configuration. The outage in non-interference conditions was 4.79%; the increase above this over the total coverage area of the narrowband transmitter is shown in the right hand columns.

Table 196: Simulation results with 4.5 km spacing, centred, within 500 m of LTE transmitter

Duplexer attenuation	Total outage				Increase in outage compared to S/N only			
	PMR frequency offset from LTE BW edge (MHz)				PMR frequency offset from LTE BW edge (MHz)			
	0.25	0.5	1	2	0.25	0.5	1	2
0 dB	13.20%	12.92%	12.28%		8.40%	8.12%	7.48%	
25 dB	5.56%	5.48%	5.53%		0.77%	0.68%	0.74%	
30 dB	5.43%	5.45%	5.40%	5.37%	0.63%	0.66%	0.61%	0.57%

Table 197 below shows the outage within 500 m of an LTE transmitter in this network configuration. The outage in non-interference conditions averaged 2.6% over the 500 m radius circles around the LTE transmitters.

Table 197: Simulation results with 4.5 km spacing, offset, within 500 m of LTE transmitter

Duplexer attenuation	Total outage				Increase in outage compared to S/N only			
	PMR frequency offset from LTE BW edge (MHz)				PMR frequency offset from LTE BW edge (MHz)			
	0.25	0.5	1	2	0.25	0.5	1	2

0 dB	49.74%	48.05%	47.34%		47.14%	45.46%	44.74%	
25 dB	16.06%	16.51%	16.31%		13.46%	13.91%	13.71%	
30 dB	16.48%	16.29%	16.39%	15.08%	13.88%	13.70%	12.79%	12.48%

A6.2.5 **Observations of results**

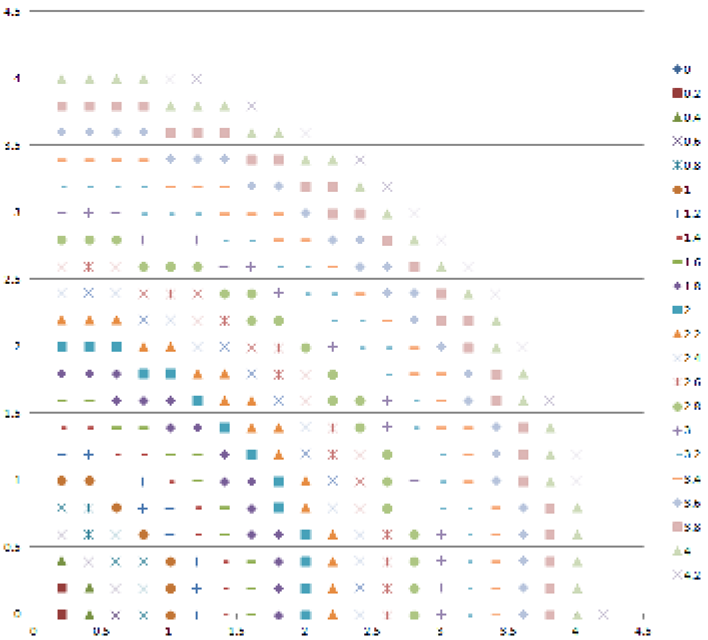
From the results, it is apparent that the density and placement of the LTE transmitter network is critical to the interference results for the narrowband network. If an acceptable degradation in coverage for a narrowband network is 1%, the higher density LTE network exceeds this in either of the two network layouts.

The LTE transmitter requires a duplexer to reduce out-of-band emissions in the narrowband mobile receive band at all separations. Of the two values used in simulations, the increase in out-of-band emission (OOBE) attenuation from 25 dB to 30 dB only has marginal effect; this is because the intermodulation performance in the receiver is already the dominant effect when 25 dB OOBE attenuation is provided. During the simulations, some experiments were carried out with higher attenuations (40 and 50 dB), but the results showed no improvement.

The degradation within 500 m of the LTE transmitter site is only under 10% in the case that the LTE transmitter is co-sited with the narrowband transmitter in the 4.5 km LTE site spacing simulation. Because of this, a further simulation was carried out to look at placement of the LTE transmitter within the narrowband transmitter coverage area.

A6.3 RESULTS FOR LTE TRANSMITTER PLACEMENT

As described in section 5.1, interference simulations from an LTE transmitter were carried out at 0.2 km radius intervals from the narrowband transmitter, and the results mapped to a 0.2 km x 0.2 km pixel grid within the circular 4.2 km radius of the narrowband coverage area. An illustration of the mapping over one quarter of the area is



shown in

Figure 181 below.

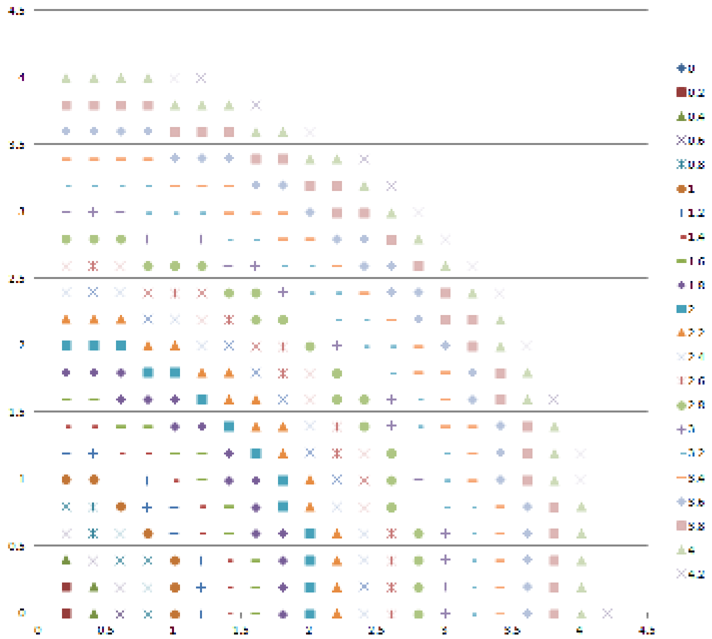


Figure 181: Mapping cell radius simulations to pixel grid

The simulations were carried out at 500 kHz offset between the edge of the LTE wanted transmitter bandwidth and the narrowband mobile receiver frequency, using a 30 dB duplexer attenuation.

Results at different radii are as follow:

Table 198: Simulation results for outage within 500 m of LTE transmitter at varying distance from narrowband transmitter site

Distance from PMR Tx (km)	Number of pixel locations	PMR mean signal strength (dBm)	Total outage within 500 m	S/N outage with no interference	Increased outage with interference
4.2	60	-91.27	24.51%	10.88%	13.63%
4.0	112	-91.17	24.33%	9.36%	14.97%
3.8	116	-90.81	22.44%	8.06%	14.38%
3.6	112	-90.27	21.58%	8.91%	12.67%
3.4	112	-89.38	20.46%	6.53%	13.93%
3.2	112	-88.10	18.72%	5.14%	13.58%
3.0	84	-87.66	16.72%	4.67%	12.05%
2.8	88	-86.39	14.89%	3.15%	11.74%
2.6	88	-85.11	15.83%	2.39%	13.44%
2.4	68	-84.16	13.48%	1.72%	11.76%
2.2	72	-82.70	12.47%	1.64%	10.82%
2.0	56	-81.27	12.75%	1.10%	11.65%
1.8	68	-79.69	10.77%	0.41%	10.36%
1.6	48	-77.75	9.86%	0.37%	9.50%
1.4	40	-75.88	9.82%	0.18%	9.63%
1.2	40	-73.32	8.10%	0.09%	8.01%
1.0	28	-70.53	7.57%	0.05%	7.52%
0.8	32	-67.11	6.26%	0.00%	6.26%
0.6	16	-63.56	5.34%	0.00%	5.34%
0.4	12	-57.46	5.73%	0.00%	5.73%
0.2	8	-54.20	4.07%	0.00%	4.07%
0.0	1	-52.45	4.16%	0.00%	4.16%

Using the number of locations at each radius as a weighting factor, the average increase in interference within 500 m of an LTE transmitter at any point in a cell is 12.08%.

A6.4 DISCUSSION OF RESULTS

The results show that the placement of LTE cells with respect to the narrowband transmitter coverage area is important when considering the results. They also show that within a 500 m radius of an LTE site, significant degradation of the narrowband coverage will result (from approximately 4% to 14%) and the acceptability of this to the narrowband service will have to be taken into account.

The LTE transmitter will require a duplexer to reduce out-of-band emissions to the level that intermodulation in the victim receiver becomes dominant. This appears to be at about 25 dB attenuation.

Further attenuation does not add significant improvement because of the intermodulation effect. The results are relatively little affected by increased frequency spacing from the edge of the LTE transmitter (because of the bandwidth and therefore the spread of frequencies over which intermodulation is caused). However the practical limit for attenuation curves in duplexers will limit the minimum spacing between LTE transmitter and victim receiver.

ANNEX 7: LTE IMPACT ON TETRAPOL

For SEAMCAT simulations, frequency allocation has been performed as presented in Figure 182 below.

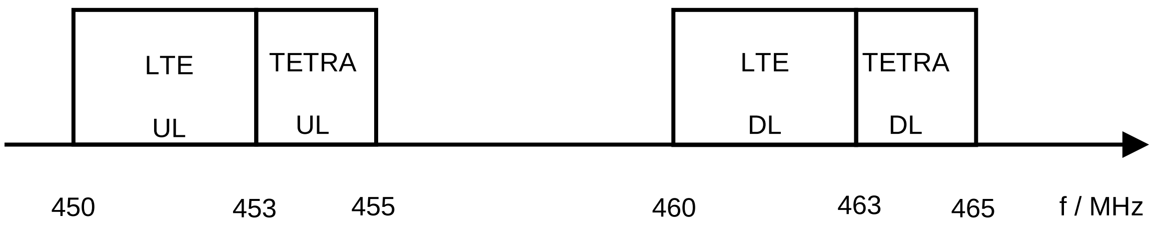


Figure 182: Illustrative Frequency Allocation of the 450-470 MHz Showing LTE and Tetrapol

In the simulations, the TETRAPOL Network is considered to be a 'Single Cell', centre of 'Infinite Network' with 'No Co-channel' Interference. This scenario which does not consider any co-channel interference within the NB system, is used for comparison with LTE PPDR purposes.

A7.1 LTE BS IMPACT ON TETRAPOL BS

Table 199 below gives the interference probability as calculated with SEAMCAT when combining unwanted emissions and blocking effects. Interference probabilities are given for the LTE BS emission mask minimum requirements, as well as with 25 dB and 30 dB additional attenuation to this mask for protection of the BS receiver against own or different BS.

Table 199: eMTC LTE BS impact on Tetrapol BS

Interferer Density (LTE BS / km²)	Cell Radius (km)	Interference Probability with BS emission mask minimum requirements [%]	Interference Probability with 25 dB additional attenuation compared to BS emission mask	Interference Probability with 30 dB additional attenuation compared to BS emission mask
Single interferer	-	20.41%	1.03%	0.62%
0.0018	8.5	22.33%	1.13%	0.60%
0.015	2.93	66.14%	6.60%	3.93%

For comparison purposes, the corresponding figures of PPDR probability of interference on Tetrapol are given in the Table 200 below (extracted from table 8 in ECC Report 240):

Table 200: LTE PPDR BS impact on Tetrapol BS (from ECC Report 240, for comparison)

Interferer Density (LTE BS / km²)	Cell Radius (km)	Interference Probability with BS emission mask minimum requirements	Interference Probability with 25 dB additional attenuation compared to BS emission mask
0.005	5.06	20.49%	1.13%
0.0091	3.75	30.66%	2.25%
0.01	3.58	32.63%	2.31%
0.02	2.53	47.26%	4.65%
0.05	1.60	66.31%	10.80%

As expected, interference probabilities of an eMTC LTE-system are significantly lower than in the comparable case of a PPDR-LTE system.

The impact of the LTE BS emission mask on Tetrapol BS is high when considering an isolated Tetrapol BS. By introducing 25 to 30 dB additional attenuation on the LTE BS emission mask within the considered Tetrapol BS reception band, the interference probability is reduced from up to 66% to well below 4% for even the worst conditions.

Please note that duplexer needed to protect the LTE400 BS reception band and providing 90dB attenuation will also provide attenuation to protect the narrow band BS reception band even in case of dense LTE400 networks.

A7.2 LTE BS IMPACT ON TETRAPOL MS

The three-sector LTE BS transmits at 461.5 MHz whereas the Tetrapol MS receive signals coming from Tetrapol BS between 463 and 465 MHz. The victim frequency is randomly chosen (discrete distribution option). Table 201 below gives the interference probability as calculated with SEAMCAT for the M2M/IoT scenario. For comparison purposes, 202 shows the corresponding results for the PPDR scenario, as in Table 9 of ECC Report 240. The shaded fields correspond to interferer densities that are not relevant to the M2M/IoT scenario, but are included to compare the results with the corresponding scenarios presented in ECC Report 240.

Table 201: eMTC LTE BS impact on Tetrapol

Interferer Density (LTE BS / km²)	Cell Radius (km)	Interference Probability with minimum requirements	Interference Probability with 25 dB additional attenuation compared to BS emission mask
Single Interferer	-	2.06%	0.08%
0.0018	8.5	1.99%	0.07%
0.015	2.93	11.55%	0.06%

Table 202: LTE PPDR BS impact on Tetrapol MS (from ECC Report 240, for comparison)

Interferer Density (LTE BS / km²)	Cell Radius (km)	Interference Probability with minimum requirements
0.005	5.06	0.32%
0.0091	3.75	0.61%
0.01	3.58	0.72%
0.02	2.53	1.32%
0.05	1.60	3.34%

The LTE BS minimum requirements are in many cases offering a sufficient level of protection with regards to Tetrapol MS. However, in dense networks, additional protection might be required. In those cases, introducing an additional attenuation of 25 dB would eliminate outages almost completely.

A7.3 LTE UE IMPACT ON TETRAPOL BS

Table 203: eMTC LTE UE impact on Tetrapol BS

Interferer Density (LTE UE / km²)	Interference Probability with minimum requirements
0.089	0.067%
0.179	0.100%
0.268	0.101%
0.358	0.129%
0.447	0.115%
0.537	0.095%

The impact of LTE UE on Tetrapol BS is negligible and absolutely acceptable from an operational point of view. As expected, the interference levels are lower than the corresponding figures from ECC Report 240 (extracted from table 10), for reference given in Table 204.

Table 204: LTE PPDR UE impact on Tetrapol BS (from ECC Report 240, for comparison)

Interferer Density (LTE UE / km²)	Interference Probability with minimum requirements
0.027	0.80%
0.082	0.13%
0.137	0.33%

A7.4 LTE UE IMPACT ON TETRAPOL MS

The LTE UE transmits at 451.5 MHz whereas the Tetrapol MS receive signals coming from Tetrapol BS between 463 and 465 MHz. The victim frequency is randomly chosen (discrete distribution option) in SEAMCAT

Table 205 below gives the interference probability as calculated with SEAMCAT when combining unwanted emissions and blocking effects. The assumed LTE UE emissions are considering 3GPP minimum requirements.

Table 205: eMTC LTE UE impact on Tetrapol MS

Interferer Density (LTE UE / km²)	Interference Probability with 3GPP MS Spectrum Mask Minimum Requirements
0.089	0.067%
0.179	0.100%
0.268	0.101%
0.358	0.129%
0.447	0.115%
0.537	0.095%

The impact of LTE UE on Tetrapol MS is negligible and absolutely acceptable from an operational point of view. As expected, the interference levels are lower than the corresponding figures from ECC Report 240 (extracted from table 11), for reference given in Table 206.

Table 206: LTE PPDR UE impact on Tetrapol MS (from ECC Report 240, for comparison)

Interferer Density (LTE UE / km²)	Interference Probability with 3GPP MS Spectrum Mask Minimum Requirements
0.027	0.05%
0.082	0.04%
0.137	0.16%

A7.5 CONCLUSIONS

Simulations for the LTE scenario in the 400 MHz band have been performed using SEAMCAT with eMTC Parameters. The interference calculated is from an eMTC LTE Network into a Tetrapol.

In both the downlink and uplink, the interference percentages calculated for eMTC LTE on Tetrapol are lower than the figures shown in ECC Report 240 for PPDR application.

The interference levels for UL for eMTC LTE on Tetrapol are well below 1% and are acceptable from the operational point of view with no additional attenuation.

Of the three cases that were studied, only the eMTC LTE BS on Tetrapol BS case may need a 25 dB attenuation additional to the BS emission mask minimum requirement. However, duplexer needed to protect the LTE400 BS reception band and providing 90dB attenuation will also provide attenuation to protect the Tetrapol BS reception band even in case of dense LTE400 networks.

ANNEX 8: EFFECT OF THE LTE TX DUPLEXER ATTENUATION

The intermodulation simulations done in this Annex do not meet all conditions for proper intermodulation simulation. As a consequence the results of these simulations should be considered very cautiously.

A8.1 INTRODUCTION

In a situation where LTE transmitters are close in frequency to narrowband receivers, there are three forms of interference which affect the performance of the narrowband PMR. These are:

- Out-of-band emissions from the LTE BS Tx;
- Blocking in the PMR receiver;
- Intermodulation performance of the PMR receiver.

The first of these can be reduced by a filter on the LTE BS Tx, which can also be the same filter that is used for duplex operation of the LTE BS Tx and Rx. The second and third are due to non-linearity in the MS receiver, and so cannot be affected by improvements at the BS.

A8.2 SIMULATION DESCRIPTION

For the simulations, an LTE BS was placed at three spot locations within the coverage of a PMR cell. Simulations were carried on at a set of locations 200 m apart within a 500 m radius of the LTE BS location to assess the effect of interference within the area close to the LTE BS. The spot locations for the LTE BS were chosen at 1km distance from the PMR BS, for strong signal effects, 2.6 km from the PMR BS (half the PMR cell radius of 5.2 km) and 4.6 km from the PMR BS (so that the 500 m radius circle around the LTE BS was fully inside the PMR BS coverage area).

For each simulation, the PMR signal strength was simulated using the SEAMCAT urban extended Hata propagation model with range dependent standard deviation, as specified in ECC Report 252, Annex 17, and the signal/noise ratio calculated. The LTE signal strength at the PMR receiver was also estimated using the same model; and then the effects of out-of-band emissions and intermodulation performance calculated, to provide a signal/(interference + noise) calculation for the simulation. A point that failed the signal/(interference + noise) ratio requirement was counted as an outage only if the signal/noise ratio in the absence of interference met the criteria for the receiver. Thus within the 500 m radius of the LTE BS, the additional outages due to interference could be counted, and presented as a percentage of all locations within that 500 m radius. Five simulations were conducted for each measurement point within the stated 500 m radius of the LTE cell.

The PMR frequency was selected to be 2.5 MHz from the edge of the LTE transmission.

The LTE BS parameters were as shown in Table 207 below.

Table 207: LTE BS parameters

Broadband LTE Inputs	
LTE B/W	5 MHz
LTE Tx Power per LTE Carrier (dBm)	43
LTE Antenna Height (m)	30
LTE Antenna System Gain (dBi) (antenna gain – feeder loss)	13

The out-of-band emissions for the LTE BS are taken from 3GPP TS 36.104, Table 6.6.3.2.1-3 operating band emissions within 5 MHz of the edge of the carrier for a Category B wide area BS <1 GHz.

The PMR system parameters were as shown in Table 208 below.

Table 208: PMR Base station characteristics

PMR Base station characteristics	
e.i.r.p. (dBm)	49
Antenna height (m)	30
Range (km)	5.2
PMR Receiver Settings	
NB Rx Antenna gain (dBi)	0
Equivalent Noise Bandwidth (kHz)	18
Channel Perf. Criterion (dB CNR)	19
LMR Receiver Specifications	
Receiver Static Sensitivity (dBm)	-112
Rx Co-channel Rejection (CCR) Ratio (dB)	10
Assumed Receiver IMR3 (dB)	65
Assumed Receiver IMR5 (dB)	75

The receiver specifications were those from TETRA, taken from ETSI EN 300 392-2. Channel Performance Criteria equates to the required signal/noise or signal/interference ratio specifications from that standard.

To show the effects of duplexer attenuation, the out-of-band emissions were reduced in 5 dB steps from 0 dB to 35 dB and the sets of simulations repeated. The sets of simulations were repeated at different offset frequencies from the edge of the wanted bandwidth of the LTE transmitter, specifically at 500 kHz, 2.5 MHz and 4.5 MHz offset to look at results at edges and middle of an adjacent band containing narrowband receivers.

A8.3 SIMULATION RESULTS

The simulation results are shown in the figures below.

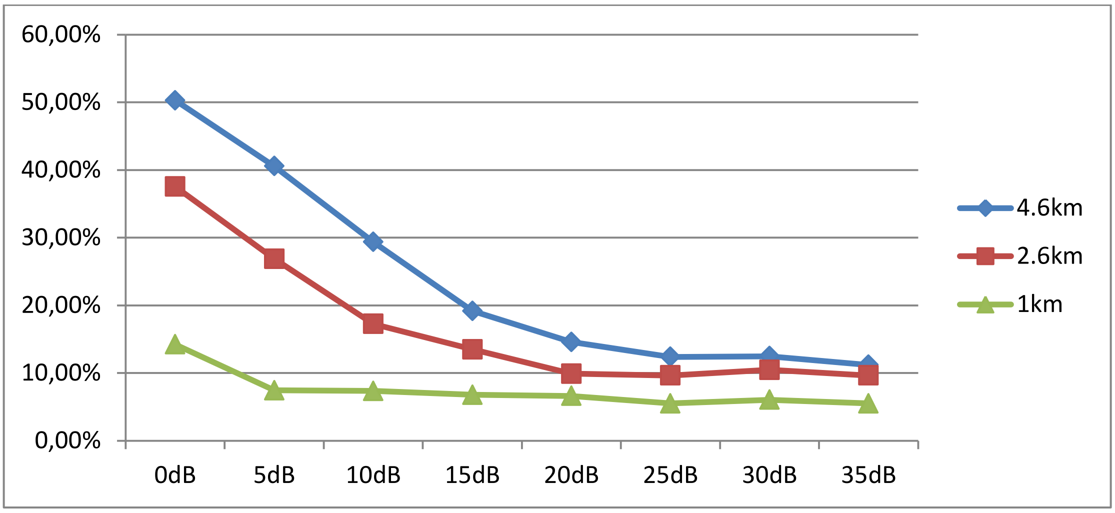


Figure 183: Simulation results at different duplexer attenuations of OOBE from LTE BS at 500 kHz offset from edge of LTE transmitter bandwidth

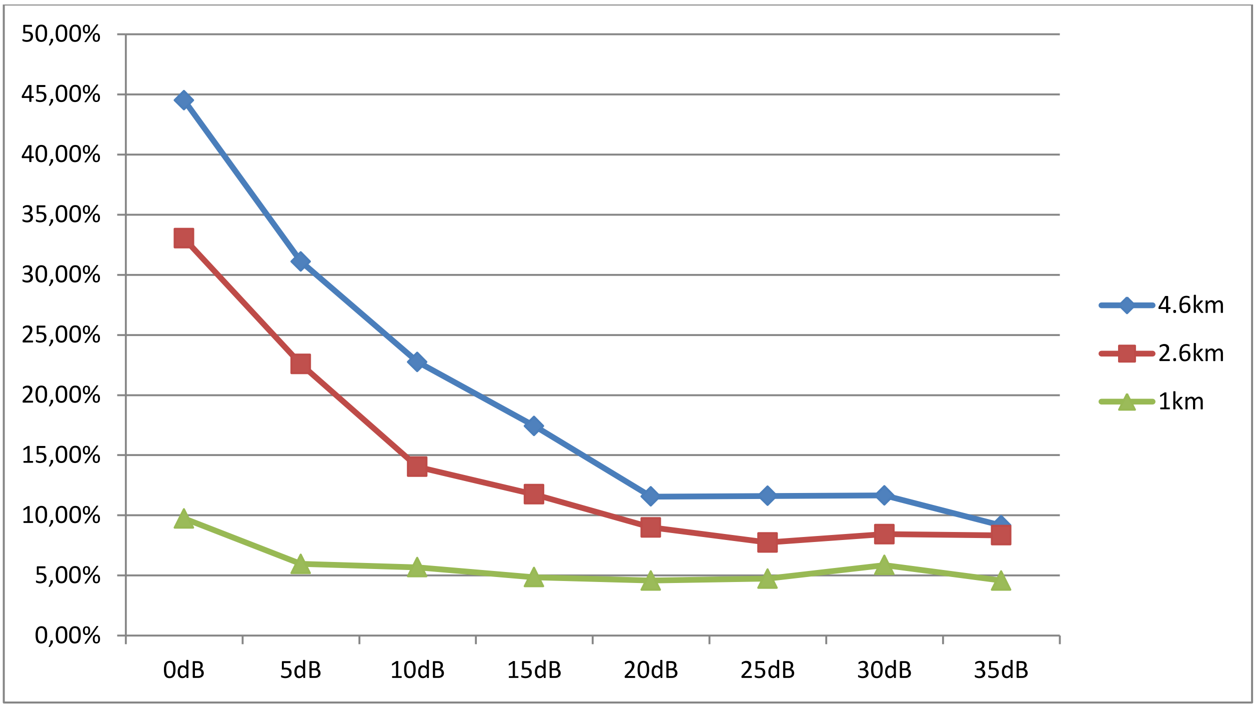


Figure 184: Simulation results at different duplexer attenuations of OOBE from LTE BS at 2.5 MHz from edge of LTE transmitter bandwidth

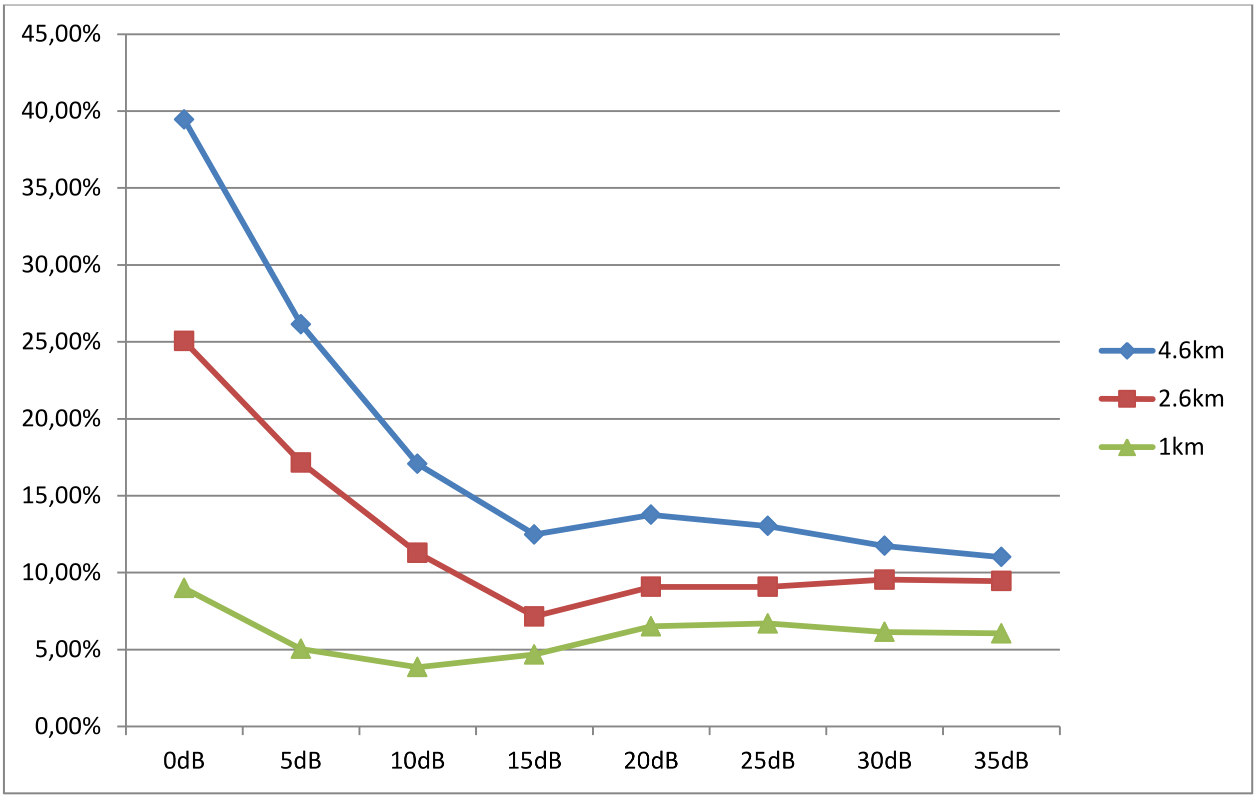


Figure 185: Simulation results at different duplexer attenuations of OOBE from LTE BS at 4.5 MHz from edge of LTE transmitter bandwidth

A8.4 ANALYSIS OF RESULTS

Figure 183 to Figure 185 show the variation in interference within a 500 m radius of an LTE BS with duplexer attenuation of OOBE with the LTE BE placed at 1 km, 2.6 km and 4.6 km from the PMR BS, using TETRA as the BS and victim MS technology.

It is apparent that increasing duplexer attenuation up to 20 dB reduces the level of interference as the out-of-band emissions from the LTE BS are attenuated. However beyond 20 dB, there is no further reduction, which implies that intermodulation within the victim PMR Rx becomes the dominant effect.

A8.5 CONCLUSIONS

Where interference is incurred to a victim PMR receiver in proximity of an LTE BS, this interference can be mitigated by filtering at the LTE BS, such as from the duplexer filter, until approximately a value of 20 dB attenuation at the wanted frequency is reached. Beyond this, little further improvement can be seen as Rx intermodulation effects become dominant.

ANNEX 9: GUIDANCE ON MEANS TO SOLVE INTERFERENCE CASES BETWEEN LTE AND DTT

This annex provides a list of potential mitigation techniques which may be considered by national administrations to solve or minimise the interference cases between LTE and terrestrial broadcasting on a local / regional / national basis. They would need to be implemented in addition to the techniques (BEM and guard band) addressed in this Report. It should be noted that this list is not exhaustive and that, for example, additional spectrum engineering techniques may be considered, such as additional frequency offset or restricted BEM.

The OOBE value -42 dBm/8 MHz for LTE UE in Table 3 of the Report has been derived with regard to fixed DTT reception. Administrations who wish to consider portable-indoor DTT reception may need, on a case-by-case basis, to implement further measures at a national/local level (see also CEPT Report 53). Examples of potential mitigation techniques which may be considered by administrations include using additional DTT filtering, reducing the in-block power of the TS, reducing the bandwidth of the TS transmissions, or using techniques contained in the non-exhaustive list of potential mitigation techniques given in CEPT Report 30

Interference from broadcasting transmitters to LTE BS receivers either due to transmitter in-band power or unwanted emissions may arise. In such cases, appropriate mitigation techniques can be applied on a case-by-case basis at national level.

The potential mitigation techniques are divided in 2 main categories:

A9.1 LOCAL INTERFERENCE MANAGEMENT BETWEEN LTE BS AND DTT

Table 209: Network mitigation techniques to solve local interference situations

Mitigation technique	Comments
Co-site LTE BS and DTT transmitters, including DTT repeaters (see also CEPT Report 21 [37])	Co-siting could be an efficient measure to minimise interference, if LTE BS could be deployed at DTT Tx site. Technical constraints are: antenna coupling, tilt and direction. A special case of co-siting is the potential use of on-channel DTT repeaters or DTT booster. Additional costs for co-siting of an LTE base station and DTT Transmitter have to be calculated.
Reducing the power of interfering transmitter (LTE BS) (see also CEPT Reports 21 [37] and 23 [38])	Reducing the LTE BS power could be an efficient measure to reduce interference problems when they occur, e.g. for cases where the adjacent broadcasting channels or image channels are used in the same area, or to reduce overloading of TV receivers. Since the LTE BS density is very high, this may affect a high number of the BS in the mobile network and lead to a reduction in coverage. The level of the required reduction in BS power depends on the level of the wanted broadcasting signal to be protected. This approach was part of the introduction of LTE 800 in Germany.
Adjusting the LTE BS transmitter antenna characteristics (height, pattern, tilt and direction) taking into account local conditions (see also CEPT Reports 21[37] and 23 [38])	General: Could be an efficient measure to reduce interference problems when they occur (e.g. reduction of overloading of DTT receiver). This technique is preferably applied when planning the LTE network. Fixed reception: Increasing the path loss by adjusting the transmitter antenna height, e.g. avoiding line-of-sight will reduce the interference impact. Values of up to 20-30 dB decoupling are the maximum to be expected, at some locations. Portable reception:

Mitigation technique	Comments
	Portable indoor reception is quite complex due to wave propagation inside a room and therefore the above mentioned measures cannot be taken into account. This approach was part of the introduction of LTE 800 in Germany.
Increasing the power of DTT transmitters (see also CEPT Reports 21 [37] and 23 [38])	General: Increasing the power of DTT transmitters to increase the wanted field strength within the GE06 constraints. Alternatively, installing additional DTT transmitter(s) to cover the area concerned. An increase of the power of the broadcasting transmitter requires planning studies taking into account possible local difficulties, i.e. possible interference on DTT reception from neighbouring DTT transmitters This may also create interference to other areas where the channel is used (e.g. due to self-interferences) and not be in conformity with cross-border coordination. Installing additional DTT transmitters need further technical studies. Economic impact of increasing power of the Broadcasting transmitter needs to be evaluated.

A9.2 HARDWARE MODIFICATION IN DTT RECEIVER OR LTE BS

Table 210: Hardware mitigation techniques to solve local interference situations

Mitigation technique	Comments
Rejection filter for 450-470 MHz	Measure to reduce local interference (including overloading). Rejection filters can be installed to reject a single carrier or channel (e.g. LTE). For the rejection of a complete range (below 470 MHz), the bandwidth will affect the required performance of the filter. A rejection filter just limits the in-band signal reception (below 470 MHz) but the out-of-band emission is not reduced Broadcast coverage area is reduced, due to insertion loss of the additional filter (for example 1 to 3 dB). This needs to be taken into account for existing and future DTT networks. More detailed studies on feasibility of such rejection filters are needed. Changes to the existing DTT standard may be required with possible increase in the receiver cost.
High-pass filters in DTT Receivers, (above 470 MHz)	General: Is a measure to minimise overloading of as well as to reduce interferences into DTT receivers by LTE UL, where no VHF DTT channels are to be received. Could be realised as an additional filter for all new receivers. Low pass filters just limits the in-band signal reception (450 - 470 MHz), but not the OOB emission above 470 MHz. A filter has an impact on the link budget (insertion loss, contributes to receiver noise figure). The insertion loss (for example 1 to 3 dB) will reduce broadcast coverage area and needs to be taken into account for existing and future DTT networks; studies on impact are needed. Changes to the existing DTT standard are required, no impact on legacy receivers. Also increases receiver cost. Limited impact on the mitigation of interference from LTE DL, due to

Mitigation technique	Comments
	limited attenuation within small frequency separation and taking into account reasonable costs, size and insertion loss. Higher impact on the mitigation of interference from LTE UL. Fixed reception: In case an antenna amplifier is applied near the roof top antenna, the filter has to be installed before that amplifier at the roof. In the UK, France and Sweden filters were provided to solve interference issues for the similar case of LTE800. Portable reception: Active antennas cannot be used, they have to be replaced.
Improved filters in LTE BS transmitters (at 470 MHz)	LTE cell coverage area is reduced due to insertion loss of the filter. An improved filter would limit the OOB emissions but not the in-band emissions. This improves adjacent channel compatibility but not blocking and overloading. All countries that introduced LTE800 ensured that the OOB emissions were less than the most stringent limit in CEPT Report 30 [11]. This makes it a generally applicable mitigation solution.

A9.3 EXAMPLE OF IMPLEMENTATION

The 450 MHz band has been in use in Sweden, Norway and Denmark since the 1970's. Originally the band was used for the analogue MTD system which was replaced by the 1G NMT-450 system around 1981, this being replaced by a Code Division Multiple Access (CDMA) 450 system in 2003. In 2015 the networks migrated to 4G (LTE Band 31). Over the years though the system has changed, the transmission sites have largely remained the same. As such problems with transmissions from the sites will have largely been dealt with, probably in the days of analogue broadcasting[24]. As such given the many years of use of this band a change in transmission mode from CDMA to LTE would not have been expected to cause many additional problems.

Another factor that contributes to the low reported number of problems is the very low number of sites deployed. Site density is far lower (between 10 and 20 times lower) than a typical mobile network deployment, Table 211.

The lower operating frequency (450 MHz) may account for some reduction in site numbers but the main cause for the reduction in numbers is the architecture of the sites and the fact outdoor reception is targeted. The 450 MHz network in Scandinavia serves industries such as logging and mining located in remote areas not catered for by the main mobile or fixed line networks. To achieve this economically antenna are mounted high, typically on broadcast structures, to provide a wide area of coverage. Mounting an antenna high reduces its potential to cause interference, Figure 186.

Targeting outdoor reception (the licence has a 95% outdoor coverage obligation) means that there is no requirement to locate the LTE 450 MHz sites close to population to provide high enough field strength for indoor coverage. Transmission sites are thus generally located away from population leading to fewer instances of interference.

Whilst mounting antenna systems high above ground level reduces the interference potential, mounting on broadcast structures also reduces interference potential. 450 MHz sites co-sited with broadcasting are unlikely to cause problems as:

The wanted broadcast signal levels are likely to be high;

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[24] Roll-out of Tetra in the UK caused problems to TV reception

TV viewers are unlikely to be using amplifiers (no local amplifier overload issues – the main cause of 800 MHz base station interference)

Though LTE Band 31 is specified as 2 x 5 MHz, it is often only used as 2 x 3 MHz in that narrow duplex gap indicated in Figure 4 (note that the ACLR of the system measured appears to be of the order of 70 dB). This reduced bandwidth means that unwanted power falling in the broadcast band will be lower than that of a full 2 x 5 MHz deployment.

The type of network deployment used in Sweden, with few sites each having a large cell radius targeting outdoor reception, means there have been few cases of interference. Such a deployment, subject to decision of national regulator, could allow for a relaxed out-of-band limit.

For networks targeting 'indoor' reception network base station density would need to be significantly higher, and the base stations would have lower antenna heights and would need to be located closer to users, i.e. in populated areas. Such a deployment would not allow relaxation of the OOB limits and might need additional mitigation measures such as those described in Table 209 and Table 210 above.

Table 211: 450 MHz Site density – Sweden & Norway

Country	Band(s)	Number of sites	
Sweden	450 MHz	~460	95% area coverage
	700 MHz – 2.6 GHz	7500 ~ 8500	35% ~ 55% area coverage (sites designed to mainly provide urban & suburban coverage)
Norway	450 MHz	~550	75% area coverage
	700 MHz – 2.6 GHz	5000 ~ 8000	27% ~ 33% area coverage (sites designed to mainly provide urban suburban coverage)

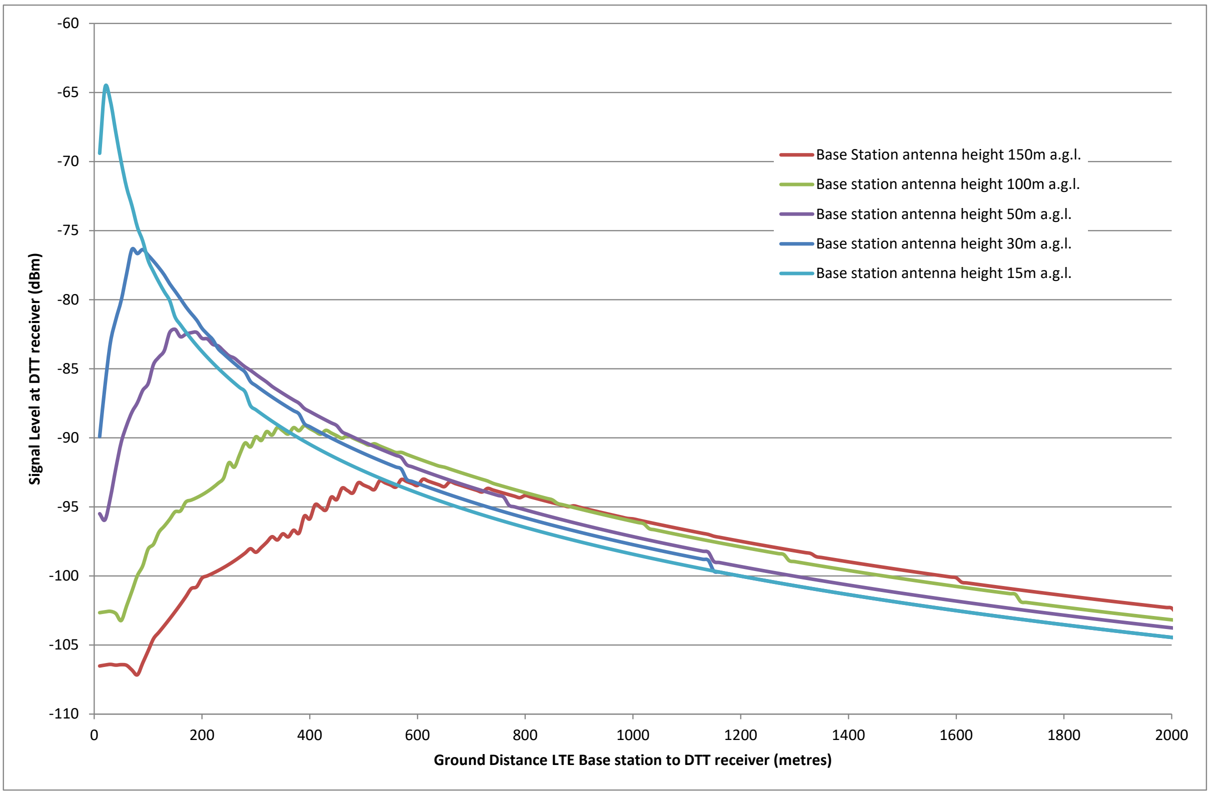

Figure 186: Signal level[25] in the broadcast band due to 450 LTE at DTT receiver for LTE BS antenna heights of 30m, 50m, 100m and 150m

Figure 187: LTE 450 MHz main site for Copenhagen (image source google maps)

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[25] Discontinuity in curves caused by discrete steps resulting from use of Excel VLOOKUP function

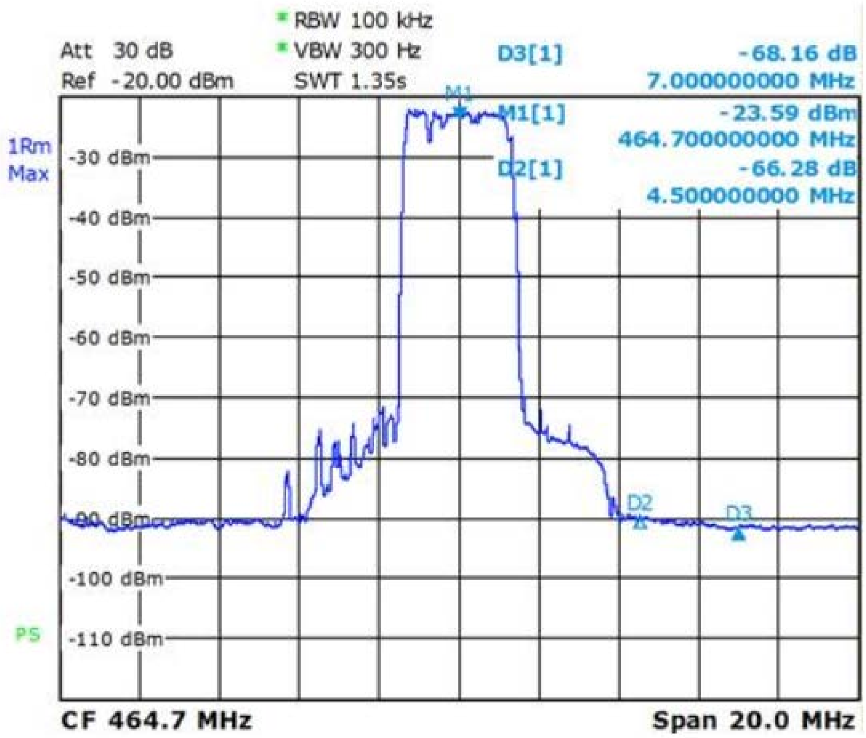


Figure 188: Off-air measurement of 450 MHz LTE base station transmission

A9.4 DISCUSSION

Depending on the network deployment, there may be areas/regions where interference to the fixed and/or portable indoor DTT reception is likely to occur. From this first assessment, it can be assumed that a single mitigation technique may not be sufficient to protect broadcasting services from interference by LTE. A combination of two or more mitigation techniques may lead to a sufficient protection of broadcasting services.

The mitigation measures to avoid interference caused by adjacent OOB emissions differ from those for blocking or overloading by in-band emissions. Blocking and overloading are likely to occur by LTE transmission in close vicinity to the DTT reception; in the case of portable reception the interference will be dominated by the LTE terminal. The adjacent OOB interference is likely to be caused by the LTE BS operating just below 470 MHz.

For most of the techniques mentioned above – e.g. appropriate filters – and for choosing a proper combination of mitigation techniques, national experience has been collected for the similar case of LTE800 and for at least one case of LTE450.

A9.5 PRACTICAL INFORMATION ON LTE 400 MHZ BASE STATIONS

A9.5.1 Examples of available LTE 400 MHz base stations

Table 212: Available LTE 450 MHz base stations

Available LTE 450 MHz base stations						
Vendor	Product name	Supported frequency	Supported bandwidth	Max transmit power	ACLR** above 470 MHz	Sector/Transmission mode
Nokia	FRAA Flexi RRH 2-pipe 450MHz 80W	FDD-LTE 450MHz (Band 31)	iBW 5MHz, occupied BW 1.3/3/5MHz options	2x40 W (49 dBm) = 64 dBm e.i.r.p.*	>75 dB/8 MHz for all configurations	Single/2TX MIMO

* 2Tx Pmax-Flexi cable loss+antenna gain = 49 dBm-0.5 dB+15.5 dB
**ACLR calculated in 8 MHz DTT channel

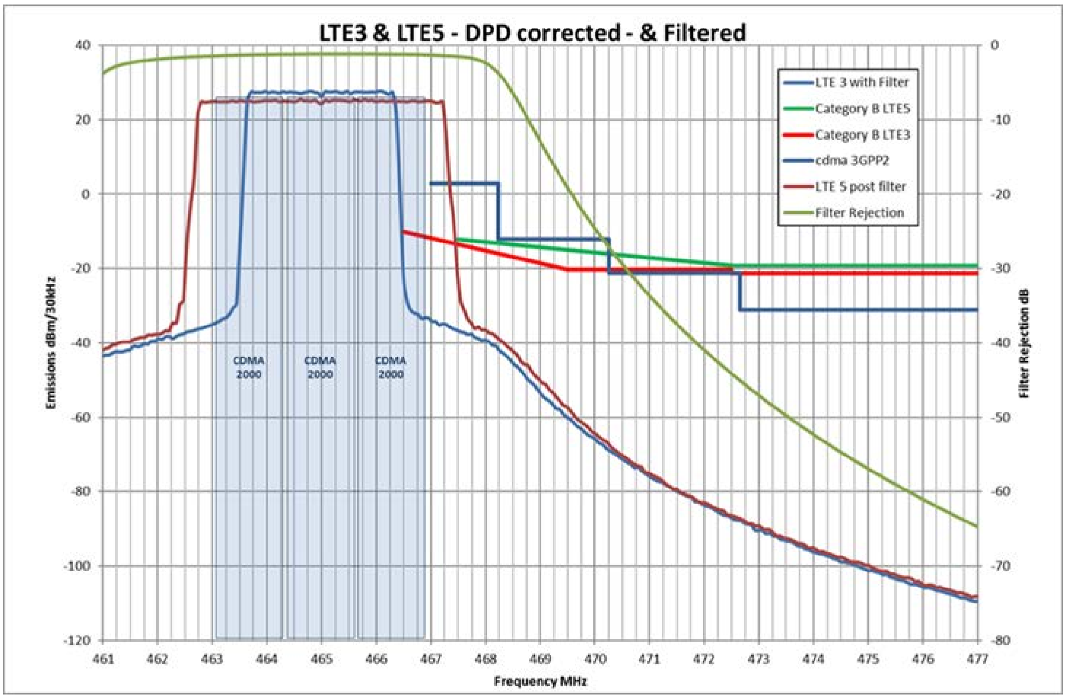


Figure 189: TX LTE450 (3 MHz and 5 MHz) Single Carrier 40W, Centre Frequency = 465 MHz

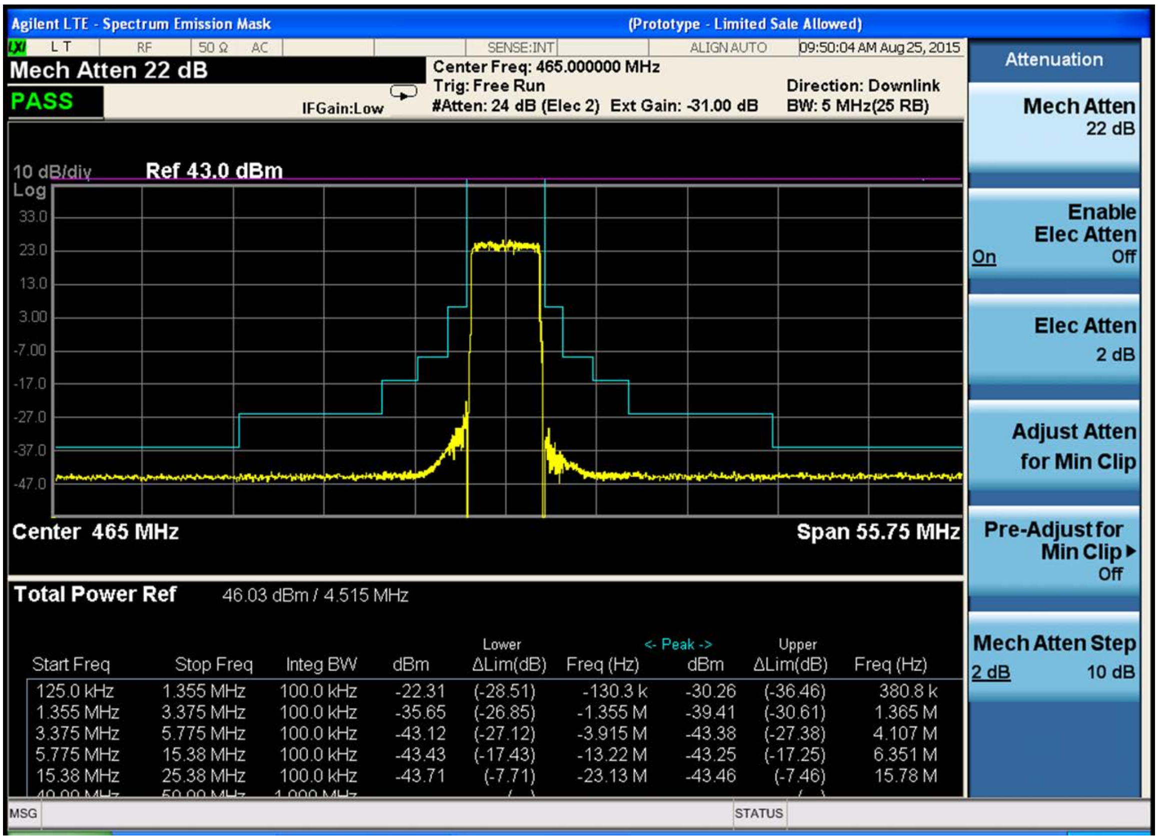


Figure 190: TX 1 LTE450 (5 MHz) Single Carrier 40W, Centre Frequency = 465 MHz

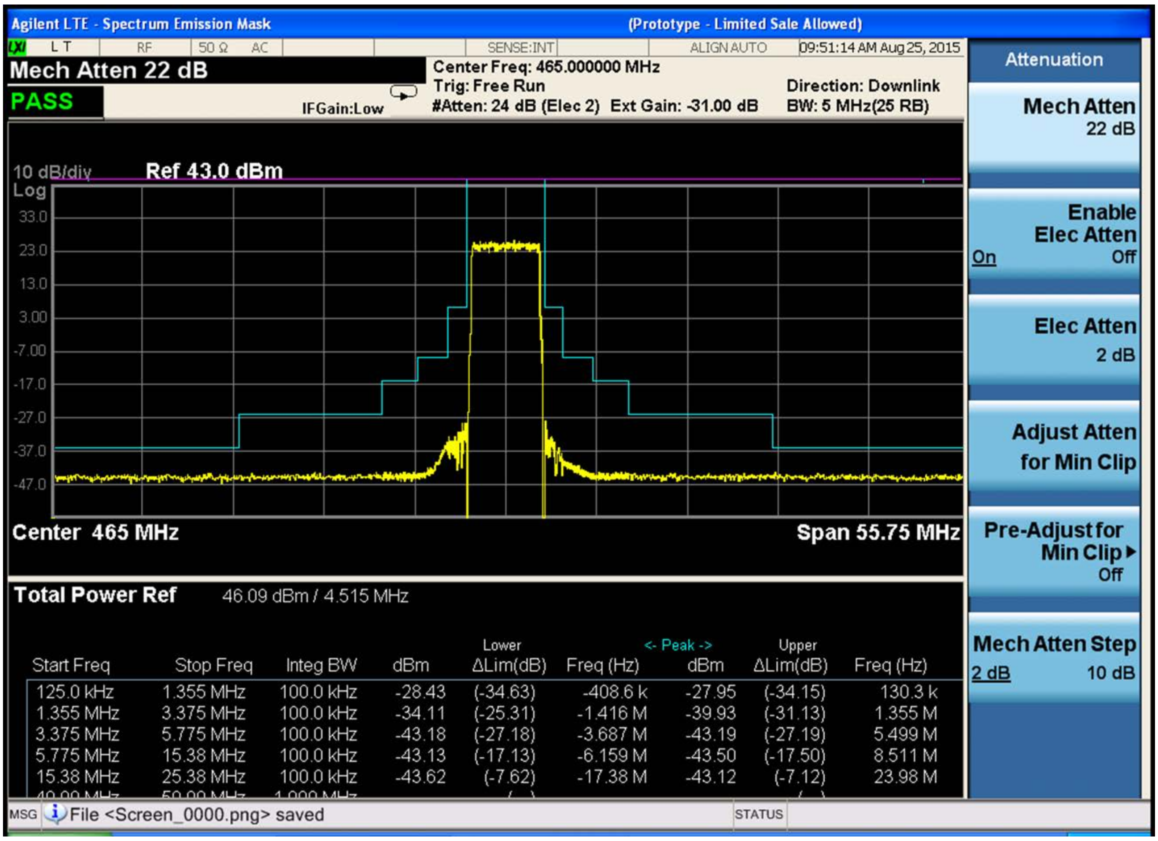


Figure 191: TX 2 LTE450 (5 MHz) Single Carrier 40W, Centre Frequency = 465 MHz

A9.5.2 Examples of available LTE 400 MHz base station antennas

Table 213: Available LTE 450 MHz XPol (MIMO/MISO) antennas

Available LTE 450 MHz XPol (MIMO/MISO) antennas			
Vendor	Sector	Configuration	Description
CommScope	Single	MIMO	XPol 410-512 MHz 65° 15 dBi - [h=1981mm]
Kathrein	Single	MIMO	XPol 380-500 MHz 88° 10.5dBi - [h=1007mm]
Kathrein	Single	MIMO	XPol 380-470 MHz 65° 14 dBi 0-14°AT - [h=1999mm]
Kathrein	Single	MIMO	XPol 380-500 MHz 65° 15 dBi - [h=2000mm]
MOBI	Single	MIMO	XPol 450-470 MHz 65° 15.5 dBi 0°T - [h=2202mm]
MOBI	Single	MIMO	XPol 450-470 MHz 65° 15.5 dBi 3°T - [h=2202mm]
MOBI	Single	MIMO	XPol 450-470 MHz 65° 15.5 dBi 9°T - [h=2202mm]

ANNEX 10: LTE IMPACT ON RADARS AT 410-430 MHZ

A10.1 LTE SPECTRUM MASK

Example of spectrum mask, with centre frequency = 425 MHz

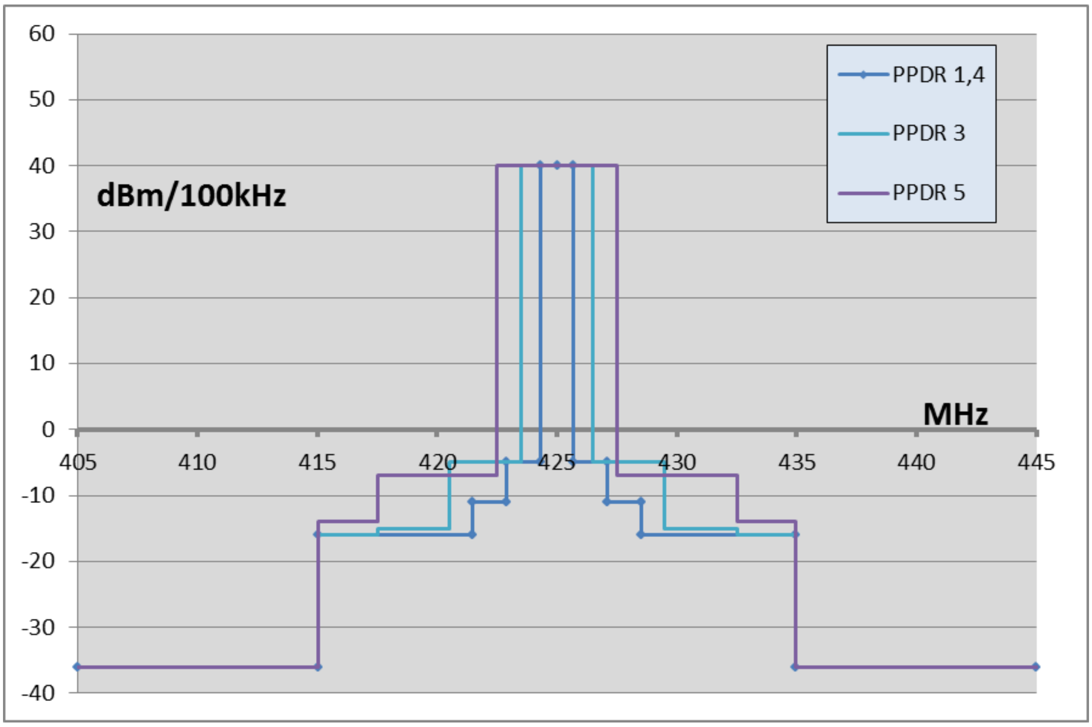


Figure 192: LTE emission mask

A10.2 COMPARISON OF PROPAGATION MODELS

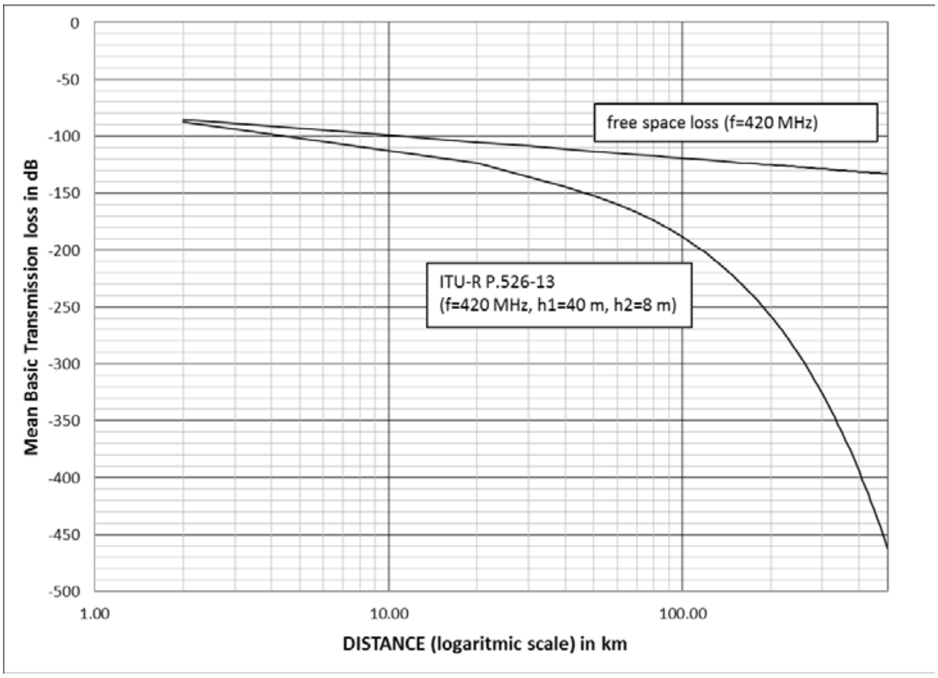


Figure 193: Transmission loss calculating with free space loss and Recommendation ITU-R P.526-13

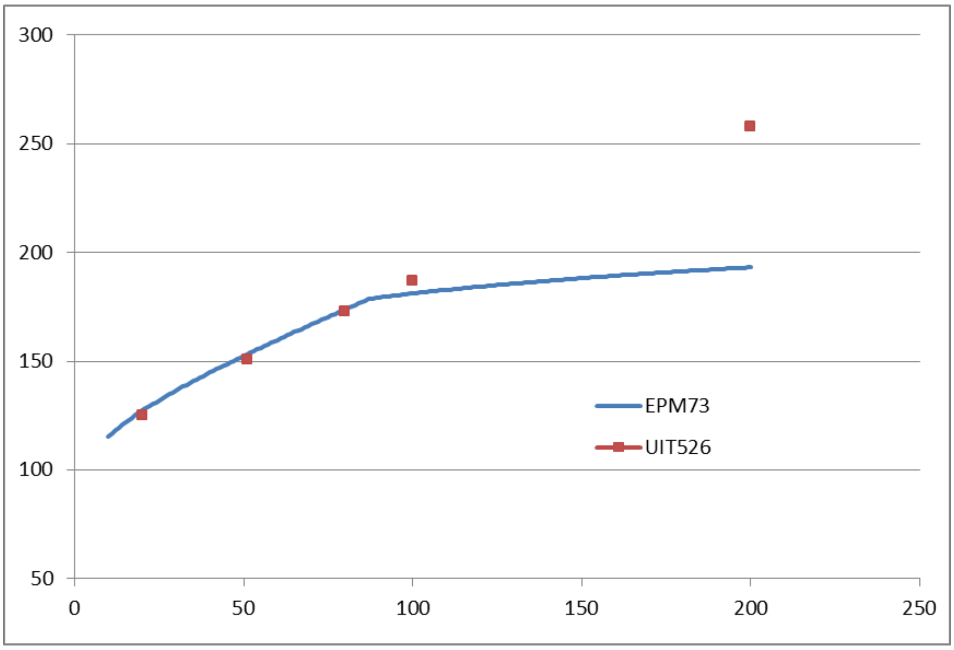


Figure 194: Transmission loss calculating with ITU-R P.526 and EPM73 (h1 = 40 m, h2 = 8 m)

The results of the two models ITU-R P. 526 and EPM73 are coherent. Beyond a specific distance, the two curves are differing. This is because EPM73 model is considering that tropospheric diffusion is the main mode of propagation. This mode of propagation (tropospheric diffusion) is not taken into account by ITU-R P. 526 model.

The additional transmission loss due to diffraction over a spherical Earth can be computed by the classical residue series formula. The ITU-R P.526-13 contains the applicable calculation method. A computer program GRWAVE, available from the ITU, provides the complete method. GRWAVE was used to obtain the path loss.

Figure 201 below illustrates the ITU-R P.526-13 model for airborne radars.

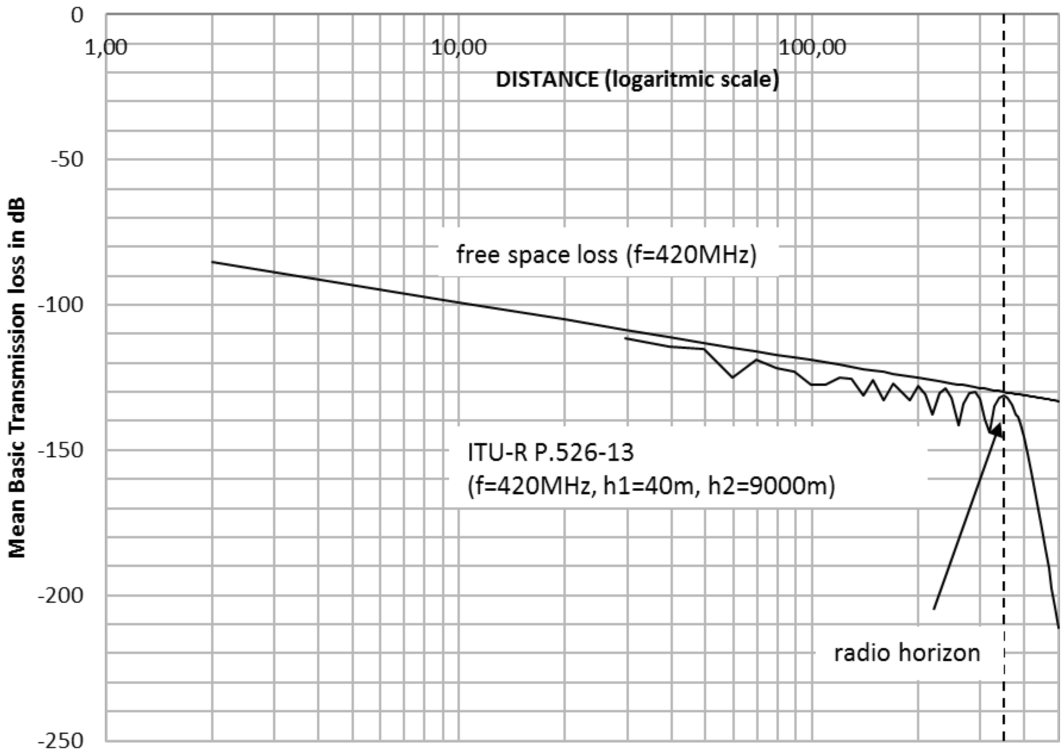


Figure 195: Transmission loss calculating with free space loss and ITU-R P.526-13

Table 214: Parameters of the propagation models situations

	Propagation model			
	General 450	MYRIAD	EPM-73	ITU-R P.526-13
Frequency (MHz)	150 – 2 000	200 – 5 000	40 – 10 000	0.1 – 10 000
Distance (km)	1 – 60	1 – 60	0 – 1 000	0 – 1 000
Digital map	use	use	not use	not use
Measurement	use	use	not use	not use
Propagation Mechanism	LOS diffraction	LOS/NLOS reflection diffraction	LOS reflection diffraction tropospheric scatter	LOS diffraction

The three distance regions can be specified in the VHF band. In the first region the most decisive propagation mechanism is LOS propagation and reflection. The limit of the first region is d_1 distance. This distance is close to the radio horizon. Propagation by diffraction is determinative in the second region, called 'diffraction region'. In the last region the most decisive propagation mechanism is tropospheric scatter. Boundary of the second and third regions is represented by the d_2. It is shown by the following Figure 196

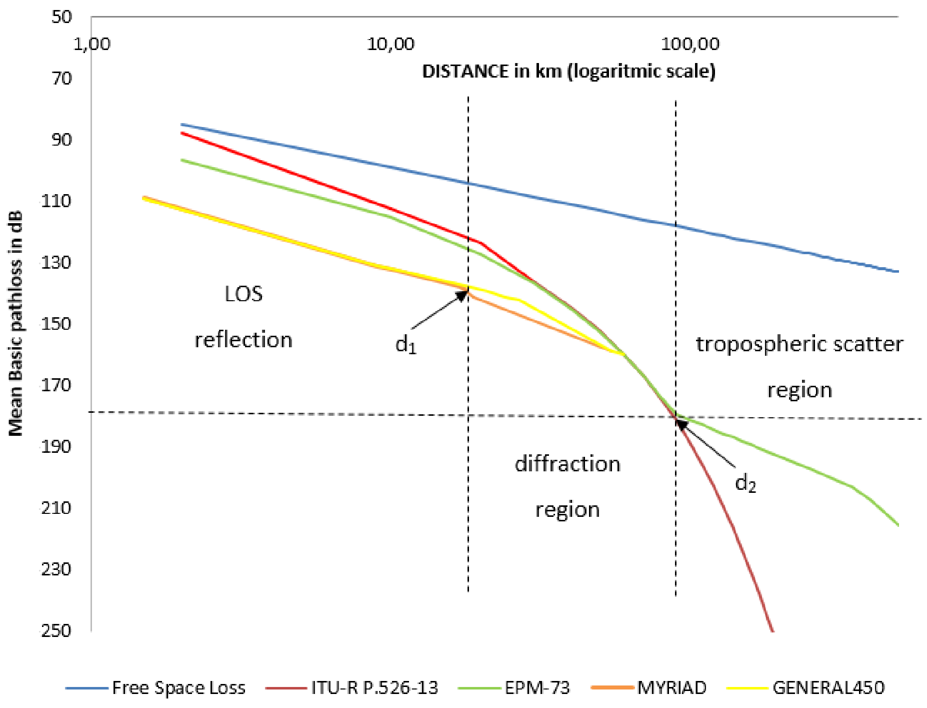


Figure 196: Used propagation models

The accuracy of the models that predict the path loss depends on the input parameters and the used propagation mechanism. For short distances (< 60 km) General 450 and MYRIAD model provide more realistic and accurate result, than EPM73 and ITU-R P.526-13 [31], because these models use digital maps tuned by measurements. Over these distances the EPM73 and ITU-R P.526-13 ensure very similar result. It is because both of the models based on propagation by diffraction in the diffraction region. In the tropospheric scatter region only EPM73 provides reliable result, because only this model uses the tropospheric scatter propagation mechanism.

A10.3 OVERVIEW OF CALCULATION IN THE CASE OF GROUND RADAR

Table 215: Separation distances for co- and adjacent channel (for ground radar)

LTE-BS →Radar		LTE-BS			Ground Radar			Dec (Polar)	Dec (Ant)	Minimum Coupling Loss (MCL) (dB)			Separation distance (km)	
Scenario ▼	Interferer main beam	P_e dBm	G_e dB	P_{fe} dB	G_r dB	P_{Fr} dB	IC dBm (1MHz)			Be/Br= 1/1.4 (1.5dB)	Be/Br= 1/3 (4.8dB)	Be/Br= 1/5 (6.9dB)	EPM73 (1)	ITU-R P.526 (1)
Co-channel	Victim main beam	37.5/41/43	15	2	38.5	0	-115.9	1.5	3	198.9	199.1	199	273/276/275	130 (<120*)
	Victim side lobes	37.5/41/43	15	2	5	0	-115.9	1.5	3	165.4	165.6	165.5	66	65
		dBm/MHz								Be/Br=0				
Adjacent channel ΔF_1 (20)	Victim main beam	6	15	2	38.5	0	-115.9	0	3	170.4	/	/	72.5	
	Victim side lobes	6	15	2	5	0	-115.9	0	3	136.9	/	/	29.6	
Adjacent channel ΔF_2 (13)	Victim main beam	-1	15	2	38.5	0	-115.9	0	3	163.4	/	/	62.9	58
	Victim side lobes	-1	15	2	5	0	-115.9	0	3	129.5	/	/	21.7	24
Adjacent channel ΔF_3 (8)	Victim main beam	-6	15	2	38.5	0	-115.9	0	3	158.4	/	/	56.2	55
	Victim side lobes	-6	15	2	5	0	-115.9	0	3	124.9	/	/	17.4	22
Spurious (-13)	Victim main beam	-26	15	2	38.5	0	-115.9	0	3	138.4	/	/	31.3	35
	Victim side lobes	-26	15	2	5	0	-115.9	0	3	104.5	/	/	4.1	5

Note 1: H_e = 30 m, H_r = 8 m

Note 2: In adjacent band Pe corresponds to OOBE level, for 1.4 MHz channel bandwidth.

*: The additional transmission loss due to diffraction over a spherical Earth can be computed by the GRWAVE computer program (available from the ITU) to obtain the path loss according to the classical ITU-R P.526-13 formula. The separation distance is 111 km for H_e = 30 m, 116 km for H_e = 40 m and 119 km for H_e = 50 m.

Table 216: Separation distances for adjacent channel (for ground radar), with a 10 dB decoupling antenna

LTE-BS →Radar		LTE-BS			Ground Radar			Dec (Polar)	Dec (Ant)	**Minimum Coupling Loss (MCL) (dB)**			Separation distance (km)	
Scenario ▼	Interferer main beam	P_e dBm/ MHz	G_e dB	P_{fe} dB	G_r dB	P_{Fr} dB	IC dBm (1MHz)			Be/Br=0			EPM73 (1)	ITU-R P.526 (2)
Adjacent channel ΔF_1 (20)	Victim main beam	6	15	2	38.5	0	-115.9	0	10	177.4	/	/	82.4	82
	Victim side lobes	6	15	2	5	0	-115.9	0	10	143.9	/	/	37.8	40
Adjacent channel ΔF_2 (13)	Victim main beam	-1	15	2	38.5	0	-115.9	0	10	156.4	/	/	53.6	54
	Victim side lobes	-1	15	2	5	0	-115.9	0	10	122.9	/	/	15.6	18
Adjacent channel ΔF_3 (8)	Victim main beam	-6	15	2	38.5	0	-115.9	0	10	151.4	/	/	47.1	45
	Victim side lobes	-6	15	2	5	0	-115.9	0	10	117.9	/	/	11.6	12

Note 1: He = 30 m, Hr = 8 m

Note 2: In adjacent band Pe corresponds to OOB level, for 1.4 MHz channel bandwidth.

A10.3.1 Propagation models used for adjacent channel scenario

There were two different tuned propagation models used for the adjacent channel scenario.

The General 450 model, applicable in the frequency range extending from 150 MHz to 2 GHz, is based upon the Okumura-Hata (COST 231) empirical model, with a number of additional features to enhance its flexibility.

The MYRIAD model, applicable in the frequency range extending from 200 MHz to 5 GHz, is a sophisticated and versatile propagation model that relies on highly realistic modelling of the propagation channel, and therefore achieves synergy of the following three vital physical elements:

- Diffraction in the vertical plane;
- Guided propagation in the horizontal plane;
- Reflections from hilly or mountainous terrain.

In addition, this model can produce LOS/NLOS information for each predicted location.

A10.3.2 **Results for ground radars in adjacent channel scenario**

A10.3.2.1 *Channel bandwidth: 1.4 MHz*

Based on the simulations the minimum separation distances are the followings (for 1.4 MHz channel bandwidth):

Table 217: Minimum separation distances without filtering (Channel bandwidth: 1.4MHz)

∆fc [MHz]	1.2 to 2.1	2.1 to 3.5	3.5 to 9.95	from 9.95
$P_{unwantedemLTE}$ (dBm/MHz) – 3GPP	5.43	-1	-6	-26
e.i.r.p.$_{unwantedemLTE}$ (dBm/MHz)	18.43	12	7	-13
L_{prop} (min) (dB)	141.43	134.9	129.9	109.9
d (MYRIAD) (km) Rural/Hilly	18/23 20/25 23/26	13/13 14/23 17/19	8/8 9/9 11/13	1.5/1.5 1.5/1.5 2/2
d (General450) (km) Rural/Hilly	26/23 27/24 28/25	14/12 15/14 16/14	8/8 9/9 10/10	1.5/1.5 1.5/1.5 2/2
d (EPM73)	35 36 37	27 28 29	22 23 23	6 6 7
d (ITU-R P.526-13) (km)	33 38 40	26 30 32	21 25 26	8 9 10

Note: h_1 = 30, 40 or 50 m, h_2 = 8 m, f = 420 MHz

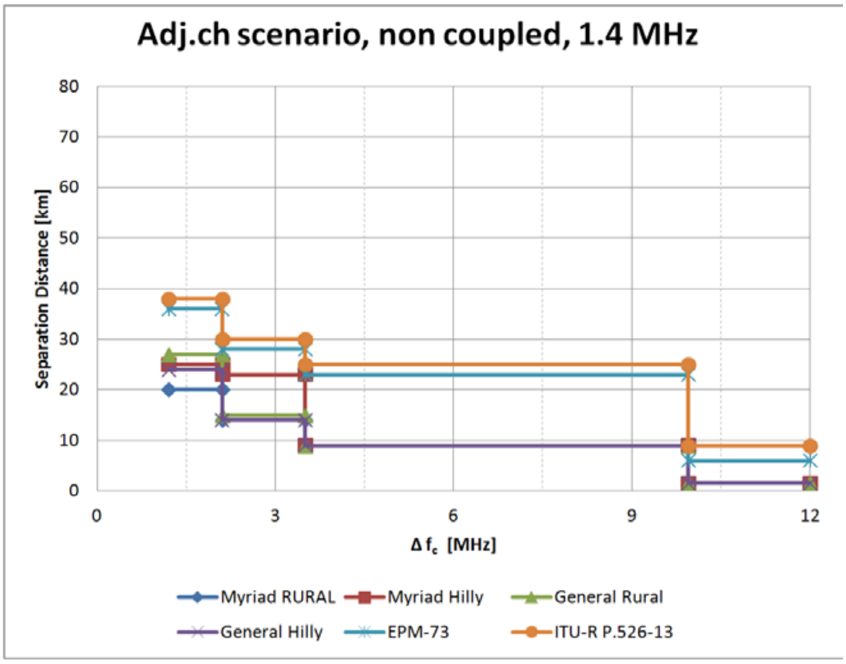


Figure 197: Separation distance as a function of frequency offset (Channel bandwidth: 1.4 MHz)

The distance between LTE and ground radar can be further reduced with appropriate filtering.

Table 218: Minimum separation distances with filtering (Channel bandwidth: 1.4 MHz)

∆fc [MHz]	1.2 to 2.1	2.1 to 3.5	3.5 to 9.95	from 9.95
$P_{unwantedemLTE}$ (dBm/MHz) – 3GPP	5.43	-1	-6	-26
e.i.r.p.$_{unwantedemLTE}$ (dBm/MHz)	18.43	12	7	-13
Amount of filtering (dB)	40	40	40	40
L_{prop} (min) (dB)	101.43	94.9	89.9	69.9
d (ITU-R P.526-13) (km)	5	3	2	<1

Note: h_1 = 30 m, h_2 = 8 m, f = 420 MHz

A10.3.2.2 *Channel bandwidth: 3 MHz*

Based on the simulations the minimum separation distances are the followings (for 3 MHz channel bandwidth):

Table 219: Minimum separation distances without filtering (Channel bandwidth: 3 MHz)

∆fc [MHz]	2 to 4.5	4.5 to 7.5	7.5 to 9.995	from 9.995
$P_{unwantedemLTE}$ (dBm/MHz) – 3GPP	4.44	-5	-6	-26
e.i.r.p.$_{unwantedemLTE}$ (dBm/MHz)	17.44	8	7	-13
L_{prop} (min) (dB)	140.34	130.9	129.9	109.9
d (MYRIAD) (km) Rural/Hilly	18/22 19/23 22/25	9/9 10/10 12/14	8/8 9/9 11/13	1.5/1.5 1.5/1.5 2/2
d (General450) (km) Rural/Hilly	24/22 24/23 27/23	10/10 10/10 12/11	8/8 9/9 11/10	1.5/1.5 1.5/1.5 2/2
d (EPM73)	34 35 36	24 28 28	22 23 24	6 6 7
d (ITU-R P.526-13) (km)	32 37 38	22 26 27	21 25 26	8 9 10

Note: h_1 = 30, 40 or 50 m, h_2 = 8 m, f = 420 MHz

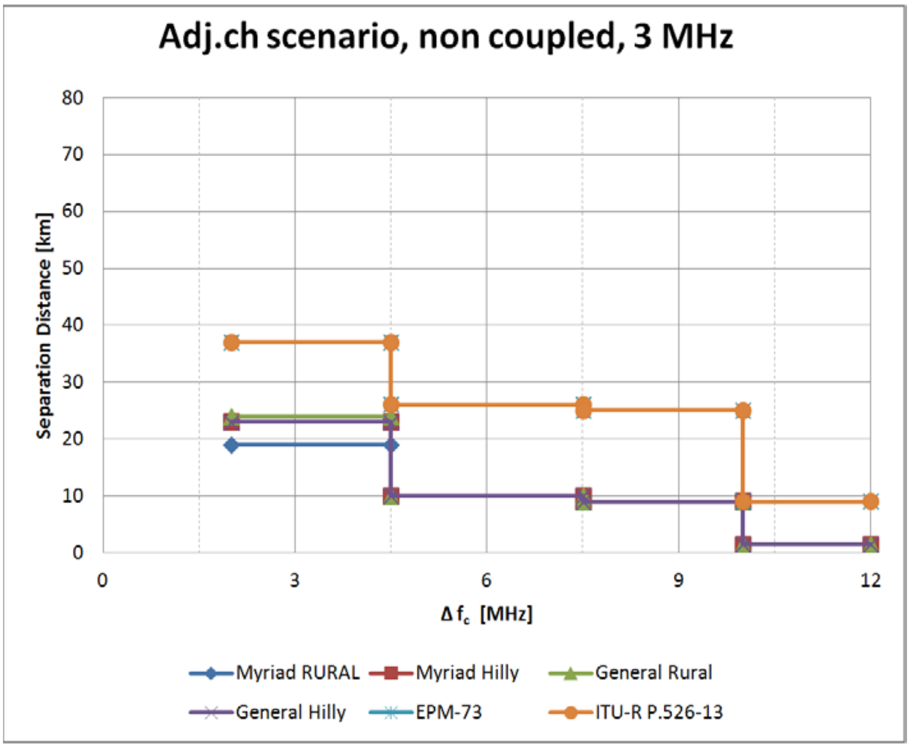


Figure 198: Separation distance as a function of frequency offset (Channel bandwidth: 3 MHz)

The distance between LTE and ground radar can be further reduced with appropriate filtering.

Table 220: Minimum separation distances with filtering (Channel bandwidth: 3 MHz)

Δfc [MHz]	2 to 4.5	4.5 to 7.5	7.5 to 9.995	from 9.995
$P_{unwantedemLTE}$ (dBm/MHz) – 3GPP	4.44	-5	-6	-26
e.i.r.p.$_{unwantedemLTE}$ (dBm/MHz)	17.44	8	7	-13
Amount of filtering (dB)	40	40	40	
L_{prop} (min) (dB)	100.34	90.9	89.9	69.9
d (ITU-R P.526-13) (km)	5	3	2	<1

Note: h_1 = 30 m, h_2 = 8 m, f = 420 MHz

A10.3.2.3 *Channel bandwidth: 5 MHz*

Based on the simulations the minimum separation distances are the followings (for 5 MHz channel bandwidth):

Table 221: Minimum separation distances without filtering (Channel bandwidth: 5 MHz)

Δfc [MHz]	3 to 7.5	7.5 to 9.95	from 9.95
$P_{unwantedemLTE}$ (dBm/MHz) – 3GPP	2.3	-4	-26
e.i.r.p. $_{unwantedemLTE}$ (dBm/MHz)	15.3	9	-13
L_{prop} (min) (dB)	138.2	131.9	109.9
d (MYRIAD) (km) Rural/Hilly	16/20 18/23 19/25	9/9 10/10 13/19	1.5/1.5 1.5/1.5 2/2
d (General450) (km) Rural/Hilly	19/19 21/21 21/23	10/10 10/10 12/13	1.5/1.5 1.5/1.5 2/2
d (EPM73)	32 33 33	25 25 26	6 6 7
d (ITU-R P.526-13) (km)	30 34 37	23 27 28	8 9 10

Note: h_1 = 30, 40 or 50 m, h_2 = 8 m, f = 420 MHz

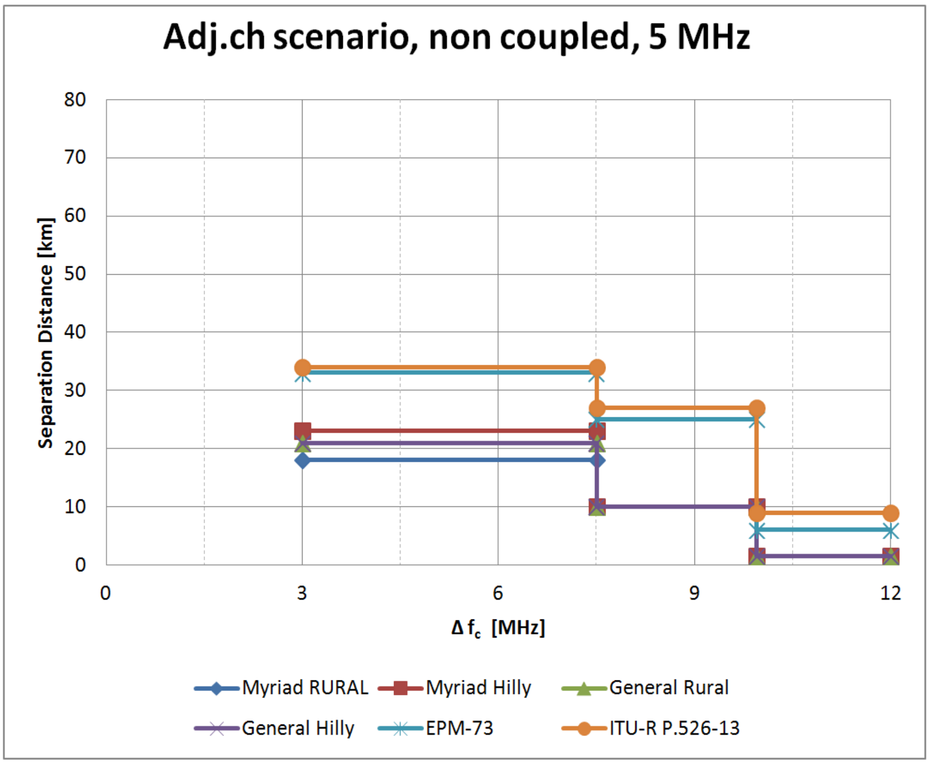


Figure 199: Separation distance as a function of frequency offset (Channel bandwidth: 5 MHz)

The distance between LTE and ground radar can be further reduced with appropriate filtering.

Table 222: Minimum separation distances with filtering (Channel bandwidth: 5 MHz)

∆fc [MHz]	3 to 7.5	7.5 to 9.95	from 9.95
$P_{unwantedemLTE}$ (dBm/MHz) – 3GPP	2.3	-4	-26
$e.i.r.p._{unwantedemLTE}$ (dBm/MHz)	15.3	9	-13
Amount of filtering (dB)	40	40	40
L_{prop} (min) (dB)	98.2	91.9	69.9
d (ITU-R P.526-13) (km)	5	3	<1

Note: h_1 = 30 m, h_2 = 8 m, f = 420 MHz

A10.4 OVERVIEW OF CALCULATION IN THE CASE OF AIRBORNE RADAR

Table 223: Separation distances for co- and adjacent channel (for airborne radar

LTE-BS →Radar		LTE-BS			Airborne Radar			Dec (Polar)	Dec (Ant)	MCL (dB)			Separation distance (km)	
Scenario ▼	Interferer main beam	P_e dBm	G_e dB	P_{fe} dB	G_r dB	P_{Fr} dB	IC dBm (1MHz)			B_e/B_r = 1/1.4	B_e/B_r = 1/3	B_e/B_r = 1/5	EL	ITU-R P.528
Co-channel	Victim main beam	37.5 41 43	15	2	22	0	-115.9	1.5	3	182.4	182.6	182.5	400 (1)	
	Victim side lobes	"	15	2	0	0	-115.9	1.5	3	160	160.6	160.5	400 (1)	
		dBm/ MHz								Be/Br=0				
Adjacent channel ΔF_1 (20)	Victim main beam	6	15	2	22	0	-115.9	0	3	153.9	/	/	400 (1)	
	Victim side lobes	6	15	2	0	0	-115.9	0	3	131.9	/	/	223	
Adjacent channel ΔF_2 (13)	Victim main beam	-1	15	2	22	0	-115.9	0	3	146.9	/	/	400 (1)	
	Victim side lobes	-1	15	2	0	0	-115.9	0	3	124.9	/	/		
Adjacent channel ΔF_3 (8)	Victim main beam	-6	15	2	22	0	-115.9	0	3	141.9	/	/	400 (1)	
	Victim side lobes	-6	15	2	0	0	-115.9	0	3	119.9	/	/	99.9	
Spurious (-13)	Victim main beam	-26	15	2	22	0	-115.9	0	3	121.9	/	/	70.7	
	Victim side lobes	-26	15	2	0	0	-115.9	0	3	99.9	/	/	5.6	

Note 1: radio electrical line of sight corresponding to He = 30 m and Hr = 9000 m
Note 2: airborne radars do not operate in the band 420-430 MHz according to the ITU database

A10.4.1 Results for airborne radars in adjacent channel scenario

Table 224: Minimum separation distances for airborne radar (Channel bandwidth: 1.4 MHz)

Δfc [MHz]	1.2 to 2.1	2.1 to 3.5	3.5 to 9.95	from 9.95
$P_{unwantedemLTE}$ (dBm/MHz) – 3GPP	5.43	-1	-6	-26
$e.i.r.p._{unwantedemLTE}$ (dBm/MHz)	18.43	12	7	-13
DEC_{ant} (min) (dB)	1.7	1.7	1.7	1.7
L_{prop} (min) (dB)	153.1	146.7	141.7	121.7
d (ITU-R P.526-13) (km)	414	402	392	66

Table 225: Minimum separation distances for airborne radar (Channel bandwidth: 3 MHz)

Δfc [MHz]	2 to 4.5	4.5 to 7.5	7.5 to 9.995	from 9.995
$P_{unwantedemLTE}$ (dBm/MHz) – 3GPP	**4.44**	**-5**	**-6**	**-26**
$e.i.r.p._{unwantedemLTE}$ (dBm/MHz)	17.44	8	7	-13
DEC_{ant} (min) (dB)	1.7	1.7	1.7	1.7
L_{prop} (min) (dB)	152.1	142.7	141.7	121.7
d (ITU-R P.526-13) (km)	412	394	392	66

Table 226: Minimum separation distances for airborne radar (Channel bandwidth: 5 MHz)

Δfc [MHz]	3 to 7.5	7.5 to 9.95	from 9.95
$P_{unwantedemLTE}$ (dBm/MHz) – 3GPP	2.3	-4	-26
$e.i.r.p._{unwantedemLTE}$ (dBm/MHz)	15.3	9	-13
DEC_{ant} (min) (dB)	1.7	1.7	1.7
L_{prop} (min) (dB)	150	143.7	121.7
d (ITU-R P.526-13) (km)	408	396	66

The distance between LTE and airborne radar can be reduced with appropriate filtering.

Table 227: Minimum separation distances for airborne radar with filtering (Channel bandwidth: 1.4 MHz)

Amount of filtering [dB]	10	20	30	40	50	60
L_{prop} (min) (dB)						
1.2 to 2.1	143.1	133.1	123.1	113.1	103.1	9.1
2.1 to 3.5	136.7	136.7	126.7	116.7	106.7	96.7
3.5 to 9.95	131.7	121.7	111.7	101.7	91.7	81.7
from 9.95	111.7	101.7	91.7	81.7	71.7	61.7
d (free space) [km]						
2 to 4.5	395*	257.7	81.5	25.7	8.1	2.6
4.5 to 7.5	388.7	122.9	38.8	12.3	3.9	1.2
7.5 to 9.995	218.6	69.1	21.8	6.9	2.2	0.7
from 9.995	21.9	6.9	2.2	0.7	0.2	0.07

Table 228: Minimum separation distances for airborne radar with filtering (Channel bandwidth: 3 MHz)

Amount of filtering [dB]	10	20	30	40	50	60
L_{prop} (min) (dB)						
1.2 to 2.1	142.1	132.1	122.1	112.1	102.1	92.1
2.1 to 3.5	132.7	122.7	112.7	102.7	92.7	82.7
3.5 to 9.95	131.7	121.7	111.7	101.7	91.7	81.7
from 9.95	111.7	101.7	91.7	81.7	71.7	61.7
d (free space) [km]						
2 to 4.5	393*	228.9	72.4	22.9	7.2	2.3
4.5 to 7.5	245.3	77.5	24.5	7.7	2.5	0.8
7.5 to 9.995	218.6	69.1	21.8	6.9	2.2	0.7
from 9.995	21.9	6.9	2.2	0.7	0.2	0.07

Table 229: Minimum separation distances for airborne radar with filtering (Channel bandwidth: 5 MHz)

Amount of filtering [dB]	10	20	30	40	50	60
L_{prop} (min) (dB)						
3 to 7.5	140	130	120	110	100	90
7.5 to 9.95	133.7	123.7	113.7	103.7	93.7	83.7
from 9.95	111.7	101.7	91.7	81.7	71.7	61.7
d (free space) [km]						
3 to 7.5	393*	179.7	56.8	18	5.7	1.8

Amount of filtering [dB]	10	20	30	40	50	60
7.5 to 9.95 from 9.95	275.2 21.9	87 6.9	27.5 2.2	8.7 0.7	2.8 0.2	0.9 0.07

A10.5 CASE OF ADJACENT CHANNEL, WITH A 10DB DECOUPLING ANTENNA

Table 230: Separation distances for adjacent channel (for airborne radar), with a 10 dB decoupling antenna

LTE-BS →Radar		LTE-BS			Airborne Radar			Dec (Polar)	Dec (Ant)	MCL (dB)			Separation distance (km)	
Scenario ▼	Interferer main beam	Pe dBm dBm/MHz	Ge dB	Pfe dB	Gr dB	PFr dB	IC dBm (1MHz)			Be/Br=0			EL	ITU-R P.528
Adjacent channel ΔF_1 (20)	Victim main beam	6	15	2	22	0	-115.9	0	10	146.9	/	/	400km (1)	
Adjacent channel ΔF_2 (13)	Victim main beam	-1	15	2	22	0	-115.9	0	10	139.9	/	/	400km (1)	
Adjacent channel ΔF_3 (8)	Victim main beam	-6	15	2	22	0	-115.9	0	10	134.9	/	/	316	
Spurious (-13)	Victim main beam	-26	15	2	22	0	-115.9	0	10	114.9	/	/	31.6	

Note 1: line of sight corresponding to He = 30 m and Hr = 9000 m

For airborne radars the decoupling antenna factor depends on the radar positions. The decoupling antenna factor also depends on the LTE BS antenna mask, and the airborne radar pattern. Assuming the LTE BS antenna is not tilted, and the airborne radar antenna main lobe can scan ±60° elevation and 360°azimuth.

The attenuation of LTE BS antenna (Kathrein, K742 242) has been calculated for several airborne positions and angles which could be considered as DECant factor.

The following Table 231 presents the attenuation of LTE BS antenna (Kathrein, K742 242) as a function of airborne position.

Table 231: Minimum separation distances for airborne radar (Channel bandwidth: 1.4 MHz)

Scenarios	1	2	3	4	5	6
Airborne radar height [m]	9000	9000	9000	9000	9000	9000
Distance between LTE BS and airborne	10	20	50	100	200	391 (radio

Scenarios	1	2	3	4	5	6
radar [km]						horizon on 9000 m)
Angle above horizontal*	65°	26.7°	10.4°	5°	2.5°	1.3°
K742 242 attenuation(*) [dB]	27.3	14.6	11.8	4.6	2.5	1.7

Scenarios	**7**	**8**	**9**	**10**	**11**	**12**
Airborne radar height [m]	5000	5000	5000	5000	5000	5000
Distance between LTE BS and airborne radar [km]	10	20	50	100	200	291 (radio horizon on 5000 m)
Angle above horizontal*	30°	14.5°	5.7°	2.9°	1.4°	1°
K742 242 attenuation(*) [dB]	18.3	25	5.1	3	1.7	1.7

A10.6 GUARD BAND AT 430 MHZ

Illustration of LTE mask on spectrum with a 1 MHz guard band related to 430 MHz

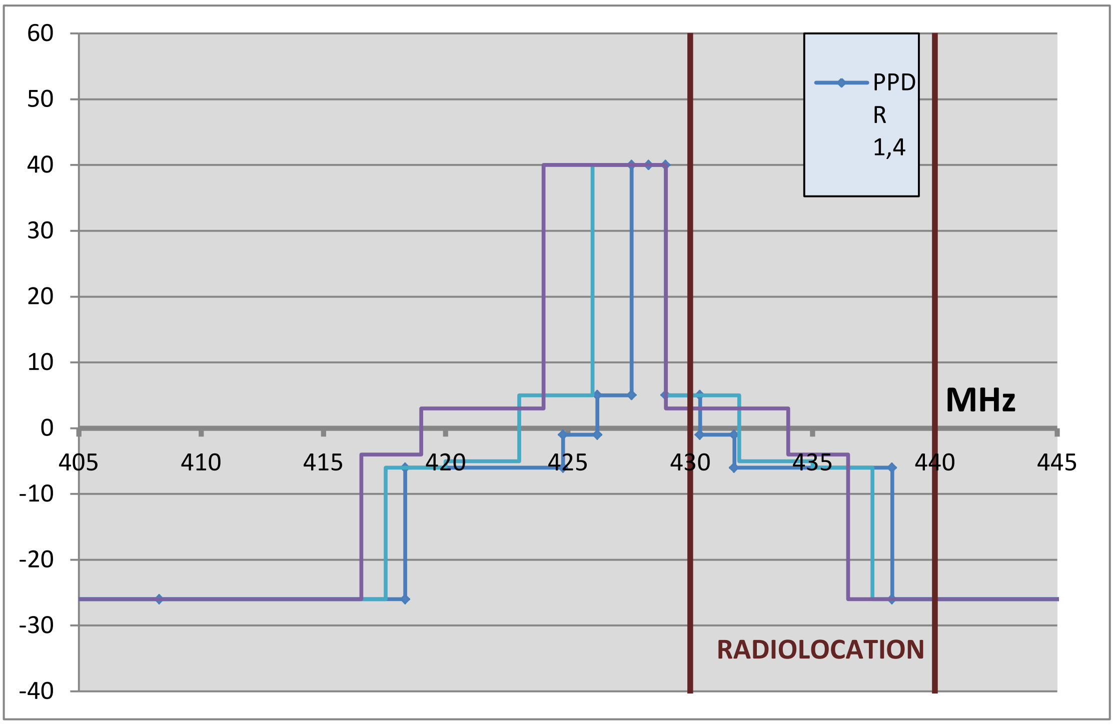
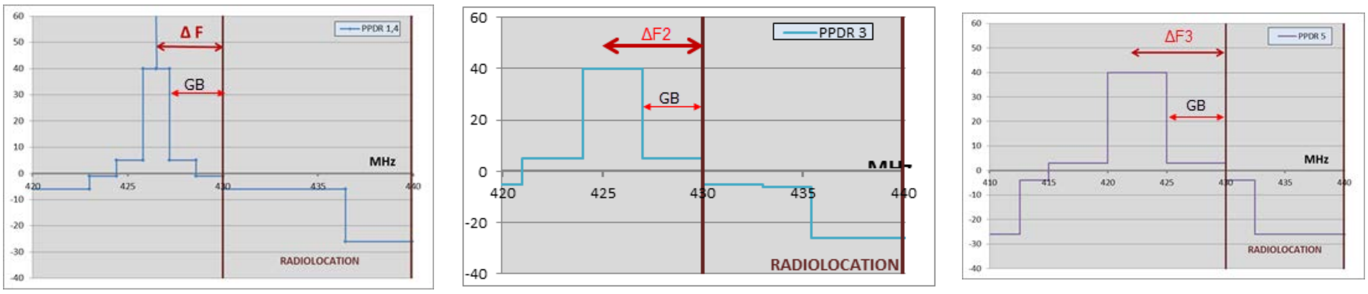


Figure 200: LTE mask

A10.7 EXAMPLE OF “MIXED” SOLUTION ACCORDING TO THE WIDTH OF LTE PPDR

Figure 201 below illustrates what are the possible centre frequency offsets (Δf) of the LTE BS channel and corresponding guard band with respect to the radiolocation primary band. Adjacent channel compatibility is feasible if the OOB and spurious emissions of the LTE falling within the radiolocation primary band do not exceed the protection criteria

1.4 MHz **3 MHz** **5 MHz**



Δ F1 = 3.5 MHz, and improving OOB: 31 dB

Δ F2 = 4.5MHz and improving OOB: 32 dB

Δ F3 = 7.5 MHz and Improving OOB: 33 dB

Figure 201: Required guard band depending on the channel bandwidth

Considering the proposed value of Guard band = 2.5 MHz, the corresponding minimum offsets are:

Table 232: Minimum frequency offset

	Channel bandwidth		
	1.4 MHz	3MHz	5 MHz
Δf (MHz)	3.2	4	5

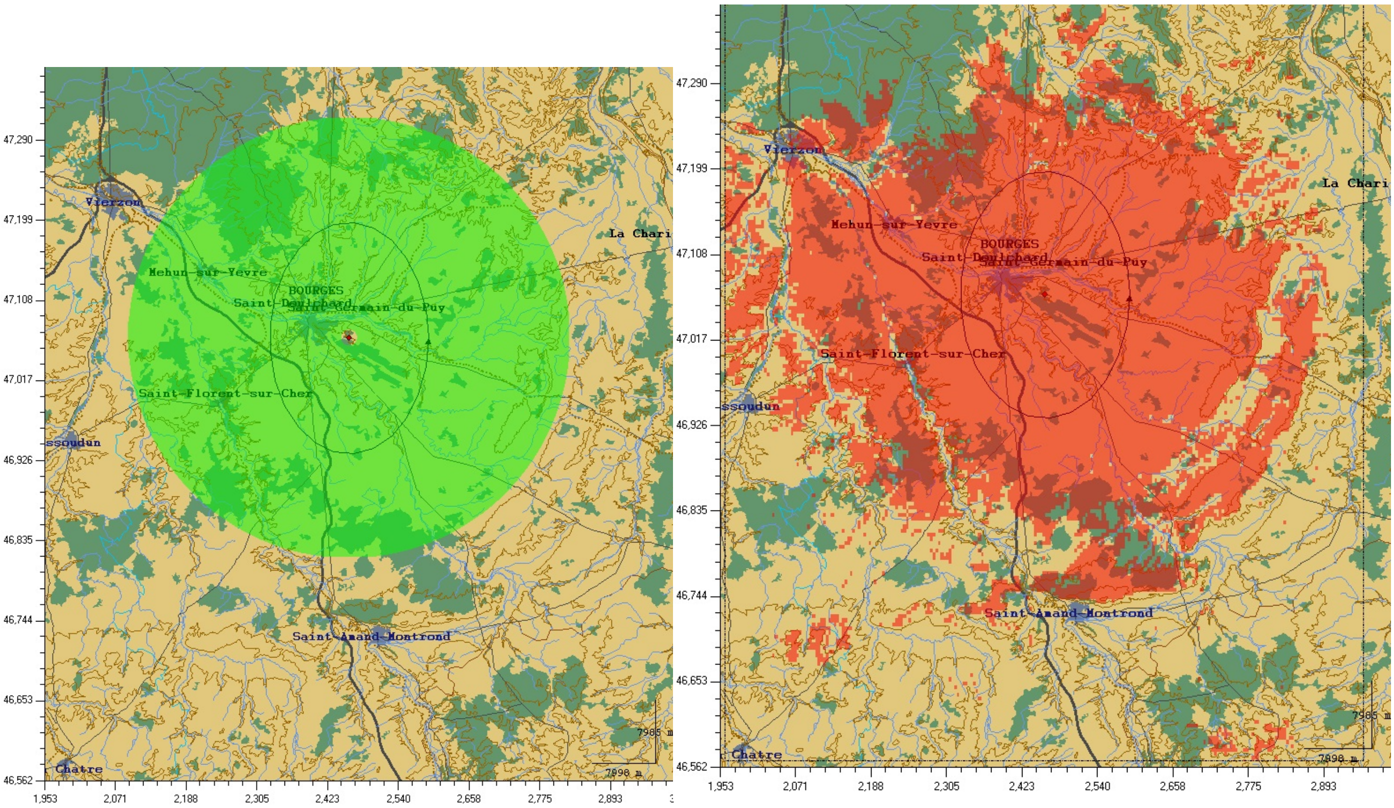
A10.8 COMPARISON OF PROPAGATION MODELS

Conditions: Propagation loss 135.8 dB, BS height 30 m, radar height 8m, calculation frequency 420 MHz, on a site in France.

First calculation: with a statistic propagation model which takes into account antenna heights

EPM73 propagation model (it has been shown that distances calculated with EPM73 and ITU-R P.526 are very close, for distances up to about 150 km)

Second calculation: with a deterministic propagation model named CARDIF (calculation including clutter), on a site in France. Result below



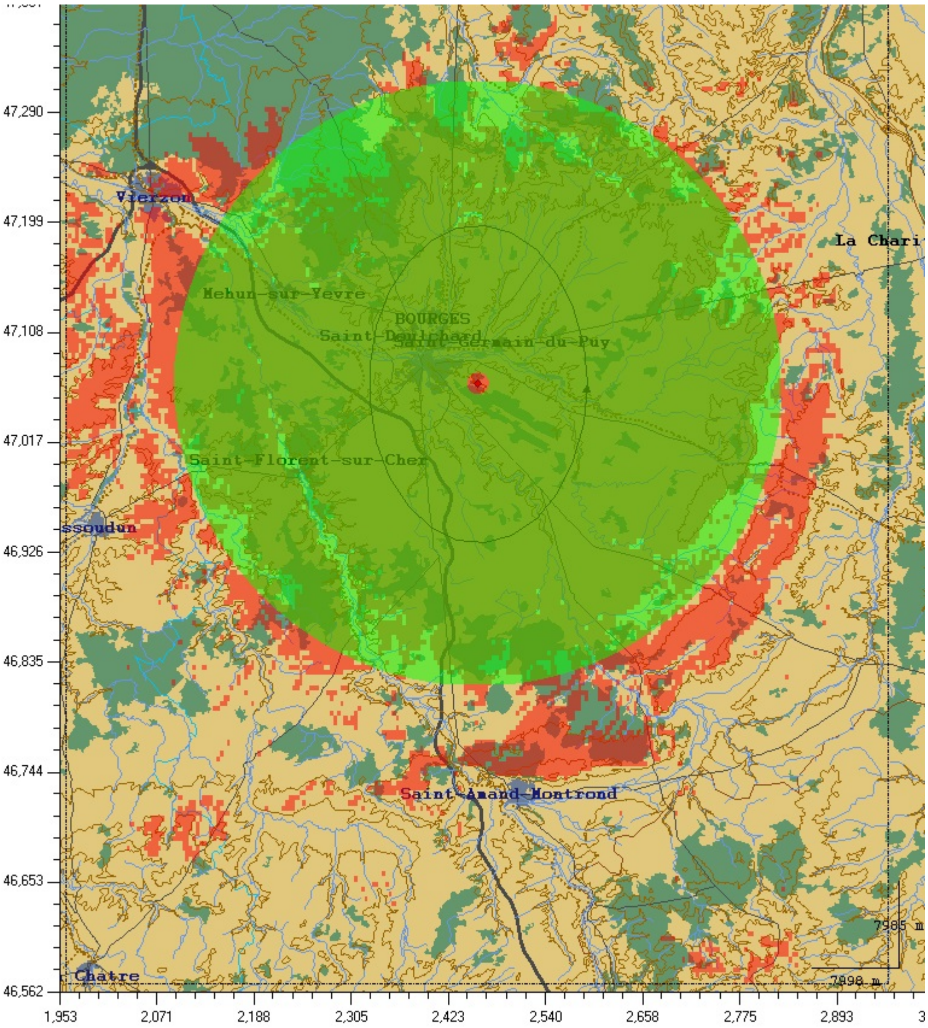
Radius of 28km

Several zones limited to 22km

Numerous zones between 30 and 35 km, a few zones at 55/58km

Figure 202: Propagation models: statistic (EPM73, ITU-R P.526) and deterministic (CARDIF)

EPM73 and CARDIF results



These results show that a deterministic (CARDIF) propagation model is obviously more precise than a deterministic one; it considers if the area is hilly, mountainous or not and furthermore it takes account of clutter. Distances shorter or higher than distances calculated with EPM73 can be found.

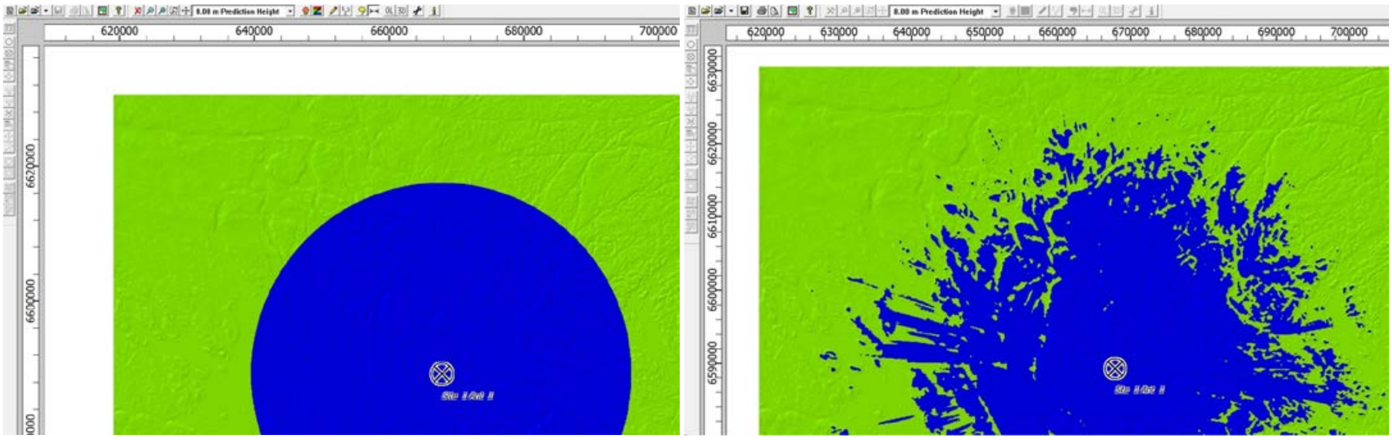
However these results are only valid for the place where calculation has been performed.

At the other hand, a statistic model gives a mean distance which gives a right idea of result independently of the area.

Therefore, this comparison shows that it is not possible to use the results obtained with a deterministic propagation model to build a conclusion for a general case

Figure 203: Results with the models: statistic (green), deterministic (red) with a French simulation tool

To confirm the previous results, another case is computed in the same condition, but with a different “simulation tool” and on a different site (Sweden)



Radius of 28km

With Cardiff the area is wider than EPM73 area in some directions

Figure 204: Results with the models: statistic (left), deterministic (right) with a Swedish simulation tool

A10.9 LTE BS OOBE AND SPURIOUS EMISSION LIMIT (DBM) AND UNWANTED EMISSIONS TARGET

Table 233 below illustrates how much additional attenuation is required for LTE OOBE and spurious emissions so as to meet acceptable power falling within the radiolocation primary allocated frequencies (430-440 MHz). Less stringent additional filter attenuation is required if 10 dB antenna decoupling is considered. It should be noted that the proposed values correspond to a free space propagation model between the airborne radar at 9000 m above the ground and the LTE BS.

The required 9 km separation distance for free space model could be reduced for ground radar due to additional attenuation from the environment. As an example, with the EPM73 propagation model, the same targeted OOBE would correspond to a separation distance of 4 km.

Table 233: Required additional attenuation

				With a 3dB decoupling attenuation		With a 10 dB decoupling attenuation	
Channel width	Delta Fc (MHz)	OOB emissions (3GPP)	Measurement bandwidth	Δ dB (required additional attenuation)	Targeted Level of OOBE/100 kHz	Δ dB (required additional attenuation)	Targeted Level of OOBE/100 kHz
1.4 MHz	0.7 to 2.1	-4dBm	100 kHz	49.9	-53.9 dBm	42.9	-46.9 dBm
	2.1 to 3.5	-11 dBm	100 kHz	42.9	-53.9 dBm	35.9	-46.9 dBm
	3.5 to 9.95	-16 dBm	100 kHz	37.9	-53.9 dBm	30.9	-46.9 dBm
3 MHz	1.5 to 4.5	-5	100 kHz	48.9	-53.9 dBm	41.9	-46.9 dBm
	4.5 to 7.5	-15	100 kHz	38.9	-53.9 dBm	31.9	-46.9 dBm
	7.5 to 9.995	-16	100 kHz	37.9	-53.9 dBm	30.9	-46.9 dBm
5 MHz	2.5 to 7.5	-8	100 kHz	45.9	-53.9 dBm	38.9	-46.9 dBm
	7.5 to 9.95	-14	100 kHz	39.9	-53.9 dBm	32.9	-46.9 dBm
Frequency range outside the out-of-band domain		**Maximum spurious level**					
	30 MHz ≤ f < 1000 MHz	- 36 dBm	100 kHz	17.9	-53.9 dBm	10.9	-46.9 dBm

ANNEX 11: MINIMUM COUPLING LOSS (MCL)CALCULATIONS FOR PMSE – 25 KHZ

A11.1 LTE UE IMPACT ON PMSE

A11.1.1 LTE UE impact on PMSE MS

The studies in ECC Report 240 considered a frequency offset of more than 10 MHz between the LTE UE and the PMSE MS. It implies that the transmitter unwanted emissions of the system is going to be -50 dBm/MHz, as the PMSE UL overlaps with the LTE 3GPP UL definition. The following Table 234 provides the results of calculations to assess the separation distances considering a frequency offset of 10 MHz. It should be noted that considering the Extended Hata (Urban) model, the distance is about 55 meters. Additional propagation models are also considered for the purpose of comparison.

Table 234: LTE MS impact on 25 kHz PMSE MS

Parameter	Extended Hata Urban	Extended Hata SRD	Free space	Dual Slope model (Break Point at 5 m)
Unwanted emission conducted power	-50 dBm/1 MHz	-50 dBm/1 MHz	-50 dBm/1 MHz	-50 dBm/1 MHz
Gain	-3 dB	-3 dB	-3 dB	-3 dB
Body loss	4 dB	4 dB	4 dB	4 dB
e.i.r.p. in the direction of the PMSE equipment	-57 dBm/1 MHz	-57 dBm/1 MHz	-57 dBm/1 MHz	-57dBm/1 MHz
e.i.r.p. in the direction of the PMSE equipment	-75.24 dBm/15 kHz	-75.24 dBm/15 kHz	-75.24 dBm/15 kHz	-75.24 dBm/15 kHz
PMSE sensitivity	-117 dBm	-117 dBm	-117 dBm	-117 dBm
PMSE sensitivity + 3 dB	-114 dBm	-114 dBm	-114 dBm	-114 dBm
C/I	17 dB	17 dB	17 dB	17 dB
I	-131 dBm	-131 dBm	-131 dBm	-131 dBm
Gain	0 dBi	0 dBi	0 dBi	0 dBi
Attenuation to meet the criterion	55.76 dB	55.76 dB	55.76 dB	55.76 dB
Distances	31 m	31 m	31 m	16 m

Assuming 4 dB body loss, it can be seen that considering a frequency offset of 10 MHz, the separation distances between the PPDR MS and the PMSE MS based on MCL calculations would be at least 16 m.

A11.1.2 LTE UE impact on PMSE BS

For this case, ECC Report 240 considered the two systems operating in adjacent blocks of spectrum. This is further considered in the following tables where an offset of 1 MHz is considered between the frequency used by the PMSE BS and the edge of the LTE UE band.

Table 235: LTE UE impact on 25 kHz PMSE BS – 1 MHz frequency offset

Parameter	1.4 MHz	3 MHz	5 MHz	Reference TS 36.101 (3/5 RB)
Unwanted emission conducted	-10 dBm/30 kHz	-13 dBm/30 kHz	-15 dBm/30 kHz	-10 dBm/1 MHz
Gain	-3 dB	-3 dB	-3 dB	-3 dB
Body loss	4 dB	4 dB	4 dB	4 dB
e.i.r.p. in the direction of the PMSE equipment	-20 dBm/15 kHz	-23 dBm/15 kHz	-25 dBm/15 kHz	-35.24 dBm/15 kHz
PMSE sensitivity	-120 dBm	-120 dBm	-120 dBm	-120 dBm
PMSE sensitivity + 3 dB	-117 dBm	-117 dBm	-117 dBm	-117 dBm
C/I	17 dB	17 dB	17 dB	17 dB
I	-134 dBm	-134 dBm	-134 dBm	-134 dBm
Gain	3 dBi	3 dBi	3 dBi	3 dBi
Attenuation to meet the criterion	117 dB	114 dB	112 dB	101.76 dB
Distances	876 m	720 m	631 m	323 m

The separation distances, based on MCL calculations, are ranging from 323 m to more than 800 m.

At a frequency offset of 1 MHz, the Tx power will be -10 dBm in 1 MHz, therefore a distance of 323 m considering 4 dB body loss.

A11.2 LTE BS IMPACT ON PMSE

A11.2.1 LTE BS impact on PMSE MS

In this case, the systems are assumed to operate in adjacent block. The following table provides results for an offset of 500 kHz.

Table 236: LTE BS impact on 25 kHz PMSE MS – 500 kHz frequency offset

Parameter	1.4 MHz	3 MHz	5 MHz
Unwanted emission conducted	-4.57 dBm/100 kHz	-6.67 dBm/100 kHz	-7.7 dBm/100 kHz
Gain	13 dBi	13 dBi	13 dBi
e.i.r.p. in 15 kHz	0.19 dBm/15 kHz	-1.91 dBm/15 kHz	-2.94 dBm/15 kHz
PMSE sensitivity	-117 dBm	-117 dBm	-117 dBm
PMSE sensitivity + 3 dB	-114 dBm	-114 dBm	-114 dBm
C/I	17 dB	17 dB	17 dB
I	-131 dBm	-131 dBm	-131 dBm
Gain PMSE MS	0 dBi	0 dBi	0 dBi
Attenuation to meet the criterion	131.19 dB	129.09 dB	128.06 dB
Distance	2.21 km	1.93 km	1.804 km

The following Table 237 provides results for an offset of 1 MHz.

Table 237: LTE BS impact on 25 kHz PMSE MS – 1 MHz frequency offset

Parameter	Offset of 1 MHz (ECC/DEC/(16)02)	1.4 MHz	3 MHz	5 MHz
e.i.r.p.	-43 dBm/100 kHz			
Unwanted emission conducted power		-8.14 dBm/100 kHz	-8.3 dBm/100 kHz	-8.4 dBm/100 kHz
Antenna gain	13 dBi	13 dBi	13 dBi	13 dBi
e.i.r.p. in 15 kHz	-51.24 dBm/15 kHz	-3.38 dBm/15 kHz	-3.57 dBm/15 kHz	-3.64 dBm/15 kHz
PMSE sensitivity	-117 dBm	-117 dBm	-117 dBm	-117 dBm
PMSE sensitivity + 3 dB	-114 dBm	-114 dBm	-114 dBm	-114 dBm
C/I	17 dB	17 dB	17 dB	17 dB
I	-131 dBm	-131 dBm	-131 dBm	-131 dBm
Gain MS PMSE	0 dBi	0 dBi	0 dBi	0 dBi
Attenuation to meet the criterion	79.76 dB	127.62 dB	127.43 dB	127.36 dB
Distances	85 m	1.753 km	1.731 km	1.723 km

Based on MCL calculations, at 1 MHz, the separation distances are more than 1 km except if the limit given in ECC/DEC/(16)02 is implemented resulting in separation distances lower than 100 m.

A11.2.2 LTE BS impact on PMSE BS

The following Table 238 provides the separation distances assuming an offset of at least 5 MHz as in ECC Report 240.

Table 238: LTE BS impact on 25 kHz PMSE BS – 5 MHz frequency offset

Parameter	ECC/DEC/(16)02	1.4 MHz	3 MHz	5 MHz	1.4/3/5 MHz
e.i.r.p.	-43 dBm/100 kHz				-80 dBm/100kHz
Tx power		-16 dBm/100 kHz	-15 dBm/100 kHz	-14 dBm/100 kHz	-96 dBm/100kHz
Antenna gain	13 dBi	13 dBi	13 dBi	13 dBi	13 dBi
e.i.r.p. in 15 kHz	-51.24 dBm/15 kHz	-11.24 dBm/15 kHz	-10.24 dBm/15 kHz	-9.24 dBm/15 kHz	-98 dBm/15 kHz
PMSE sensitivity	-120 dBm	-120 dBm	-120 dBm	-120 dBm	-120 dBm
PMSE sensitivity + 3 dB	-117 dBm	-117 dBm	-117 dBm	-117 dBm	-117 dBm
C/I	17 dB	17 dB	17 dB	17 dB	17 dB
I	-134 dBm	-134 dBm	-134 dBm	-134 dBm	-134 dBm
Gain MS PMSE	3 dBi	3 dBi	3 dBi	3 dBi	3 dBi
Attenuation to meet the criterion	85.76 dB	122.76 dB	123.76 dB	124.76 dB	39 dB
Distances	0.733 km	8.23 km	8.8 km	9.37 km	0.004 km

Considering the general spurious emissions limits given in 3GPP TS 36.104 [13], coexistence is unlikely to be reached due to large separation distances. Considering the level given in ECC/DEC/(06)02 [44] (e.i.r.p. limit of -43 dBm/100 kHz) are much smaller. Coexistence is expected if the BS spurious meet the minimum requirements of -96 dBm/100kHz emissions in emissions in the band 450-455 MHz (3GPP TS 36.104 [13] – see Annex 2).

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A11.3 ADDITIONAL SCENARIOS COMPARED TO ECC REPORT 240

In case of TDD links are considered, then, both the MS and the BS will be operating on the same frequency, resulting in frequency offsets smaller than those considered in ECC Report 240. This section considered the LTE UE impact on PMSE MS and LTE BS impact on PMSE BS. This could also happen if the PMSE MS is transmitting in the frequency range 455-460 MHz.

A11.3.1 LTE UE impact on PMSE MS

The following Table 239 provides the results for an offset of 500 kHz.

Table 239: LTE MS impact on 25 kHz PMSE MS – 500 kHz frequency offset

Parameter	1.4 MHz	3 MHz	5 MHz	Reference TS 36.101 (3/5 RB)
Emission limits (dBm)	-10 dBm/30 kHz	-13 dBm/30 kHz	-15 dBm/30 kHz	-10 dBm/1 MHz
Gain	-3 dB	-3 dB	-3 dB	-3 dB
Body loss	4 dB	4 dB	4 dB	4 dB
e.i.r.p. in the direction of the PMSE equipment	-20 dBm/15 kHz	-23 dBm/15 kHz	-25 dBm/15 kHz	-35.24 dBm/15 kHz
PMSE sensitivity	-117 dBm	-117 dBm	-117 dBm	-117 dBm
PMSE sensitivity + 3 dB	-114 dBm	-114 dBm	-114 dBm	-114 dBm
C/I	17 dB	17 dB	17 dB	17 dB
I	-131 dBm	-131 dBm	-131 dBm	-131 dBm
Gain	0 dBi	0 dBi	0 dBi	0 dBi
Attenuation to meet the criterion	111 dB	108 dB	106 dB	95.76 dB
Distances	108 m	97 m	93 m	77 m

A11.3.2 LTE BS impact on PMSE BS

The following Table 240 provides the results for an offset of 500 kHz.

Table 240: LTE BS impact on 25 kHz PMSE BS – 500 kHz frequency offset

Parameter	1.4 MHz	3 MHz	5 MHz
Tx power	-4.57 dBm in 100 kHz	-6.67 dBm in 100 kHz	-7.7 dBm in 100 kHz
Antenna gain	13 dBi	13 dBi	13 dBi
e.i.r.p. in 15 kHz	0.19 dBm in 15 kHz	-1.91 dBm in 15 kHz	-2.94 dBm in 15 kHz
PMSE sensitivity	-120 dBm	-120 dBm	-120 dBm

Parameter	1.4 MHz	3 MHz	5 MHz
PMSE sensitivity + 3 dB	-117 dBm	-117 dBm	-117 dBm
C/I	17 dB	17 dB	17 dB
I	-134 dBm	-134 dBm	-134 dBm
Gain MS PMSE	3 dBi	3 dBi	3 dBi
Attenuation to meet the criterion	137.19 dB	135.09 dB	134.06 dB
Distances	20.9 km	18.3 km	17.22 km

ANNEX 12: LTE IMPACT ON SRD

A12.1 THEORETICAL CONSIDERATIONS BASED ON A RAYLEIGH DISTRIBUTION

A12.1.1 Amplitude density distribution

Progression corresponds to a Rayleigh distribution.

According to [39], the formula is the amplitude distribution (note: not the power distribution)

$$f_{A(U)} = \frac{U}{\sigma^2} \cdot e^{-\frac{U^2}{2 \cdot \sigma^2}}$$

Where:

- U: Amplitude of the receiving signal (field strength, etc.)
- σ: Standard distribution
- 2· σ2: Quadratic mean value of the receiving signal amplitude

A12.1.2 Power density distribution

The above relationship is hereafter converted to power values. Whereby the following applies:

$$P = \frac{U^2}{R} \qquad \rightarrow \qquad U = \sqrt{P \cdot R}$$

Where:

$$f_{A(P)} = \frac{\sqrt{P \cdot R}}{\sigma^2} \cdot e^{-\frac{P \cdot R}{2 \cdot \sigma^2}}$$

and

$$2 \cdot \sigma^2 = \left(U_{mittel}\right)^2 = P_{mean} \cdot R$$

$$f_{A(P)} = \frac{\sqrt{P \cdot R}}{\frac{1}{2} \cdot P_{mean} \cdot R} \cdot e^{-\frac{P}{P_{mean}}} \qquad f_{A(P)} = \frac{2 \cdot \sqrt{P}}{\sqrt{R} \cdot P_{mean}} \cdot e^{-\frac{P}{P_{mean}}}$$

Theoretical considerations, mathematical approximation

A12.1.3 Probability density distribution of reception power

The following relationship accurately reflects the reality of the received level distribution as it is quantified in the interior of actual vehicles.

Probability density distribution for level below a power "P" (linear statement of power) if a Rayleigh distribution can be assumed:

$$p_{A(P)} = 1 - e^{-\frac{P}{P_{mean}}}$$

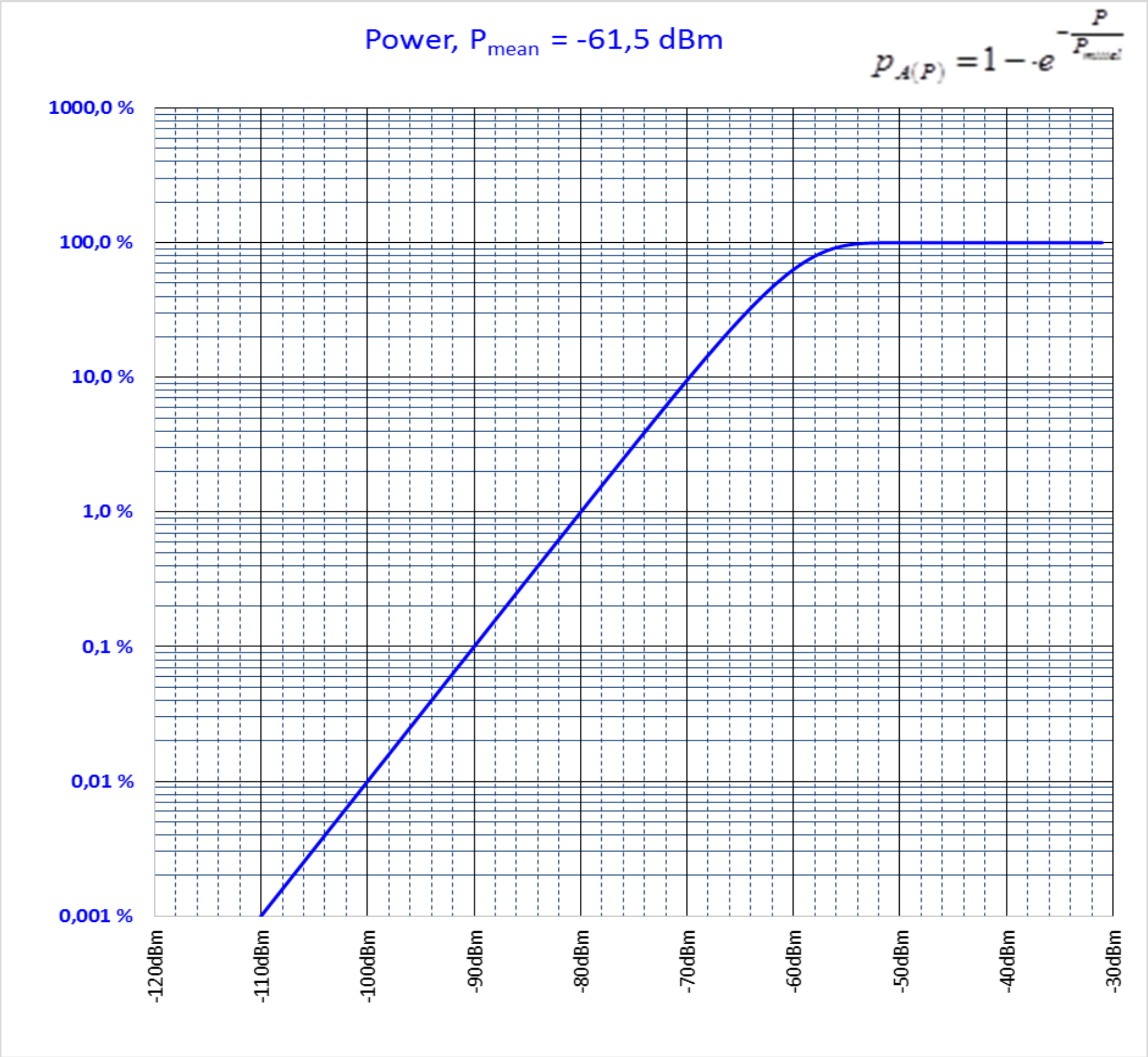


Figure 205: Example of a calculated of probability level density

Logarithmic dimensional details:

$$p_{A(P)} = 1 - e^{-\frac{P}{P_{mean}}}$$

$$= 1 - e^{-\frac{10^{\frac{P[dBm]}{10}}}{10^{\frac{P_{mean}[dBm]}{10}}}} = 1 - e^{-10^{\left(\frac{P[dBm]}{10} - \frac{P_{mean}[dBm]}{10}\right)}}$$

$$p_{A(P)} = 1 - e^{-10^{\frac{1}{10}\cdot\left(P[dBm] - P_{mean}[dBm]\right)}}$$

The relationship found very accurately reflects the reality in the vehicle. The only drawback is that P_{mean} is not the mean value defined across all measuring points as per the measuring instructions

$P_{mean\_value[dBm]} = \frac{1}{n} \cdot \sum_{m=1}^{m=n} m\_measured\_value_{[dBm]}$ [26]. Rather, if P = P_{mean}, pA (P) = 63.21% and not the required 50%. To counteract this deficit, the above relationship is provided with a correction value "kP":

$$p_{A(P)} \quad = 1 - e^{-10^{\frac{1}{10}\left(P[dBm] - P_{mean\_value[dBm]} - k_P\right)}}$$

Calculation of "kP":

If P[dBm] = P_{mean} value[dBm] and pA (P) = 50% = 0.5, the following applies:

$$0{,}5 = 1 - e^{-10^{\frac{1}{10}(-k_P)}}$$

$$\Leftrightarrow \quad 0{,}5 = e^{-10^{\frac{1}{10}(-k_P)}} \Leftrightarrow \ln(0{,}5) = -10^{\frac{1}{10}\cdot(-k_P)} \Leftrightarrow \log(-\ln(0{,}5)) = \frac{1}{10}\cdot(-k_P)$$

$$\Leftrightarrow \quad -10 \cdot \log(-\ln(0{,}5)) = k_P$$

$$k_P = 1{,}59 dB$$

This then points to the relationship below:

$$p_{A(P)} \quad = 1 - e^{-10^{\frac{1}{10}\left(P[dBm] - P_{mean\_value[dBm]} - 1{,}59 dB\right)}}$$

Whereby:

- P[dBm]: e.g. Sensitivity of a receiver in dBm
- P_{mean} value[dBm]: dBm mean value ($= \frac{1}{n} \cdot \sum_{m=1}^{m=n} m\_measured\_value_{[dBm]}$ across all levels at the receiver
- pA (P): Describes the share of received levels below P[dBm].

Example: Averaged dBm level: -60 dBm ($= \frac{1}{n} \cdot \sum_{m=1}^{m=n} m\_measured\_value_{[dBm]}$ Sought: Probability of received levels below -100 dBm:

$$p_{A(P)} \quad = 1 - e^{-10^{\frac{1}{10}(-100 dBm - -60 dBm - 1{,}59 dB)}} = 0{,}00693\%$$

[26] Measuring instructions at Daimler AG

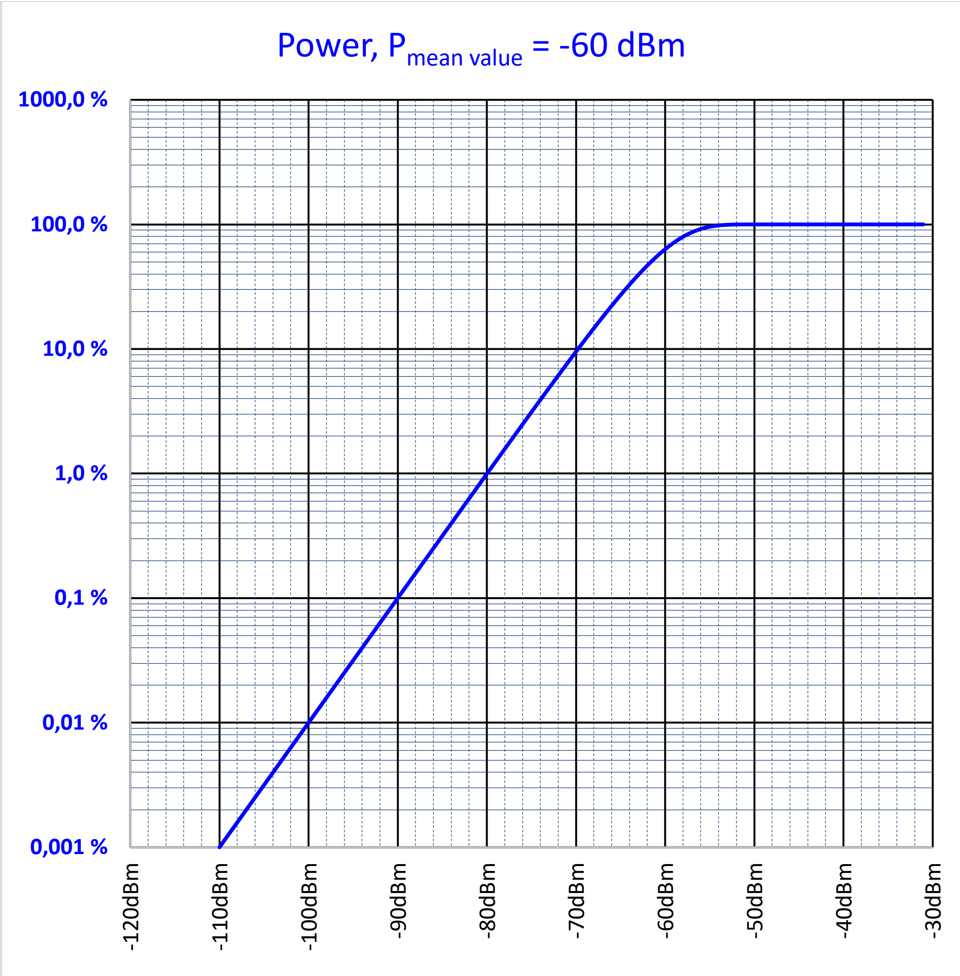


Figure 206: Calculated probability level density for $P_{mean_}$value = -60 dBm

A12.1.4 Density distribution

Now the density distribution should be considered. To this end, the probability distribution is derived:

Linear:

$$\frac{d}{dP}\left(p_{A(P)}\right)=\frac{1}{P_{mean}}e^{-\frac{P}{P_{mean}}}$$

Logarithmic:

0

$$\frac{d}{dP}\left(p_{A(P)}\right)=-e^{-10^{\frac{1}{10}\left(P\,[dBm]-P_{mean\_value}[dBm]-1{,}59dB\right)}}\cdot\ln(10)\cdot(-1)\cdot\left(10^{\frac{1}{10}\left(P\,[dBm]-P_{mean\_value}[dBm]-1{,}59dB\right)}\right)\cdot\frac{1}{10}$$

$$\frac{d}{dP}\left(p_{A(P)}\right)=\frac{\ln(10)\cdot 10^{\frac{1}{10}\left(P\,[dBm]-P_{mean\_value}[dBm]-1{,}59dB\right)}}{10}\cdot e^{-10^{\frac{1}{10}\left(P\,[dBm]-P_{mean\_value}[dBm]-1{,}59dB\right)}}$$

$$f_{A(P)} = \frac{\ln(10) \cdot 10^{\frac{1}{10} \cdot \left(P_{[dBm]} - P_{mean\_value[dBm]} - 1{,}59dB\right)}}{10} \cdot e^{-10^{\frac{1}{10}\left(P_{[dBm]} - P_{mean\_value[dBm]} - 1{,}59dB\right)}}$$

Whereby:

- M:Number of all measuring points
- P[dBm]: Power in dBm for which the probability density applies (e.g. sensitivity of a receiver)
- P_{Mean} value[dBm]: dBm mean value ($= \frac{1}{n} \cdot \sum_{m=1}^{m=n} m\_measured\_value_{[dBm]}$) across all levels at the receiver
- fA (P): Describes the number of measuring points for an interval of 1 dB.

In the case of real measurements with "M" measuring points, the density distribution "fA (P)" is as follows:

$$f_{A(P)} = M \cdot \frac{\ln(10) \cdot 10^{\frac{1}{10} \cdot \left(P_{[dBm]} - P_{mean\_value[dBm]} - 1{,}59dB\right)}}{10} \cdot e^{-10^{\frac{1}{10}\left(P_{[dBm]} - P_{mean\_value[dBm]} - 1{,}59dB\right)}}$$

Whereby:

- M:Number of all measuring points
- P[dBm]: Power in dBm for which the probability density applies (e.g. sensitivity of a receiver)
- P_{Mean} value[dBm]: dBm mean value ($= \frac{1}{n} \cdot \sum_{m=1}^{m=n} m\_measured\_value_{[dBm]}$) across all levels at the receiver
- fA (P): Describes the number of measuring points for an interval of 1 dB.

A12.1.5 Comparison of real measurement with previous relationships

The following measurement relates to a real measurement taken in the vehicle. The original measurements can be found in [40] and [41].

The measurement yielded a mean value of: $-61{,}8dBm = \frac{1}{20000} \cdot \sum_{m=1}^{m=20000} m\_measured\_value_{[dBm]}$

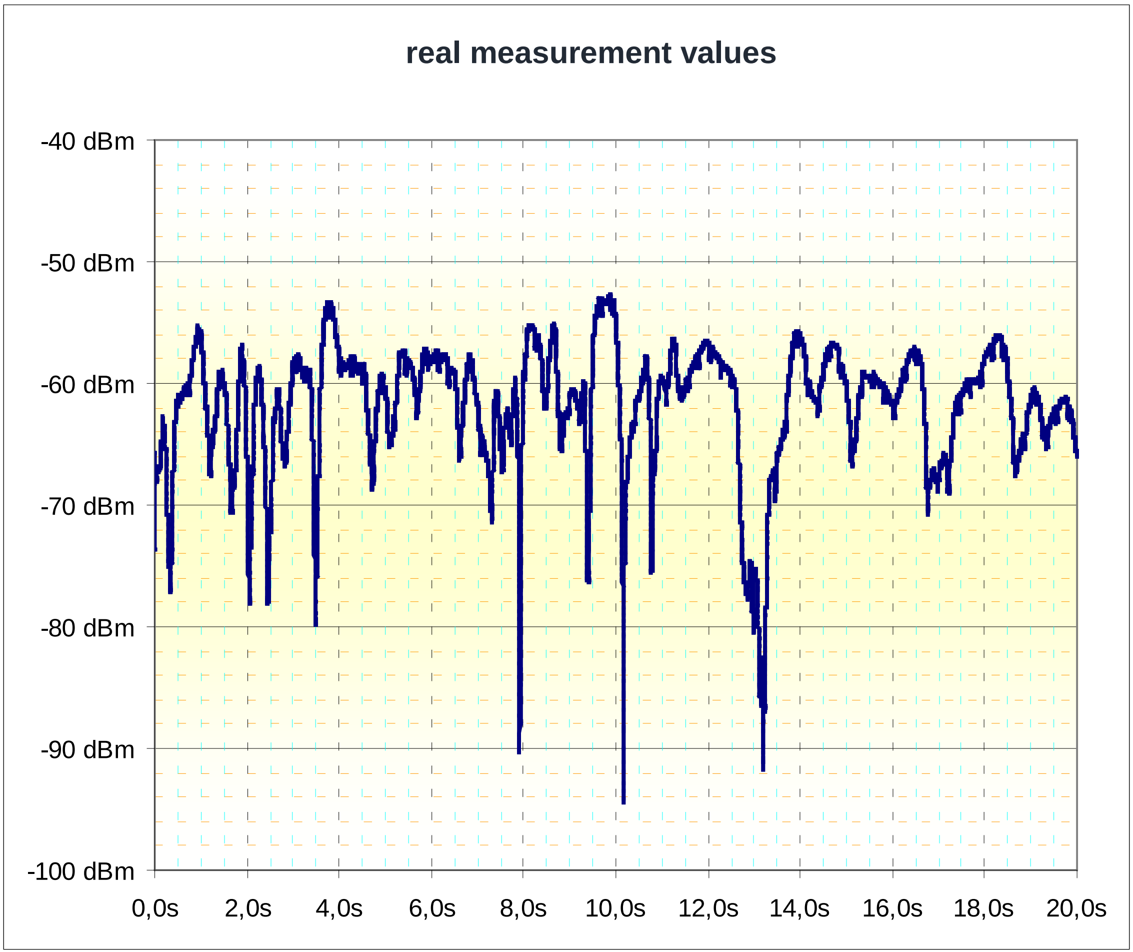
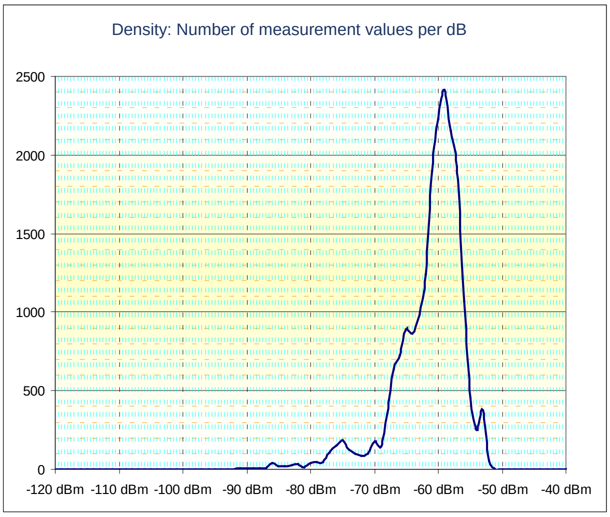
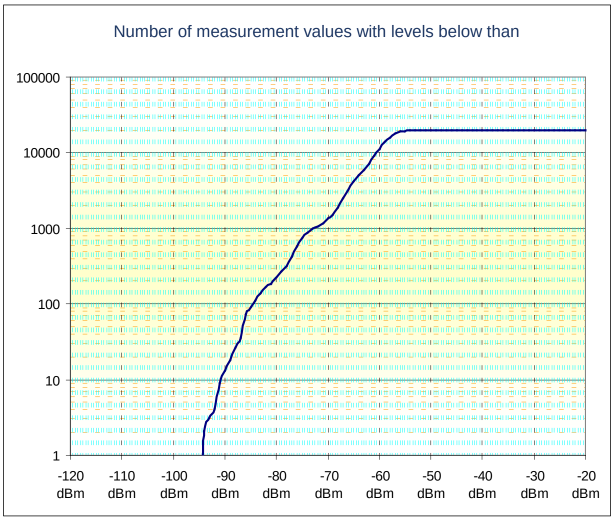


Figure 207: Example of a real measurement (receiving level)

Table 241: Comparison between real measurements and calculation

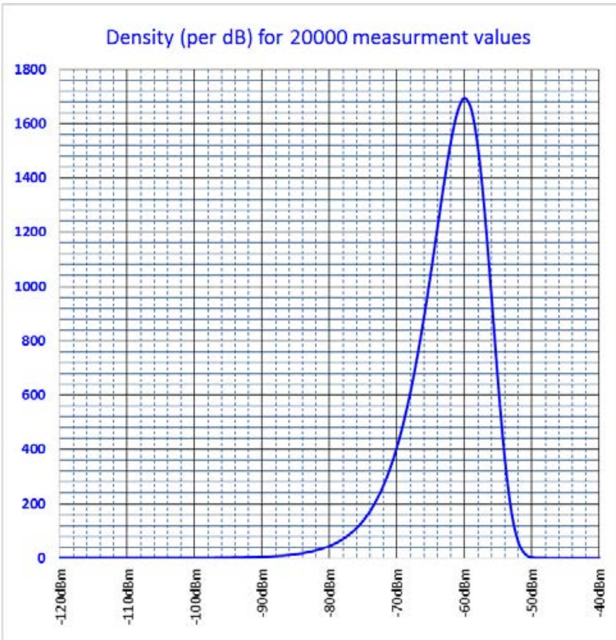
Density distribution	Probability density distribution
Measurement (20 000 readings)	

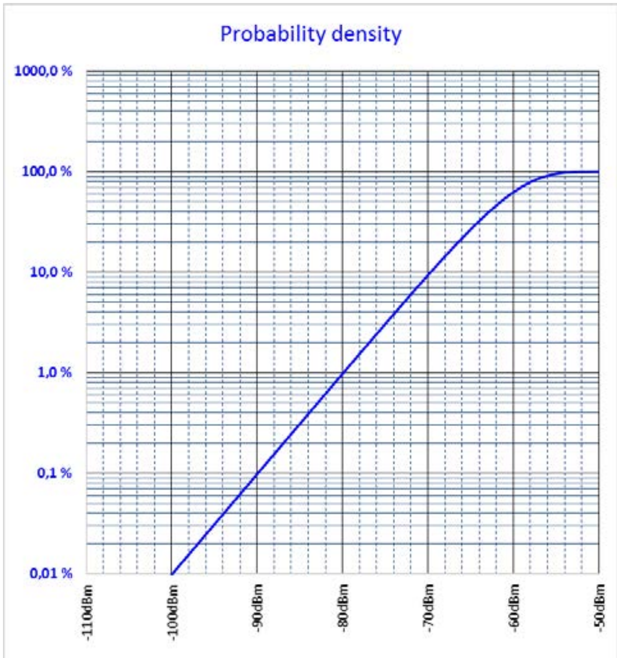
Density distribution	Probability density distribution
	

Calculation (P_{mean} value = -60.0 dBm)

$$f_{A(P)} = M \cdot \frac{\ln(10)\cdot 10^{\frac{1}{10}\cdot\left(P\,[dBm] - P_{mean\_value}\,[dBm] - 1{,}59dB\right)}}{10} \cdot e^{-10^{\frac{1}{10}\cdot\left(P\,[dBm] - P_{mean\_value}\,[dBm] - 1{,}59dB\right)}}$$

$$p_{A(P)} = 1 - e^{-10^{\frac{1}{10}\cdot\left(P\,[dBm] - P_{mean\_value}\,[dBm] - 1{,}59dB\right)}}$$





A12.1.6 **Useful signal and interference signal**

If an interference signal is present in the same space, the following correlations apply:

A12.1.6.1 *Example*

The situation is depicted in the following graphic:

The cellular phone and key are located in the same place in the vehicle. E.g. the key and cellular phone are carried by the vehicle user, whereby both components do not necessarily need to be in the same pocket. It is sufficient if both devices are located in the direct vicinity of the individual (e.g. key in right pants pocket and cellular phone in left pants pocket)

Spurious emissions of the mobile unit include

-36 dBm/100 kHz e.i.r.p.

and would exist in the usable band of the vehicle receiver (433.92 MHz ≤ 165 kHz) at the designated level.

It is also assumed that the spurious emissions can be compared to white noise, which leads to a necessary noise level signal for the useful signal receiver (vehicle) of

S/N =+13 dB

The key itself has a transmission power of

-20 dBm e.i.r.p.

The probability density of both devices is included in the following graphic

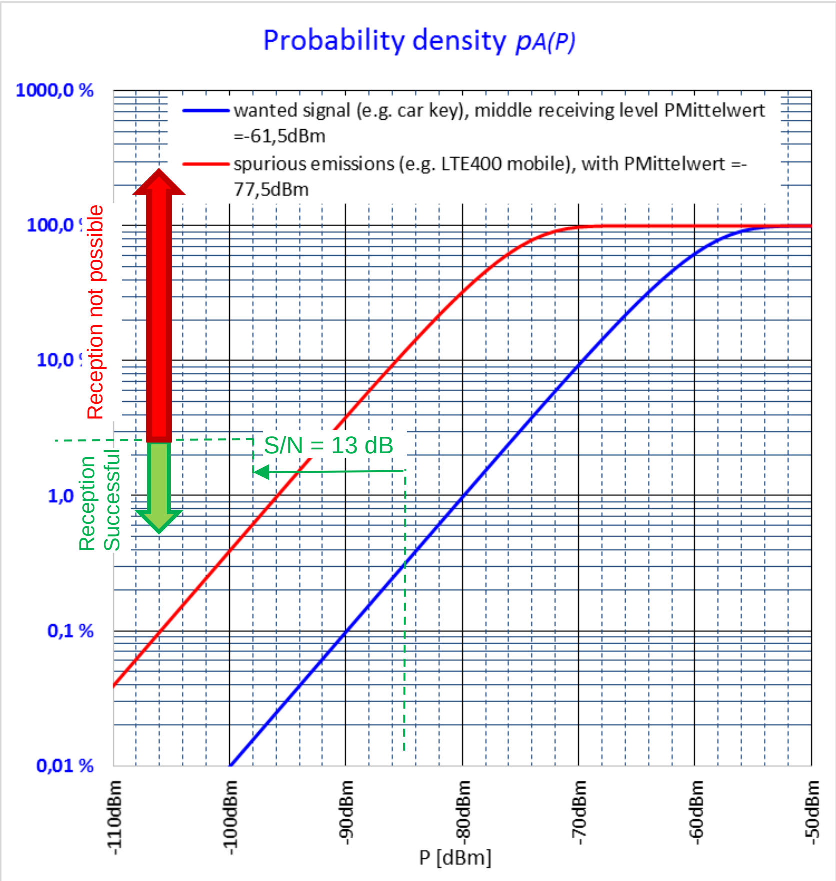


Figure 208: Example of Probability density for key (-20 dBm) and LTE mobile (-36 dBm@100 kHz spurious emission), while Mobile station (MS) and key are located in the same area

As the key and cellular phone do not have a defined position with respect to each other and are accepted at random, the key and cellular phone levels received by the vehicle antennas are also distributed at random.

What can be derived from the above graphic: Let us assume that the key generates a level of -80 dBm at the vehicle antenna. The vehicle receiver can only successfully receive this signal if

Its sensitivity is sufficient (typically approx. -105 dBm)

The minimum required distance between the useful signal and interference signal (here: 13 dB) is fulfilled. (see green arrow at top)

If one now carries out a projection with respect to the probability density for the cellular phone (green line from tip of arrow to red curve), there is a probability of approx. 1.3%. I.e. 1.3% of all base noises from the cellular phone are sufficiently low and do not cause any interference. However, all remaining levels cause a failure consistent with

100% - 1.3% = 98.7%!

A12.1.6.2 *Invoice*

In order to acquire the sought intersecting point along the probability density curve for the interferer (red line), one can assume the general probability density function

$$p_{A(P)} = 1 - e^{-10^{\frac{1}{10}\cdot\left(P_{[dBm]} - P_{mean\_value\,[dBm]} - 1{,}59\,dB\right)}}$$

whereby

$$P_{mean\_value[dBm]} = \frac{1}{n}\cdot\sum_{m=1}^{m=n} measured\_value_{[dBm]\_m}$$

for the interference signal. To receive a better assignment,

$$P_{[dBm]} \rightarrow P_{Interf\,[dBm]} \qquad (unwanted\ \ signal)$$
$$P_{[dBm]} \rightarrow P_{Usefull\,[dBm]} \qquad (wanted\ \ signal)$$

is introduced.

For the borderline case from which the levels of an interference signal (PInterf.[dBm]) prevent the useful signal from being interpreted with PUseful[dBm] by the receiver, the following applies:

$$P_{[dBm]} \rightarrow P_{Interf\,[dBm]} = P_{Usefull\,[dBm]} - S/N_{[dB]}$$

(S/N: signal to noise -> C/I: carrier to Interferer)

Applied to $p_{A(P)} = 1 - e^{-10^{\frac{1}{10}\cdot\left(P_{[dBm]} - P_{mean\_value\,[dBm]} - 1{,}59\,dB\right)}}$, one finds

$$p_{A(P_{Usefull\,[dBm]})} = 1 - e^{-\frac{1}{10}\left(P_{Interf\,[dBm]} - \frac{S}{N}([dB]) - P_{mean_{value_{ceiling[dBm]}}} - 1.59\,[dB]\right)}$$

Equation 0 describes the probability of base noises that lie above the limit value. These do not cause interference with the receiver, however. The number of base noises that lie above the limit value is:

$$p_{AInterf}\left(p_{Usefull[dBm]}\right) = 1 - p_A\left(p_{Usefull[dBm]}\right)$$

$$p_{A(P_{AInterf}(P_{Usefull[dBm]}))} = e^{-10^{\frac{1}{10}\left(P_{Usefull\,[dBm]} - \frac{S}{N}([dB]) - P_{mean_{value_{Interf[dBm]}}} - 1.59\,[dB]\right)}}$$

Sample calculation:

Puseful[dBm] = -80 dBm

P_{mean} value_interf.[dBm] = -76 dBm

S/N[dB] = 13 dB

$$p_{AInterf(-80dBm)} = e^{-10^{\frac{1}{10}(-80dBm-13dB-(-76dBm)-1,59dB)}} = 98,63\%$$ Interference probability for useful signal of -80 dBm.

Now the frequency (statistically) of the useful signal must also be considered to obtain a quantifiable statement in the end.

For this purpose, the relationship in 0 can be referred to:

$$f_{A(P)} = \frac{\ln(10)\cdot 10^{\frac{1}{10}\cdot(P_{[dBm]}-P_{mean\_value\ [dBm]}-1,59dB)}}{10}\cdot e^{-10^{\frac{1}{10}(P_{[dBm]}-P_{mean\_value\ [dBm]}-1,59dB)}}$$

and with the conventions from 0, the following formula can be derived:

$$f_{A\left(P_{Useful[dBm]}\right)} = \frac{\ln(10)\cdot 10^{\frac{1}{10}\cdot\left(P_{Useful[dBm]}-P_{mean\_value\ Useful[dBm]}-1,59dB\right)}}{10}\cdot e^{-10^{\frac{1}{10}\left(P_{Useful[dBm]}-P_{mean\_value\ Useful[dBm]}-1,59dB\right)}}$$

$f_{A\left(P_{Nutz[dBm]}\right)}$ describes the frequency (statistically) of received levels in a 1 dB window.

For the failure probability in the presence of an interferer, all relevant received levels – starting with the lowest process able input power by the receiver (= sensitivity) – must be added and weighted with $f_{A\left(P_{Useful[dBm]}\right)}$

$$p_{Atotal} = \left(\begin{array}{l} p_{A(Sensitivity\_dBm)}\cdot f_{A(Sensitivity\_dBm)} + p_{A(Sensitivity\_dBm+1dB)}\cdot f_{A(Sensitivity\_dBm+1dB)} + \\ + p_{A(Sensitivity\_dBm+2dB)}\cdot f_{A(Sensitivity\_dBm+2dB)} + \ldots \end{array} \right)$$

give rise to:

It points to the total failure probability

$$p_{Ag} = \sum_{n=0dB}^{n=\infty dB} \left(\begin{array}{l} \left(e^{-10^{\frac{1}{10}\left(P_{Sensitivity[dBm]}+n[dB]-S/N[dB]-P_{mean\_value\_Interf\ [dBm]}-1,59dB\right)}} \right)\cdot \\ \left(\frac{\ln(10)\cdot 10^{\frac{1}{10}\cdot\left(P_{Sensitivity[dBm]}+n[dB]-P_{mean\_value Useful[dBm]}-1,59dB\right)}}{10}\cdot e^{-10^{\frac{1}{10}\left(P_{Sensitivity[dBm]}+n[dB]-P_{mean\_value Useful[dBm]}-1,59dB\right)}} \right) \end{array} \right)$$

To be added to the above failure probability are all failure probabilities that due to the limited reception sensitivity of the receiver cannot be processed, which is also the case in the undisturbed state.

In the context, the previous equation can be leveraged.

$$p_{A(P)} = 1 - e^{-10^{\frac{1}{10}(P_{[dBm]}-P_{mean\_value\ [dBm]}-1,59dB)}}$$

Whereby P[dBm] becomes Psensitivity[dBm] and P_{mean} value[dBm] becomes P_{mean} value_usef.[dBm].

Its points to the sum total failure probability of:

$$p_{Atotal} = \sum_{n=0dB}^{n=\infty dB} \left(\left(e^{-10^{\frac{1}{10}\cdot\left(P_{Sensitivity[dBm]}+n[dB]-S/N[dB]-P_{mean\_value\_Interf}[dBm]-1,59dB\right)}} \right) \cdot \left(\frac{\ln(10)\cdot 10^{\frac{1}{10}\cdot\left(P_{Sensitivity[dBm]}+n_{[dB]}-P_{mean\_value\_Useful[dBm]}-1,59dB\right)}}{10} \right) \cdot \left(e^{-10^{\frac{1}{10}\cdot\left(P_{Sensitivity[dBm]}+n[dB]-P_{mean\_value\_Useful[dBm]}-1,59dB\right)}} \right) \right) + 1 - e^{-10^{\frac{1}{10}\cdot\left(P_{Sensitivity[dBm]}-P_{mean\_value\_Useful[dBm]}-1,59dB\right)}}$$

Whereby:

Psensitivity[dBm]: e.g. sensitivity of a receiver)

Pmean_value_usef.[dBm]: dBm mean value (e $= \frac{1}{n}\cdot\sum_{m=1}^{m=n} m\_measured\_value_{[dBm]}$ across all levels at receiver for the useful signal

Pmean_value_interf.[dBm]: dBm mean value ($= \frac{1}{n}\cdot\sum_{m=1}^{m=n} m\_measured\_value_{[dBm]}$) across all levels at receiver for the interference signal

S/N[dB]: Minimum required useful signal for interference signal (signal to noise) in dB so that the receiver can reliably process the useful signals.

A12.1.6.3 *Calculation examples*

Key -22 dBm; LTE = -36 dBm, same location (e.g. driver's seat)

Sensitivity of vehicle receiver: -108 dBm

Table 242: Calculation with key -22 dBm; LTE 400 = -36 dBm, same location (e.g. driver's seat)

	Key	e.i.r.p. transmission power	-22.00 dBm
	LTE	e.i.r.p. interference power (@ 100 kHz*))	-36.00 dBm
	*) The receiver IF bandwidth is 165 kHz, which leads to a 10xlog (165 kHz/100 kHz) = 2.17 dB higher interference entry (-33.83 dBm). The system-determining bandwidth, however, is the demodulation bandwidth, which is lower than the IF bandwidth. As such, the value for 100 kHz represents a good estimate.		
	Key	Mean path attenuation	35.00 dB
	LTE	Mean path attenuation	35.00 dB
		Gain, receiving antenna	-5.00 dBi
Key	Useful signal	Mean reception performance	-62.00 dBm
LTE	Interference signal	Mean reception performance	-76.00 dBm
Resulting failure probability for receiver sensitivity of -108.00 dBm			

	Key	e.i.r.p. transmission power	-22.00 dBm
			44.269%

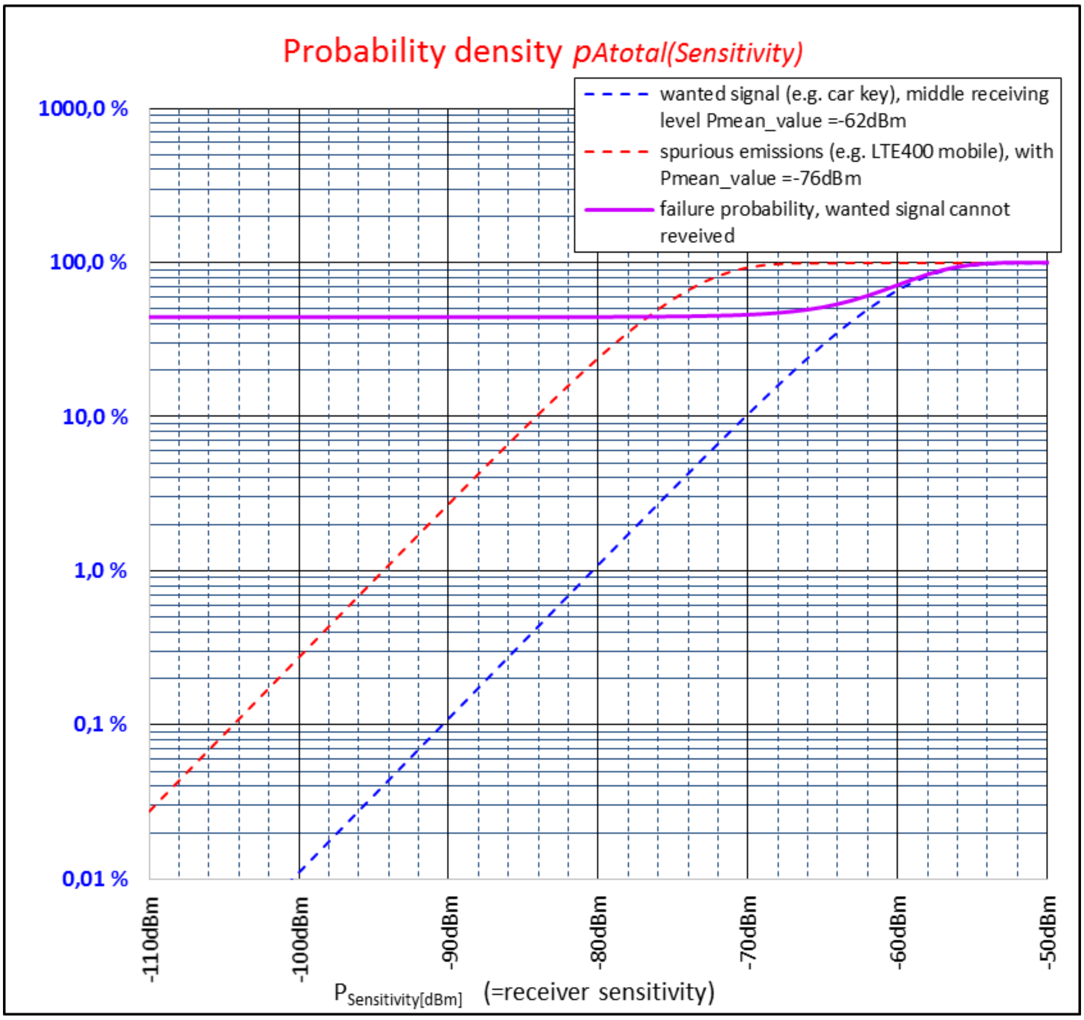


Figure 209: Calculation with key -22 dBm; LTE = -36 dBm, same location (e.g. driver's seat)

Key -20 dBm; LTE 400 = -36 dBm, same location (e.g. driver's seat)

Sensitivity of vehicle receiver: -108 dBm

Table 243: Calculation with key -20 dBm; LTE = -36 dBm, same location (e.g. driver's seat)

	Key	e.i.r.p. transmission power	-20.00 dBm
	LTE	e.i.r.p. interference power (@ 100 kHz*))	-36.00 dBm
	*) The receiver IF bandwidth is 165 kHz, which leads to a 10xlog (165 kHz/100 kHz) = 2.17 dB higher interference entry (-33.83 dBm). The system-determining bandwidth, however, is the demodulation bandwidth, which is lower than the IF bandwidth. As such, the value for 100 kHz represents a good estimate.		
	Key	Mean path attenuation	35.00 dB
	LTE	Mean path attenuation	35.00 dB
		Gain, receiving antenna	-5.00 dBi
Key	Useful signal	Mean reception performance	-60.00 dBm
LTE	Interference signal	Mean reception performance	-76.00 dBm
Resulting failure probability for receiver sensitivity of -108.00 dBm			
			33.386%

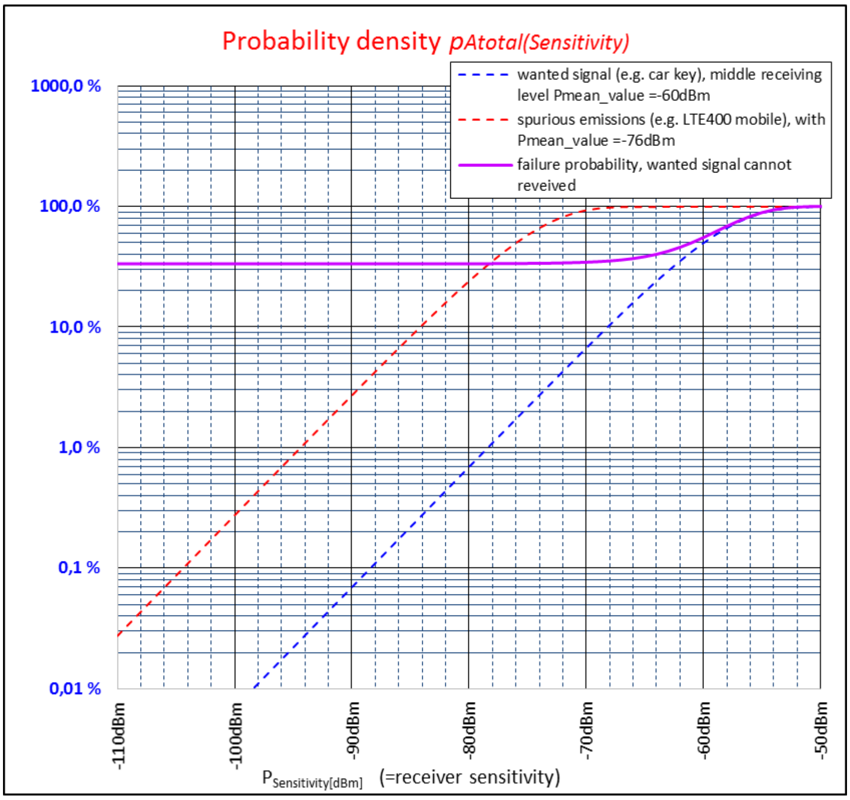


Figure 210: Calculation with key -20 dBm; LTE 400 = -36 dBm, same location (e.g. driver's seat)

Key -18 dBm; LTE 400 = -36 dBm, same location (e.g. driver's seat)

Sensitivity of vehicle receiver: -108 dBm

Table 244: Calculation with key 18 dBm; LTE = -36 dBm, same location (e.g. driver's seat)

	Key	e.i.r.p. transmission power	-18.00 dBm
	LTE	e.i.r.p. interference power (@ 100 kHz*))	-36.00 dBm
	*) The receiver IF bandwidth is 165 kHz, which leads to a 10xlog (165 kHz/100 kHz) = 2.17 dB higher interference entry (-33.83 dBm). The system-determining bandwidth, however, is the demodulation bandwidth, which is lower than the IF bandwidth. As such, the value for 100 kHz represents a good estimate.		
	Key	Mean path attenuation	35.00 dB
	LTE	Mean path attenuation	35.00 dB
		Gain, receiving antenna	-5.00 dBi
Key	Useful signal	Mean reception performance	-58.00 dBm
LTE	Interference signal	Mean reception performance	-76.00 dBm
Resulting failure probability for receiver sensitivity of -108.00 dBm			
			24.025%

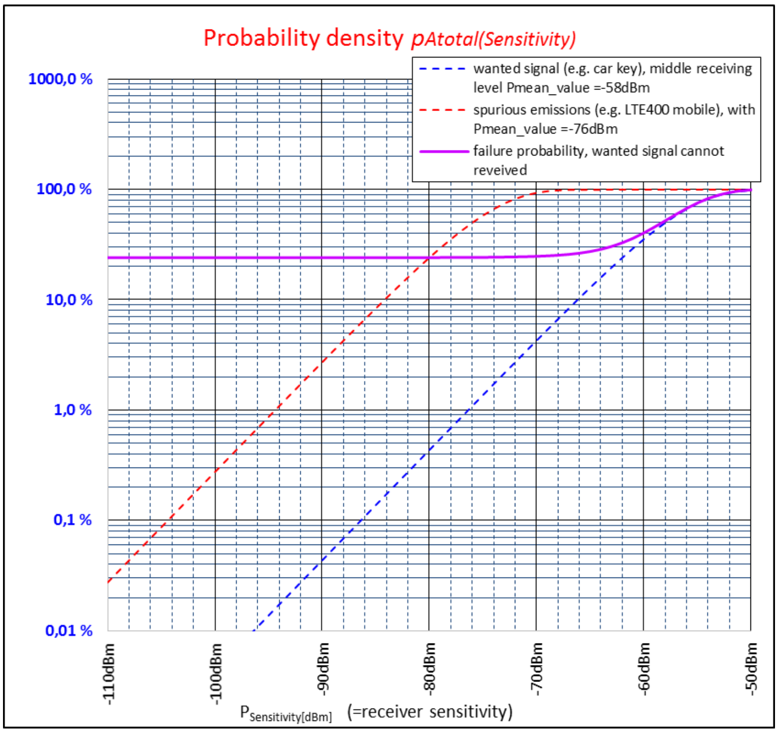


Figure 211: Calculation with key -18 dBm; LTE = -36 dBm, same location (e.g. driver's seat)

Key -18 dBm; LTE 400 = -46 dBm, same location (e.g. driver's seat)

Sensitivity of vehicle receiver: -108 dBm

Table 245: Calculation with key -18 dBm; LTE = -36 dBm, same location (e.g. driver's seat)

	Key	e.i.r.p. transmission power	-18.00 dBm
	LTE	e.i.r.p. interference power (@ 100 kHz*))	-46.00 dBm
	*) The receiver IF bandwidth is 165 kHz, which leads to a 10xlog (165 kHz/100 kHz) = 2.17 dB higher interference entry. The system-determining bandwidth, however, is the demodulation bandwidth, which is lower than the IF bandwidth. As such, the value for 100 kHz represents a good estimate.		
	Key	Mean path attenuation	35.00 dB
	LTE	Mean path attenuation	35.00 dB
		Gain, receiving antenna	-5.00 dBi
Key	Useful signal	Mean reception performance	-58.00 dBm
LTE	Interference signal	Mean reception performance	-86.00 dBm
Resulting failure probability for receiver sensitivity of -108.00 dBm			
			3.065%

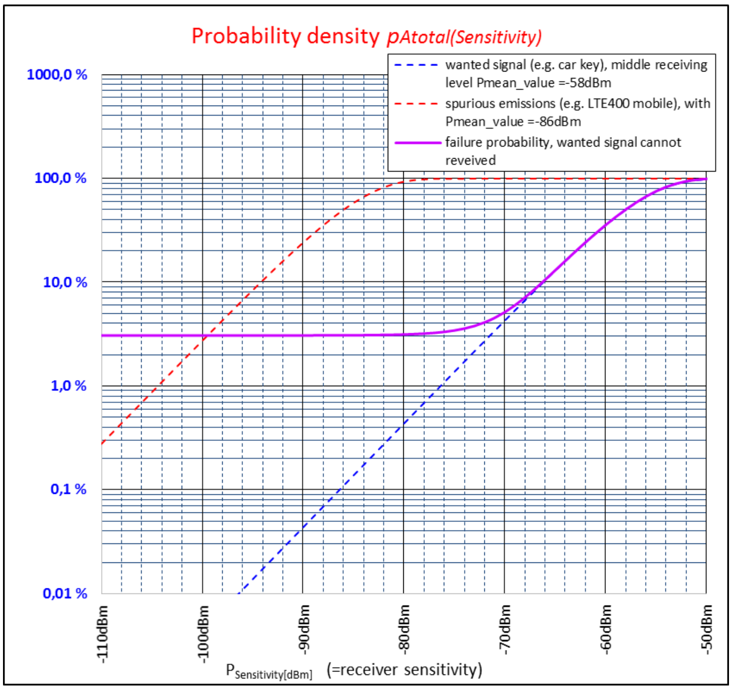


Figure 212: Calculation with key -18 dBm; LTE = -46 dBm, same location (e.g. driver's seat)

Key -18 dBm (driver's seat); LTE = -36 dBm (rear seat bench, 10 dB lower path attenuation)

Sensitivity of vehicle receiver: -108 dBm

Table 246: Calculation with key -18dBm; LTE = -36 dBm, (rear seat bench, 10 dB lower path attenuation)

	Key	e.i.r.p. transmission power	-18.00 dBm
	LTE	e.i.r.p. interference power (@ 100 kHz*))	-36.00 dBm
	*) The receiver IF bandwidth is 165 kHz, which leads to a 10xlog (165 kHz/100 kHz) = 2.17 dB higher interference entry (-33.83 dBm). The system-determining bandwidth, however, is the demodulation bandwidth, which is lower than the IF bandwidth. As such, the value for 100 kHz represents a good estimate.		
	Key	Mean path attenuation	35.00 dB
	LTE	Mean path attenuation	25.00 dB
		Gain, receiving antenna	-5.00 dBi
Key	Useful signal	Mean reception performance	-58.00 dBm
LTE	Interference signal	Mean reception performance	-66.00 dBm
Resulting failure probability for receiver sensitivity of -108.00 dBm			
			75.975%

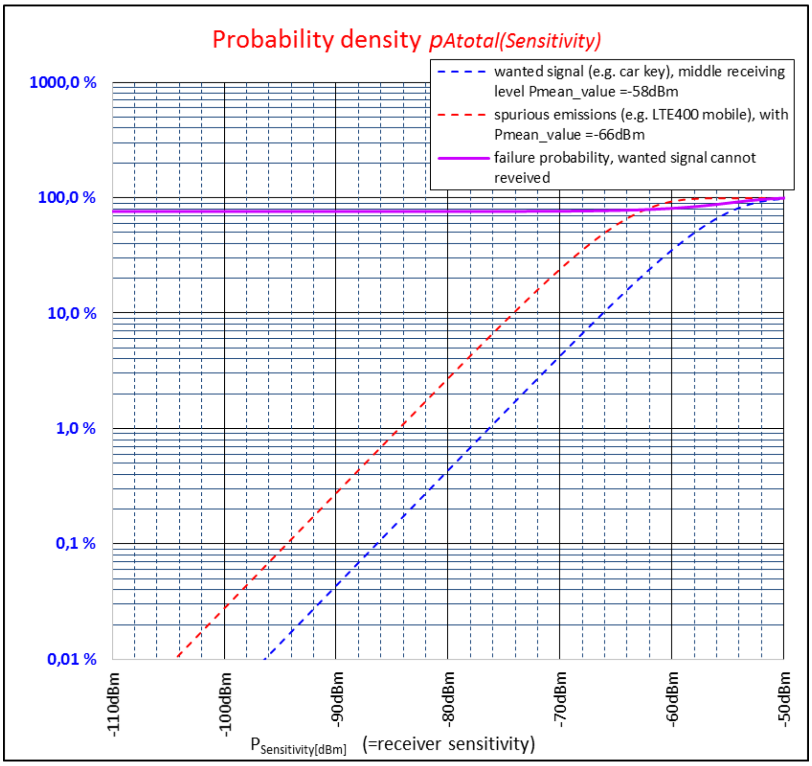


Figure 213: Calculation with key -18 dBm; LTE = -36 dBm, (rear seat bench, 10 dB lower path attenuation

Key -18 dBm (driver's seat); LTE = -96 dBm (rear seat bench, 10 dB lower path attenuation)

Sensitivity of vehicle receiver: -108 dBm

Table 247: Calculation with key -18dBm; LTE = -96 dBm, (rear seat bench, 10 dB lower path attenuation)

	Key	e.i.r.p. transmission power			-18.00 dBm
	LTE	e.i.r.p. interference power (@ 100 kHz*))			-96.00 dBm
	*) The receiver IF bandwidth is 165 kHz, which leads to a 10xlog (165 kHz/100 kHz) = 2.17 dB higher interference entry (-33.83 dBm). The system-determining bandwidth, however, is the demodulation bandwidth, which is lower than the IF bandwidth. As such, the value for 100 kHz represents a good estimate.				
	Key	Mean path attenuation			35.00 dB
	LTE	Mean path attenuation			25.00 dB
		Gain, receiving antenna			-5.00 dBi
Key	Useful signal	Mean reception performance			-58.00 dBm
LTE	Interference signal	Mean reception performance			-126.00 dBm
Resulting failure probability for receiver sensitivity of -108.00 dBm					
					0.001%

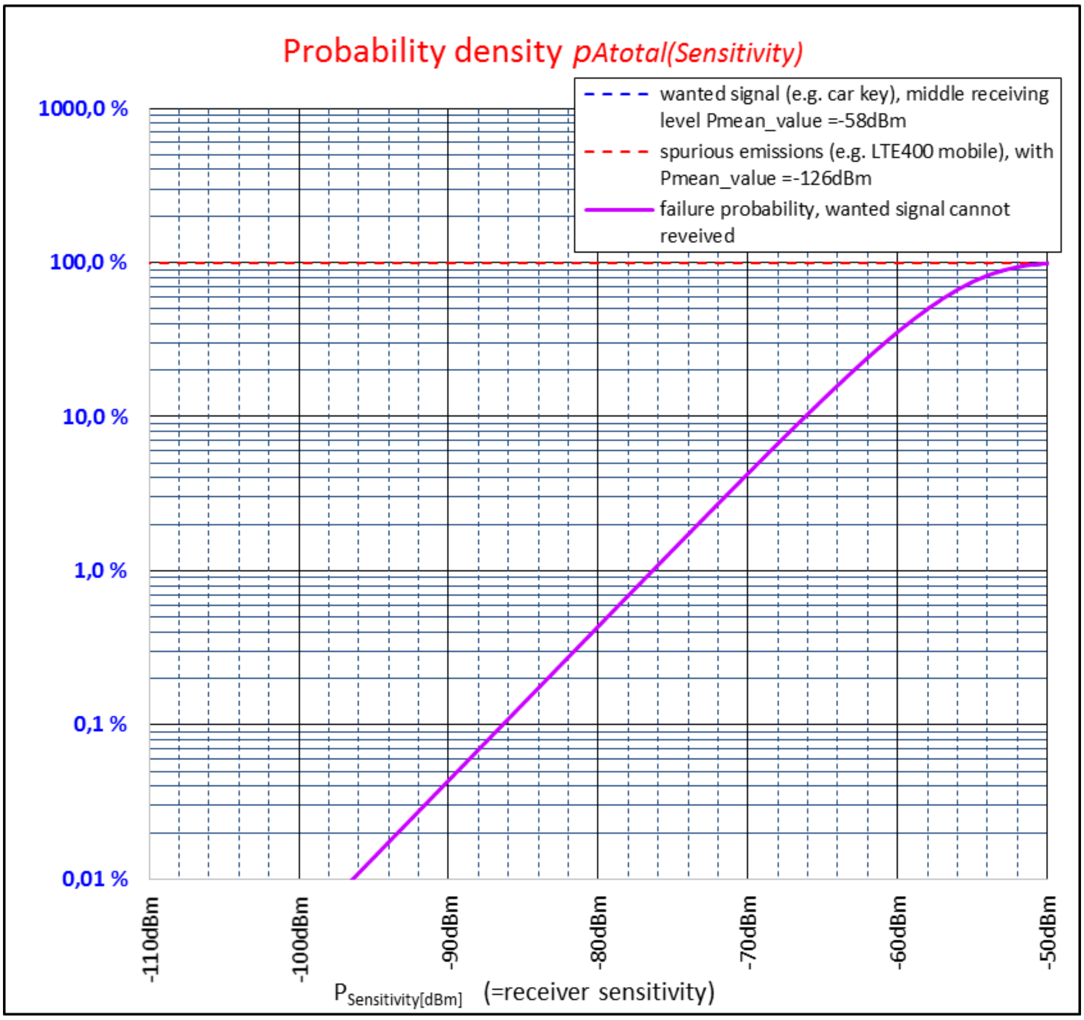


Figure 214: Calculation with key -18 dBm; LTE = -96 dBm, (rear seat bench, 10 dB lower path attenuation)

Key -24 dBm (worst case); undisturbed (no LTE), receiver sensitivity -98.5 dBm (worst case)

Sensitivity of vehicle receiver: -98.5 dBm

Table 248: Calculation with key -24 dBm; worse receiver sensitivity (-98.5 dBm); no LTE 400

	Key	e.i.r.p. transmission power	-24.00 dBm
	LTE	e.i.r.p. interference power (@ 100 kHz*))	-36.00 dBm
	*) The receiver IF bandwidth is 165 kHz, which leads to a 10xlog (165 kHz/100 kHz) = 2.17 dB higher interference entry (-33.83 dBm). The system-determining bandwidth, however, is the demodulation bandwidth, which is lower than the IF bandwidth. As such, the value for 100 kHz represents a good estimate.		
	Key	Mean path attenuation	55.00 dB
	LTE	Mean path attenuation	200.00 dB
		Gain, receiving antenna	-1.00 dBi
Key	Useful signal	Mean reception performance	-80.00 dBm

	Key	e.i.r.p. transmission power	-24.00 dBm
LTE	Interference signal	Mean reception performance	-237.00 dBm
Resulting failure probability for receiver sensitivity of -98.50 dBm			
			0.869%

Figure 215: Calculation with key -24 Bm; worse receiver sensitivity (-98.5 dBm); no LTE

ANNEX 13: LINK BUDGETS

Link budgets are used to calculate cell ranges based on the uplink limited networks.

A13.1 LEGACY LTE SYSTEMS

Table 249: LTE 3 MHz link budget

PMR parameters		Uplink UE->BS (QPSK)	Link	Downlink BS ->UE (QPSK)	Link	Comments
Centre frequency	MHz	455.0	UE	465.0	BS	
Channel bandwidth	MHz	3.0	UE	3.0	BS	
Number of max available RB		15.0		15.0		
Number of transmitted RB		1.0	UE	15.0	BS	Number of RB used in link budget calculation
Resource block bandwidth	MHz	0.180	UE	0.180	BS	
Effective bandwidth	MHz	0.180	UE	2.7	BS	
Noise figure (F)	dB	5.0	BS	9.0	UE	See Rep. ITU-R M.2110
Boltzmann's constant (k)	Ws/K	0.0		0.0		
Absolute temperature (T)	K	290.0		290.0		
Noise power (Pn)	dBm	-116.4	BS	-100.7	UE	Pn(dBm) = F+10log(k*T*B*106)+30
SNIR at cell-edge	dB	-5.0	BS	-3.0	UE	Including 3 dB Noise rise
Link through UE at cell-edge	kbps	28.8	UE	945.0	BS	See ETSI TR 136 942 V11.0.0 (2012-10)
Receiver sensitivity (Rx P_{min})	dBm	-121.4	BS	-103.7	UE	Rx P_{min} = Pn +SNIR
Cell-edge coverage probability	%	75.0		75.0		For 90% cell coverage probability
Gaussian confidence factor for cell-edge coverage probability	%	0.7		0.7		
Shadowing loss standard deviation (□)	dB	8.5		8.5		Value often used in mobile network planning for dense urban and urban environments
Building entry loss standard deviation (□w)	dB	6.0		6.0		See Rec. ITU-R P.1812. Table 6
Total loss standard deviation (□T)	dB	10.4		10.4		sT = SQRT(σ² + σw²)
Loss margin (Lm)	75%	7.0		7.0		Lm = □□□% * □T
Rx P_{mean}	dBm	-114.4	BS	-96.7	UE	Rx P_{mean} = Rx P_{min} + Lm
Transmitted power (Ptx)	dBm	23.0	UE	46.0	BS	MIMO 2x2; Ptx = 43 dBm + 3 dB = 46 dBm
Antenna height	m	1.5	UE	30.0	BS	

PMR parameters		Uplink UE->BS (QPSK)	Link	Downlink BS ->UE (QPSK)	Link	Comments
Cable loss (Lcable)	dB	0.0	UE	2.0	BS	
Antenna gain (Giso)	dBi	-3.0	UE	15.0	BS	
Giso- Lcable	dBi	13.0	BS	-3.0	UE	
Ptx e.i.r.p.	dBm	20.0	UE	59.0	BS	Ptx e.i.r.p.=Ptx+Giso- Lcable
Average building entry loss (L_{wall})	dB	11.0		11.0		See Rec. ITU-R P.1812. Table 6
Typical body loss	dB	4		4		
Max allowed path loss (Lpmax)	dB	136.4	UE	136.7	BS	Lp = e.i.r.p.+(Giso- Lcable) - L_{wall} l- L_{body} -P_{mean}
PMR BS cell range (R)	km	3.15				Urban cell range calculated from uplink Lpmax by Extended Hata model
PMR BS cell range (R)	km	5.43				Suburban cell range calculated from uplink Lpmax by Extended Hata model
PMR BS cell Radius (r)	km	1.58				Urban cell radius (r = R/2)
PMR BS cell Radius (r)	km	2.72				Suburban cell radius (r = R/2)

Table 250: LTE 5 MHz link budget

PMR parameters		Uplink UE->BS (QPSK)	Link	Downlink BS ->UE (QPSK)	Link	Comments
Centre frequency	MHz	455.0	UE	465.0	BS	
Channel bandwidth	MHz	5.0	UE	5.0	BS	
Number of max available RB		25.0		25.0		
Number of transmitted RB		1.0	UE	25.0	BS	Number of RB used in link budget calculation
Resource block bandwidth	MHz	0.180	UE	0.180	BS	
Effective bandwidth	MHz	0.180	UE	4.5	BS	
Noise figure (F)	dB	5.0	BS	9.0	UE	See Rep. ITU-R M.2110
Boltzmann's constant (k)	Ws/K	0.0		0.0		
Absolute temperature (T)	K	290.0		290.0		
Noise power (Pn)	dBm	-116.4	BS	-98.4	UE	Pn(dBm) = F+10log(k*T*B*106)+30
SNIR at cell-edge	dB	0	BS	0	UE	Including 3 dB Noise rise
Link through at cell-edge	kbps	24	UE	2600	BS	See ETSI TS 136 213 (2017)
Receiver sensitivity (Rx P_{min})	dBm	-116.4	BS	-98.4	UE	Rx P_{min} = Pn +SNIR

PMR parameters		Uplink UE->BS (QPSK)	Link	Downlink BS ->UE (QPSK)	Link	Comments
Cell-edge coverage probability	%	75.0		75.0		For 90% cell coverage probability
Gaussian confidence factor for cell-edge coverage probability	%	0.67		0.67		
Shadowing loss standard deviation (□)	dB	8.5		8.5		Value often used in mobile network planning for dense urban and urban environments
Building entry loss standard deviation (□w)	dB	6.0		6.0		See Rec. ITU-R P.1812. Table 6
Total loss standard deviation (□T)	dB	10.4		10.4		σT = SQRT(□² + □w²)
Loss margin (Lm)	75%	7.0		7.0		Lm = □□□% * □T
Rx P_{mean}	dBm	-109.4	BS	-91.4	UE	Rx P_{mean}= Rx P_{min} + Lm
Transmitted power (Ptx)	dBm	23.0	UE	46.0	BS	MIMO/MISO 2x2; Ptx = 43 dBm + 3 dB = 46 dBm
Antenna height	m	1.5	UE	30.0	BS	
Cable loss (Lcable)	dB	0.0	UE	2.0	BS	
Antenna gain (Giso)	dBi	-3.0	UE	15.0	BS	BS antenna pattern: ITU-R F.1336-4 rec 3, with Antenna H/V 3 dB beam widths 65°/15°; ka=kp=kh= 0.7 and kv= 0.3; antenna tilt = -3
Giso- Lcable	dBi	13.0	BS	-3.0	UE	
Ptx e.i.r.p.	dBm	20.0	UE	59.0	BS	Ptx e.i.r.p.=Ptx+Giso- Lcable
Average building entry loss (L_{wall})	dB	11.0		11.0		See Rec. ITU-R P.1812. Table 6
Typical body loss	dB	4		4		
Max allowed path loss (Lpmax)	dB	127.4	UE	132.4	BS	Lpmax = e.i.r.p.+(Giso- Lcable) - L_{wall} - L_{body} -P_{mean}, SNR margin at cell edge = 5 dB
PMR BS cell range (R)	km	1.74				Urban cell range calculated from uplink Lpmax by Extended Hata model
PMR BS cell range (R)	km	3				Suburban cell range calculated from uplink Lpmax by Extended Hata model
PMR BS cell Radius (r)	km	0.87				Urban cell radius (r = R/2)
PMR BS cell Radius (r)	km	1.5				Suburban cell radius (r = R/2)

A13.2 LTE EMTC SYSTEMS

Table 251: LTE eMTC link budget

PMR parameters		Uplink UE ->BS (QPSK)	Link	Downlink BS ->UE (QPSK)	Link	Comments
Centre frequency	MHz	455	UE	465	BS	
Channel bandwidth	MHz	3	UE	3	BS	Two NB Systems a 6RB
Number of max available RB		6	UE	12	BS	
Number of transmitted RB		1.0	UE	6.0	BS	Number of RB used in link budget calculation
Resource block bandwidth	MHz	0.180	UE	0.180	BS	
Effective bandwidth	MHz	0.180	UE	1.08	BS	
Noise figure (F)	dB	5.0	BS	9.0	UE	See Rep. ITU-R M.2110
Boltzmann's constant (k)	Ws/K	0.0		0.0		
Absolute temperature (T)	K	290.0		290.0		
Noise power (P_n)	dBm	-116.4	BS	-104.7	UE	P_n(dBm) = F+10log(k*T*B*106)+30
SNIR at cell-edge	dB	-18.6	BS	-14.5	UE	Including 3 dB Noise rise
Link through UE at cell-edge	kbps	1	UE	3	BS	See Coverage analysis of LTE-M, Category-M1, Sierra Wireless, Ericsson, altair, Nokia et al
Receiver sensitivity (Rx P_{min})	dBm	-135.0	BS	-119.2	UE	Rx P_{min} = Pn +SNIR
Cell-edge coverage probability	%	75.0		75.0		For 90% cell coverage probability
Gaussian confidence factor for cell-edge coverage probability	%	0.7		0.7		
Shadowing loss standard deviation (σ)	dB	8.5		8.5		Value often used in mobile network planning for dense urban and urban environments
Building entry loss standard deviation (σw)	dB	6.0		6.0		Indoor coverage See Rec. ITU-R P.1812. Table 6
Total loss standard deviation (σT)	dB	10.4		10.4		sT = SQRT(σ2 + σw2)
Loss margin (Lm)	75%	7.0		7.0		Lm = µ75% * σ T
R_x P_{mean}	dBm	-128.0	BS	-112.2	UE	R_x P_{mean} = R_x P_{min} + Lm
Transmitted power (P_{tx})	dBm	23.0	UE	42.0	BS	No MIMO 38 + 4 dB power boosting
Antenna height	m	1.5	UE	30.0	BS	
Cable loss (L_{cable})	dB	0.0	UE	2.0	BS	
Antenna gain (G_{iso})	dBi	-3.0	UE	15.0	BS	
G_{iso}-L_{cable}	dBi	13.0	BS	-3.0	UE	

PMR parameters		Uplink UE ->BS (QPSK)	Link	Downlink BS ->UE (QPSK)	Link	Comments
Ptx e.i.r.p.	dBm	20.0	UE	52.0	BS	Ptx e.i.r.p.=Ptx+Giso- Lcable
Average building entry loss (L_{wall})	dB	11.0		11.0		Indoor coverage See Rec. ITU-R P.1812. Table 6
Typical body loss	dB	0.0		0.0		IoT: no body loss
Max allowed path loss (L_{pmax})	dB	150.0	UE	150.2	BS	L_p = e.i.r.p.+(G_{iso}-L_{cable}) - L_{wall} -L_{body} -P_{mean}
PMR BS cell range (R)	km	7.70				Urban cell range calculated from uplink L_{pmax} by Extended Hata model
PMR BS cell Radius (r)	km	3.85				Urban cell radius (r = R/2)

A13.3 DIGITAL TERRESTRIAL TELEVISION (DTT)

Table 252: DTT link budget

DTT parameters		Downlink all environments (High power transmitter)	Notes
Transmitter e.i.r.p.	dBm	85.15	
Antenna height	m	200.00	
Centre frequency	MHz	474.00	Channel 21
Channel bandwidth	MHz	8.00	
Effective bandwidth	MHz	7.6	
Noise figure (F)	dB	7	
Boltzmann's constant (k)	Ws/K	1.38E-23	
Absolute temperature (T)	K	290	
Noise power (Pn)	dBm	-98.17	Pn(dBm) = F+10log(k*T*B*106)+30
SNR at cell-edge	dB	21	
Receiver sensitivity (Pmin)	dBm	-77.17	P_{min} = Pn(dBm) +SNR(dB)
Cell-edge coverage probability	%	95	
Gaussian confidence factor for cell-edge coverage probability of 95% (µ95%)	%	1.64	

DTT parameters		Downlink all environments (High power transmitter)	Notes
Shadowing loss standard deviation (σ)	dB	5.50	
Building entry loss standard deviation (σw)	dB	0.00	
Total loss standard deviation (σT)	dB	5.50	σT = SQRT(σ2 + σw2)
Loss margin (Lm)	95%	9.05	Lm = µ95% * σT
Pmedian (95%)	dBm	-68.12	Pmedian = P_{min} + Lm
Minimum field strength	dBµV/m	53.46	
Cable loss (Lcable)	dB	3.00	
Antenna gain (Giso)	dBi	12.15	
Giso - Lcable	dBi	9.15	DTT Tx antenna: ITU-R 2383 (with -1° antenna tilt implemented in the antenna pattern)
Max allowed path loss (Lpmax)	dB	162.42	Lpmax = e.i.r.p.+(Giso Lcable) -Pmedian
DVB-T coverage radius calculated by ITU-R P 1546-5	km	40.5	Urban
		38.6	Urban with -1° antenna tilt

A13.4 LPWAN

Table 253: Low Power Wide Area Network (LPWAN)125 kHz bandwidth SF12 CR 4/5 link budget

LORA parameters		Uplink UE -> BS (QPSK) Outdoor	UE -> BS (QPSK) Indoor	Link	Downlink BS -> UE (QPSK) Outdoor	BS -> UE (QPSK) Indoor	Link	Comments
Centre frequency	MHz	425	425	UE	425	425	BS	
Channel BW	MHz	0.125	0.125	UE	0.125	0.125	BS	
Spreading factor (SF)		12	12		12	12		
SNR	dB	-21.9	-21.9		-21.9	-21.9		
Noise Figure (NF)	dB	3	3		7	7		
Receiver sensitivity	dBm	-141.9	-141.9	BS	-137.9	-137.9	UE	Rx Pmin
Cell-edge coverage probability	%	75.0	75.0		75.0	75.0		For 90% cell coverage probability
Gaussian confidence factor for cell-edge coverage probability (□□		0.7	0.7		0.7	0.7		
Shadowing loss standard deviation (□)	dB	8.5	8.5		8.5	8.5		Value often used in mobile network planning for dense urban and urban environments
Building entry loss standard deviation (□w)	dB	0	6.0		0	6.0		
Total loss standard deviation (□T)	dB	0	10.4		0	10.4		□T = SQRT(□2 + □w2)
Loss margin (Lm)	75%	5.95	7.0		5.95	7.0		Lm = □ * □T
Rx Pmean	dBm	-135.95	-134.9	BS	-131.95	-130.9	UE	Rx Pmean = Rx Pmin + Lm
Transmitted power (Ptx)	dBm	12.15	12.15	UE	25.55	25.55	BS	
Antenna height	m	1.5	1.5	UE	25.0	25.0	BS	
Cable loss (Lcable)	dB	0.0	0.0	UE	2.0	2.0	BS	
Antenna gain (Giso)	dBi	0.0	0.0	UE	5.6	5.6	BS	
Giso-Lcable	dBi	3.6	3.6	BS	0.0	0.0	UE	
Ptx e.i.r.p.	dBm	12.15	12.15	UE	29.15	29.15	BS	Ptx e.i.r.p.=Ptx+Giso-Lcable
Average building entry loss (Lwall)	dB		11.0			11.0		

LORA parameters		Uplink UE -> BS (QPSK) Outdoor	UE -> BS (QPSK) Indoor	Link	Downlink BS -> UE (QPSK) Outdoor	BS -> UE (QPSK) Indoor	Link	Comments
Max allowed path loss (Lpmax)	dB	151.7	139.6	UE	161.1	149.05	BS	Lp = e.i.r.p.+(Giso-Lcable)RX - Lwall -Pmean
PMR BS cell range (R)	km	8.1	3.7					Urban cell range calculated from uplink Lpmax by Extended Hata model
PMR BS cell range (R)	km	37.8	19.9					Rural cell range calculated from uplink Lpmax by Extended Hata model
PMR BS cell Radius (r)	km	4.05	1.85					Urban cell radius (r = R/2)
PMR BS cell Radius (r)	km	18.9	9.95					Rural cell radius (r = R/2)

Table 254: Low Power Wide Area Network (LPWAN) 250 kHz bandwidth SF12 CR 4/5 link budget

LORA parameters		Uplink UE -> BS (QPSK) Outdoor	UE -> BS (QPSK) Indoor	Link	Downlink BS -> UE (QPSK) Outdoor	BS -> UE (QPSK) Indoor	Link	Comments
Centre frequency	MHz	425	425	UE	425	425	BS	
Channel BW	MHz	0.250	0.250	UE	0.250	0.250	BS	
Spreading factor (SF)		12	12		12	12		
SNR	dB	-21.9	-21.9		-21.9	-21.9		
Noise Figure (NF)	dB	3	3		7	7		
Receiver sensitivity	dBm	-138.9	-138.9	BS	-134.9	-134.9	UE	Rx Pmin
Cell-edge coverage probability	%	75.0	75.0		75.0	75.0		For 90% cell coverage probability
Gaussian confidence factor for cell-edge coverage probability (□□		0.7	0.7		0.7	0.7		
Shadowing loss standard deviation (□)	dB	8.5	8.5		8.5	8.5		Value often used in mobile network planning for dense urban and urban environments
Building entry loss standard deviation (□w)	dB	0	6.0		0	6.0		
Total loss standard deviation (□T)	dB	0	10.4		0	10.4		□T = SQRT(□2 + □w2)
Loss margin (Lm)	75%	5.95	7.0		5.95	7.0		Lm = □ * □T
Rx Pmean	dBm	-132.95	-131.9	BS	-128.95	-127.9	UE	Rx Pmean = Rx Pmin + Lm
Transmitted power (Ptx)	dBm	12.15	12.15	UE	25.55	25.55	BS	
Antenna height	m	1.5	1.5	UE	25.0	25.0	BS	
Cable loss (Lcable)	dB	0.0	0.0	UE	2.0	2.0	BS	
Antenna gain (Giso)	dBi	0.0	0.0	UE	5.6	5.6	BS	
Giso-Lcable	dBi	3.6	3.6	BS	0.0	0.0	UE	
Ptx e.i.r.p.	dBm	12.15	12.15	UE	29.15	29.15	BS	Ptx e.i.r.p.=Ptx+Giso-Lcable
Average building entry loss (Lwall)	dB		11.0			11.0		
Max allowed path loss (Lpmax)	dB	148.7	136.6	UE	158.1	146.05	BS	Lp = e.i.r.p.+(Giso-Lcable)RX

LORA parameters		Uplink UE -> BS (QPSK) Outdoor	UE -> BS (QPSK) Indoor	Link	Downlink BS -> UE (QPSK) Outdoor	BS -> UE (QPSK) Indoor	Link	Comments
								- Lwall -Pmean
PMR BS cell range (R)	km	6.7	3					Urban cell range calculated from uplink Lpmax by Extended Hata model
PMR BS cell range (R)	km	32.5	16.4					Rural cell range calculated from uplink Lpmax by Extended Hata model
PMR BS cell Radius (r)	km	3.35	1.5					Urban cell radius (r = R/2)
PMR BS cell Radius (r)	km	16.25	8.2					Rural cell radius (r = R/2)

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