CEPT ECC Electronic Communications Committee

ECC Report 327

Technical studies for the update of the Ultra Wide Band (UWB) regulatory framework in the band 6.0 GHz to 8.5 GHz

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0 EXECUTIVE SUMMARY

0.1 OVERVIEW

The applications that are investigated in this Report are used for radiodetermination and location tracking, tracing and data acquisition. They operate in the field of logistics and traffic management, home security applications and access control, indoor positioning applications and vehicular applications.

Study results presented in this Report evaluate whether compatibility with incumbent system in the band 6.0 GHz to 8.5GHz could be achieved, when UWB devices are operating with -41.3 dBm/MHz either as fixed installations or in road vehicles and whether a limited number of indoor devices can operate with an increase TX power of up to -31.3 dBm/MHz.

In order to adequately assess the compatibly situation, the future use cases have been analysed and, where necessary, appropriate mitigation factors have been identified. It can be stated that in contrast to the originally assumed use cases in ECC Report 64 [5] the deployment of UWB has mainly focused on location tracking and low data rate communications based on IEEE802.15.4z [44] standards rather than the assumed high and ultra-high data rate systems based on e.g. the ECMA 368 [49] standard or ETSI TS 102 455 [48]. Since the completion of ECC Report 64 in 2005, such high and ultra-high data rate UWB systems did not materialise. Rather, WAS/RLAN systems became the dominant technologies for high and ultra-high data rate transmissions. This leads to a significant reduction of the assumed activity factors.

Furthermore, today's technology can provide several operational channels also in the band between 6.0 GHz and 8.5 GHz which can be taken into account in the band apportionment and thus reducing the density of devices in a potential victim band further.

These effects have mainly been taken into account in the aggregation investigations.

In this Report, the peak power effect of UWB devices have been investigated for the first time in more detail, especially in the fixed service investigations.

The different types of applications and their parameters studied in this Report are summarised in the Table below.

Table 1: Summary of the applications and their parameters

Application	Assumed Density	Activity factor	Transmit Power (e.i.r.p.)
Fixed outdoor application			
Parking management application	Urban: max. 40 devices/km or 400 devices/km^2 Suburban: 100 device/ km^2 Rural: 10 devices/km^2	AF: 0.05%	-41.3 dBm/MHz mean e.i.r.p. power density in 1 ms 0 dBm/50 MHz (Max), peak e.i.r.p. power
Outdoor logistics	Outdoor logistics: max. 1000/km^2 Urban: 50/km^2 Suburban: 100/km^2 Rural: 10/km^2	AF: 0.3%	-41.3 dBm/MHz mean e.i.r.p. power density in 1 ms 0 dBm/50 MHz (Max), peak e.i.r.p. power
Physical access control system (PACS)	Urban: 200/km^2 Suburban: 50/km^2 Rural: 10/km^2	AF: 0.006%	-41.3 dBm/MHz mean e.i.r.p. power density in 1 ms 0 dBm/50 MHz (Max), peak e.i.r.p. power

Application	Assumed Density	Activity factor	Transmit Power (e.i.r.p.)
Vehicular applications fixed outdoor installations	Max. 40 devices per km of road; 400 devices per km², 10 km road length in 1 km² Urban: 400/km² Suburban: 50/km² Rural: 10/km²	Urban AF: 5% Suburban: 2% Rural: 0.5%	-41.3 dBm/MHz mean e.i.r.p. power density in 1 ms 0 dBm/50 MHz (Max), peak e.i.r.p. power
General vehicular outdoor applications for ITS			
Vehicular applications, vehicle installations	6000 per km² max. (10 3-lane roads two directions dense traffic), typical 1000 per km² Urban: 1000/km² Suburban: 100/km² Rural: 25/km²	AF: 1% max AF typical: 0.4% AF: 0.04% for V2V	-41.3 dBm/MHz mean e.i.r.p. power density in 1 ms 0 dBm/50 MHz (Max), peak e.i.r.p. power
High power indoor devices			
Indoor systems with higher power	Urban: 1000 to 2500 devices/km² Suburban: 100 to 250/km² Rural: 25/km²	AF: 1%	-31.3 dBm/MHz mean e.i.r.p. power density in 1 ms 10 dBm/50 MHz (Max), peak e.i.r.p. power

Due to the mentioned additional mitigation factors the overall interference potential of the applications investigated in this Report is lower than the interference potential of the already regulated generic UBW devices based on ECC Decision (06)04[45].

This Report outlines that the three following factors are key in assessing the compatibility between UWB devices with relaxed conditions as described in section 0.1, and incumbents systems across the band 6-8.5 GHz:

- Reduced densities of UWB devices compared to the ones considered in ECC Report 64 [5];
- Consideration of use cases associated with low data rate and low activity factors as the one considered in ECC Decision (06)04;
- Ability for UWB devices to spread, on an aggregate basis, across a number of possible operational channels.

For each considered application, the assumed device density taken into account in the studies, is described in Table 1. It was noted that if the deployment densities assumed in this report are exceeded, further studies on additional mitigation techniques may be required in order to ensure coexistence with outdoor stations of radiocommunication services.

For fixed outdoor installations, coexistence would be possible[1] based on the following assumptions:

- Maximum mean e.i.r.p. power of -41.3 dBm/MHz, peak power in 50 MHz of 0 dBm;
- Maximum height of 10 m;
- Directive antennas are down tilted to provide additional attenuation of 5dB for parking management, outdoor logistics and fixed vehicular applications;
- Omnidirectional antennas for data acquisition for authentication / access control (PACS);

[1] It is noted that for these installations, in a few specific geometrical cases with low probability, single-interference studies have shown that separation distances are more than 1 km.

- Duty Cycle < 5% per second (see Table 4).

For indoor installations (both fixed installations and portable devices), coexistence would be possible based on the following assumptions:

- Maximum mean e.i.r.p. power of -31.3 dBm/MHz, peak power in 50 MHz of 10 dBm;
- Duty Cycle < 5% per second (see Table 3);
- Networked/controlled operation.

For vehicular applications coexistence would be possible based on the following assumptions:

- Maximum mean e.i.r.p. power of -41.3 dBm/MHz, peak power in 50 MHz of 0 dBm;
- Maximum height of 4 m;
- omnidirectional antennas;
- Duty Cycle < 1% per second (see Table 5).

0.2 FIXED SERVICE (FS)

MCL calculations show a maximum separation distance of 11226 m for the outdoor line of sight scenario. Taking into account vertical geometries this distance can be reduced to 10965 m.

For outdoor NLOS scenarios the maximum separation distance is 1484 m. Taking into account vertical geometries this distance can be reduced to 250 m. That behaviour can be explained by using a suburban/urban clutter model, adding minimum 16.7 dB attenuation for distances greater than 250 m.

Outside of the FS main lobe, the minimum separation distance is about 50 m without applying any clutter.

Additional results leading to smaller distances than shown above, covering also indoor scenarios, peak power scenarios and a FS antenna scenario with lower peak gain are included in ANNEX 2.

For the indoor high-power UWB applications, a geometrical minimum required separation distance for aggregated propagation effects study was performed with indoor high-power UWB using the geometrical approach where the effective FS antenna gain is calculated based on the relative position of the UWB device compared to the FS receiver. Recommendation ITU-R P.452-16 was used to model propagation losses, Recommendation ITU-R P.2109 [36] to model building entry losses, and Recommendation ITU-R P.2108 for clutter losses. All the propagation losses were aggregated into one statistical loss, which was used to determine the minimum separation distance at different percentiles p. Four different scenarios were considered consisting of two types of buildings, traditional and thermally efficient, and two types of propagation conditions. The first considers propagation losses and building entry losses, and another one considers clutters losses besides propagation losses and building entry losses. The overall CDF of the losses was computed and evaluated for p = 1%, p = 10%, and p = 50%, where p represents the percentile of the overall losses. The results assuming no clutter and traditional buildings span from 0.25 km to 25.5 km, whereas for thermally efficient buildings they span from 0 km to 19.75 km. The results assuming clutter and traditional buildings span from 0 km to 0.26 km, whereas for thermally efficient buildings they span from 0 km to 0.25 km.

Two Monte Carlo studies were carried out. Results from a large number of Monte Carlo events show that the percentage of events for which the short-term threshold (I/N = 19 dB) is not exceeded for more than $4.5 \cdot 10^{-5}$% (which was used as a proxy for short-term protection criterion). The long-term threshold (I/N = -20 dB) is not exceeded for more than 1.7%, which is below 20%. Although there are no clear guidelines given in the regulatory literature regarding the allowed exceedance time for the peak power criterion, considering that the other 2 examined criteria are met, it can be assumed that this criterion is also met.

A simultaneous assessment of RLAN and UWB systems has not been done. Given that the significantly lower interference levels of UWB compared to RLAN, a significant increase of the overall impact is not expected.

It is noted that the simulations carried out used space- and time-based distributions for calculating a percentage of interference[2]. Therefore, results are in terms of time-space percentage and not in terms of time percentage only. This needs to be taken into account in the interpretation of results.

0.3 FIXED SATELLITE SERVICE (FSS)

MCL calculations show a maximum separation distance of 25386 m from the FSS receiver for the LOS scenario. Taking into account vertical geometries and the corresponding elevation angles this distance can be reduced to 156 m, even without taking clutter into account.

For NLOS scenarios the maximum separation distance is 1428 m from the FSS receiver. Taking into account vertical geometries this distance can be reduced to 156 m.

Outside of the FSS main beam, the minimum separation distance is about 34 m without applying any clutter.

The MCL calculations included in this Report are based on the assumption of a FSS systems operating in dense urban environments. The compatibility studies take into account the FSS antenna patterns for an elevation of 10° and the relative heights of 20 m between the FSS antenna and the UWB devices. Different dish sizes have been considered. Only the outdoor UWB deployment has been taken into account.

For all dish sizes above 3 m, the minimum separation distance in main beam direction of the FSS is 30 m in the considered urban environment. For smaller antenna dish sizes this distance increases to 190 m for a dish size of 1.8 m and 250 m for a dish size of 1.2 m in the considered urban environment.

MCL calculations for FSS systems operating in rural environment have not been considered.

Aggregate interference studies using Monte-Carlo methodology show that the long term and short-term interference criterion is met in all scenarios for mean and peak e.i.r.p. based on a sensitivity analysis on the difference of FSS deployment in rural and urban environment with specific FSS height and dish antenna diameter associated to their deployment as well as on the size of the exclusion zone and elevation angle.

0.4 RADIO ASTRONOMY SERVICE (RAS)

For the investigation of any potential compatibility issues between UWB and RAS, an extensive analysis has been performed taking into account single entry scenarios and aggregation scenarios with the focus on outdoor deployments.

For the compatibility with the RAS, the local Tx-side clutter zone type and the Tx antenna heights play a key role. As long as (all) antennas of an installation are within the clutter, no interference at the RAS observatory is expected once the UWB device is beyond about 1 km distance. However, some of the proposed usage scenarios involve relatively high antennas, which can at least in part exceed the local clutter heights and will utilise a relatively high number density of devices and activity factors. In these cases, coordination with the RAS on a national level will be necessary in a given area around the RAS stations. Based on generic (flat-terrain) analyses, the coordination zone could be of the order of 10 km radius around a site, but local terrain and clutter properties would permit to install devices in a fair number of positions within such a coordination zone without putting RAS operations in danger.

The results for the vehicular-to-vehicular case show that for UWB devices attached to vehicles compatibility with RAS is given for most sites that were studied here. This is owing to the low traffic density and the clutter conditions around the stations. In fact, RAS stations are in most cases purposefully located in remote areas for exactly this reason. A minimal separation distance of 0.5 km to 1 km should suffice for adequate protection. Unfortunately, for the Jodrell Bank station the situation is somewhat worse, as there is more traffic and higher population density in the area than can be found at the other RAS sites. Here, an exclusion zone of up to 4-5 km may be needed. Taking into account that the considered activity factor of 0.4% in the V2V investigation is

[2] There are ongoing studies within ECC to provide a methodology on how to derive “short term” protection criteria for FS for any sharing and compatibility studies. The results were not yet available at the time of publication of this Report

significantly higher than the assumed activity factor for this kind of application (AF ≤ 0.04%) this exclusion or control zone could be changed when the real AFs are taken into account.

0.5 SPACE SCIENCE SERVICES

0.5.1 EESS (SPACE-TO-EARTH), SRS (SPACE-TO-EARTH) AND METEOROLOGICAL-SATELLITE SERVICE (SPACE-TO-EARTH)

The single-entry studies included in the Report show mitigation distances between 300 m and 3600 m for a UWB device operating with 100% duty cycle and assuming a LoS path towards the installations.

In addition, aggregated interference investigations have been performed, taking into account the UWB applications deployments assumed in this Report. The calculations of aggregated interference into SRS/EESS/MetSat earth stations, assuming flat terrain around the Earth stations, without consideration of clutter, show that the SRS/EESS/MetSat protection criteria are met with the application of the following minimal separation distances between the concerned earth stations and any UWB application:

- For UWB fixed outdoor installation:
  - 2 km around SRS earth station for near Earth SRS missions and 1.5 km for deep space SRS missions;
  - 100 m around EESS and MetSat earth station.
- For UWB vehicle installation
  - 10 km around SRS earth station for near Earth SRS missions and 8 km for deep space SRS missions;
  - 700 m around EESS earth station;
  - 400 m around MetSat earth station.

Additional site specific simulations have been performed for UWB vehicles installations to assess the impact of considering terrain and clutter on the required separations distances. These simulations show that the consideration of terrain and clutter, as appropriate, leads to significantly lower separation distances:

- 5 km around the SRS earth station located in Cebreros (Spain), when considering terrain without additional clutter;
- 300 m around the SRS earth station located in Cebreros (Spain), when considering terrain with additional clutter (17 dB) around the UWB stations;
- 500 m around the EESS station located in Weilheim (Germany) when considering terrain without additional clutter.

In the case of UWB indoor positioning applications, it is anticipated that the indoor to outdoor attenuation together with additional factors (such as body loss and clutter loss and the separation distances between indoor UWB deployments and SRS/EESS/MetSat earth stations) would provide enough mitigation to avoid interference from the specific UWB indoor deployments considered in this Report to SRS/EESS/MetSat earth stations. This scenario was therefore not addressed in these aggregated interference assessments.

0.5.2 EESS (EARTH-TO-SPACE), SRS (EARTH-TO-SPACE) AND METEOROLOGICAL-SATELLITE SERVICE (EARTH-TO-SPACE)

No impact from UWB systems is expected into EESS, SRS and MetSat spacecraft receivers in the context of the ECC Report.

0.5.3 EESS(PASSIVE) USED UNDER RR NO. 5.458 (6425-7250 MHZ)

The spectrum sharing studies with EESS passive sensors in the band 6425 MHz to 7250 MHz show negative interference margin for most of the proposed applications and corresponding interference scenarios considered in this Report. This applies to both the single-entry and the aggregate interference calculations.

However, the degradation of the radio environment experienced by EESS passive sensors caused by the applications presented in this Report is expected to be generally smaller than that caused by the operation of generic UWB devices based on the existing regulation in ECC Decision (06)04 and the related assumed activity factors and device densities in ECC Report 64 [5].

TABLE OF CONTENTS

0 Executive summary 2
0.1 Overview 2
0.2 Fixed Service (FS) 4
0.3 Fixed Satellite Service (FSS) 5
0.4 Radio Astronomy Service (RAS) 5
0.5 SPACE Science services 6
0.5.1 EESS (SPACE-TO-EARTH), SRS (SPACE-TO-EARTH) AND METEOROLOGICAL-SATELLITE SERVICE (SPACE-TO-EARTH) 6
0.5.2 EESS (EARTH-TO-SPACE), SRS (EARTH-TO-SPACE) AND METEOROLOGICAL-SATELLITE SERVICE (EARTH-TO-SPACE) 6
0.5.3 EESS(PASSIVE) USED UNDER RR NO. 5.458 (6425-7250 MHZ) 6
1 Introduction 11
2 Allocations and applications in the band 6-8.5 GHz 13
3 UWB in the frequency range of 6 GHz to 8.5 GHz 14
3.1 Overview 14
3.2 Logistics and traffic management 14
3.2.1 Application overview 14
3.2.2 System configuration and description 16
3.2.3 Deployment assumptions 17
3.3 Home security applications and access control 18
3.3.1 Application overview 18
3.3.2 System configuration and description 19
3.3.3 Deployment assumptions 22
3.3.4 Mitigation factors 23
3.4 Indoor positioning applications 23
3.4.1 Introduction 23
3.4.2 System configuration and description 24
3.4.3 Deployment assumptions 24
3.5 Vehicular applications 25
3.5.1 Application overview 25
3.5.2 System configuration and description 26
3.5.3 Antenna patterns 27
3.5.4 Deployment Assumptions 29
3.6 Mitigation factors and techniques 31
3.7 Deployment assumptions for UWB used in this study 31
4 Services and applications in the 6 - 8.5 GHz frequency range 33
4.1 Fixed Service 33
4.1.1 Introduction 33
4.1.2 Protection Criteria 33
4.1.3 FS system parameters and assumptions 33
4.1.4 FS link lengths 35
4.2 Fixed satellite service Space-to-Earth 36
4.3 Radio Astronomy in the band 6.55 to 6.6752 GHz 36
4.4 EESS (SPACE-TO-EARTH), SRS (SPACE-TO-EARTH) AND METEOROLOGICAL-SATELLITE SERVICE (SPACE-TO-EARTH) 36
4.4.1 EESS (Space-to-Earth) in the band 8025-8400 MHz 36
4.4.2 SRS (Space-to-Earth) in the band 8400-8500 MHz 37

4.4.3 Meteorological-Satellite Service (Space-to-Earth) ... 37
4.5 EESS (EARTH-TO-SPACE), SRS (EARTH-TO-SPACE) and METEOROLOGICAL-SATELLITE SERVICE (EARTH-TO-SPACE) ... 37
4.5.1 EESS (Earth-to-space) in the band 7190-7250 MHz ... 37
4.5.2 SRS (EARTH-TO-SPACE) IN THE BAND 7145-7235 MHZ ... 37
4.5.3 Meteorological-Satellite Service (EARTH-TO-SPACE) ... 38
4.6 EESS (passive) used under RR No. 5.458 (6425-7250 MHz) ... 38
5 Sharing studies ... 41
5.1 Introduction ... 41
5.2 Fixed services ... 41
5.2.1 MCL Calculations ... 41
5.2.2 Site Generic Monte Carlo simulations - long and short term analysis - Study A ... 54
5.2.3 Site Generic Monte Carlo simulations - Study B ... 66
5.3 Fixed-satellite service Space-to-earth ... 70
5.3.1 FSS MCL calculation ... 70
5.3.2 UWB vs FSS Monte Carlo analysis ... 73
5.4 Radio Astronomy in the band 6.55-6.6752 GHz ... 92
5.4.1 Use of the band by RAS and Regulatory Status ... 92
5.4.2 Parameters used in the study ... 93
5.4.3 Interference scenarios and methodologies ... 94
5.4.4 Conclusions for the RAS ... 108
5.5 EESS (SPACE-TO-EARTH), SRS (SPACE-TO-EARTH) AND METEOROLOGICAL-SATELLITE SERVICE (SPACE-TO-EARTH) ... 109
5.5.1 Single-entry compatibility studies ... 109
5.5.2 Aggregate studies - general approach ... 111
5.5.3 Generic aggregate studies for UWB fixed outdoor applications ... 114
5.5.4 Generic aggregate studies for UWB vehicle installations ... 118
5.5.5 Site specific aggregate studies for UWB vehicle installations ... 122
5.5.6 Conclusions for the studies on UWB aggregate interference into EESS/SRS/MetSat earth stations ... 125
5.6 EESS (passive) used under RR No. 5.458 (6425-7250 MHz) ... 126
5.6.1 Single-entry analysis ... 126
5.6.2 Aggregate-effect impact ... 127
5.6.3 Comparison with the existing UWB regulation ... 131
6 Conclusion ... 134
6.1 Overview ... 134
6.2 Fixed Service (FS) ... 136
6.3 Fixed Satellite Service (FSS) ... 137
6.4 Radio Astronomy Service (RAS) ... 137
6.5 SPACE Science services ... 138
6.5.1 EESS (SPACE-TO-EARTH), SRS (SPACE-TO-EARTH) AND METEOROLOGICAL-SATELLITE SERVICE (SPACE-TO-EARTH) ... 138
6.5.2 EESS (EARTH-TO-SPACE), SRS (EARTH-TO-SPACE) AND METEOROLOGICAL-SATELLITE SERVICE (EARTH-TO-SPACE) ... 138
6.5.3 EESS(PASSIVE) USED UNDER RR NO. 5.458 (6425-7250 MHZ) ... 138
ANNEX 1: ECA table 6-8.5 GHz ... 140
ANNEX 2: Surface Plots for MCL evaluations ... 143
ANNEX 3: FS peak power considerations ... 156
ANNEX 4: List of References ... 161

LIST OF ABBREVIATIONS

Abbreviation	Explanation
BLE	Bluetooth Low Energy
CEPT	European Conference of Postal and Telecommunications Administrations
CIMR	Copernicus Imaging Microwave Radioaltimeter
C-ITS	Cooperative ITS
CW	Continuous wave
DOP	dilution of precision
e.i.r.p.	Effective isotropic radiated power
ECC	Electronic Communications Committee
FS	Fixed Service
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
I/N	Interference to noise ratio
Ip/N	Peak interference to noise ratio
IR-UWB	Impulse Radio Ultra Wide-Band
IR-UWB IC	Impulse Radio Ultra Wide-Band, correlation receiver
ITS	Intelligent Transport System
LDC	Low Duty Cycle
LoS	Line of Sight
LTA	Location tracking and sensor applications for automotive and transportation environments
MCL	Minimum Coupling Loss
NF	Noise Figure
PACS	Physical Access Control System
pfd	Power flux density
PP	Point to point
RA	Radio Astronomy
RF	Radiofrequency
RR	Radio Regulations
Rx	Receiver
TPC	Transmission Power Control
Tx	Transmitter
UWB	Ultra Wide band
VRU	Vulnerable Road User

1 INTRODUCTION

In the past 10 years, the Ultra Wide Band (UWB) regulatory framework has been developed driven by a generic approach on the one side and different individual applications on the other side.

The current regulation ECC Decision (06)04 [45] and EC Decision 2019/785/EU [4] for generic indoor and outdoor UWB devices which operate in the band 6.0 GHz to 8.5 GHz limit their e.i.r.p. emission to -41.3 dBm/MHz and do not permit the fixed outdoor operation of these devices. For UWB devices which are installed in road and rail vehicles with Low Duty Cycle (LDC) mitigation technique, the regulations limit their e.i.r.p. emission to -53.3 dBm/MHz, based on the application of the exterior limit as defined in 2019/785/EU. The corresponding study results are shown in ECC Report 64 [5] and ECC Report 170 [7]. These regulatory conditions were supported by several studies, including ECC Report 64[45] and ECC Report 170[7]. ECC Report 64 assumed device densities of up to 10000 devices/km^2 in a single operational UWB channel for urban environments, 1000 devices/km^2 for suburban and 100 devices/km^2 for rural environments of which 80% operating indoor and 20% outdoor.

The worst case analyses presented in ECC Report 64 had established a protection requirement for FS/FSS within the bands 3.4-4.8 GHz and 6-8.5 GHz at -70 dBm/MHz. As noted in *considering q)* of ECC Decision (06)04, complementary technical studies presented in CEPT Report 9 [53] (using different propagation models and assuming 100% of UWB devices operating indoor with an average 1% activity factor) provided some level of confidence regarding the protection of outdoor stations from the Fixed Service and the Fixed-Satellite Service with a maximum mean e.i.r.p. spectral density level of -41.3 dBm/MHz. It is important to note that the studies of this Report have been made with a density/duty cycle which are much lower than those considered when defining the current regulatory values.

ECC Report 64 [5], CEPT Report 45 [6], ECC Report 170 [7] and ECC Report 278 [27] have been developed. Based on the mentioned Reports a set of regulations have been developed as ECC Decisions, ECC Recommendations and EC Decisions. For the frequency range 6.0 GHz to 8.5 GHz relevant for this Report and the applications assumed, the ECC Decision (06)04 [45] is valid. In this ECC Decision several considerations have been taken mainly based on the ECC Report 64:

- From ECC Decision (06)04:
  - Maximum Mean e.i.r.p. power spectrum density of -41.3 dBm/MHz measured in 1 MHz bandwidth in 1 ms;
  - maximum peak power limit of 0 dBm/50 MHz;
  - for vehicular application an external limit of -53.3 dBm/MHz is specified;
  - that this ECC Decision is not applicable to (see *decide 4*) devices and infrastructure used at a fixed outdoor location or connected to a fixed outdoor antenna.
- From ECC Report 64:
  - Device density in
    - urban environment of 10000 devices/km^2;
    - suburban environment of 1000 devices/km^2;
    - rural environment of 100 devices/km^2;
  - No band apportionment has been assumed.

This Report provides an update of the existing compatibly results in the mentioned ECC Reports providing the basis for a revision of the existing UWB regulatory framework in Europe with the goal of a simplification of the rule set and to extent the application field of UWB. The focus of the investigations presented in this Report are the frequency bands between 6 GHz to 8.5 GHz.

The applications presented in the report including the possible mitigation techniques and factors are mainly based on the ETSI TR 103 314 [1]. The results of the compatibility studies included in this ECC report should give guidance for a potential updated UWB regulation in ECC Decision (06)04 to allow the use of UWB fixed outdoor installations, the vehicular use of UWB with maximum external mean e.i.r.p. power spectrum density of -41.3 dBm/MHz and the increase of indoor maximum mean e.i.r.p. power spectrum density to -31.3 dBm/MHz.

The technical studies took into account the wall-loss and clutter based on Recommendation ITU-R P.2108 [23] and Recommendation ITU-R P.2109 [36].

In order to adequately assess the compatibly situation, the future use cases have been analysed and, where necessary, appropriate mitigation factors have been identified. It can be stated that in contrast to the originally assumed use cases in ECC Report 64 [5] the deployment of UWB has mainly focused on location tracking and low data rate communications based on IEEE802.15.4z [44] standards rather than the assumed high and ultra-high data rate systems based on e.g. the ECMA 368 [49] standard, ETSI TS 102 455 [48]. This leads to a significant reduction of the assumed activity factors. In addition, the actual penetration and densities is far smaller than assumed during the original ECC Report 64 investigations. Furthermore, today’s technology can provide several operational channels also in the band between 6.0GHz and 8.5Ghz which can be taken into account in the band apportionment and thus reducing the density of devices in a potential victim band further.

2 ALLOCATIONS AND APPLICATIONS IN THE BAND 6-8.5 GHZ

The focus of the studies will be the services operating in the band 6.08.5 GHz including:

- Fixed Service (FS), operating in the 5925-8500 MHz band, although the studies are based on the 6 GHz band, to be in alignment with recent studies in 6 GHz (ECC Report 316 [24]);
- Radio Astronomy Service (RAS), operating in the 6550-6675.2 MHz band;
- Fixed-Satellite Service (s-E) (FSS);
- Earth Exploration-Satellite Service (EESS), operating in the 8025-8400 MHz(s-E) and in the 7190-7250 MHz (E-s) bands and EESS (passive) in the 6425-7075 MHz and 7075-7250 MHz bands;
- Space Research Service (SRS), operating in the 8400-8500 MHz (s-E) and in the 7145-7235 MHz (E-s) bands;
- Meteorological Satellite service (MetSat), operating in the 7450-7550 MHz, 7750-7900 MHz bands (s-E) and 8175-8215 MHz bands (E-s).

3 UWB IN THE FREQUENCY RANGE OF 6 GHZ TO 8.5 GHZ

3.1 OVERVIEW

With the arrival of UWB in mainstream consumer products, standardised solutions for UWB products are becoming more important and prevalent. While the previous IEEE 802.15.4a [46] standard was only used by a number of manufacturers, its successor IEEE 802.15.4z [44] has been adopted up by car manufacturers and mobile phone makers. Two industry consortia, Car Connectivity Consortium and FiRa Consortium, are building standardised solutions on top of this latest IEEE standard. This interest has led to a major increase of chip manufacturers providing standard compliant silicon. The availability of cheaper chipsets for consumer applications means that also other applications areas such as industrial location tracking are switching to standard compliant transmissions.

The channel plan of IEEE 802.15.4a and 4z is identical. It includes 11 channels with 500 MHz bandwidth, as well as 4 channels with roughly 1 GHz bandwidth. However, the latter are not implemented by any chip vendor and are not included in the specifications of the industry consortia. In the 6.0 to 8.5 GHz range, there are 4 channels available, centred at 6.5, 7.0, 7.5 and 8.0 GHz. This channel plan does not make optimal use of the available spectrum in much of the world and therefore the on-going standardisation efforts in Task Group IEEE 802.15.4ab [42] are considering alternative frequency plans such that 5 channels can be included in this frequency range.

In this section, an overview of the planned UWB applications which could drive the development of the updated regulatory framework will be presented. The section is split into the main application areas to be considered in this Report. Based on these applications the main required sharing parameters can be extracted.

3.2 LOGISTICS AND TRAFFIC MANAGEMENT

3.2.1 Application overview

In this set of applications, different use cases are covered:

- Parking management applications and;
- Outdoor logistics application.

3.2.1.1 Parking management application

In large cities drivers seeking an available parking space represent a significant pollution source. In addition, time is wasted, and traffic jams may occur. Currently up to 30% of traffic in inner city is created by cars looking for a parking space. This results an increased CO_2 and other emissions, which could be avoided by smart data. To improve logistics and help reducing pollution, intelligent infrastructure systems within the framework of Smart Cities have started to evolve. An important component of such systems is a sensor capable of detecting if a parking lot is occupied or not. The current technology is mainly based on inductive sensing which has some limitations under certain conditions reducing its reliability. By using UWB fixed outdoor systems installed on streetlight, a larger scale monitoring of the parking slots will be possible without having to install a sensor in each of the slots. In addition, identification of a vehicle via UWB allows for identification, which can include permits and payments methods.

3.2.1.2 Logistics applications

In outdoor storage area for large equipment like vehicles and machinery the equipment needs to be precisely positioned in order to allow for a smooth delivery of the devices. Due to the large areas a precise localisation system is required.

In Figure 1 and Figure 2, such a storage for construction machinery equipment is depicted.

Figure 1: Construction equipment outdoor storage area

Figure 2: Outdoor storage area with antenna positions

In Figure 1 and Figure 2 only two antennas are visible. For a positioning operation at least three antennas are required.

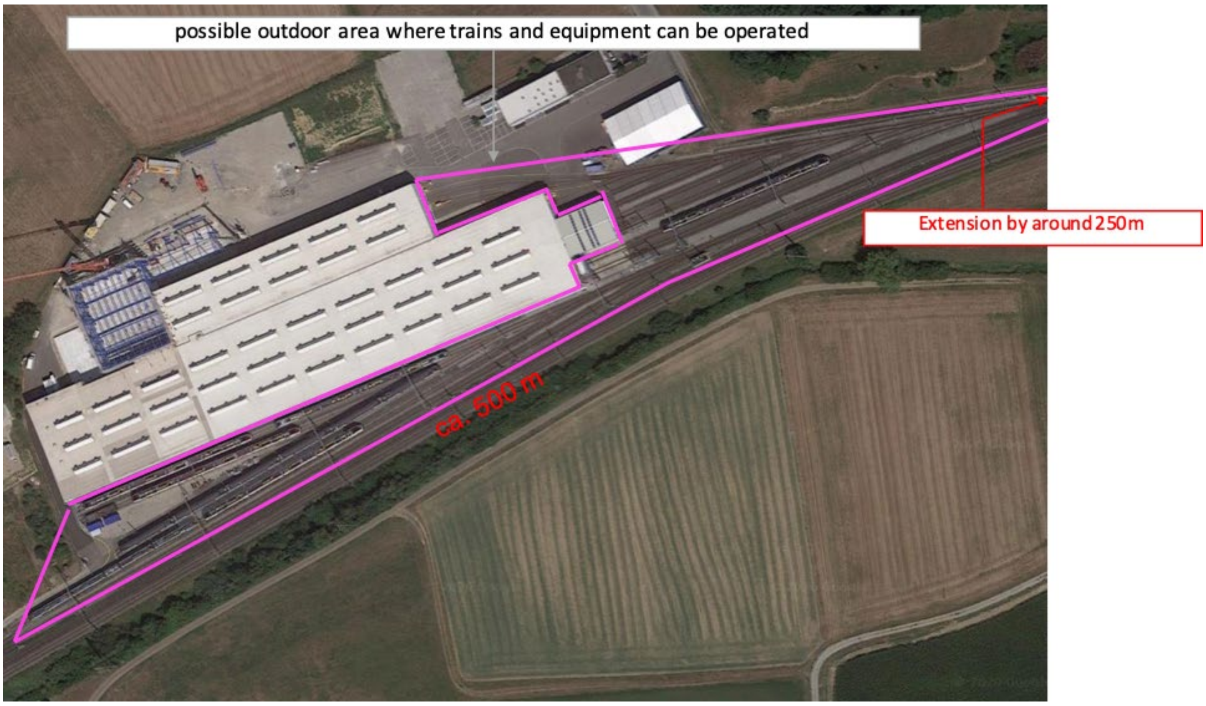

Figure 3: Monitoring of train positions in a maintenance area, indoor and outdoor

In Figure 3, a use case is depicted where the position of a train has to be monitored indoor and outdoor. Here the train position needs to be precise enough to be able to identify the exact track position. Similar use cases can be envisaged in train shunting areas.

3.2.2 System configuration and description

In this class of applications, the positioning system consists of fixed outdoor nodes which are installed in a typical height of 5 m above ground with a maximum height of 10 m. The antennas are down-tilted to allow for an optimum coverage of the area to be monitored (see Figure 1, Figure 2 and Figure 4).

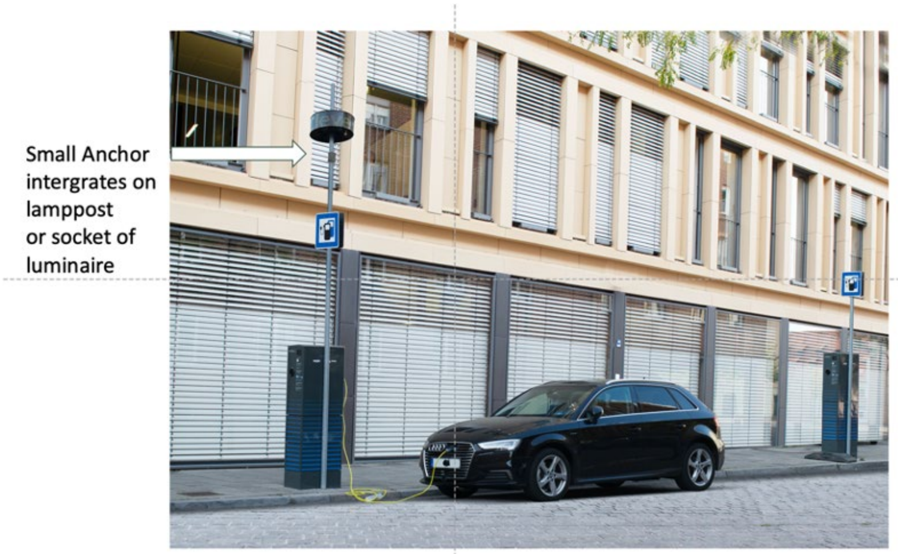

Figure 4: Typical fixed anchor installation used in the system

A movable or portable tag is positioned on or in the object to be tracked. For the logistics use case, these tags are temporary mounted onto the equipment to be tracked (e.g. magnetic fixture). The parking management application uses an active card, with the same size as a credit card, positioned on the windscreen, the dashboard or in the glove compartment of a vehicle (see Figure 5). These tags are covered by the existing generic UWB regulation or low duty cycle (LDC) based UWB regulation.

Figure 5: Typical movable tag in car used by the system

The fixed nodes exchange periodic synchronisation messages every 100 ms to 1 s. Some systems use larger synchronisation periods. A simplified typical setup is depicted in Figure 6, where only two fixed nodes are depicted. For a typical operation, at least three fixed nodes are required. The numbers given here are based on a specific implementation available on the market.

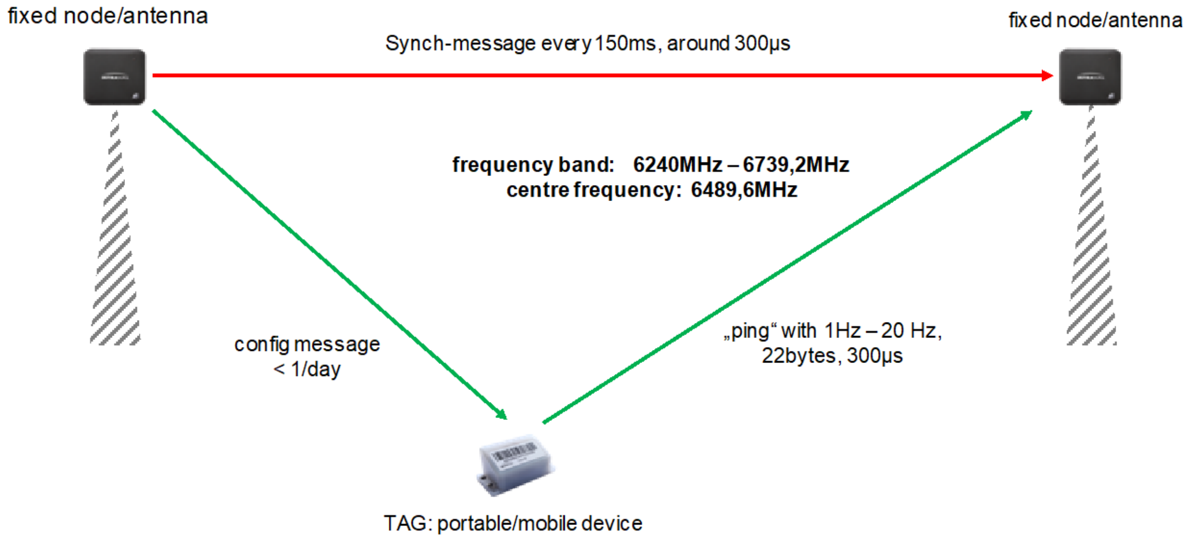

Figure 6: Typical system configuration with two fixed nodes

3.2.3 Deployment assumptions

In this section, the deployment assumptions of this class of fixed outdoor applications are summarised.

Table 1: Outdoor logistics and parking management application, deployment assumptions

System Parameter	Value/Description
Signal Type	Ultra Wide Band (UWB)
Frequency Range	6-8.5 GHz
Transmit Power (e.i.r.p.)	-41.3 dBm/MHz mean e.i.r.p. power density in 1 ms 0 dBm/50 MHz (Max), peak e.i.r.p. power
Operational Bandwidth	System dependent, typical > 50 MHz
Data Rates	110 kbit/s – 27 Mbit/s
Tx to Rx Range	Typical 50 m or less
Additional mitigation technique	Antenna: Mainly down tilt antenna systems installed on streetlight, existing installations or specific installations on the logistic storage area. Antenna heights: typically, around 5 m maximum up to 10 m
Cumulated T_{on}-time of fixed units	Typical 1 ms or less per interval; maximum 5 ms, duty cycle < 5% here: T_{on} = 300 µs/150 ms → Duty cycle 0.2%
Repetition interval of fixed installation transmissions	Typical 150 ms, minimum 100 ms
Expected density Urban	Parking application: max. 40 devices/km of road 400/km² Outdoor logistics: max. 1000 devices/km² at limited areas only → averaged over urban area: 50/ km²
Expected density Suburban	Parking application: 100/km² Outdoor logistics: max. 100/km²
Expected density Rural	Parking application: 10/km² Outdoor logistics: max. 10/km²
Activity Factor AF parking	0.05%
Activity Factor AF outdoor logistics	0.3%

3.3 HOME SECURITY APPLICATIONS AND ACCESS CONTROL

3.3.1 Application overview

The primary purpose of a physical access control system (PACS) is to authenticate and authorise a person so that they can pass through a physical portal. However, the architecture of a PACS may vary significantly based on the application (hotel, residential or office access), technology (door types, interface technologies), and manufacturer. Figure 7 shows a basic system structure as it is typically used in office access applications.

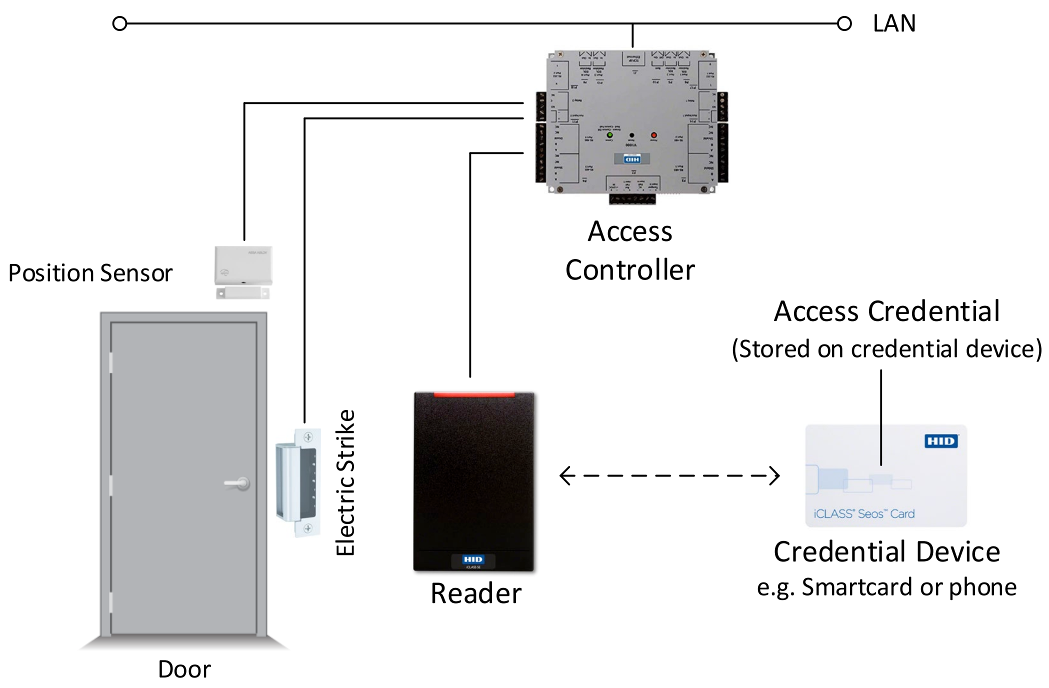

Figure 7: Basic PACS architecture

The following list describes the role of each component within a typical Physical Access Control System (PACS):

- Access Credential: Data object, a piece of knowledge (PIN, password) or a facet of a person's physical being (face, fingerprint, etc.) that provides proof of identity;
- Credential Device: Stores the access credential in case it is a data object (e.g. smartcard or phone). Often a credential device is referred to as the access credential;
- Reader: Retrieves and authenticates the access credential (from the credential device) and sends it to the access controller;
- Access Controller: Compares the access credential to an access control list and grants or denies access (controls the door lock). It may also send transaction logs and status information to a database and/or backend system.

In many installations, reader devices may also include the access controller functionality. Such readers are typically referred to as offline or standalone readers. If the unlocking mechanism is included as well, a device is referred to as smart door lock (more typically used in residential applications). Smart door locks especially, are often battery powered, and power consumption (battery lifetime) is a key parameter for them.

In the case of physical access, an electronic device needs to authenticate a person, which requires different methodologies than those used for electronic devices authenticating each other. Authentication methods for persons are typically split into three broad categories: “Something you know”, “Something you have” and “Something you are” (see also description of access credential above). For a PACS, “Proof of Presence” is as important as the Authentication, when granting access through a particular physical portal at a given moment in time. UWB can provide exactly this information in a secure manner.

3.3.2 System configuration and description

Here the main technical requirements relevant of the application for coexistence investigations are given:

- Bandwidth 500 MHz;
- Data rate 6.8 Mbit/s;
- TX power: -41.3 dBm/MHz e.i.r.p.;
- Location precision in general as precise as possible, below 10 cm;

- Spectrum band general UWB frequency ranges 6-9 GHz;
- Antenna techniques: typical omnidirectional (for intent detection at all directions);
- Fixed outdoor is required.

Conventionally, an access sequence consists of four parts: Proof of Presence, Intent, Authentication and Authorisation. The user approaches the door and presents their access credential / credential device (Proof of Presence and Intent). The reader then checks the validity of the access credential (Authentication) and sends it to the access controller, which grants or denies access (Authorisation).

Seamless access is defined an experience achieved, where access is granted without intrusive actions to show Intent (e.g. presenting a card, entering a PIN), whilst maintaining the same level of security. The secure and accurate ranging capability of UWB makes it a suitable technology to enable such an experience.

The following sequence is proposed for such a scenario (compliant with FiRa Consortium Approach):

- Out-of-band Authentication (via Bluetooth Low Energy or other RF technology)
- Proof of Presence & Intent detection based on secure UWB ranging data
- Authorisation of access rights

Bluetooth Low Energy (BLE) is used for device discovery and application selection (in case the device hosts multiple UWB applications). A secure communication channel is established between the devices, which is used by the reader to retrieve the access credential. Future implementation could also be based on UWB only devices. After successful Authentication of the access credential, the reader negotiates the UWB RF parameters and shares a temporary session key with the credential device. At this point the BLE communication channel may be terminated and secure ranging starts. Apart from providing the session key exchange to secure the UWB communications, BLE offers lower energy consumption overhead during the device discovery phase, particularly in scenarios where devices are running multiple BLE applications in parallel. At the start of secure ranging, the two devices are not synchronised and a receiver may consume significant power when active (around 200 mW in first generation IR-UWB ICs). Using BLE for discovery and channel establishment allows the UWB receive time to be minimised.

By acquiring regular UWB ranging information (based on IEEE802.15.4z [44]), the reader can determine Proof of Presence and Intent. Depending on various factors like door types, security requirements, the Intent criterion can vary significantly. It can be a simple distance threshold (e.g. user within 1 metre of the door) or a complex algorithm taking into account user trajectory, speed, position and history to determine the Intent to go through a door. Note that UWB in its basic form will only provide distance information. More complex Intent detection criteria require multiple reader devices working together (e.g. trilateration/multilateration of credential device), or additional features like angle-of-arrival detection within a single device. For this purpose, the UWB antennas are typically omnidirectional. The radiation pattern plots in Figure 8 and Figure 9 are an example for an elliptical monopole antenna used for such an application at channel 9 of the IEEE802.15.4 defined band group 2 (7987.2 MHz centre frequency). In Figure 10, the pattern is given in relation to a typical outdoor installation. The main radiation direction is in the horizontal plane with attenuation in the vertical direction (2 dB at 30°,7 dB at 60°). The given pattern has been measured as an isolated device; thus, the antenna has not been installed on the wall. Additional attenuation can be assumed when installed especially to the back side of the antenna.

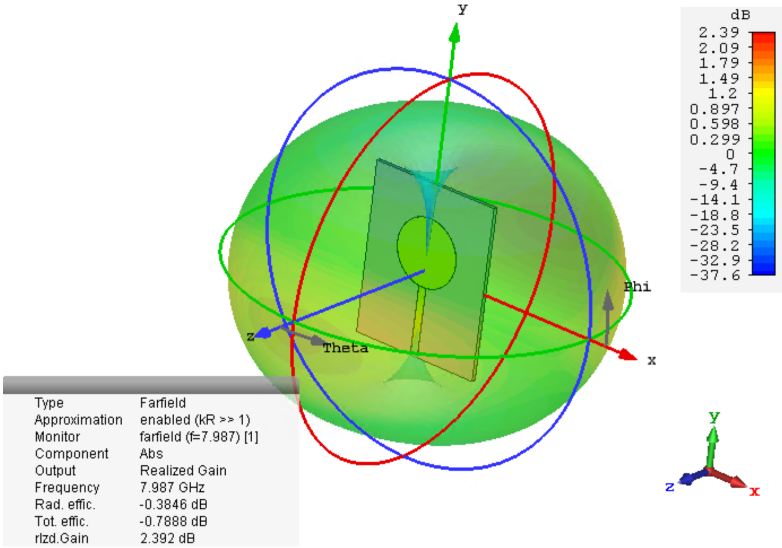

Figure 8: 3D plot of realised gain at 7987 MHz

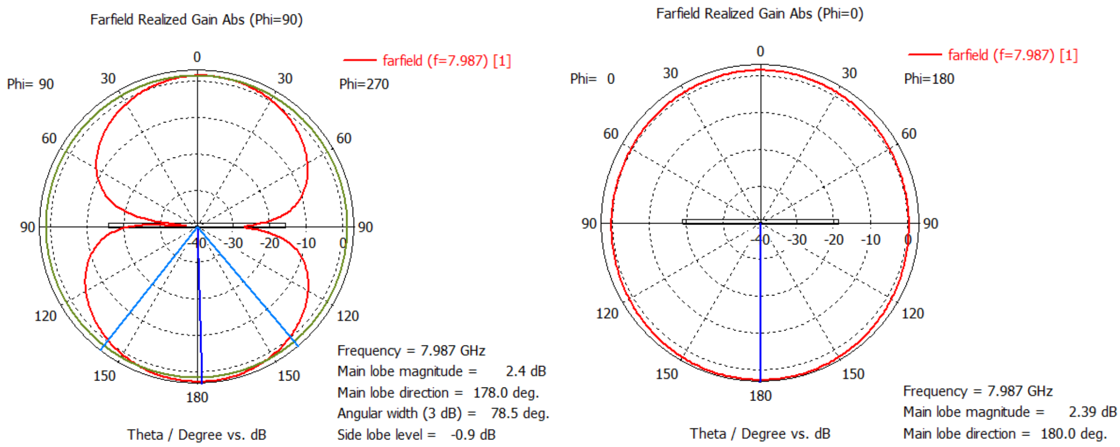

Figure 9: 2D plots of realised gain at 7987 MHz

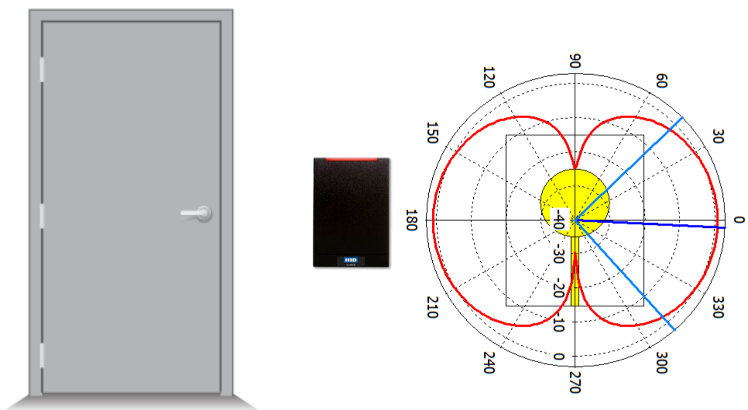

Figure 10: Radiation pattern, installed (main lobe is horizontally around the reader)

When the Proof of Presence and the Intent criteria are met, the reader will release the access credential to the access controller and the access grant/deny decision is made (Authorisation). It should be noted, that in the case of standalone readers or smart door locks, Authorisation may occur right after the transfer of the access credential, as the reader includes the access controller functionality. In this scenario, the UWB channel would only be established if a user has authorisation to pass through the door. This can significantly reduce energy consumption.

In traditional PACSs, the Intent is actively indicated by the user (e.g. by presenting a card), whilst in seamless access the system needs to infer it. A poorly defined or implemented algorithm can lead to security issues. For example, a simple Intent detection algorithm that opens the door when an authorised user is with 2 meters, may open all doors in a corridor, when the said user walks along it without the intention to go through any of them. For high security portals (e.g. door to company server room), traditional technologies may be preferred over seamless access as convenience may have lower priority. However, even in these scenarios, UWB may be considered as a seamless second factor to grant access (e.g. fingerprint paired with UWB device ranging).

3.3.3 Deployment assumptions

Table 2: Physical access control system (PACS), deployment assumptions

System Parameter	Value/Description
Signal Type	Ultra Wide Band (UWB)
Frequency Range	6-8.5 GHz
Transmit Power (e.i.r.p.)	-41.3 dBm/MHz mean e.i.r.p. power density in 1 ms 0 dBm/50 MHz (Max), peak e.i.r.p. power
Operational Bandwidth	System dependent, typical > 50 MHz
Data Rates	Up to 6.8 Mbit/s
Tx to Rx Range	typical 10 m or less
Existing Mitigation techniques	TPC and LDC
Additional mitigation technique	Antenna: installed on wall, outdoor Antenna heights: typical 1.5 m Limited antenna gain in vertical direction
Cumulated T_{on}-time during bidirectional UWB communication (1 interval)	typical 5 ms or less per interval; max. 50 ms LDC requirements will be kept in any case: T_{on} max. < 5 ms T_{off} mean < 38 ms (averaged over 1 s) $\sum T_{off}$ > 950 ms per second
Repetition interval of transmissions	typical > 200 ms for functions with user interaction typical > 500 ms for functions without user interaction
Repetition interval of fixed installation transmissions	typical > 200 ms for functions with user interaction typical > 500 ms for functions without user interaction
Expected density Urban	200/km² (Building entry doors) (Note 1)
Expected density Suburban	50/km² (Building entry doors)
Expected density Rural	10/km² (Building entry doors)
Activity Factor AF	0.006% (Note 2)
Note 1: Paris: 20000 persons/ km²; 100 persons per Building → 200 Building per km², 100% penetration. Note 2: Every 15 minutes one access with 50 ms activity with a single access point, only distance measurement	

3.3.4 Mitigation factors

- PACS reader and door locks will only activate UWB if an appropriate device is discovered over the 2.4 GHz BLE link;
- Most PACS readers are mounted indoors, only entrance doors to a building need to be mounted outdoors;
- The antennas are typically omnidirectional with overall rather low gain to allow ranging in all horizontal directions;
- Very low vertical antenna gain > -10 dBi, see Figure 10;
- The UWB communication / ranging is kept to a minimum as credential devices are typically battery powered;
- Very low Activity Factor AF of 0.006%.

3.4 INDOOR POSITIONING APPLICATIONS

3.4.1 Introduction

Infrastructure based UWB RTLS, like the ones operating according to the industrial omlox RTLS standard [43], allow in principle to fulfil these requirements. UWB technology allows uniquely precise ranging and therefore is enabling locating systems with a very high precision. Infrastructure based RTLS systems allow creation of trusted and reliable measurement systems, on which public authorities could rely.

Every person involved in such an event would need to be registered. When entering the event place visitors and staff will get a personalised badge and will leave the badges at the exits. They agree to be tracked during the event. The badges will be tracked with a high precision and with a high update rate during the event. The back-end tracing system computes all contact traces between all visitors/staff and stores them anonymously. Only in the case an infection would be detected sometime after the event, the relevant contacts will be derived from the traces of the infected person and anonymity will be lifted from those contacts. Contact information then will be forwarded to the public health authority. In addition, relevant contacts will be informed in parallel directly.

UWB technology deployment is normally limited to the extremely low power spectral density of only -41.3 dBm/MHz. This limitation allows precise ranging at shorter distances, which would be sufficient for normal sized rooms, like small office spaces, meeting rooms and apartments.

There are huge exhibition and concert halls as depicted in Figure 11, Figure 12 and Figure 14, where the dimension of the geo-space requires increased link budget in order to cover the hall dimensions in a seamless way. Seamless and reliable coverage is an important feature required for reliable contact tracing in order to allow public authorities to set up sufficiently comprehensive tracing actions in case of an infection.

Figure 11: Berlin Philarmony, stage
(photo: Josef Lehmkuhl).

Figure 12: Rock concert in the Mehr! theater, Hamburg
(photo: mehtoo).

In addition to larger dimensions there are many event buildings of medium size (opera, theatre …), example in Figure 13, where sufficient good dilution of precision (DOP) for accurate positioning can be only reached, if medium and longer distances can be bridged with sufficient link budget.

For deploying such efficient RTLS systems for automatic contact tracing with proven/certified reliability a mean PSD of -31.3 dBm/MHz would be required.

Figure 13: Semper Opera, Dresden (photo: W.Bulach)

Figure 14: Ice hockey Slovakia vs. Austria (photo: Zaxxon)

This seamless and reliable contact tracing is pre-condition for enabling larger cultural events in the pandemic situation at all, and most likely will continue to be for a longer time in the future.

3.4.2 System configuration and description

The system requirements is based on the assumption that the system will provide positioning and communication services as an integrated part with OOB:

- Bandwidth > 500 MHz;
- Data rate 6 Mbit/s - 12 Mbit/s (27Mbit/s);
- TX power -31.3 dBm/MHz;
- Location precision 0.1 m to 0.5 m;
- Required range: 25 m to 250 m;
- 6.0 GHz to 8.5 GHz;
- Very low duty cycle: < 1%;
- Networked UWB transmission;
- Possible combination with data communication, but mostly OOB;
- Indoor only, infrastructure-based applications.

Mitigation factors mentioned are well known and proven in the UWB based regulations. Here an extension of these mitigation factors and techniques to other frequency ranges and applications is proposed.

3.4.3 Deployment assumptions

Table 3: UWB deployment assumptions for high power indoor use case indoor positioning

System Parameter	Value/Description
Signal Type	Ultra Wide Band (UWB)

System Parameter	Value/Description
Frequency Range	6 GHz to 8.5 GHz
Transmit Power (e.i.r.p.)	e.i.r.p. mean -31.3 dBm/MHz e.i.r.p. mean +10 dBm/50 MHz
Operational Bandwidth	≥ 500 MHz
Data Rates	Example: 110 kbps – 27Mbit/s
Tx to Rx Range	Example: typical 250 m or less
Existing Mitigation techniques	LDC and indoor only
Additional mitigation technique and factors	Networked/controlled operation.
Cumulated T_{on}-time during 1 second for the fixed components	typical <10 ms per second; Duty cycle: 1% max: < 50 ms, Duty Cycle 5%
UWB message length	Typical message length transmitted by the fixed installation < 5 ms.
Repetition rate of portable or mobile device transmissions	Typically < 1 Hz
Repetition interval of fixed installation transmissions	Typically 1 Hz to 10 Hz
Expected device density Urban	1000/km^2
Expected device density Suburban	100/km^2
Expected device density Rural	25/km^2
Activity factor AF	0.1%

3.5 VEHICULAR APPLICATIONS

3.5.1 Application overview

In a future highly automated traffic system including communicating vehicles and other traffic participants (vulnerable road user, see also ETSI STF565 [22] a very high precise positioning information is required for each of the participants (vehicles, pedestrians, animals, etc.). The participants can evaluate their position by different means like GPS, optical sensors or UWB ranging operations. This position information together with additional characteristics of the traffic participants are distributed using a cooperative intelligent transport system (C-ITS). The receiving party can then build a detailed picture of its surroundings including all traffic participants.

A very high precision is especially required at dense traffic crossing situations, where precisions down to 10 cm are required. In these urban scenarios the coverage with GNSS can be very limited and thus an additional system for a high precision positioning will be required.

A general overview of possible use cases in a cooperative ITS environment is given in Project HIGHTS Deliverable 2.1 (March 2015): "Use cases and Application Requirements" [21] as a result of the EU Horizon2020 project HIGHTS (High Precision Positioning for Cooperative-ITS).

3.5.2 System configuration and description

The system requirements are based on the assumption that the system will provide positioning and communication services as an integrated part of an overall C-ITS system:

- Bandwidth > 500 MHz;
- Data rate 110 kbit/s - 12 Mbit/s (27Mbit/s);
- Mean TX power -41.3 dBm/MHz;
- Location accuracy 0.01 m to 0.5 m;
- Required range: 10-100 m;
- Band 6-8.5 GHz;
- Very low duty cycle: < 5%;
- Down tilt fixed outdoor antennas for UWB beacon transmission on fixed infrastructure;
- Omnidirectional antennas on vehicles with typical height of 1.5 m;
- Possible combination with data communication;
- Geolocation database possible.

The mentioned mitigation factors are well known and proven in the UWB based regulations. Here an extension of these mitigation factors and techniques to other frequency ranges and applications is proposed.

In the domain of intelligent transport systems (ITS), very high precision positioning is required in specific traffic situations like high density road crossings involving different traffic participants from cars to trucks to pedestrians (vulnerable road users, VRU). It can be assumed that an accuracy of 25 cm under dynamic behaviour is required to identify the used lane or the position of a pedestrian at the road-side.

A solution for this issue can be the deployment of UWB based beacons at fixed roadside units as depicted in Figure 15. The traffic participant's device can then determine its position and can communicate this position using a cooperative ITS system like ETSI ITS-G5 [56].

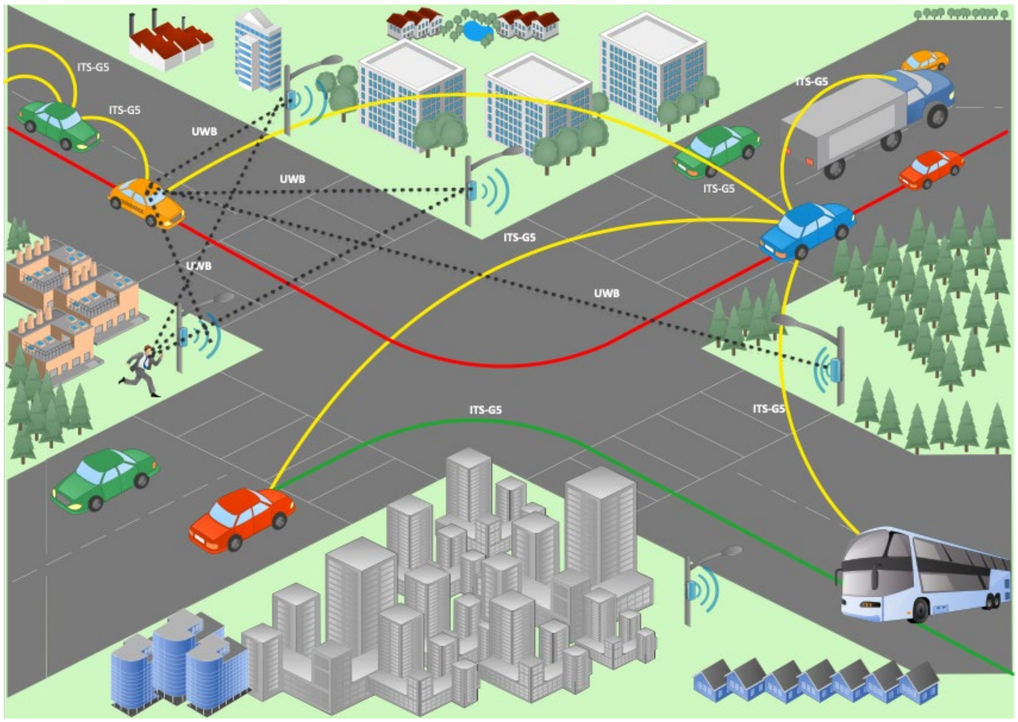

Figure 15: High precision positioning in cooperative ITS environments

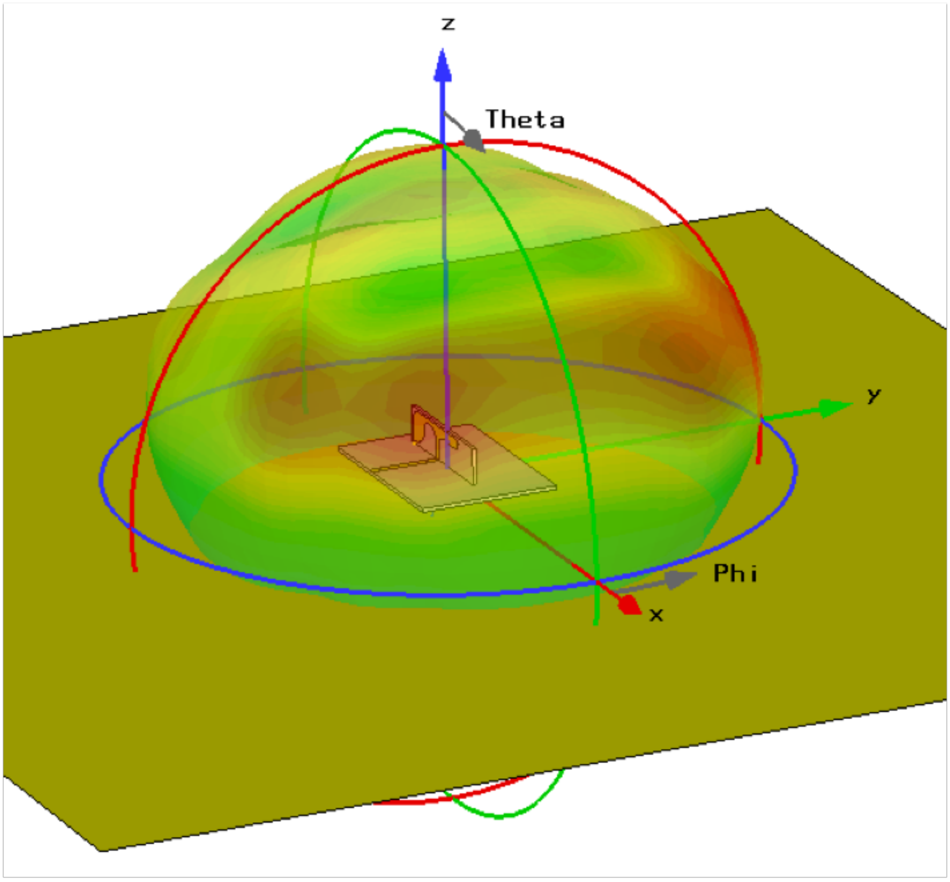

Figure 16: Typical UWB antenna for fixed installation

3.5.3 Antenna patterns

In Figure 16, a typical antenna for UWB fixed installation is depicted the main direction of the beam is the Z direction. More details can be seen in Figure 17 to Figure 19.

Azimuth (blue ring)(Theta 90)

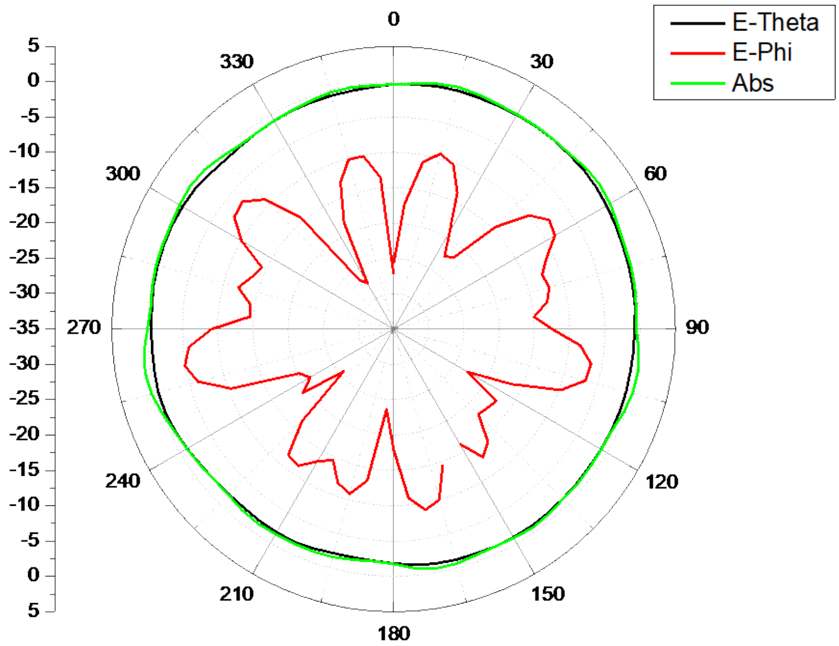

Figure 17: Azimuth diagram of UWB antenna in Figure 16

Elevation (green ring)(Phi 0)

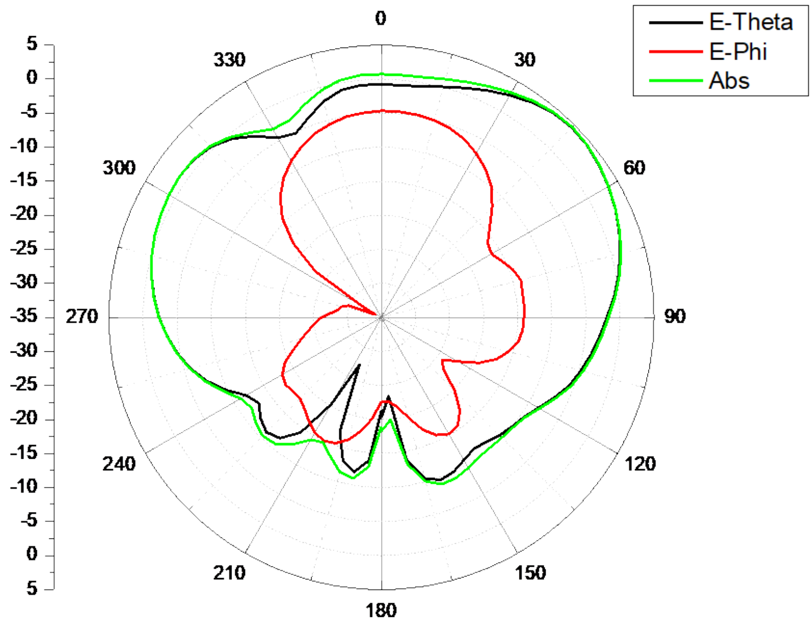

Figure 18: Elevation diagram (Phi 0°) of UWB antenna in Figure 16

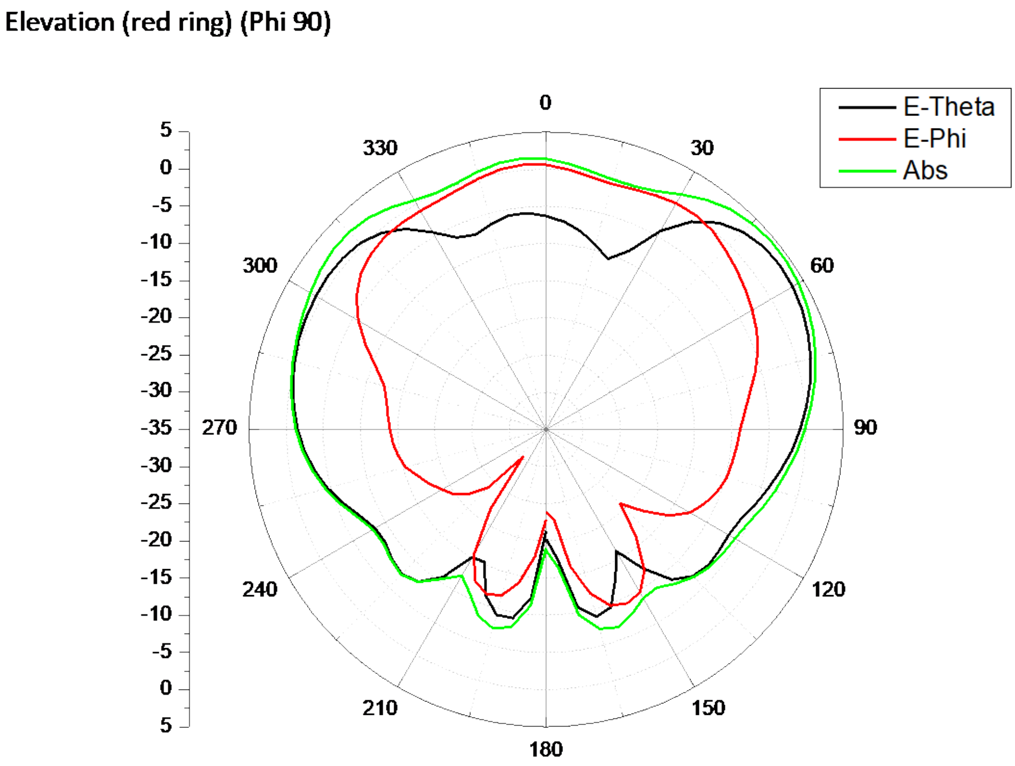

Figure 19: Elevation diagram (Phi 90°) of UWB antenna in Figure 16

In Figure 18 and Figure 19, it can be seen that the difference in gain between the main direction 40° to 60° and the lowest direction is in the range of at least 10 dB. In a broad range of directions between 90° and 270° the attenuation is better than 5 dB.

3.5.4 Deployment Assumptions

In this clause the technical parameter of this class of vehicular applications are summarised. In Table 4 the typical parameter for the fixed outdoor application in vehicular environments are collected. Table 5 shows the parameter of UWB devices installed in and on vehicles participating in the ITS related communications. These parameters are similar to the generic use of UWB in the band above 6 GHz with a limited duty cycle.

Table 4: Vehicular applications fixed outdoor installations, deployment assumptions

System Parameter	Value/Description
Signal Type	Ultra Wide Band (UWB)
Frequency Range	6-8.5 GHz
Transmit Power (e.i.r.p.)	-41.3 dBm/MHz mean e.i.r.p. power density in 1 ms 0 dBm/50 MHz (Max), peak e.i.r.p. power
Operational Bandwidth	System dependent, typical > 50 MHz
Data Rates	110 kbit/s – 27 Mbit/s
Tx to Rx Range	typical 50 m or less

System Parameter	Value/Description
Additional mitigation technique	Antenna: Mainly down tilt antenna systems installed on streetlight, existing installations or specific installations on the logistic storage area. Antenna heights: typically around 5 m maximum up to 10 m
Cumulated T_{on}-time of fixed units	Typical 1 ms or less per interval; maximum 5 ms, duty cycle < 5%
Repetition interval of fixed installation transmissions	Typical 150 ms, minimum 100 ms
Expected density Urban	Max. 40 devices per km of road; 400 devices per km², 10 km road length in 1 km²
Expected density Suburban	50/km²
Expected density Rural	10/km² in villages, overall < 1/km²
Activity Factors Urban	AF < 5%, during peak hours
Activity Factors Suburban	AF < 2%, during peak hours
Activity Factors Rural	AF < 0.5%, during peak hours

Table 5: Vehicular applications, vehicle installations, deployment assumptions

System Parameter	Value/Description
Signal Type	Ultra Wide Band (UWB)
Frequency Range	6-8.5 GHz
Transmit Power (e.i.r.p.)	-41.3 dBm/MHz (Max) 0 dBm/50 MHz (Max)
Operational Bandwidth	System dependent, typical > 50 MHz
Data Rates	110 kbit/s – 27 Mbit/s
Tx to Rx Range	Typical 50 m or less
Additional mitigation technique	Antenna: omnidirectional antennas Antenna heights: typically, around 1 m to 1.5 m maximum up to 4 m
Cumulated T_{on}-time of vehicle units	Typical 1 ms or less per interval; maximum 5 ms, duty cycle < 1%
Repetition interval of vehicle transmissions	100-1000 ms Typical: 300 ms Slow traffic in urban environments: 1000 ms
Expected density Urban	Max. 600 devices per 1 km road (3 lane road two directions, dense traffic) Typical: 100 devices per 1 km road 6000 per km² max. (10 3-lane roads two directions dense traffic),

System Parameter	Value/Description
	typical maximum 1000 per km²
Expected density Suburban	100 per km²
Expected density Rural	25 per km²
Activity Factor (Note 1)	AF < 0.4%
Note 1: For vehicular-to-infrastructure and vehicular-to-pedestrians. For vehicular-to-vehicular AF ≤ 0.04% for event driven positioning tasks.	

3.6 MITIGATION FACTORS AND TECHNIQUES

For the fixed outdoor use cases a typical antenna gain of 5 dBi can be assumed. The antennas are down tilt and thus a significant sidelobe attenuation can be assumed.

For the indoor case an indoor-to-outdoor attenuation of 17 dB (see ECC Report 302 [20]) can be assumed for traditional buildings. Higher levels are reached for thermally optimised buildings.

3.7 DEPLOYMENT ASSUMPTIONS FOR UWB USED IN THIS STUDY

The UWB system parameter set presented in Table 6 are considered for the studies in this Report. To fulfil the requirements of a given use case a specific combination of the parameters will be required.

Table 6: Application assumptions and classification for simulations

	Application	Assumed Density	Activity factor	Comments
Fixed outdoor application				
#1	Parking management application	Parking application: Urban: max. 40 devices/km → 400 devices/km² Suburban: 100 device/km² Rural: 10 devices/km²	Every 5 minutes one parking activity per fixed access point with 50 ms message length per transaction with three access points: AF: 0.05%	Table 1
#2	Outdoor logistics	Outdoor logistics: max. 1000/km², in limited areas only, Urban: 50/km² (average over an urban area) Suburban: 100/km² Rural: 10/km²	Every 1 minutes one logistic activity with 50 ms message length per transaction with three access points: AF: 0.3%	Table 1 Only limited areas of deployment e.g. 0,5 km times 0,5 km Rural area mainly
#3	Physical access control system (PACS)	Urban: 200/km² Suburban: 50//km² Rural: 10/km²	Every 15 minutes one access with 50 ms activity with a single access point, only distance measurement: AF: 0.006%	Table 2

	Application	Assumed Density	Activity factor	Comments
#4	Vehicular applications fixed outdoor installations	Max. 40 devices per km of road; 400 devices per km², 10 km road length in 1 km² Urban: 400/km² Suburban: 50/km² Rural: 10/km²	Depending on traffic density worst case mean values in an area. Urban AF: 5% Suburban: 2% Rural: 0.5%	Table 4
General vehicular outdoor applications for ITS				
#5	Vehicular applications, vehicle installations	6000 per km² max. (10 3 lane roads two directions dense traffic), typical 1000 per km² Urban: 1000/km² Suburban: 100/km² Rural: 25/km²	Similar to ITS applications in 5.9 GHz ECC Decision (08)01 [50] AF: 1% mean max AF typical: 0.4% AF: 0.04% for V2V	Table 5
High power indoor devices				
#6	Indoor systems with higher power	Urban: 1000 to 2500 devices/km² Suburban: 100 to 250/km² Rural: 25/km²	DC: 5% AF: 1%	Table 3

Table 7: Applications based on the existing UWB regulation in ECC Decision (06)04 [45] and ECC Report 64 [5]

Application	Assumed Density in ECC Report 64, Note 1	Activity factor from ECC Decision (06)04 considering j)	e.i.r.p. power density
Generic UWB devices, indoor	Urban: 8000/km² per band Suburban: 800/km² per band Rural: 80/km² per band	AF: 5%	Mean: -41.3 dBm/MHz Peak: 0 dBm/50 MHz
Generic UWB devices, outdoor	Urban: 2000/km² per band Suburban: 200/km² per band Rural: 20/km² per band	AF: 5%	Mean: -41.3 dBm/MHz Peak: 0 dBm/50 MHz
Note 1: In ECC Decision (06)04, a relation of 20% outdoor and 80% indoor has been assumed in considering j). The overall densities of 10000/km², 1000/km² and 100/km² are used in the ECC Report 64 investigations.			

4 SERVICES AND APPLICATIONS IN THE 6 - 8.5 GHZ FREQUENCY RANGE

4.1 FIXED SERVICE

4.1.1 Introduction

This section describes a method for assessing the interference on Fixed Service (FS) systems from Ultra Wide Band (UWB) systems described in ETSI TR 103 314 [1] in the frequency range 6-8.5 GHz and section 3.

4.1.2 Protection Criteria

The following values have been considered for the protection of the Fixed Service:

- Long-term criterion based on a I/N > -20 dB for less than 20% of the time as advised by Recommendation ITU-R F.758-6 [8] Table 4 for UWB and;
- Peak-power limitation based on ITU-R Report SM.2057 [25], annex 2, equation 69, page 327;
- Short-term criterion of I/N > +19 dB for less than $4.5*10^{-5}$%.

All criteria will be considered in this Report for the FS studies.

4.1.3 FS system parameters and assumptions

The technical characteristics of point-to-point (PP) FS links are summarised in Table 8 for the lower 6 GHz band and in Table 9 for the upper 6 GHz band. The characteristics are derived from Recommendation ITU-R F.758-6 [8] and Report ITU-R F.2326 [58]:

Other deliverables describing typical deployment of FS stations in the 6 GHz band and relevant for the assessment of interference in this Report are:

- Recommendation ITU-R F.383-9 [18]: "Radio-frequency channel arrangements for high-capacity fixed wireless systems operating in the lower 6 GHz (5925-6425 MHz) band";
- Recommendation ITU-R F.384-11 [19]: "Radio-frequency channel arrangements for medium- and high-capacity digital fixed wireless systems operating in the 6425-7125 MHz band";
- Recommendation ITU-R F.699-7 [10]: "Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to about 70 GHz", with peak side-lobe levels appropriate for single-entry interference studies;
- Recommendation ITU-R F.1245-2 [11]: "Mathematical model of average and related radiation patterns for line-of-sight point-to-point fixed wireless system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 GHz to about 70 GHz", with average side-lobe levels appropriate for aggregate interference studies.

Table 8: System parameters for PP FS systems for the frequency range 5925-6425 MHz

Parameter	Value	
	Type 1	Type 2
Modulation	64-QAM	128-QAM
Channel spacing and receiver noise bandwidth (MHz)	40	29.65
Tx output power range (dBW)	Between −8 and 2.0 (Mode*: −4.3)	Between −11 and 2 (Mode: −2.1)
Tx output power density range (dBW/MHz)	Between −24 and −14.0	Between −25.7 and −9.7
Feeder/multiplexer loss range (dB)	Between 2.5 and 5.6 (Mode: 3.4)	Between 1.1 and 3 (Mode: 1.3)
Antenna gain range (dBi)	Between 38.1 and 45.0 (Mode: 38)	Between 38.7 and 46.6 (Mode: 45)
Antenna pattern	Recommendation ITU-R F.699 for single-entry interference Recommendation ITU-R F.1245 for aggregate interference	
Antenna height (m)	Between 15 and 110 (Mode: 55)	
e.i.r.p. range (dBW)	Between 20.6 and 37.5 (Mode: 30.3)	Between 25.7 and 45.9 (Mode: 41.6)
e.i.r.p. density range (dBW/MHz)	Between 4.6 and 21.5 (Mode: 14.3)	Between 10.9 and 31.1 (Mode: 26.9)
Receiver noise figure typical (dB)	5	4
Receiver noise power density typical N_{RX} (dBW/MHz)	−139	−140
Normalised Rx input level for 1 × 10^{-6} BER (dBW/MHz)	−112.5	−110.5
Nominal long term interference power density (dBW/MHz) without feeder loss	−139 + I/N	−140 + I/N
Protection requirement (dB)	I/N = −20 (Recommendation ITU-R F.758: Table 4) [26]	
Link Length (km)	Between 10 and 80 (Mode: 40)	

Table 9: System parameters for PP FS system for the frequency range 6425-7125 MHz

Parameter	Value
Modulation	64-QAM
Channel spacing and receiver noise bandwidth (MHz)	40

Parameter	Value
Tx output power range (dBW)	Between −15 and 3 (Mode*: -2)
Tx output power density range (dBW/MHz)	Between −31 and −13
Feeder/multiplexer loss range (dB)	Between 0 and 6.3 (Mode: 1.8)
Antenna gain range (dBi)	Between 32.6 and 47.4 (Mode: 38)
Antenna pattern	Recommendation ITU-R F.699 for single-entry interference [10] Recommendation ITU-R F.1245 for aggregate interference [11]
Antenna height (m)	Between 15 and 110 (Mode: 55)
e.i.r.p. range (dBW)	Between 5.8 and 48.8 (Mode: 34.2)
e.i.r.p. density range (dBW/MHz)	Between −0.2 and 32.7 (Mode: 18.2)
Receiver noise figure typical (dB)	Between 4.5 and 5
Receiver noise power density typical N_{RX} (dBW/MHz)	−139.5
Normalised Rx input level for 1 × 10^{-6} BER (dBW/MHz)	−113
Nominal long term interference power density (dBW/MHz) without feeder loss	−139.5 + I/N
Protection requirement (dB)	I/N = −20 (Recommendation ITU-R F.758: Table 4) [26]
Link Length (km)	Between 10 and 80 (Mode: 40)
* Where a typical value (Mode) is provided	

4.1.4 FS link lengths

Probability distributions of minimum, median and maximum link lengths were reported by 25 CEPT administrations in 2017 for 5925-7125 MHz and by 6 CEPT administrations for 5925-6425 MHz.

Figure 20 shows the FS Link Lengths Reported by CEPT administrations in the band 5925-7125 MHz. The figure is derived from data in ECC Report 173 [57].

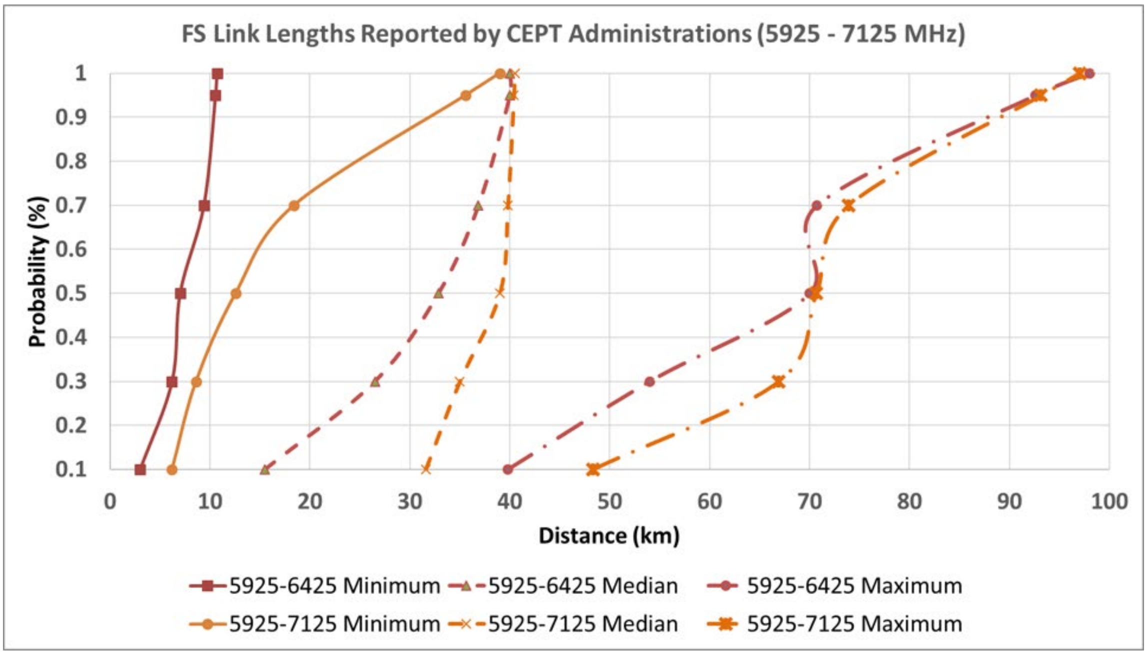

Figure 20: FS Link Lengths Reported by CEPT administrations (5925-7125 MHz) CEPT Report 45 [6]

4.2 FIXED SATELLITE SERVICE SPACE-TO-EARTH

See section 5.3.

4.3 RADIO ASTRONOMY IN THE BAND 6.55 TO 6.6752 GHZ

See section 5.4.

4.4 EESS (SPACE-TO-EARTH), SRS (SPACE-TO-EARTH) AND METEOROLOGICAL-SATELLITE SERVICE (SPACE-TO-EARTH)

4.4.1 EESS (Space-to-Earth) in the band 8025-8400 MHz

The band 8025-8400 MHz is allocated to the Earth exploration satellite service (space-to-Earth). Recommendation ITU-R SA.1027-6 [28] provides the applicable sharing criteria for space-to-Earth transmissions from satellites in low-Earth orbit applying to both the Earth exploration-satellite and meteorological-satellite services. The table below describes the relevant long-term and short-term criteria for EESS earth stations.

Table 10: Sharing criteria for Earth exploration-satellite and meteorological-satellite earth stations using spacecraft in low-Earth orbit

MHz	Interfering signal power (dBW) in the reference bandwidth to be exceeded no more than 20% of the time	Interfering signal power (dBW)in the reference bandwidth to be exceeded no more than p% of the time
8025-8400	–150 dBW per 10 MHz	–133 dBW per 10 MHz p = 0.0050

In accordance with recommends 3 of Recommendation ITU-R SA.1027-6 [28], system performance degradation due to emissions from stations in services with lower allocation status than that of the EESS (as it is the case for UWB) should not exceed 1% of the applicable interference criteria.

Typical altitudes of science satellites are around 700 km.

4.4.2 SRS (Space-to-Earth) in the band 8400-8500 MHz

The frequency band 8400-8500 MHz is allocated on a primary basis to the Space Research service (Space-to-Earth). In addition, the use of the band 8 400-8 450 MHz for the SRS is limited to deep space (RR No. 5.465).

For space research deep space missions (targeted for objectives further than 2×10^6 km from the Earth), protection criteria are contained in Recommendation ITU-R SA.1157 [29]. Based on this Recommendation, the maximum allowable interference for deep-space earth-station receivers shall not exceed – 221 dB(W/Hz) at the receiver input terminals in bands near 8 GHz, with an associated time percentage of 0.001%.

For SRS Near-Earth missions (missions closer than 2×10^6 km from the Earth), protection criteria are provided in Recommendation ITU-R SA.609 [30]. Based on this Recommendation, the maximum allowable interference for near-Earth earth-station receivers shall not exceed – 216 dB(W/Hz) at the receiver input terminals in bands near 8 GHz, with an associated time percentage of 0.001% for manned missions and of 0.1% of for unmanned missions.

In addition, Recommendation ITU-R SA.1743 [31] provides guidance for the apportionment of interference from emissions and radiations from other radio sources that can contribute to the maximum allowable degradation of radiocommunication links of the space research and space operations services. For potential sources of interference other than co-primary services in the band, the degradation should not be more than 1% of the total allowable degradation derived from the Recommendations mentioned above.

4.4.3 Meteorological-Satellite Service (Space-to-Earth)

The frequency band 7450-7550 MHz is allocated on a primary basis to the Meteorological-Satellite Service (Space-to-Earth), limited to geostationary-satellite systems (RR No.5.461A). In addition, the band 7750-7900 MHz is allocated on a primary basis to the Meteorological-Satellite Service (Space-to-Earth), limited to non-geostationary-satellite systems (RR No.5.461B).

For the band 7750-7900 MHz, Recommendation ITU-R SA.1027-6 [28] applies for the protection criteria of MetSat space-to-Earth transmissions (see section 4.5.1).

4.5 EESS (EARTH-TO-SPACE), SRS (EARTH-TO-SPACE) AND METEOROLOGICAL-SATELLITE SERVICE (EARTH-TO-SPACE)

4.5.1 EESS (Earth-to-space) in the band 7190-7250 MHz

The frequency band 7190-7250 MHz is allocated on a primary basis to the EESS (Earth-to-space).

Recommendation ITU-R SA.514-3 [34] provides the protection criteria for command and data transmission systems operating in the EESS and METSAT services. For frequencies between 300 MHz and 10 GHz, “the power spectral density of noise-like interference or the total power of CW-type interference in any single band or in all sets of bands 1 kHz wide shall not exceed -161 dB(W/kHz) at the receiver input for more than 0.1% of the time”.

4.5.2 SRS (EARTH-TO-SPACE) IN THE BAND 7145-7235 MHZ

The frequency band 7145-7190 MHz is allocated on a primary basis to the Space Research service, deep space (Earth-to-space). In addition, the band 7190-7235 MHz is allocated to the SRS (Earth-to-space).

For space research deep space missions, protection criteria are contained in Recommendation ITU-R SA.1157 [29]. Based on this Recommendation, the maximum allowable interference for deep-space space station receivers shall not exceed – 190 dB(W/20 Hz) at the receiver input terminals in bands near 7 GHz, with an associated time percentage of 0.001%.

For SRS Near-Earth missions, protection criteria are provided in Recommendation ITU-R SA.609 [30]. Based on this Recommendation, the maximum allowable interference for near-Earth space station receivers shall not exceed –177 dB(W/kHz) at the input terminals of the receiver, for 0.1% of the time for both manned and unmanned spacecraft.

In addition, Recommendation ITU-R SA.1743 [31] provides guidance for the apportionment of interference from emissions and radiations from other radio sources that can contribute to the maximum allowable degradation of radiocommunication links of the space research and space operations services. For potential sources of interference other than co-primary services in the band, the degradation should not be more than 1% of the total allowable degradation derived from the Recommendations mentioned above.

It should also be noted that SRS (Earth-to-space) transmitters operate with high power transmitters (up to several tens of kW for deep space transmissions) with high gain antennas (up to 70 dBi), which may lead to interference into UWB systems potentially installed nearby these SRS Earth stations.

4.5.3 Meteorological-Satellite Service (EARTH-TO-SPACE)

The frequency band 8175-8215 MHz is allocated on a primary basis to the Meteorological-Satellite Service (Earth-to-space).

Recommendation ITU-R SA.514-3 [34] provides the protection criteria for command and data transmission systems operating in the EESS and METSAT services.

4.6 EESS (PASSIVE) USED UNDER RR NO. 5.458 (6425-7250 MHZ)

As per ITU-R RR No. 5.458, 'In the band 6425-7075 MHz, passive microwave sensor measurements are carried out over the oceans. In the band 7075-7250 MHz, passive microwave sensor measurements are carried out. Administrations should bear in mind the needs of the Earth exploration-satellite (passive) and space research (passive) services in their future planning of the bands 6425-7075 MHz and 7075-7 250 MHz'.

The technical and operational characteristics of EESS (passive) systems can be found in Recommendation ITU-R RS.1861 [32]. This ITU-R Recommendation covers EESS (passive) systems in many frequency ranges, including the 6425-7250 MHz band.

Within Europe, this band will be implemented in the Copernicus Imaging Microwave Radiometer mission, CIMR, which is the high-priority passive microwave satellite mission for the expansion of the European Union’s Copernicus programme, providing measurements having global coverage and serving a wide range of applications. The primary objectives of CIMR are to gather key polar ice and snow parameters and also key sea parameters from observations of the oceans and seas, including in coastal areas. In addition, the envisaged long-term commitment of the CIMR mission will allow to extend data records of Essential Climate Variables, like soil moisture, land surface temperature, lake surface water temperature, among others, which are crucial for monitoring the impact of climate change and anthropogenic forcing on natural and agricultural ecosystems.

Technical and operational characteristics for the CIMR instrument operating in the 6425-7250 MHz band are provided in the table below.

Table 11: Technical and operational characteristics of the EESS (passive) sensor CIMR in the 6.425-7.25 GHz band

Parameters	Characteristics for CIMR
Sensor type	Conical scan
Orbit parameters	
Altitude	820 km
Sensor antenna parameters	
Maximum beam gain	51.5 dBi
Polarisation	V, H
Instantaneous field of view	19 km × 11 km
Footprint size	164.15 km^2
Off-nadir pointing angle	46.5°
Incidence angle at Earth	55°
Elevation angle	35.04°
Sensor receiver parameters	
Slant-path distance	1291.92 km
Channel bandwidth	400 MHz centred at 6.925 GHz
Free-space losses Recommendation ITU-R P.525-3 [17]	171.43 dB
Atmospheric attenuation	0.08 dB
Measurement spatial resolution	
Horizontal resolution	19 km
Vertical resolution	11 km

The performance and interference criteria of EESS (passive) sensors are captured in Recommendation ITU-R RS.2017-0 [33] and are reported in the following table for the band 6425-7250 MHz.

Table 12: Interference criteria for satellite passive remote sensing in the 6.425-7.25 GHz band

Frequency band(s) (GHz)	Reference bandwidth (MHz)	Maximum interference level (dBW)	Percentage of area or time permissible interference level may be exceeded (Note 1) (%)	Scan mode (N, C, L) (Note 2)
6.425-7.25	200	−166	0.1	N, C

Note 1: For a 0.01% level, the measurement area is a square on the Earth of 2 000 000 km^2, unless otherwise justified; for a 0.1% level, the measurement area is a square on the Earth of 10 000 000 km^2 unless otherwise justified; for a 1% level, the measurement time is 24 h, unless otherwise justified.

Note 2: N: Nadir, Nadir scan modes concentrate on sounding or viewing the Earth's surface at angles of nearly perpendicular incidence. The scan terminates at the surface or at various levels in the atmosphere according to the weighting functions. L: Limb, Limb scan modes view the atmosphere "on edge" and terminate in space rather than at the surface, and accordingly are weighted zero at the surface and maximum at the tangent point height. C: Conical, Conical scan modes view the Earth's surface by rotating the antenna at an offset angle from the nadir direction.

It has to be emphasised that the interference criteria given in Recommendation ITU-R RS.2017-0 [33] represent the total interference levels admissible by EESS (passive) sensors from all sources (aggregate interference). Hence, when addressing multiple potential sources of interference to EESS (passive) sensors in a given band, the total allowable interference level needs to be apportioned among these sources (various Services and number of transmitters). Considering that the apportionment factors are typically in the range between 1 and 5%, equivalent to 13 to 20 dB, the apportionment of 13 dB has been used for the relevant studies in this Report, so the maximum interference level in the reference bandwidth of 200 MHz with apportionment, taking in due account other services and systems in operation, is of -179 dBW.

5 SHARING STUDIES

5.1 INTRODUCTION

Studies are performed taking into account the results of the following ECC Reports

- ECC Report 170 [7]
- ECC Report 64 [5]
- ECC Report 278 [27] (Car Access systems)
- ECC Report 302 [20]
- ECC Report 316 [24]

Additional CEPT Reports are also relevant in relation to UWB applications:

- CEPT Report 9 [53]
- CEPT Report 27 [54]
- CEPT Report 34 [55]

The focus of the studies will be the services operating in the band 6-8.5 GHz including:

- Fixed Service, see section 5.2;
- Fixed-Satellite Service, see section 5.3;
- Radio Astronomy Service, see section 5.4;
- Earth Exploration Satellite Service and Space Research Service, see section 5.5 and 5.6.

5.2 FIXED SERVICES

5.2.1 MCL Calculations

5.2.1.1 Methodology

This Report has mainly embraced Minimum coupling loss (MCL) and geometric considerations related to the antenna patterns of the involved systems. With MCL, a set of assumptions is used to derive the loss required on the interference path in order that an interferer does not violate a predetermined interference protection criterion. The geometric consideration calculates the relative gain between the potential interferer and the victim based on given antenna patterns.

5.2.1.2 Propagation models for MCL calculations

The following propagation models are applied:

- Path propagation losses were modelled according to Recommendation ITU-R P.452 [15]. The used percentage of time is 20%;
- Clutter losses were modelled according to Recommendation ITU-R P.2108 [23]. This model is applicable for distances greater than 250 m and only for urban and suburban environments. In the investigation, the following values of p will be used: p=1%, 10%, 50% and 90%. The model predicts that the clutter loss is below 23 dB for 10% of the locations and 90% of the locations are below 39 dB;
- Building entry loss was modelled according to Recommendation ITU-R P.2109 [36] for indoor scenarios. A traditional building type was considered. A fixed value of 50% for the percentage of locations was used.

Note: Section 5.2.1.8 adopts a different approach by calculating the CDF of aggregate losses accounting for basic transmission loss, clutter loss, and building entry loss, instead of fixing percentiles of each individual loss mechanism.

Figure 21 shows the result of the total propagation loss for different values of the percentage of locations for the outdoor scenario.

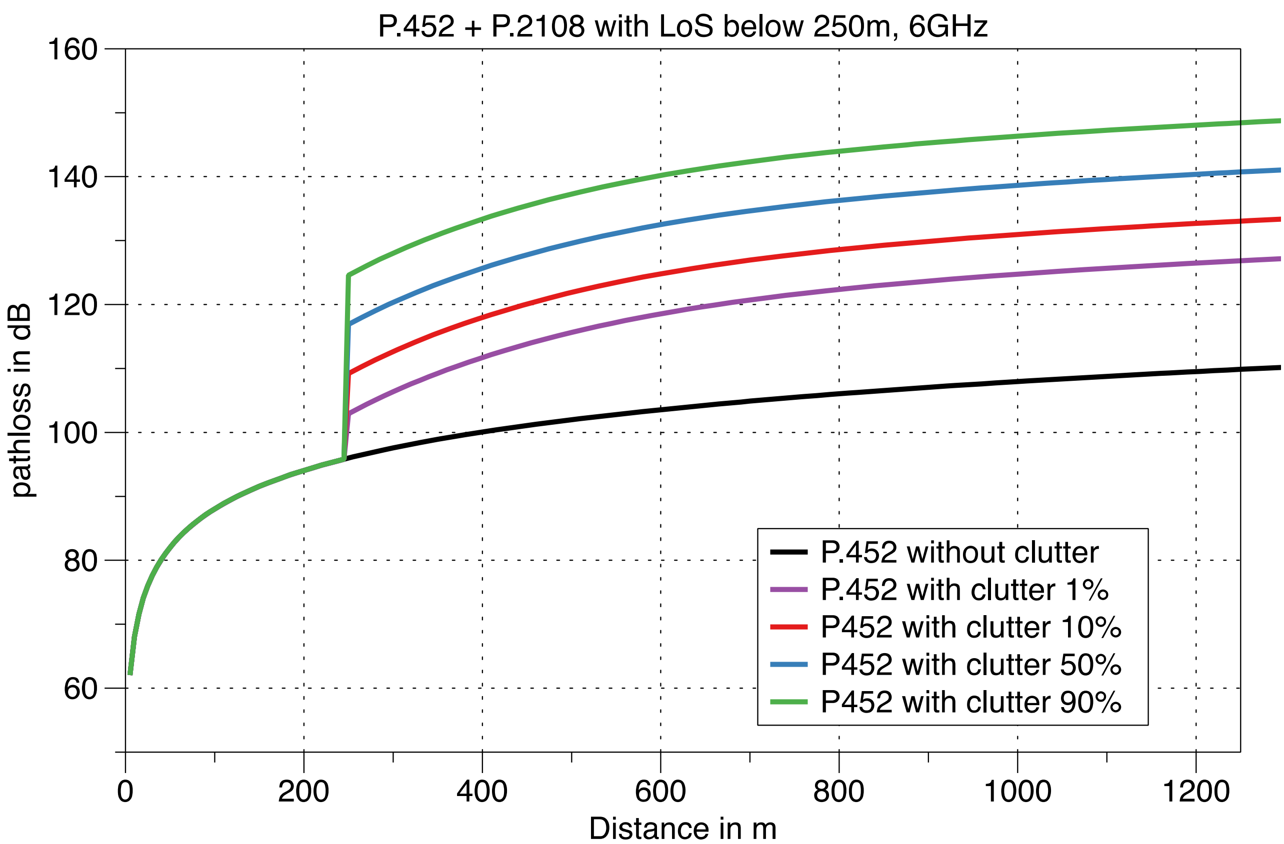

Figure 21: Total Propagation loss, variation of % of locations

5.2.1.3 Parameters

Parameters of the FS receivers were chosen to be in alignment with recent studies in 6 GHz (ECC Report 302 [20]). Table 13 gives an overview of used parameters for the following MCL study. Results for a wider variation of parameters is given in ANNEX 2.

Table 13: MCL parameters

Parameter	Value	Comment
Frequency	6.0 GHz	Worst case frequency of the consider FS band overlapping with UWB band
FS Antenna Pattern	Antenna pattern from Recommendation ITU-R F.699-8	The elevation angle is assumed to be 0° for calculations
UWB Antenna Pattern mitigation	5 dB down tilt	Simplified assumption for single interferer case. e.i.r.p. values are used.
UWB Antenna height fixed outdoor	5 m	Based on ETSI TR 103 314 [1]
FS Antenna height	25 m	
FS antenna gain	46.6 dBi	(Type 2 of Table 17 of ECC Report 302 [20] is assumed)
FS Feeder loss	2 dB	(Type 2 of Table 17 of ECC Report 302 [20] is assumed)

Parameter	Value	Comment
FS Receiver Noise Figure	4 dB	(Type 2 of Table 17 of ECC Report 302 [20]]is assumed)
UWB e.i.r.p. max	-41.3 dBm/MHz	fixed outdoor, vehicular
	-31.3 dBm/MHz	indoor
	0 dBm/50 MHz (-34 dBm/MHz)	Used for peak power study
UWB bandwidth	> 50 MHz	Based on existing generic UWB regulation
Building entry loss	>= 16.6 dB	Recommendation ITU-R P.2109 [36] used for indoor scenarios (traditional buildings, p=50%)
	0 dB	Used for outdoor scenarios
Polarisation loss	0 dB	3 dB could be assumed in aggregated scenarios
Body loss	0 dB	

5.2.1.4 Results main lobe FS - main lobe outdoor UWB applications

In Table 14 and Table 15 the separation distances were calculated based on the required attenuation, applying afterwards the UWB antenna pattern mitigation of 5 dB and the propagation models mentioned in section 5.2.1.2.

Table 14: MCL calculation UWB → FS, outdoor, 6 GHz, variation of % of location for the clutter loss

LINK BUDGET	Units	P = 1%	P = 10%	P = 50%	P = 90%	LoS
Emission part: UWB						
Bandwidth	MHz	≥ 50 MHz	≥ 50 MHz	≥ 50 MHz	≥ 50 MHz	≥ 50 MHz
Tx power mean e.i.r.p.	dBm/MHz	-41.3	-41.3	-41.3	-41.3	-41.3
Frequency	MHz	6000	6000	6000	6000	6000
Reception part: FS						
Long term interference criteria (I/N ≤ -20 dB) including 4 dB NF	dBm/MHz	-130	-130	-130	-130	-130
Feeder loss	dB	2	2	2	2	2
Antenna gain	dBi	46.6	46.6	46.6	46.6	46.6
Allowable Interfering power level 'I' at receiver antenna input (for FS main lobe)	dBm/MHz	-174.6	-174.6	-174.6	-174.6	-174.6

LINK BUDGET	Units	P = 1%	P = 10%	P = 50%	P = 90%	LoS
Propagation models	See section 5.2.1.2					
MAIN LOBE UWB - MAIN LOBE FS						
Allowable Interfering power level at receiver antenna input	dBm/MHz	-174.6	-174.6	-174.6	-174.6	-174.6
Required Attenuation (dB)		133.3	133.3	133.3	133.3	133.3
Separation distance UWB->FS (m)	m	1,484	780	464	305	11,226

Table 15: MCL calculation UWB → FS, indoor, 6 GHz, variation of % of location for the clutter loss

LINK BUDGET	Units	P = 1%	P = 10%	P = 50%	P = 90%	LoS
Emission part: UWB						
Bandwidth	MHz	≥ 50 MHz	≥ 50 MHz	≥ 50 MHz	≥ 50 MHz	≥ 50 MHz
Tx power mean e.i.r.p.	dBm/MHz	-31.3	-31.3	-31.3	-31.3	-31.3
Frequency (GHz)	MHz	6000	6000	6000	6000	6000
Reception part: FS						
Long-term interference criteria (I/N ≤ -20 dB) including 4 dB NF	dBm/MHz	-130	-130	-130	-130	-130
Feeder loss	dB	2	2	2	2	2
Antenna gain	dBi	46.6	46.6	46.6	46.6	46.6
Allowable Interfering power level 'I' at receiver antenna input (for FS main lobe)	dBm/MHz	-174.6	-174.6	-174.6	-174.6	-174.6
Propagation models		See section 5.2.1.2, fixed 16.6 dB indoor-to-outdoor attenuation corresponding to 50% of the building-entry loss cdf				
MAIN LOBE UWB - MAIN LOBE FS						
Allowable Interfering power level at receiver antenna input	dBm/MHz	-174.6	-174.6	-174.6	-174.6	-174.6

LINK BUDGET	Units	P = 1%	P = 10%	P = 50%	P = 90%	LoS
Required Attenuation (dB)		126.7	126.7	126.7	126.7	126.7
Separation distance UWB->FS (m)	m	756	493	322	250	5.040

5.2.1.5 Peak power MCL calculation for outdoor UWB applications

In order to ensure that the data traffic is not interrupted, the peak power criterion proposed in Report ITU-R SM.2057 [25], eq. 69, pg. 327 that was specifically designed for UWB applications will be used. The criterion is shown in (1), and it has been derived from a practical interference test in Appendix 1 to Annex 2 in [25]. A practical evaluation of the two criteria, I/N<-20 dB and I_{P50}/N_{A50}<+5 dB in 50 MHz, was also performed comparing the BER degradation for different types of UWB devices in Report ITU-R SM.2057, annex 7, section 4 [25]. This evaluation concluded that both criteria for UWB are needed to protect FS.

Based on the above, the aggregate peak power objective $I_{P50}/N_A 50 \leq +5dB$ is assumed to be sufficient to protect the fixed service. It can be noted that it is equivalent to [25] , eq. 69, pg. 327:

$$I_{P50}(dBm/50\ MHz) \leq I_A(dBm/MHz) + 42\ dB \qquad (1)$$

Where:

- I_{P50}: peak interference power (dBm) in 50 MHz;
- I_A: average (r.m.s.) interference power (dBm) in 1 MHz;
- N_{A50}: average (r.m.s.) FS noise power (dBm) in 50 MHz.

In the following, MCL calculation for the 6 GHz case have been considered as the worst-case for the FS interference analyses using the peak-power criterion. Here only the fixed outdoor case has been considered.

The basic parameter of the FS and UWB are given in Table 13.

Table 16: MCL calculation UWB → FS, outdoor, peak-power, 6 GHz, variation of % of location for the clutter loss

LINK BUDGET	Units	P = 1%	P = 10%	P = 50%	P = 90%	LoS
Emission part: UWB						
Bandwidth	MHz	≥ 50 MHz	≥ 50 MHz	≥ 50 MHz	≥ 50 MHz	≥ 50 MHz
Tx mean power spectral density e.i.r.p	dBm/MHz	-41.3	-41.3	-41.3	-41.3	-41.3
Frequency	MHz	6000	6000	6000	6000	6000
Peak power e.i.r.p. defined in 50 MHz	dBm	0	0	0	0	0
Reception part: FS						
Long term interference criteria	dBm/MHz	-105	-105	-105	-105	-105

LINK BUDGET	Units	P = 1%	P = 10%	P = 50%	P = 90%	LoS
(I/N ≤ 5 dB) including 4 dB NF						
Feeder loss	dB	2	2	2	2	2
Antenna gain	dBi	46.6	46.6	46.6	46.6	46.6
Allowable Interfering power level 'I' at receiver antenna input (for FS main lobe)	dBm/MHz	-149.6	-149.6	-149.6	-149.6	-149.6
Propagation models	See section 5.2.1.2					
MAIN LOBE UWB - MAIN LOBE FS						
Allowable Interfering power level at receiver antenna input	dBm/MHz	-149.6	-149.6	-149.6	-149.6	-149.6
Required Attenuation (dB)		132.6	132.6	132.6	132.6	132.6
Separation distance UWB->FS (m)	m	1,372	737	446	294	10,328

The presented tables show that the peak power (when the peak power of the UWB signal is limited to 0 dBm/50 MHz) mitigation distances in the MCL case are lower than the values calculated for the mean power limits.

5.2.1.6 Geometric antenna gain considerations

Vertical antenna pattern of the FS receiver

The sketch in Figure 20 should illustrate an UWB device with a significantly lower height compared to the height of the FS receiver, e.g. h_{UWB} = 5 m and h_{FS} = 25 m. The FS line goes along the horizontal line, whereas the connection between the UWB device and the FS receiver is forming an angle θ to the horizontal FS line. A flat ground is assumed for the following calculations.

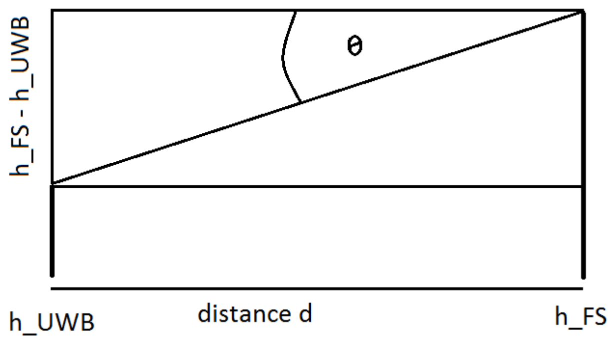

Figure 22: This sketch should illustrate the angle θ between the FS line and the connecting line from the low-lying UWB device into the FS receiver at a larger height

5.2.1.7 Contour plots for MCL evaluations for Fixed Service compatibility with outdoor UWB applications

In the following Figure 23 to Figure 27, MCL calculations are evaluated over a two-dimensional surface contour plot, representing the scenarios given in Table 14. A Fixed Service receiver is placed at the position (0,0), directed to the right. For all the respective points on the surface, the impact of an UWB device on the FS receiver is evaluated, taking into account the antenna patterns. The red contour shows the two dimensional separation distance. The coloured areas highlight the amount to which the results lie above or below the criterion *I/N* =-20 dB. The parameters used and also the results are noted on the plots, respectively.

Peak radius results represent the maximum range of interference coming from the height level of the UWB device, when a constant ground level of 0 m is assumed. This is usually located in the main lobe direction.

Circle radius results represent the minimum range of interference coming from the height level of the UWB device, when a constant ground level of 0 m is assumed. This is usually located in the back lobe area.

Main beam to main beam results represent the MCL calculation results given in Table 14, where no vertical geometry was considered.

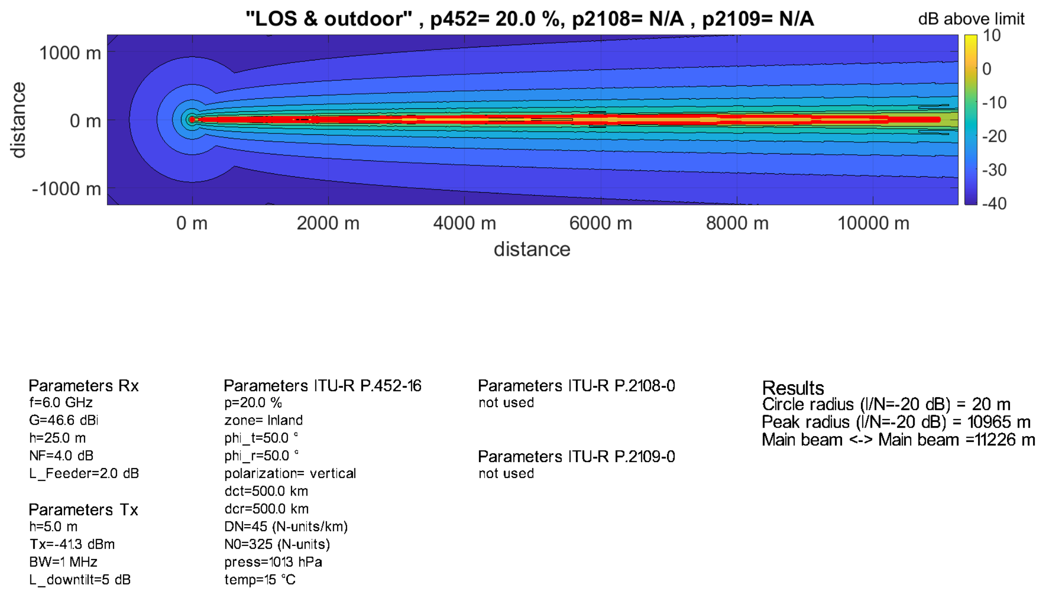

Figure 23: Geometric consideration of separation distance for the scenario highlighted in Table 14, scenario "LOS" - no clutter

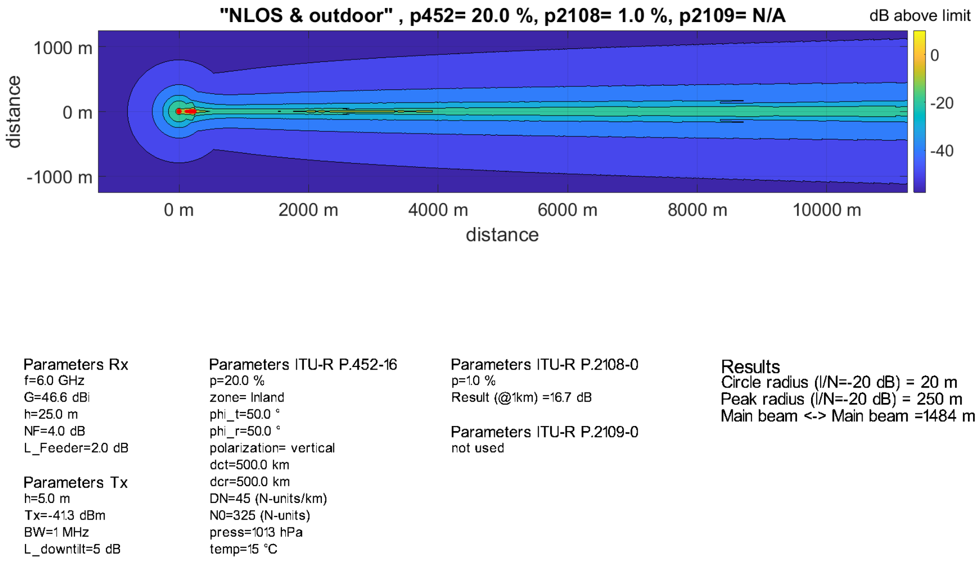

Figure 24: Geometric consideration of separation distance for the conditions highlighted in Table 14, scenario "NLOS" - clutter @ 1 %

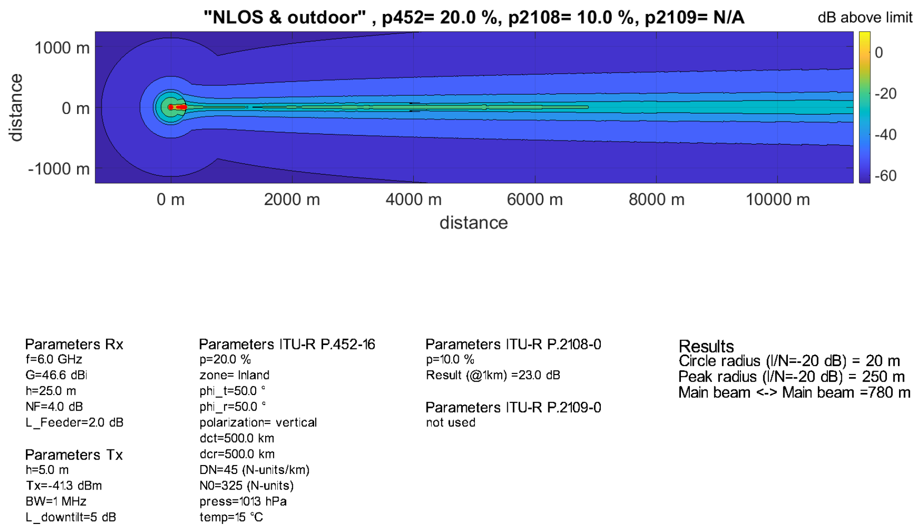

Figure 25: Geometric consideration of separation distance for the conditions highlighted in Table 14, scenario "NLOS" - clutter @ 10 %

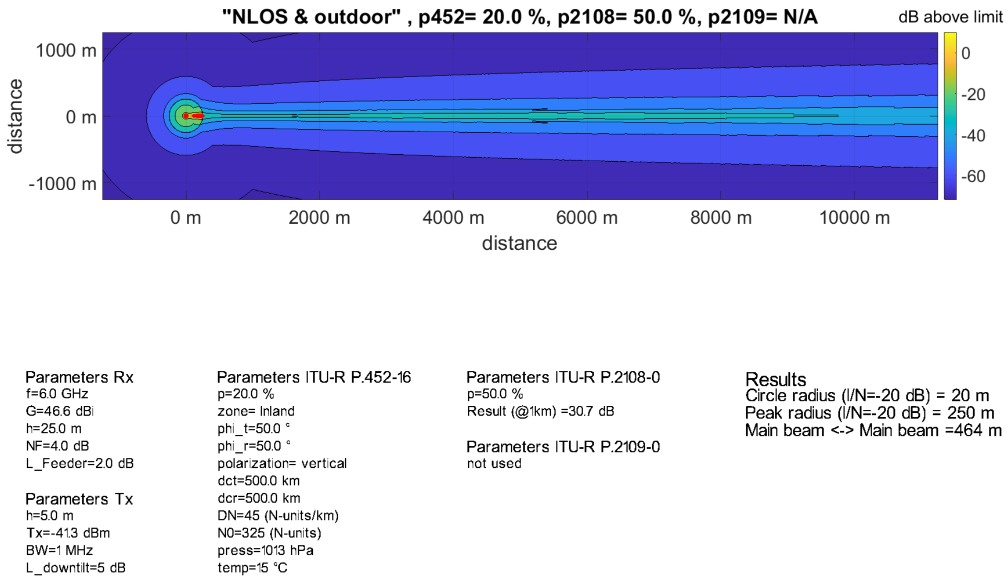

Figure 26: Geometric consideration of separation distance for the conditions highlighted in Table 14, scenario "NLOS" - clutter @ 50 %

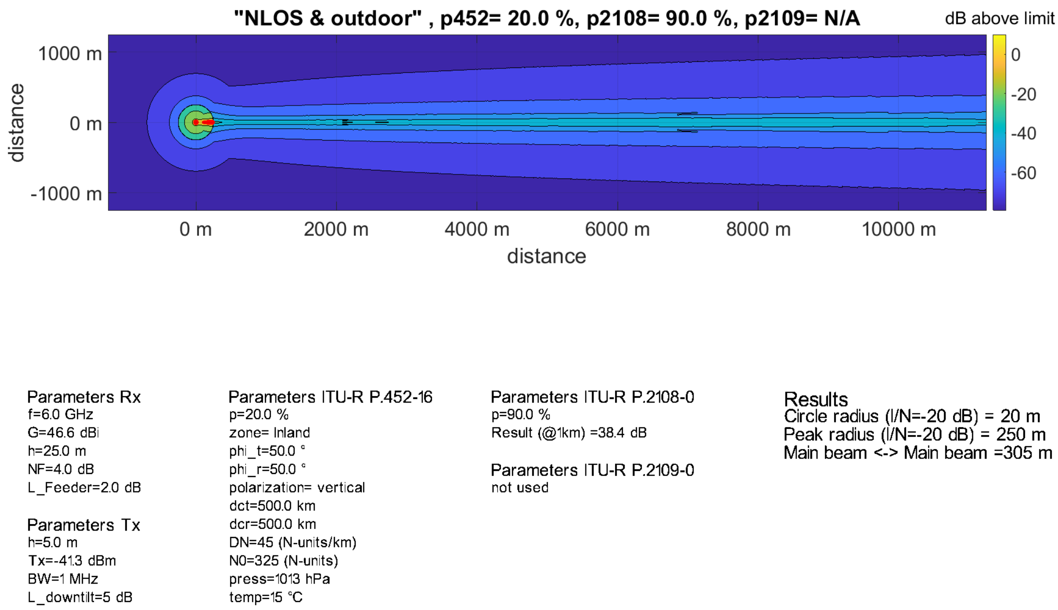

Figure 27: Geometric consideration of separation distance for the conditions highlighted in Table 14, scenario "NLOS" - clutter @ 90%

Taking the antenna patterns into account, angle θ prevents the UWB device from falling into the FS main beam. Consequently, the separation distance based on main lobe to main lobe calculations is greater than for representative geometries. Except for LOS cases where angle θ trends to be zero due to the long distance needed.

One can clearly recognise the border at a distance of 250 m beyond which clutter losses are applied.

lower peak gain Additional results, covering also indoor scenarios, peak power scenarios and a FS antenna scenario are included in ANNEX 2.

5.2.1.8 Geometrical MCL study for Fixed Service compatibility with indoor high-power UWB applications

This section provides a minimum required separation study performed by aggregating all propagation effects into one and determine the required separation distance at different percentiles of the aggregated losses. The combined propagation effects consist of 2 or 3 sources of losses, depending on the scenario, given by statistical models. First, only propagation losses (ITU-R P.452) and building losses (ITU-R P.2109 [36]) are considered. For the second scenario, clutter losses (ITU-R P.2108) were also considered in addition. This study provides a more complete view by considering all propagation losses as a whole, rather than separating each effect on its own and by focusing on the interference evaluation in the azimuth of the main beam of the fixed service, rather than averaging over the possible geographical positioning that may hide some critical cases. With this aggregated approach, all the different propagation effects are considered as a whole and it's no longer possible to distinguish between different scenarios, e.g., a high clutter vs low clutter situation, since different combinations of the propagation losses can have the same overall effect. This holistic view of the propagation effects is particularly useful for uncoordinated services, where no assumption can be made on the environment of the services.

The methodology used to obtain these results is based on the CDFs of propagation losses considered in the interference scenarios. Starting from the CDFs given in ITU-R P.452, ITU-R P.2108, and ITU-R P-2109:

1. Draw N samples independently from each CDF by randomly generating the parameter p uniformly distributed in the valid range. (Note that for P.452 the valid range is between 0.001% -50% and when the generated p was above 50%, it was set to 50%, the same approach as ECC Report 302 [20] and ECC Report 316 [24]).

2. Add the samples from the different CDFs together. (This can be done since the losses are in dB scale). Now the N samples are representative for the aggregated CDF.

3. Obtain the aggregate CDF from the N samples obtained at step 2.

4. Once the aggregate CDF is obtained, values for any percentile value p can be obtained.

This has to be done for every distance since the CDFs for P.452, P.2108, P.2109 are distance dependent. The CDF of P.2109 does not depend on the distance directly, but on the angle, which in turn is distance dependent. For the results presented in this study, N=1000000 was used.

Similar to the MCL results, the geometrical approach described above where the effective FS antenna gain is calculated based on the relative position of the UWB device compared to the FS receiver.

Table 28: MCL parameters for indoor UWB study

MLC parameter	
h_{FS} $[m]$	25
$G_{max,FS}$ $[dBi]$	46.6 (3.7 m)
T $[K]$	290

MLC parameter	
NF_{FS} $[dB]$	4
$L_{feeder,FS}$ $[dB]$	2
h_{UWB} $[m]$	5
$eirp_{UWB}$ $[\frac{dBm}{MHz}]$	-31.3
$L_{downtilt}$ $[dB]$	0
$frequency_{FS}$	$6175\ MHz$
$I-N$	$-20\ dB$
$\frac{N\_FS}{1MHz}$	$-\frac{110dBm}{MHz}$

Four different scenarios were considered consisting of two types of buildings, traditional and thermally efficient, where the latter offers a higher attenuation, and two types of propagation conditions. The first considers propagation losses and building entry losses, and another one considers clutters losses besides propagation losses and building entry losses. The overall cdf of the losses was computed and evaluated for p = 1%, p = 10%, and p = 50% where p represents the percentile of the overall attenuation. The scenarios without clutter loss can be attributed to rural deployments or to scenarios where the UWB device is above the clutter.

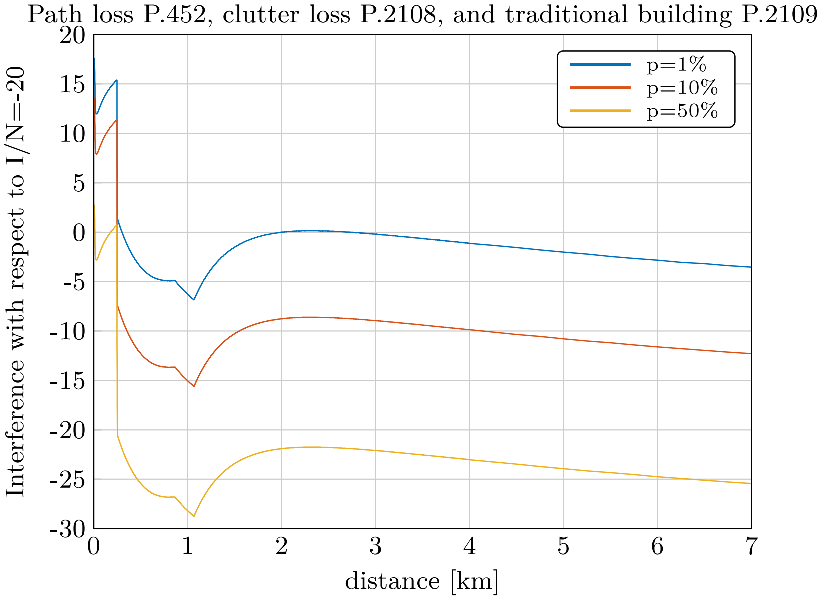

Figure 28: Interferece compared to the I/N=-20 dB criterion for FS antenna heights h_{FS} = 25 m and h_{UWB} = 5 m with p = 1%, 5%, 50% using Path loss P.452, clutter loss P.2108, and traditional building P.2109

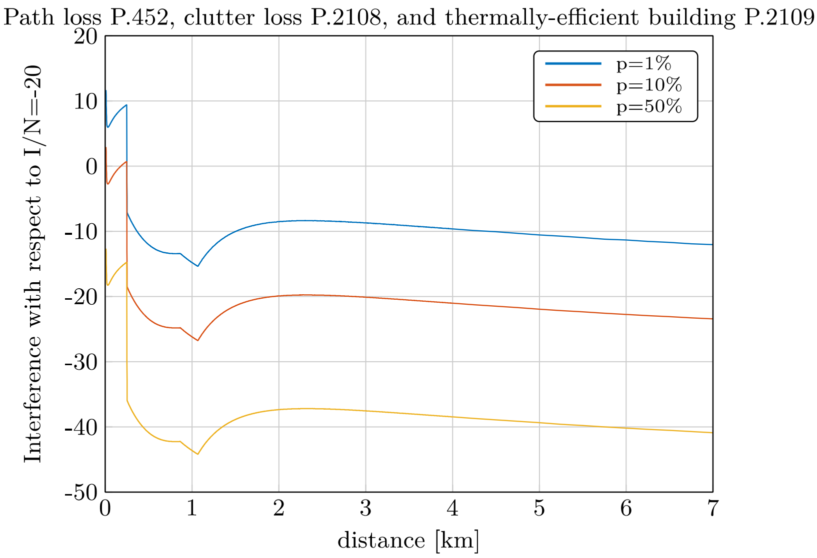

Figure 29: Interferece compared to the I/N=-20 dB criterion for FS antenna heights h_{FS} = 25 m and h_{UWB} = 5 m with p = 1%, 5%, 50% using Path loss P.452, clutter loss P.2108, and thermally-efficient building P.2109

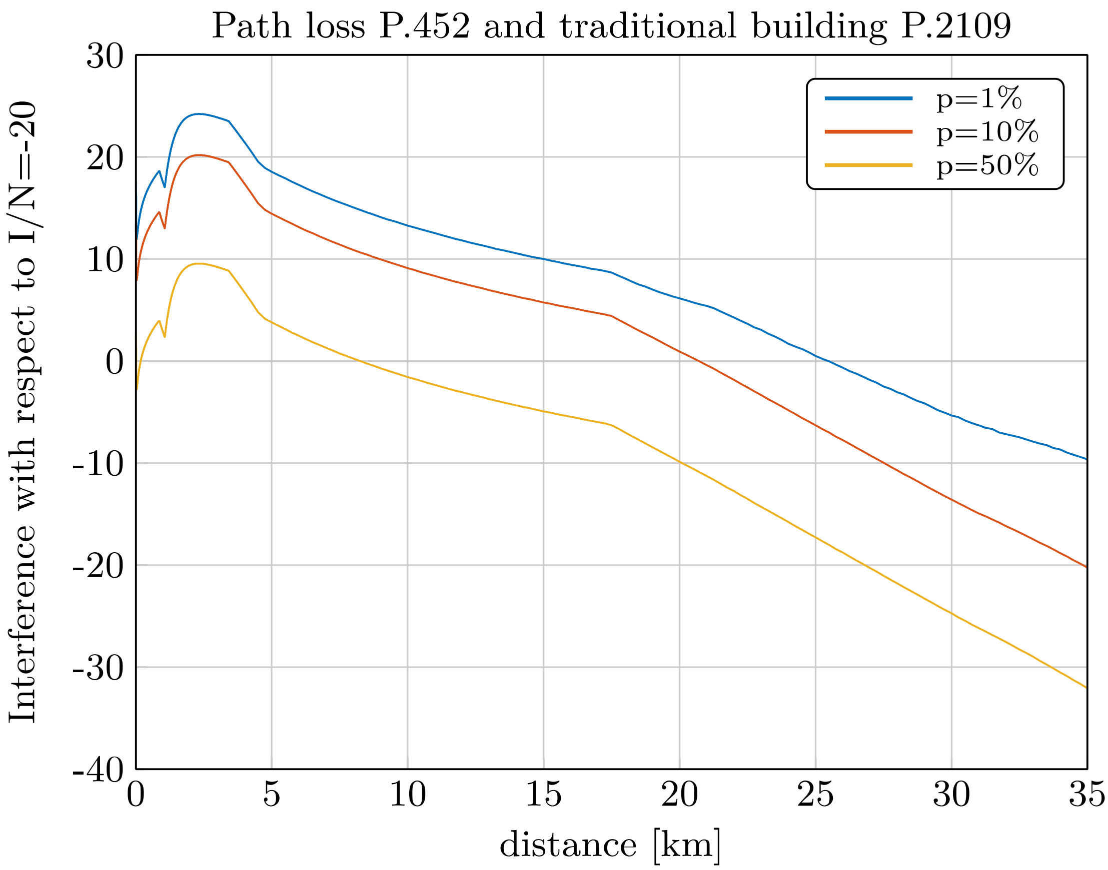

Figure 30: Interferece compared to the I/N=-20 dB criterion for FS antenna heights h_{FS} = 25 m and h_{UWB} = 5 m with p = 1%, 5%, 50% using Path loss P.452, and traditional building P.2109

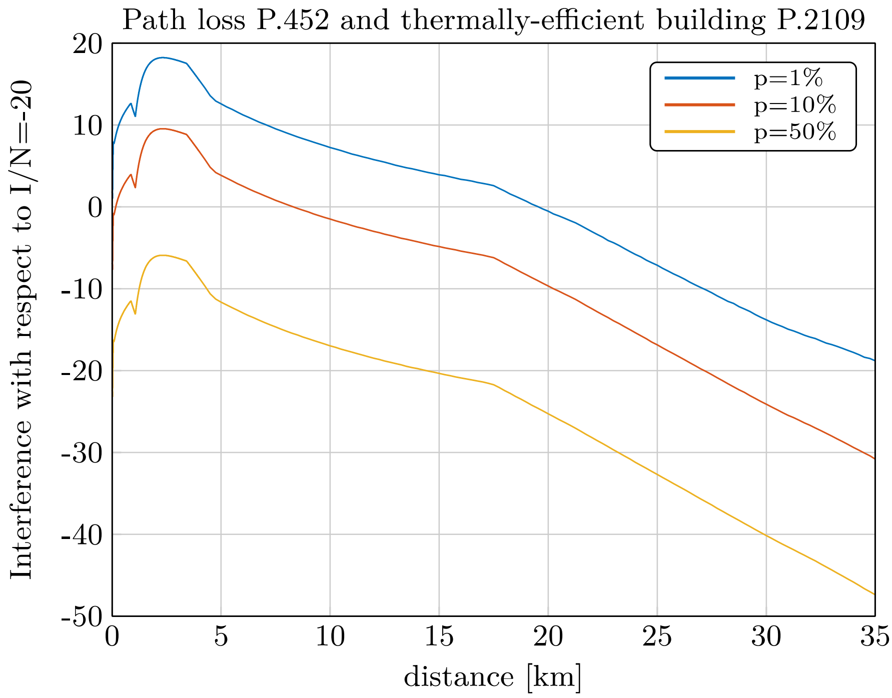

Figure 31: Interferece compared to the I/N=-20 dB criterion for FS antenna heights h_{FS} = 25 m and h_{UWB} = 15 m with p = 1%, 5%, 50% using Path loss P.452, and thermally-efficient building P.2109

The MCL results for indoor high-power applications are summarised in the below table .

Tabel 3: MCL indoor UWB summary

	With clutter loss		Without clutter loss	
	Traditional building	Thermally efficient building	Traditional building	Thermally efficient building
P = 1%	0.26 km[3]	0.25 km	25.5 km	19.75 km
P = 10%	0.25 km	0.25 km	21 km	8.5 km
P = 50%	0.25 km	0 km	8.5 km	0 km

As can be seen, there is big variation in the results spanning from 0 km to 25.5 km depending on the assumed propagation conditions and chosen percentages.

5.2.1.9 Conclusion MCL FS

MCL calculations show a maximum separation distance of 11226 m for the LoS scenario. Taking into account vertical geometries this distance can be reduced to 10965 m.

For NLoS scenarios the maximum separation distance is 1484 m. Taking into account vertical geometries this distance can be reduced to 250 m. That behaviour can be explained by using a suburban/urban clutter model, which adds a minimum of 16.7 dB attenuation for distances greater than 250 m.

[3] Strictly speaking, the received interference exceeds the allowed threshold by a fraction of a dB around 2.5 km separation distance and and it drops below the allowed thresold at 2.7 km. However, given the small amount exceeded and due to statistical uncertainties, it may be considered negligible from a practical perspective and the minimum separation distance becomes 0.26 km.

Outside of the FS main beam, the minimum separation distance is about 50 m without applying any clutter.

Additional results leading to smaller distances than shown above, covering also indoor scenarios, peak power scenarios and a FS antenna scenario with lower peak gain are included in ANNEX 2.

5.2.2 Site Generic Monte Carlo simulations - long and short term analysis - Study A

5.2.2.1 Introduction

This section contains the results of a Monte Carlo analysis using SEAMCAT assessing short-term interference from indoor and outdoor UWB for a site-general scenario in an urban environment.

5.2.2.2 UWB mean power versus peak power

UWB signals are defined by a mean power spectral density (typically -41.3 dBm/MHz) and a maximum peak power spectral density (typically 0 dBm/50 MHz).

The calculations are first carried out based on mean power values. In a second step, peak power is considered.

Emissions at peak power need to be limited in occurrence such that the mean power limit is still fulfilled. For an ideal UWB system with 500 MHz bandwidth and the corresponding pulse length of 2 ns, up to 186 pulses per ms can be transmitted at peak power level while still respecting the mean power limit.

From this, a raw peak duty cycle (r_{PDC}) can be calculated:

$$r_{PDC} = 186 * 2\text{ns} / 1\text{ ms} = 0.0372\% \qquad (2)$$

However, given the very short nature of the pulse, the filter effect needs to be considered (500 MHz /30 MHz)

$$PDC = r_{PDC} * 500\text{ MHz} / 30\text{ MHz} = 0.62\% \qquad (3)$$

This *PDC* is used in the analysis when analysing the impact from peak emissions.

5.2.2.3 UWB Body loss

A body loss of 4 dB is applied to 50% of outdoor cases where the device is portable and to 50% of indoor cases.

5.2.2.4 UWB deployment scenarios, density and associated peak e.i.r.p.

Table 17 gives an overview of the used UWB system parameters.

Table 17: Overview of UWB system parameters

Parameter	Value
Centre frequency (MHz)	6500
Antenna peak gain (dBi)	0 (Note 1)
Antenna pattern	Omni-directional in all directions (Note 1)
Antenna height (m)	See Table 27 and Table 28
Polarisation mismatch (assuming aggregate cases)	Random polarisation as in ECC Report 302 [20]

Parameter	Value
e.i.r.p.	See Table 20 (mean) and Table 21 (peak) (indoor) and Table 23 (mean) and Table 24 (peak) (outdoor)
Simulated densities of active devices	See Table 25 and Table 31 (mean) and Table 26 and Table 32 (peak)
Note 1: Fixed outdoor installations will have more directional antennas while maintaining the same e.i.r.p. level. An omnidirectional antenna therefore overestimates the interference.	

Based on the use cases described in section 3, Table 18 is derived that shows the density of simultaneously active UWB devices.

Table 18: UWB density (devices/km^2)

	Application	Devices / km^2	Activity Factor	Simultaneously Active Devices / km^2
Indoor urban	Other indoor devices (Note 1)	2500	1%	25
	High power indoor	2500	1%	25
Outdoor urban	Other outdoor devices (Note 1)	400	1%	0.4
	Parking	400	0.25%	0.1
	Outdoor Logistics	50	0.3%	0.15
	PACS	200	0.01%	0.02
	Vehicular Fixed	400	5%	20
	Vehicular Mobile	1000	1%	10
Note 1: These devices operate under the rules in ECC Decision (06)04 as generic UWB devices taking into account the main use case of location and tracking with a limited AF as compared to the original assumptions in ECC Decision (06)04 and ECC Report 64. These devices are added to the MC simulations to give the reader the complete interference picture. The assumed densities and activity factors in these simulations are smaller than the ones considered in the ECC Report 64 based on the explanations in section 1.				

These devices are expected to operate with bandwidths of 500 MHz in the 6 to 8.5 GHz frequency range. Since this would allow 5 channels in the frequency range, the simulation considers 1/5 of the devices per square kilometre in each channel.

The indoor UWB density and heights used in the simulation for indoor case are defined in Table 19. Those use cases where a body loss is applicable are marked with (*).

Table 19: Indoor UWB density per 500 MHz channel

Type	Devices / km^2	Height a.g.l.
Simultaneously active devices based on existing regulation *	5	Distributed over various floors (see Table 9)
Simultaneously active devices with higher power *	5	
Total indoor UWB devices	10	

For the assessment of e.i.r.p. values an antenna gain of 0 dBi is used (see Table 17). The UWB power distribution used in the simulation for indoor case is defined in Table 20 with mean e.i.r.p. levels and Table 21 for peak e.i.r.p. levels.

Table 20: Indoor UWB mean e.i.r.p. and associated weights

Parameter	Existing regulation		High Power	
mean e.i.r.p. level (dBm/MHz)	-41.3		-31.3	
mean e.i.r.p. level (dBm/30 MHz)	-26.5		-16.5	
Body Loss (dB)	4	0	4	0
indoor mean e.i.r.p. levels (including Body Loss) (dBm)	-30.5	-26.5	-20.5	-16.5
Weight of UWB mean e.i.r.p. (%)	25%	25%	25%	25%

Table 21: Indoor UWB peak e.i.r.p. and associated weights

Parameter	Existing regulation	High Power			Not active	remarks
Peak e.i.r.p. level (dBm/50 MHz)	0	10			-	
Peak e.i.r.p. level (dBm/30 MHz)	-4.4	5.6			-	
Body Loss (dB)	4	0	4	0	-	
Indoor peak e.i.r.p. levels (including Body Loss) (dBm)	-8.4	-4.4	1.6	5.6	-200	
Weight of UWB peak e.i.r.p. (%) (Note 1)	0.155%	0.155%	0.155%	0.155%	99.38%	Indoor inner ring
Weight of UWB peak e.i.r.p. (%) (Note 2)	25%	25%	25%	25%	0%	Indoor outer ring

Note 1: The PDC of 0.62% (derived in subsection 1.2.1.) splits equally to each of the e.i.r.p levels. For 99.38% of the simulated events the UWB is considered not active (i.e. with an e.i.r.p. of -200 dBm).
Note 2: The UWB devices considered not active are simply not simulated.

The outdoor UWB density and heights used in the simulation for indoor case are defined in Table 22. Those use cases where a body loss is applicable are indicated.

Table 22: Outdoor UWB density

Type	Devices / km^2	Height a.g.l. (m)
Existing regulation (Note 1)	0.8	1.5
Parking Management	0.2	5 (90%) / 10 (10%)
Outdoor Logistics	0.03	5 (80%) / 10 (20%)

Type	Devices / km²	Height a.g.l. (m)
PACS	0.0024	2
Vehicular Fixed	4	5 (95%) / 10 (5%)
Vehicular mobile	2	1.5
Total outdoor UWB devices	7	5 (90%) / 10 (10%)
Note 1: The devices under existing regulation are 11.4% of the total number of outdoor devices. The body loss applies therefore only to 5.7% of the total number of outdoor devices.		

The UWB power distribution used in the simulation for outdoor case is defined in Table 23 with mean e.i.r.p. levels and Table 24 for peak e.i.r.p. levels and with antenna gain of 0 dBi.

Table 23: Outdoor UWB mean e.i.r.p. and associated weights

Parameter	Value	
mean e.i.r.p. level (dBm / MHz)	-41.3	
mean e.i.r.p. level (dBm / 30 MHz)	-26.5	
Body Loss (dB)	4	0
UWB outdoor e.i.r.p. levels (including Body Loss) (dBm)	-30.5	-26.5
Weight of UWB outdoor e.i.r.p. (%)	5.7%	94.3%

Table 24: Outdoor UWB peak e.i.r.p. and associated weights

Parameter	Value	
peak e.i.r.p. level (dBm / 50 MHz)	0	
peak e.i.r.p. level (dBm / 30 MHz)	-4.4	
Body Loss (dB)	4	0
UWB outdoor peak e.i.r.p. levels (including Body Loss) (dBm)	-8.4	-4.4
Weight of UWB outdoor peak e.i.r.p. (%)	5.7%	94.3%

Table 25 provides the summary overview of UWB device density for mean e.i.r.p. analysis.

Table 25: Summary overview UWB devices to simulate for mean e.i.r.p. analysis

Parameter	Value	Comments
Outdoor devices	7 / km²	
Indoor devices	10 / km²	
radius	5 km	Note that an exclusion of 20 m is considered as in ECC Report 316 [24]
Simulated devices	41% outdoor - 547 59% indoor - 788	Note that for the indoor UWB devices 1 UWB indoor is within a ring of radius 180 m (excluding the exclusion zone) and 787

Parameter	Value	Comments
		UWB devices are in the ring from 180 m to 5 km (see Table 31 for calculation details)
Note: In a second set of simulation, the number of simulated devices is doubled to take into account an unbalanced distribution over the 5 UWB channels.		

Table 26 provides the summary overview of UWB device density for peak e.i.r.p. analysis. It is based on Table 25 but applying the peak duty cycle of 0.62%.

Table 26: Summary overview UWB devices to simulate for peak e.i.r.p. analysis

Parameter	Value	Comments
Outdoor devices	0.0434 / km^2	= 7 x 0. 62%
Indoor devices	0.062 / km^2	= 10 x 0. 62%
radius	5.4 km	Note that an exclusion of 20 m is considered as in ECC Report 316 [24].
Simulated devices (Note 2)	41.2% outdoor - 4 58.8% indoor - (6 in outer ring, 1 in inner ring)	Note that for the indoor UWB devices, 0.0062 (Note 1) UWB indoor is within a ring of radius 180 m (excluding the exclusion zone) and 6 UWB devices are in the ring from 180 m to 5.4 km (see Table 32 for calculation details)
Note 1: This is simulated with 1 single UWB device to which a power category with -200 dBm is added for 99.38% of the simulated events, see Table 3. Note 2: In a second set of simulation, the number of simulated devices is doubled to take into account an unbalanced distribution over the 5 UWB channels.		

5.2.2.5 UWB antenna height distribution

The UWB antenna height distribution is described according to Table 27 and Table 28. For indoor devices it is based on the same methodology as in ECC Report 316 [24].

The outdoor height distribution in Table 27 was derived by combining the height information of the applications described in Table 22.

Table 27: UWB outdoor height distribution including fixed outdoor

Height (m)	Probability (%)
1.5	39.82
2	0.03
5	56.9
10	3.25

Table 28: UWB indoor height distribution (ECC Report 302 - urban case [20])

(a) from 0 m to 20 m: no UWB allowed

(b) 20 m to 180 m

Floor	Height (m)	>50k	ECC Report 302 [20]
ground	1.5	35.14%	77.85%
1	4.5	24.74%	17.85%
2	7.5	13.40%	2.85%
3	10.5	26.72%	1.45%

(c) from 180 m to 5 km

Floor	Height (m)	>50k	ECC Report 302 [20]
ground	1.5	35.14	77.85
1	4.5	24.74	17.85
2	7.5	13.40	2.85
3	10.5	9.31	0.52
4	13.5	6.24	0.36
5	16.5	3.78	0.24
6	19.5	2.91	0.16
7	22.5	2.16	0.09
8	25.5	1.50	0.05
9	28.5	0.92	0.02

5.2.2.6 Technical characteristics of FS in the band 5925-6425 MHz

The FS system parameter and assumptions are the same as in ECC Report 316 [24].

The technical characteristics of point-to-point (PP) Fixed Service (FS) links are derived from ECC Report 302 [20] , which refers to Recommendation ITU-R F.758 [26] and Report ITU-R F.2346 [47]. Other deliverables describing typical deployment of FS stations in the 6 GHz band were also referenced including Recommendation ITU-R F.383-9 [18], Recommendation F.384-11[19], Recommendation F.699-7 [10] and Recommendation F.1245-2 [11].

The technical characteristics of PP FS links are summarised in the below table for the 5925-6425 MHz range.

Table 29: Typical System for PP FS systems for the frequency range 5925-6425 MHz

Parameter	Value
Centre frequency (MHz)	6500
Channel spacing and receiver noise bandwidth (MHz)	30
Feeder/multiplexer loss (dB)	1.3 (it is being deduced from the antenna peak gain of the FS) (Type 2 of Table 17 of ECC Report 302 [20] is assumed)

Parameter	Value
Effective Antenna peak gain (dBi)	37.4 dBi = 38.7 dBi - 1.3 dB (Antenna peak gain – Feeder loss) (Type 2 of Table 17 of ECC Report 302 [20] is assumed)
Antenna diameter (m)	1.8 m
Antenna pattern	Recommendation ITU-R F.1245-2 [11] specified for aggregate interference
Antenna height (m) (Rx)	25 m, 55 m (values from ECC Report 302 [20])
Receiver noise figure (NF) typical (dB)	5
Receiver Noise floor (dBm)	-94 (= -173.97 + 10log10(BW in Hz) +NF)
Protection requirement (dB)	Short-term: I/N = +19 dB not exceeded for $4.5 \cdot 10^{-5}$% (reduced by a factor of 10 from Recommendation ITU-R SF.1650-1 [9]) Long-term: I/N = -20 dB for 20%

5.2.2.7 Methodology and approach considered

INTERFERENCE CRITERION AND METHODOLOGY

In this Report, the same methodology as in ECC Report 316 [24] based on I/N = 19 dB not exceeded for more than $4.5 \cdot 10^{-5}$% of the time in any month (for errored seconds) ECC Report 316 [24] has been used to evaluate the fixed-service short-term criterion (Table 29).

SEAMCAT Monte Carlo methodology was used to generate I/N results. 10 million events were simulated as a first round of simulation. Since the results show that the calculated I/N respects the short-term limit by at least 27 dB, it was not necessary to simulate more than 10 millions.

PATH LOSS CALCULATION

The Path loss calculation is summarised in Table 30. The WINNER model [35] has been used up to 1 km, where the first 40 m is upper bounded by free-space model Recommendation ITU-R P. 525-3 [17]. For distances farther than 1 km, Recommendation ITU-R P.452-16 [15] with clutter loss (Recommendation ITU-R P.2108-0 [23]) is used.

Table 30: Propagation models

Horizontal Distance	Propagation Model	For Indoor only	Clutter
$0\,\text{m} \leq d < 40\,\text{m}$	Free-space	ITU-R P.2109 [36] (70% traditional, 30% modern, uniform distribution of probability from 1% to 99%)	not applicable
$40\,\text{m} \leq d < 1000\,\text{m}$	WINNER model (Urban Macrocell C2)	ITU-R P.2109 (70% traditional, 30% modern, uniform distribution of probability from 1% to 99%)	LOS and NLOS ratio probability determination is inherent to the WINNER model

Horizontal Distance	Propagation Model	For Indoor only	Clutter
$d \geq 1000$ m	Recommendation IT U-R P.452-16 (time percentage: uniform distribution from 0.001% to 50%)	ITU-R P.2109 (70% traditional, 30% modern, uniform distribution of probability from 1% to 99%)	ITU-R P.2108-0 (Location percentage: uniform distribution from 0.001% to 99%)

PROXIMITY OF BUILDINGS TO THE FS AND FRESNEL ZONE

In ECC Report 316 [24], an analysis of the results showed an unrealistic positioning for single interfering devices. The Fresnel zone and the proximity of the building structures is dealt in ECC Report 316 by applying an algorithm that post-processed the data by removing data sets if the I/N is above the short-term interference limit. In such a case, the interfering transmitter which are within 20 m from the FS are excluded from the results or the height of the interferer transmitter is capped to 10.5 m if the transmitter is within a distance of 200 m from the FS. This process reported on ECC Report 316 is performed after the simulation are run, i.e., post-processing.

In this contribution, an alternative to this post-processing methodology is used. During the run time of the simulation, an exclusion zone of 20 m (i.e., no interfere is allowed in a circle of 20 m around the FS) and any interferer that are within a distance of 180 m from the FS are capped to 10.5 m. This is possible to simulate such a condition in SEAMCAT by setting input parameters so that two rings where the interferers (with two different height distribution) are uniformly distributed as illustrated in Figure 32 (i.e. UWB mean e.i.r.p. analysis) and Figure 33 (i.e. UWB peak e.i.r.p. analysis).

The radius of the inner ring is calculated to obtain an integer value as the number of UWB to simulate in this ring as shown in Table 31 for the mean e.i.r.p. analysis and in Table 32 for the peak e.i.r.p. analysis.

Note that the UWB outdoor have a maximum height of 10 m, therefore they are only subject to the exclusion zone of 20 m.

Table 31: Calculation of the simulated UWB devices (mean analysis)

Parameter	Value
Exclusion zone (EZ) radius	20 m
Disc 1 radius	180 m
Disc 2 radius	5000 m
Simultaneously active devices per km^2	17
Outdoor ratio	41%
Indoor ratio	59%
Surface for outdoor (disc 2 – EZ)	78.53
Ring 1 (disc 1 – EZ) surface area (for indoor) (height capped to 10.5 m) (km^2)	0.1
Ring 2 (disc 2 – disc 1) surface area (for indoor) (any heights) (km^2)	78.43
Simulated devices outdoor (any heights) (rounded value)	547
Simulated devices indoor (height capped to 10.5 m)	1
Simulated devices indoor (any heights) (rounded value)	787

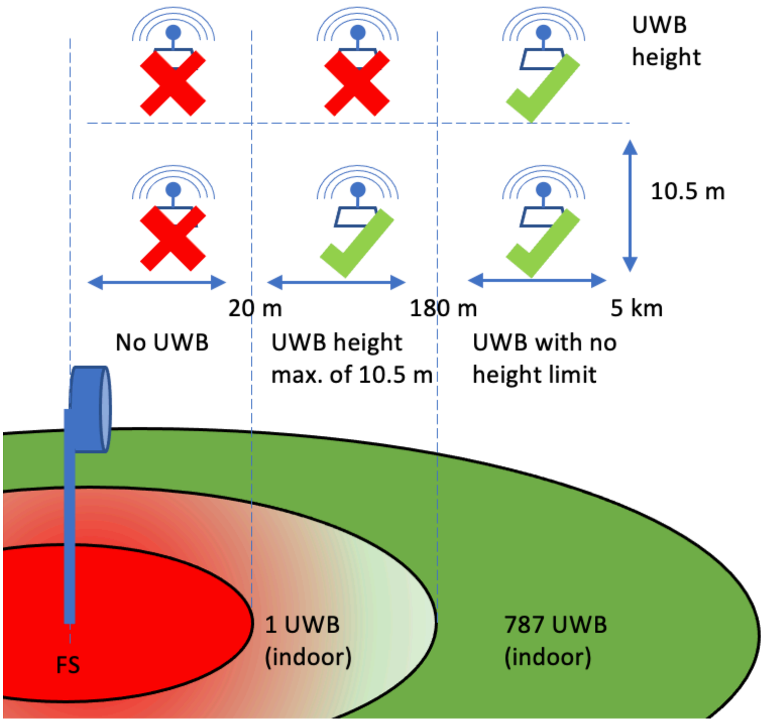

Figure 32: Illustration of the clearance from nearby building structures to the FS (mean analysis) - indoor UWB only

Table 32: Calculation of the simulated UWB devices (peak analysis)

Parameter	Value
Exclusion zone (EZ) radius	20 m
Disc 1 radius	180 m
Disc 2 radius	5400 m
Simultaneously active devices per km^2 (17 *0.62%)	0.1054
Outdoor ratio	41%
Indoor ratio	59%
Surface for outdoor (disc 2 – EZ)	91.6
Ring 1 (disc 1 – EZ) surface area (for indoor) (height capped to 10.5 m) (km^2)	0.1
Ring 2 (disc 2 – disc 1) surface area (for indoor) (any heights) (km^2)	91.5
Simulated devices outdoor (any heights) (rounded value)	4
Simulated devices indoor (height capped to 10.5 m)	0.00625
Simulated devices indoor (any heights) (rounded value)	6

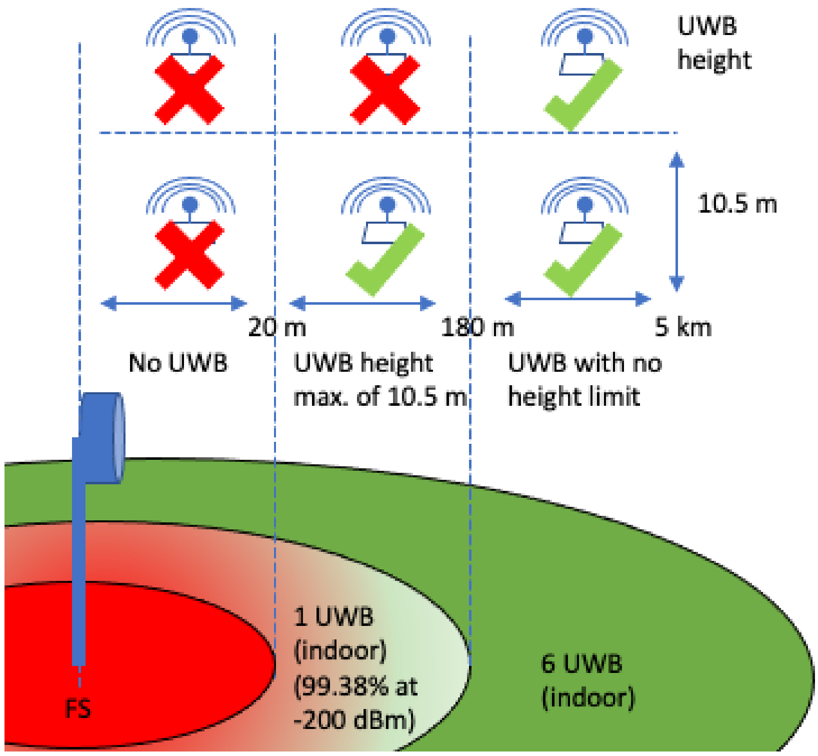

Figure 33: Illustration of the clearance from nearby building structures to the FS (peak analysis) - indoor UWB only

5.2.2.8 Simulation scenarios

This study shows the simultaneous impact of indoor and outdoor UWB devices onto the FS receiver. Table 33 presents a summary of the scenarios that have been considered.

The overall results are shown in terms of the inverse CDF of the I/N to be able to assess the short-term interference criterion.

Table 33: Summary of the simulation scenarios

Scenario	Description	Remarks
Scenario 1	(547 devices outdoors, 788 devices indoors) FS height: 25 m UWB height distribution: Table 27 (outdoor) and Table 28 (indoor: ECC Report 302 [20] and >50k) Mean e.i.r.p. values	Scenario_SE24_UWB_1_H1 (ECC Report 302 [20]) (Baseline) scenario_SE24_UWB_1_H8 (>50K)
Scenario 2	Double devices of scenario 1 (1094 devices outdoors, 1576 devices indoors) Mean e.i.r.p. values	Sensitivity analysis: doubling the number of UWB devices. Scenario_SE24_UWB_2_H1 (ECC Report 302 [20]) Scenario_SE24_UWB_2_H8 (>50K)

Scenario 3	(4 devices outdoors, 6 devices indoors in outer ring and 1 in inner ring) FS height: 25 m UWB height distribution: Table 27 (outdoor) and Table 28 (indoor: ECC Report 302 [20] and >50k) Peak e.i.r.p. values	Sensitivity analysis: peak e.i.r.p. analysis scenario_SE24_UWB_3_H1 (ECC Report 302 [20]) (Baseline) Scenario_SE24_UWB_3_H8 (>50K)
Scenario 4	Double devices of Scenario 3 (8 devices outdoors, 12 devices indoors in outer ring and 2 in inner ring) Peak e.i.r.p. values	Sensitivity analysis: peak e.i.r.p. analysis and doubling the number of UWB devices. Scenario_SE24_UWB_4_H1 (ECC Report 302 [20]) Scenario_SE24_UWB_4_H8 (>50K)

5.2.2.9 *Results for simultaneous indoor and outdoor operation*

Figure 34 presents the inverse CDF of the I/N values on the FS (25 m height) for scenario 1 for a mean e.i.r.p. analysis where UWB devices are operating simultaneously indoor and outdoor. For this study, 10 millions of events per simulation have been run. This figure presents the impact between the baseline study with the UWB height (see ECC Report 302 [20]) and the sensitivity analysis with a UWB height for a city with >50000 households for the indoor case. It shows that for scenario 1, irrespective of UWB height configurations for indoor, the resulting I/N is at least 27 dB below the short-term limit.

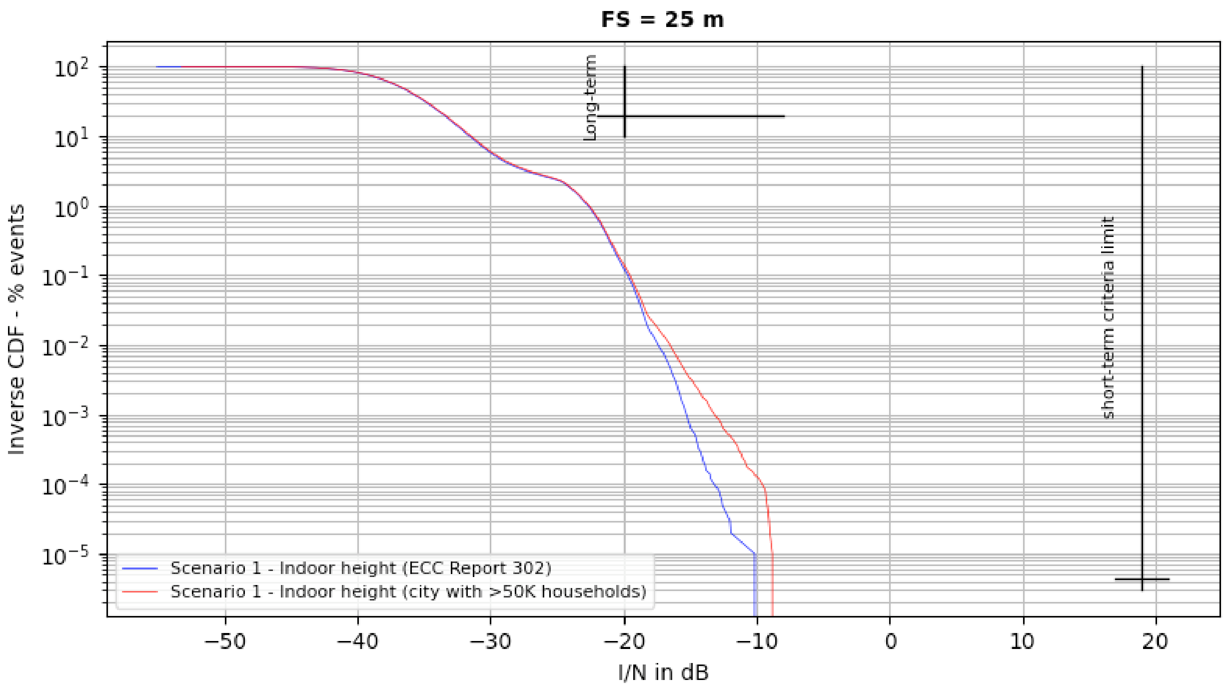

Figure 34: Results of I/N for a FS of 25 m and two different UWB indoor height distributions (mean e.i.r.p. analysis)

Figure 35 presents the inverse CDF of the I/N values for scenario 2 and scenario 1 where UWB devices are operating simultaneously indoor and outdoor. Scenario 2 is the results of a mean e.i.r.p. sensitivity analysis where the number of UWB is doubled (i.e. nothing else is changed in the simulation input files). The curve of scenario 1 already presented in Figure 34 are added to Figure 35 for comparison. It shows that for scenario 2, the resulting I/N remains at least 27 dB below the short-term limit.

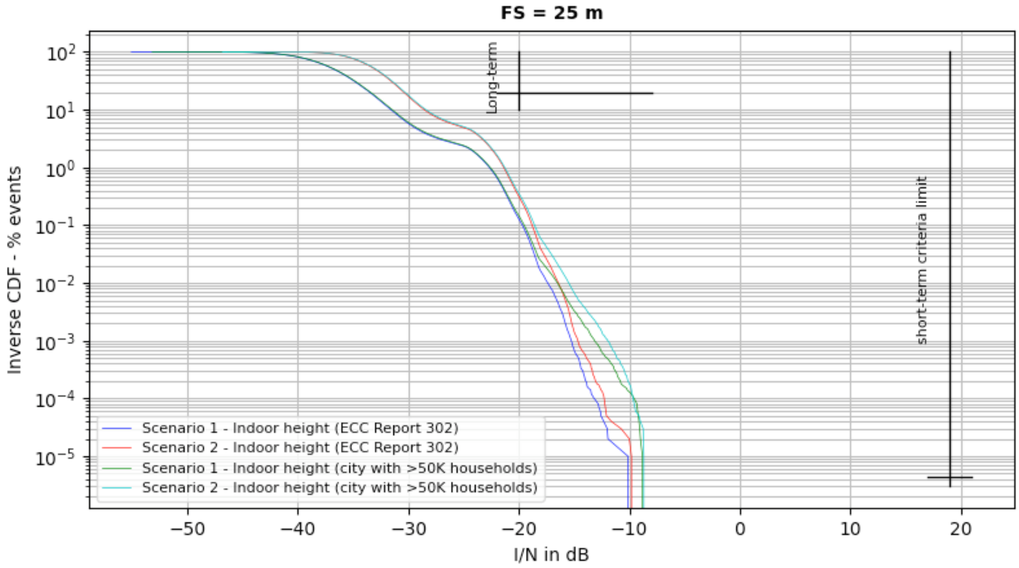

Figure 35: Results of I/N with scenario 1 and scenario 2 (i.e. doubling the number of UWB compared to scenario 1) - (mean e.i.r.p. analysis)

Figure 36 presents the inverse CDF of the I/N values on the FS (25 m height) for scenario 3 with peak e.i.r.p. for UWB operating indoor and outdoor. For this study, 100 millions of events per simulation have been run. This figure presents the impact between the two UWB height (i.e. ECC Report 302 [20] and the sensitivity analysis for a city with more than 50000 households) for the indoor case. It shows that for scenario 3, irrespective of UWB height configuration in indoor, the resulting I/N is below the short-term limit.

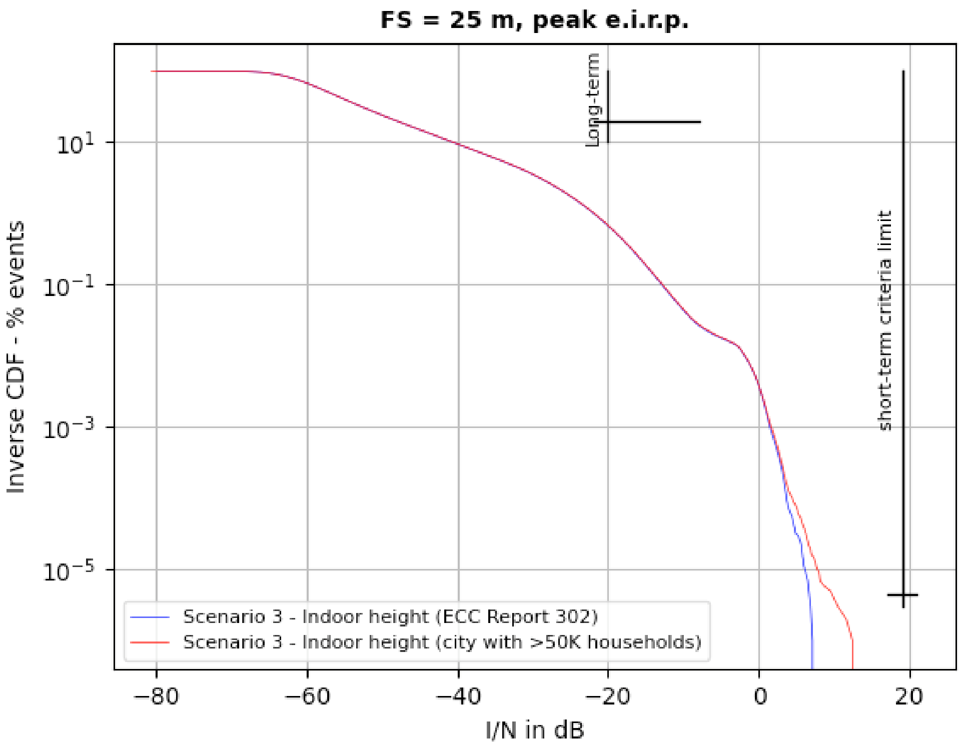

Figure 36: Results of I/N for a FS of 25 m and two different UWB indoor height distributions (peak e.i.r.p. analysis)

Figure 37 presents the inverse CDF of the I/N values on the FS (25 m height) for scenario 4 with peak e.i.r.p. where the number of UWB devices operating indoor and outdoor is doubled compared to scenario 3. For this study, 100 millions of events per simulation have been run. This figure presents the impact between the two

UWB height (i.e. ECC Report 302 [20] and the sensitivity analysis for a city with >50000 households) for the indoor case. It shows that for scenario 4, irrespective of UWB height configuration in indoor, the resulting I/N is below the short-term limit.

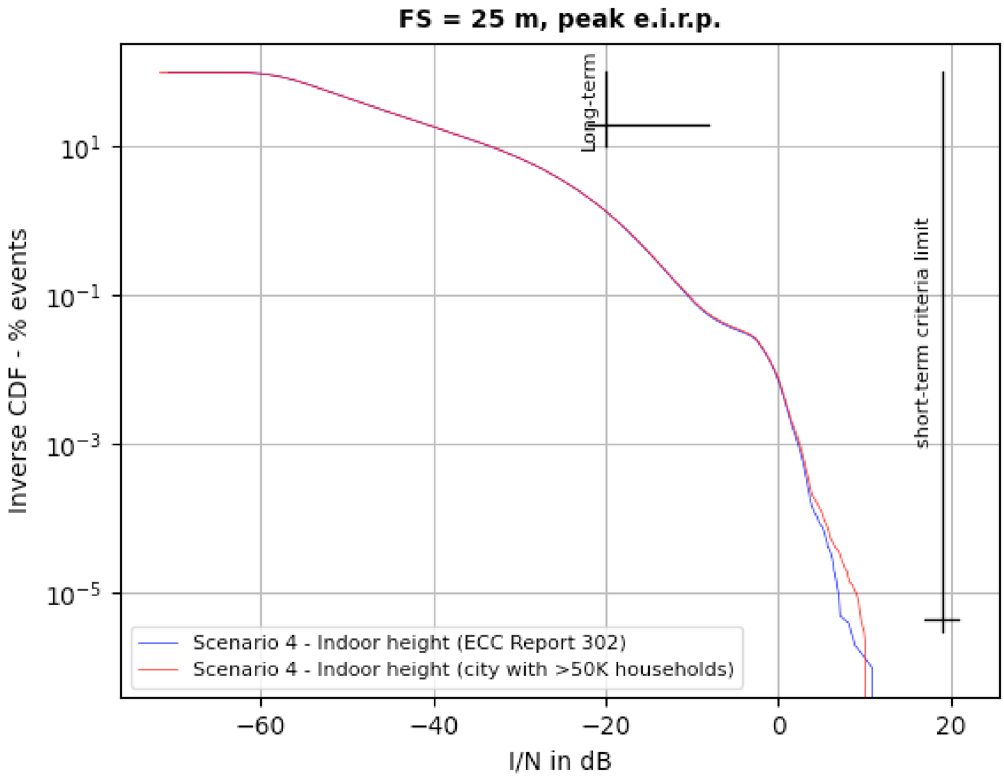

Figure 37: Results of I/N for a FS of 25 m and two different UWB indoor height distributions with doubling the number of UWB compared to scenario 3) - (peak e.i.r.p. analysis)

5.2.2.10 Summary of the site-general Monte Carlo analysis - study A

This contribution presents a site-general Monte Carlo simulations that have been performed using 10 million events (for UWB with mean e.i.r.p. analysis) and using 100 million events (for UWB with peak e.i.r.p. analysis) to assess whether the short-term criterion is met when indoor and outdoor UWB devices are both in operation simultaneously.

The simulations are performed using SEAMCAT.

The methodology is similar to what is used in ECC Report 316 [24]. The studies have considered a sensitivity analysis on the difference of antenna heights between FS Rx and UWB and also doubling the number of UWB devices from the baseline for UWB devices with mean and peak e.i.r.p. analysis.

Results from large number of Monte Carlo events show that the short-term interference criterion is met by at least 27 dB with FS = 25 in all scenarios for the mean e.i.r.p. and also met for peak e.i.r.p. analysis.

A simultaneous assessment of RLAN and UWB systems has not been done. Given that the UWB simulation snapshot with the highest impact on FS is still about 10 dB below the corresponding RLAN snapshot, a significant increase of the overall impact can be excluded.

5.2.3 Site Generic Monte Carlo simulations - Study B

5.2.3.1 UWB applications

For study B, the same UWB application assumptions have been taken as given in section 0 for study A.

5.2.3.2 FS specifications

The technical characteristics of point-to-point (PP) Fixed Service (FS) links are taken from Recommendation ITU-R F.758 [26] and shown in Table 34.

Table 34: FS parameters

Parameter	Value
Centre frequency (MHz)	6500
Bandwidth (MHz)	30
Feeder/multiplexer loss (dB)	1.3
Antenna peak gain (dBi)	38.7
Antenna diameter (m)	1.8
Antenna pattern	Recommendation ITU-R F.1245-2 [11]
Antenna height (m) (Rx)	25
Receiver noise figure typical (dB)	5
Receiver Noise floor (dBm/MHz)	-109
Protection requirement (dB)	Long-term: I/N = -20 dB not to be exceeded for 20% from Recommendation ITU-R.758 [26] Peak-interference: I/N = +5 dB not to be exceeded Report ITU-R SM.2057 [25], ECC Report 64 [5]

5.2.3.3 Study Model

In order to distinguish between the space and time dynamics of the interference, for each spatial deployment 5 million time instances are simulated by choosing randomly the devices to transmit according to a uniform distribution and the activity factor in a square area of 15 km by 15 km. The FS receiver is placed in the centre of the squared area. The transmit power of each UWB devices is chosen according to Table 3. In total 400 spatial deployments were simulated.

The Path loss calculation is based on Recommendation ITU-R P.452-16 [15] with a time percentage uniformly distributed and with clutter loss according to Recommendation ITU-R P.2108 [23], which has been extended to below 250 m to 40 m, and uniformly probability. For indoor devices with heights above 12 m, no clutter loss was applied. Note that the clutter loss was fixed for different time instances of the same deployment, whereas the propagation loss was changed for each time iteration. For indoor devices, an indoor-outdoor attenuation according to Recommendation ITU-R P.2109 [36] was applied with a 70% traditional-30% thermally efficient split and uniform distribution of probability from 0.001% to 99.999%. The propagation models are summarised in Table 35.

Same as in ECC Report 316 [24], no UWB devices are considered within 20 m from the FS and the height of the interferer transmitter is capped to 10.5 m if the transmitter is within 200 m from the FS.

Table 35: Propagation models

Horizontal Distance	Propagation Model	For Indoor only	Clutter
$20 \text{ m} \leq d < 40 \text{ m}$	Recommendation ITU-R P.452-16 15](time percentage: uniform distribution from 0.001% to 50%)	ITU-R P.2109 [36] (70% traditional, 30% modern, uniform distribution of probability from 0.001% to 99.999%)	not applicable
$d \geq 40 \text{ m}$	Recommendation ITU-R P.452-16 [15] (time percentage: uniform distribution from 0.001% to 50%)	ITU-R P.2109 (70% traditional, 30% modern, uniform distribution of probability from 0.001% to 99.999%)	ITU-R P.2108-0 [23] (Location percentage: uniform distribution from 0.001% to 99.999%) Applied only below UWB heights of 12 m

Table 36 summarises the simulate scenarios.

Table 36: Summary of the simulation scenarios

Scenario	Power distribution from Table 2	Devices sharing the same frequency band
Scenario 1a	Scenario 1 – mean UWB power	1/5
Scenario 1b	Scenario 1– mean UWB power	2/5
Scenario 2a	Scenario 2– peak UWB power	1/5
Scenario 2b	Scenario 2– peak UWB power	2/5

5.2.3.4 Scenario 1 – mean power

Figure 38 shows the inverse CDF of the I/N values for scenario 1, where the UWB devices transmit with the mean power. The different lines correspond to different deployments, whereas the CDF was obtained by letting different UWB devices transmit randomly.

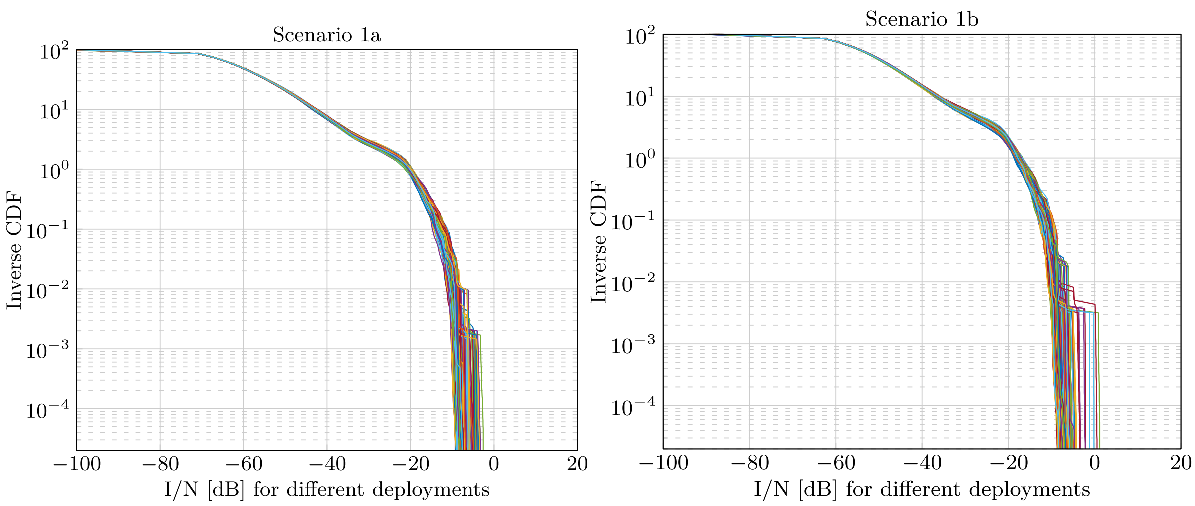

Figure 38: Results of I/N obtained from different deployments for scenario 1 where the left figure shows scenario 1a and the right figure shows scenario 1b

5.2.3.5 Scenario 2

Figure 39 shows the inverse CDF of the I/N values for scenario 2, where the UWB devices transmit with peak power and a reduced occurrence reflected in the activity factor. The different lines correspond to different deployments, whereas the CDF was obtained by letting different UWB devices transmit randomly.

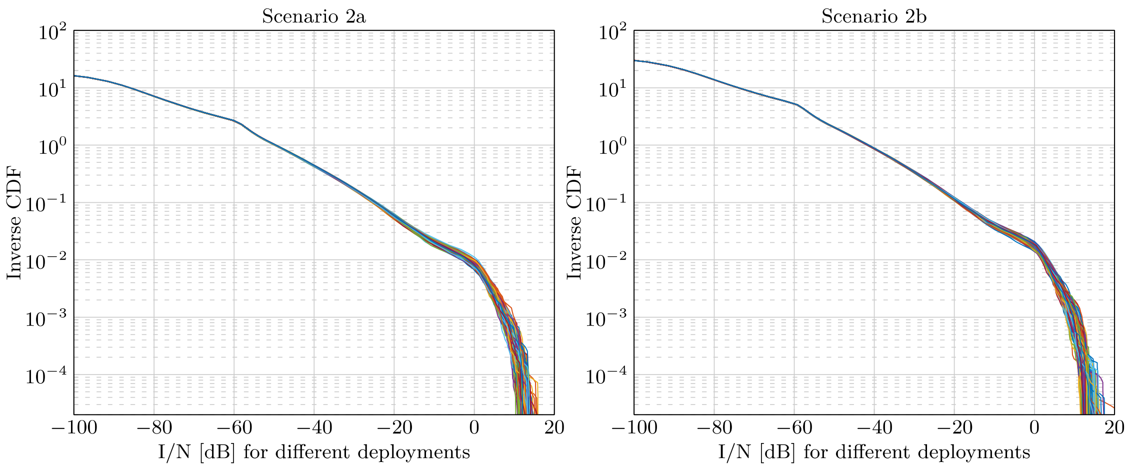

Figure 39: Results of I/N obtained f from different deployments for Scenario 2 where the left figure shows scenario 2a and the right figure shows scenario 2b

5.2.3.6 FS Protection exceedance rate

Figure 40 presents the CDF of the long-term protection criterion I/N=-20 dB exceedance rate for the considered scenarios.

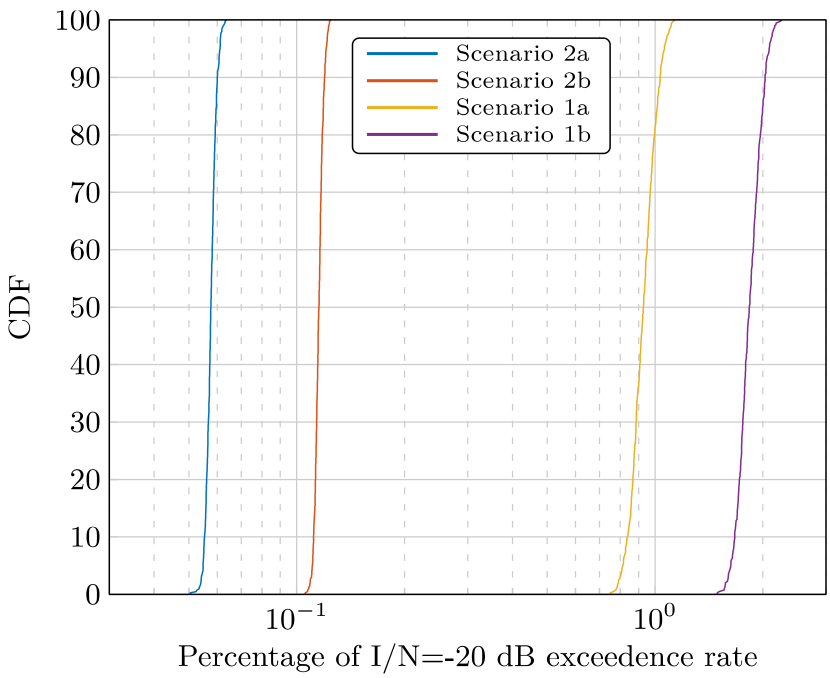

Figure 40: Results of I/N=-20 dB exceedance rate

Figure 40 the CDF of the peak interference protection criterion I/N=+5 dB exceedance rate for scenario 2.

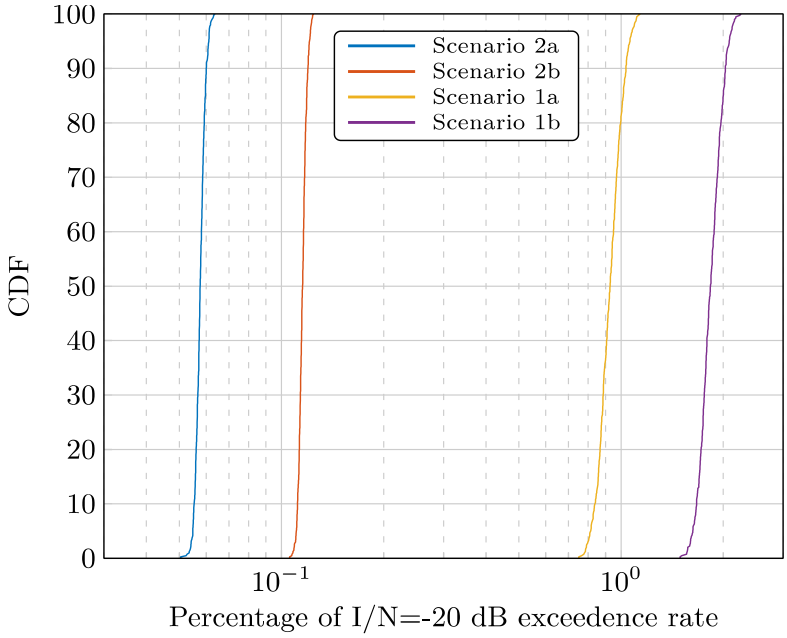

Figure 41: Results of I/N=5 dB exceedance rate

5.2.3.7 Summary of the site-general Monte Carlo analysis - Study B

This study presents a Monte Carlo analysis between UWB devices and FS performed for 5 million time events and 400 spatial events. The study evaluates the exceedance threshold of the long-term interference and peak interference by simulating different time instances for a fixed deployment by selecting randomly which UWB are active. The study considers a sensitivity analysis of the peak transmit power by defining two scenarios:

5 all UWB devices transmit with mean power and

6 the devices transmit with peak power with a reduced occurrence of 0.62% such that both the mean and peak power limitations are fulfilled.

The study has considered a sensitivity analysis of the number of UWB devices from the baseline for UWB devices by doubling the number of active devices.

The results show that the long-term protection criterion of I/N=-20 dB is exceeded by $5x10^{-2}$% to 2.2% depending on the scenario. Taking the median of the results, long-term protection criterion is exceeded by 0.93%, 1.8%, 0.06%, and 0.12% in scenario 1a, 1b, 2a, and 2b, respectively. The peak interference criterion of I/N=+5 dB is exceeded by $2x10^{-3}$% to $7x10^{-3}$% in the simulated scenario when the devices transmit with the peak power and is not exceeded in the simulated scenario when the devices transmit with mean power. Taking the median of the results, the peak interference criterion is exceeded by 0.0026% in scenario 2a, and by 0.0051% in scenario 2b.

Comparing the different results from Scenario 1, mean power UWB transmission, and Scenario 2, peak power UWB transmission, it can be concluded that it's important that the simulation should be conducted reflecting the practical operation of the devices as closely as possible in order to obtain realistic results.

5.3 FIXED-SATELLITE SERVICE SPACE-TO-EARTH

5.3.1 FSS MCL calculation

For the Fixed-satellite service for the space-to-earth direction MCL calculations the same pathloss models will be used as in the FS case as given in 5.2.1.2.

5.3.1.1 FSS parameters and assumptions

The FSS station parameters are based on assumptions used in ECC Report 278 [27].

The typical characteristics of C band receive earth stations are summarised in Table 37. It has always been assumed that the same parameters may also be applicable to receiving earth stations in the 6-8.5 GHz band.

Table 37: FSS Earth Station Characteristics in C band

Antenna Diameter (m)	System Noise Temp (K)	Antenna Rx Gain (dBi)	Radiation Pattern
9	71	49.2	RR Appendix-7 (WRC-07)
6	71	45.5	RR Appendix-7 (WRC-07)
4.5	150	43.0	RR Appendix-7 (WRC-07)
3	150	39.5	RR Appendix-7 (WRC-07)
1.8	150	35.1	RR Appendix-8 (WRC-07)
1.2	120	31.5	RR Appendix-8 (WRC-07)

Like in ECC Report 278 [27], the mean frequency for the considered bands, 7575 MHz, will be used. To take into account that these are professional installations, it is assumed that no UWB devices are present in a zone with a radius of 10 times the dish diameter.

The FSS antenna is assumed to operate 10° tilted upwards.

Similar to ECC Report 278 [27], an insertion loss between antenna and receiver input of 2 dB is assumed.

Unlike ECC Report 278 [27], the antenna height is fixed to 25 metres, to take into account that the high density UWB deployments considered will occur in urban environments.

The protection criteria used are the same as in previous studies and based on ITU-R Recommendation SF.1006 [12], Recommendation F.1094 [13] and Recommendation S.1432 [14]. The long-term protection criterion of I/N=-20 dB with a maximum allowed exceedance of 20% of time was used. For the peak power analysis the protection criterion of I/N=5 dB was used.

5.3.1.2 Contour plot results

In the following figure MCL calculations are evaluated over a two-dimensional surface contour plot. A Fixed Satellite Service receiver is placed at the position (0,0), directed to the right. For all the respective points on the surface, the impact of an UWB device on the FSS receiver is evaluated, taking into account the antenna patterns. The red contour shows the two dimensional separation distance. The coloured areas highlight the amount to which the results lie above or below the criterion I/N =-20 dB. The parameters used and also the results are noted on the plots, respectively.

Peak radius results represent the maximum range of interference coming from the height level of the UWB device, when a constant ground level of 0 m is assumed. This is usually located in the main lobe direction.

Circle radius results represent the minimum range of interference coming from the height level of the UWB device, when a constant ground level of 0 m is assumed. This is usually located in the back lobe area.

Main beam to main beam results represent the MCL calculation where no vertical geometry was considered and both antennas are pointing at each other.

Taking into account vertical geometries and the corresponding elevation angles the maximum separation distance of 156 m was found for the outdoor scenario in combination with the smallest dish size of 1.2 m. In Figure 42 the related result is shown for a 1.2 m dish FSS antenna. In Figure 43 the related result is shown for a 9 m dish FSS antenna.

Additional results which show altogether lower separation distances for UWB peak power analysis and UWB indoor devices are given in ANNEX 2:.

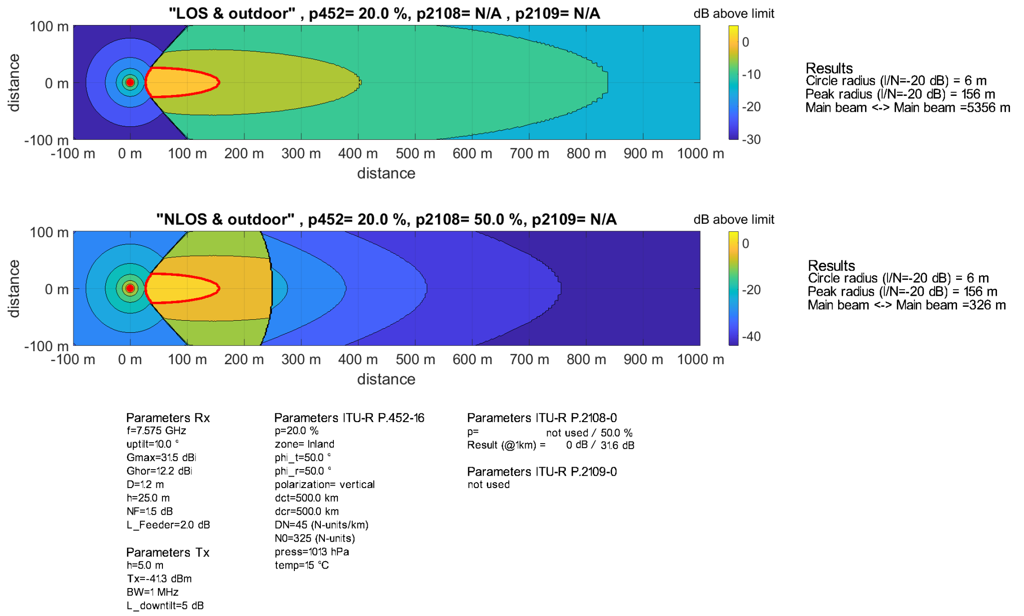

Figure 42: Geometric consideration of separation distance for outdoor UWB, FSS dish size = 1.2 m

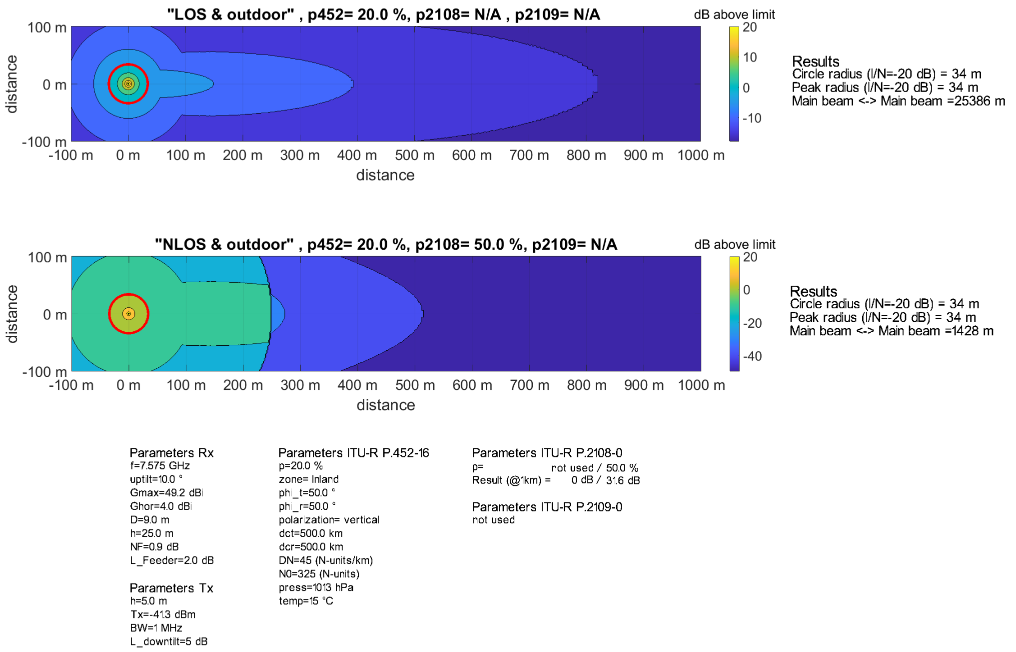

Figure 43: Geometric consideration of separation distance for outdoor UWB, FSS dish size = 9 m

5.3.1.3 Conclusion for MCL calculation

MCL calculations show a maximum separation distance of 25386 m from the FSS receiver for the LoS scenario. Taking into account vertical geometries and the corresponding elevation angles this distance can be reduced to 156 m, even without taking clutter into account.

For NLoS scenarios the maximum separation distance is 1428 m from the FSS receiver. Taking into account vertical geometries this distance can be reduced to 156 m.

Outside of the FSS main beam, the minimum separation distance is about 34 m without applying any clutter.

Additional results leading to smaller distances than shown above, covering also indoor scenarios and peak power scenarios are included in ANNEX 2.

In this Report, no aggregated investigations have been performed nor any FSS systems operating in rural environment have been considered.

5.3.2 UWB vs FSS Monte Carlo analysis

This study analyses the short-term interference impact of UWB into Fixed Satellite Service (FSS) system Even though the focus is to the short-term, the results on the long-term criteria is also shown.

This contribution presents a site-general Monte Carlo simulation that assesses whether the long-term and the short-term criteria are met when indoor and outdoor UWB devices are both operating simultaneously. The simulations are performed using SEAMCAT.

The studies present a sensitivity analysis on the exclusion zone and uptilt of the FSS Rx and UWB. The study analyses the impact of UWB mean and peak e.i.r.p.

5.3.2.1 Short-Term Interference Assessment from UWB into FSS

This section contains the results of a Monte Carlo analysis using SEAMCAT assessing long-term and short-term interference from indoor and outdoor UWB for a site-general scenario in a rural and urban environment.

5.3.2.2 Technical characteristics of FSS

FSS EARTH STATION DEPLOYMENT

In this study, the FSS Earth station is assumed to be located in two types of environments.

The first environment is rural. An illustrative example of an existing deployment is the Space Study National Center in Aussaguel (France) co-share antennas of FSS operators which is a rural environment as shown in the below figure. This study presents generic study results and is not about this site.

Figure 44: Illustration of a FSS rural deployment in Aussaguel, France (source: Google)

The second environment is urban. It is assumed that the FSS earth station is located in central urban on roof top of the height building to avoid any electromagnetic interference due to surrounding buildings. This will give a relative height of 0 m with the highest UWB devices being simulated.

FSS EARTH STATION RECEIVER TECHNICAL CHARACTERISTICS

The technical characteristics of FSS earth station receiver are summarised in the below table.

Table 38: FSS system characteristics summary

Parameter	Value
Centre frequency (MHz)	7000
Gateway receiver bandwidth (MHz)	1.2 (Recommendation ITU-R M.1184 (System D, Table 4a) [51] and ECC Report 64 [5])
Insertion loss between antenna and receiver input) (dB)	2 CEPT Report 45 [6]
Antenna pattern	Recommendation ITU-R S.465-6 [52]
Dish antenna diameter (m)	Rural: 5.5 EC Decision 2019/785/EU [4] Urban: 3 and 1.4
Uptilt elevation angle (degree)	Fixed: 10 EC Decision 2019/785/EU [4] Fixed: 27 (Flensburg (Northern Germany) - 7E GEO satellite) Fixed: 34.5 (Munich (Southern Germany) - 7E GEO satellite) Variable: 5 - 85 (Earth station tracking a LEO satellite) (i.e. using uniform distribution)
Antenna height (m) (Rx)	5.5 for rural deployment EC Decision 2019/785/EU [4] 25 for urban environment (equivalent to roof top)

Parameter	Value
System noise temperature (K)	200 (5.5 m dish antenna) EC Decision 2019/785/EU [4] 150 (3 m dish antenna) [6] 100 (1.4 m dish antenna)
Receiver noise figure (NF) typical (dB) - Note 1	2.27 (5.5 m dish antenna) 1.81 (3 m dish antenna)
Receiver Noise floor (dBm) - Note 2	-110.79 (5.5 m dish antenna) -111.26 (3 m dish antenna) -111.89 (1.4 m dish antenna)
Protection requirement (dB)	Short-term: -1.33 dB I/N for 0.005% of the time/events. Long term: I/N = -20 dB for 20% of the time/events.
Note 1: Noise Figure (dB) = 10 * log10 $\left(\frac{T_{Noise}(K)}{T_{Ref}(K)}+1\right)$ with Tref = 290 K Note 2: Noise Floor = -173.97 + 10*log10(BW in Hz) +NF Note 3: https://www.groundcontrol.com/Satellite_Look_Angle_Calculator.htm	

5.3.2.3 Technical characteristics of UWB in the 6 GHz band for the purpose of this study

MEAN POWER VERSUS PEAK POWER

UWB signals are defined by a mean power spectral density (typically -41.3 dBm/MHz) and a maximum peak power spectral density (typically 0.dBm/50 MHz).

The calculations are first carried out based on mean power values. In a second step, peak power is considered.

Emissions at peak power need to be limited in occurrence such that the mean power limit is still fulfilled. For an ideal UWB system with 500 MHz bandwidth and the corresponding pulse length of 2 ns, up to 186 pulses per ms can be transmitted at peak power level while still respecting the mean power limit.

From this, a raw peak duty cycle (rPDC) can be calculated:

$$rPDC = 186 * 2ns / 1 ms = 0.0372\% \quad (4)$$

However, given the very short nature of the pulse, the filter effect needs to be considered (500 MHz / 1.23 MHz):

$$PDC = rPDC * 500 MHz / 1.23 MHz = 15.1\% \quad (5)$$

This PDC is used in the analysis when analysing the impact from peak emissions.

BODY LOSS

A body loss of 4 dB is applied to 50% of outdoor cases where the device is portable and to 50% of indoor cases.

UWB TECHNICAL CHARACTERISTICS

Table 39 presents the basic UWB system characteristics used for the simulation.

Table 39: UWB system characteristics summary

Parameter	Value
Centre frequency (MHz)	7000
Antenna peak gain (dBi)	0 (Note 1)
Antenna pattern	Omni-directional in all directions (Note 1)
Antenna height (m)	See Table 49 for outdoor deployment and Table 50 for indoor
Polarisation mismatch (assuming aggregate cases)	Random polarisation as in ECC Report 302 [20]
e.i.r.p.	See Table 45 (indoor) and Table 46 (outdoor) for mean e.i.r.p. analysis and Table 21 (indoor) and Table 48 (outdoor) for peak e.i.r.p. analysis
Note 1: Fixed outdoor installations will have more directional antennas while maintaining the same e.i.r.p. level. An omnidirectional antenna therefore overestimates the interference.	

UWB DEPLOYMENT DENSITY

Based on the use cases described in section 3, (i.e. Table 3), the number of active UWB devices has been calculated for rural and urban environment as summarised in Table 40 Table 41 respectively.

Table 40: UWB rural density overview for the band 6-8.5 GHz

	Application	Devices / km^2	Activity Factor	Simultaneously Active Devices / km^2
Indoor	Existing regulation* (note)	25	1%	0.25
	High power indoor*	25	1%	0.25
Outdoor	Existing Regulation*	10	1%	0.1
	Parking	10	0.25%	0.025
	Outdoor Logistics	10	0.3%	0.03
	PACS	10	0.01%	0.001
	Vehicular Fixed	10	5%	0.5
	Vehicular Mobile	25	1%	0.25
Note: Those use cases where a body loss is applicable are marked with (*).				

Table 41: UWB urban density overview for the band 6 to 8.5 GHz

	Application	Devices / km^2	Activity Factor	Simultaneously Active Devices / km^2
Indoor	Existing regulation* (note)	2500	1%	25
	High power indoor*	2500	1%	25
Outdoor	Existing Regulation*	400	1%	4
	Parking	400	0.25%	1

	Application	Devices / km^2	Activity Factor	Simultaneously Active Devices / km^2
	Outdoor Logistics	50	0.3%	0.15
	PACS	200	0.01%	0.02
	Vehicular Fixed	400	5%	20
	Vehicular Mobile	1000	1%	10
Note: Those use cases where a body loss is applicable are marked with (*).				

These devices are expected to operate with bandwidths of 500 MHz in the 6 to 8.5 GHz frequency range. Since this would allow 5 channels in the frequency range, the simulation considers 1/5 of the devices per square kilometre in each channel.

The indoor UWB density and heights above ground level (a.g.l.) used in the simulation for indoor case are defined in Table 42 for rural and urban case. Those use cases where a body loss is applicable are marked with (*).

Table 42: Indoor UWB density per 500 MHz channel and associated height

Type	Rural devices / km^2	Urban devices / km^2	Height a.g.l.
Simultaneously active devices based on existing regulation *	0.05	5	Distributed over various indoor floors see Table 50.
Simultaneously active devices with higher power *	0.05	5	
Total indoor UWB devices	0.1	10	
Those use cases where a body loss is applicable are marked with (*).			

The outdoor UWB density and heights used in the simulation are defined in Table 43 for rural and urban case.

Table 43: Outdoor UWB density per 500 MHz and associated height

Type	Rural devices / km^2	Urban devices / km^2	Height a.g.l. (m)
Existing regulation * (note)	0.02	0.8	1.5
Parking Management	0.005	0.2	5 (90%) / 10 (10%)
Outdoor Logistics	0.006	0.03	5 (80%) / 10 (20%)
PACS	0.0002	0.0024	2
Vehicular Fixed	0.1	4	5 (95%) / 10 (5%)
Vehicular mobile	0.05	2	1.5
Total outdoor UWB devices	0.1812	7	5 (90%) / 10 (10%)
UWB devices under existing regulation over the total number of outdoor devices	11.04%	11.37%	

Type	Rural devices / km^2	Urban devices / km^2	Height a.g.l. (m)
Body loss applied to the total number of outdoor devices.	5.52%	5.69%	This value is used in Table 46 and subsequently in Table 48.
Note: Those use cases where a body loss is applicable are marked with (*).			

The calculation of the total number of simulated UWB devices is summarised Table 44.

Table 44: Calculation of the simulated UWB devices

Parameter	Rural environment	Urban environment	Remarks
exclusion zone (EZ) radius m	50, 100 and 150	30 and 50	
disc 1 radius (km)	5	5	
disc 1 area (km^2)	78.54	78.54	
Total simultaneously active devices / km^2 (outdoor + indoor)	0.2812	17	
outdoor ratio	64%	41%	
indoor ratio	36%	59%	
surface area for outdoor (disc 1 - EZ)	78.54	78.54	The size of EZ is insignificant compare to the total area simulated
surface area for indoor (disc 1 - EZ)	78.54	78.54	
Peak duty cycle (PDC)	15.1%	15.1%	See section 5.3.2.3
mean e.i.r.p. analysis			
simulated devices outdoor (rounded value)	14	547	The number of simulated devices is independent from the size of the EZ
simulated devices indoor (rounded value)	8	788	
peak e.i.r.p. analysis (= Mean * PDC)			
simulated devices outdoor (rounded value)	2	83	For rural: = 14 x 15.1% For urban: = 547 x 15.1%
simulated devices indoor (rounded value)	1	119	For rural: = 8 x 15.1% For urban: = 788 x 15.1%

UWB MEAN E.I.R.P.

The UWB mean e.i.r.p distribution for indoor case is defined in Table 45.

Table 45: Indoor UWB mean e.i.r.p. and associated weights

Parameter	Existing regulation		High power	
e.i.r.p. level (dBm/MHz)	-41.3		-31.3	
e.i.r.p. level (dBm/1.2 MHz)	-40.5		-30.5	
Body Loss (dB)	4	0	4	0
indoor e.i.r.p. levels (including Body Loss) (dBm)	-44.5	-40.5	-34.5	-30.5
Weight of UWB e.i.r.p. (%)	25%	25%	25%	25%

The UWB mean e.i.r.p distribution for outdoor case is defined in Table 46.

Table 46: Outdoor UWB mean e.i.r.p. and associated weights

Parameter	Rural environment	
e.i.r.p. level (dBm / MHz)	-41.3	
e.i.r.p. level (dBm/1.2 MHz)	-40.5	
Body Loss (dB)	4	0
UWB outdoor e.i.r.p. levels (including Body Loss) (dBm)	-44.5	-40.5
Weight of UWB outdoor e.i.r.p. (%)	5.52% (rural) 5.69% (urban)	94.48% (rural) 94.31% (urban)

UWB PEAK E.I.R.P.

The UWB peak e.i.r.p. distribution for indoor case is defined in Table 47.

Table 47: Indoor UWB peak e.i.r.p. and associated weights

Parameter	Existing regulation		High Power	
peak e.i.r.p. level (dBm/50 MHz)	0		10	
peak e.i.r.p. level (dBm/1.2 MHz)	-32.4		-22.4	
Body Loss (dB)	4	0	4	0
indoor peak e.i.r.p. levels (including Body Loss) (dBm)	-36.4	-32.4	-26.4	-22.4
Weight of UWB peak e.i.r.p. (%) rural and urban	25%	25%	25%	25%

The UWB peak e.i.r.p distribution for outdoor case is defined in Table 48.

Table 48: Outdoor UWB peak e.i.r.p. and associated weights

Parameter	Value	
e.i.r.p. level (dBm / 50 MHz)	0	
e.i.r.p. level (dBm/1.2 MHz)	-32.4	
Body Loss (dB)	4	0
UWB outdoor e.i.r.p. levels (including Body Loss) (dBm)	-36.4	-32.4
Weight of UWB outdoor e.i.r.p. (%)	5.52% (rural) 5.69% (urban)	94.48% (rural) 94.31% (urban)

UWB ANTENNA HEIGHT DISTRIBUTION

The UWB antenna height distribution for outdoor environment is described according to Table 49 for rural and urban scenario. For the indoor environment, the UWB height devices are distributed according to Table 50 for rural and urban scenario.

The outdoor height distribution in Table 49 was derived by combining the height information of the applications described in Table 43.

Table 49: UWB outdoor height distribution including fixed outdoor

(a) from 0 m to exclusion zone radius: No UWB is allowed

(b) from exclusion zone radius to 5 km

Height (m)	Probability (%)
1.5	39.82
2	0.03
5	56.9
10	3.25

For indoor devices, the height is based on the similar methodology as in ECC Report 316 [24] for the urban case and for the rural case, 2 floors houses is assumed and the height are caped to the second floor.

Table 50: UWB indoor height distribution

(a) from 0 m to exclusion zone radius: No UWB is allowed

(a) from to exclusion zone radius to 5 km

Floor	Rural Height (m)	Rural Probability (%)	Urban Height (m)	Urban Probability (%)
ground	1.5	71	1.5	35.14
1	4.5	29	4.5	24.74
2	-	-	7.5	13.40
3	-	-	10.5	9.31

Floor	Rural Height (m)	Rural Probability (%)	Urban Height (m)	Urban Probability (%)
4	-	-	13.5	6.24
5	-	-	16.5	3.78
6	-	-	19.5	2.91
7	-	-	22.5	2.16
8	-	-	25.5	1.50
9	-	-	28.5	0.92

5.3.2.4 Interference Criterion and Methodology

In this Report, the short-term interference criteria is based on an I/N = -1.33 dB not exceeded for more than 0.005% of the time/events and the long-term interference criteria is based on an I/N = -20 dB not exceeded for more than 20% of the time/events (Table 38).

SEAMCAT Monte Carlo methodology was used to generate I/N results using 10 million events.

5.3.2.5 Path Loss Calculation

The Path loss calculation is summarised in Table 51. The WINNER model ETSI TR 103 416 [1] has been used up to 1 km, where the first 40 m is upper bounded by free space model ETSI TR 102 495 [3]. For distances farther than 1 km, Recommendation ITU-R P.452-16 [15] with clutter loss (Recommendation ITU-R P.2108-0 [23]) is used.

Table 51: Propagation models

Horizontal Distance	Propagation Model	For Indoor only	Clutter
$0\ \mathrm{m} \leq d < 40\ \mathrm{m}$	Free space	ITU-R P.2109 [36] (70% traditional, 30% modern, uniform distribution of probability from 1 to 99%)	not applicable
$40\ \mathrm{m} \leq d < 1000\ \mathrm{m}$	WINNER model (Urban Macrocell C2 or Rural Macrocell D1)	ITU-R P.2109 (70% traditional, 30% modern, uniform distribution of probability from 1 to 99%)	LOS and NLOS ratio probability determination is inherent to the WINNER model
$d \geq 1000\ \mathrm{m}$	Recommendation I TU-R P.452-16 [15] (time percentage: uniform distribution from 0.001% to 50%)	ITU-R P.2109 (70% traditional, 30% modern, uniform distribution of probability from 1% to 99%)	Urban environment: ITU-R P.2108-0 [23] (Location percentage: uniform distribution from 0.001% to 99%) for Urban environment Rural environment: ITU-R P.452 (Sparse houses condition, i.e. nominal height of 4 m and nominal distance of 100 m)

5.3.2.6 Exclusion zone from FSS earth station to UWB devices

In a rural environment, different sizes of exclusion zones are chosen: 50 m, 100 m and 150 m (see below figure). It is assumed that the building surrounding the FSS in rural environment are houses with 2 floors maximum. This gives sufficient clearance from the building when simulating a 10 degree uptilt inclination of the FSS antenna.

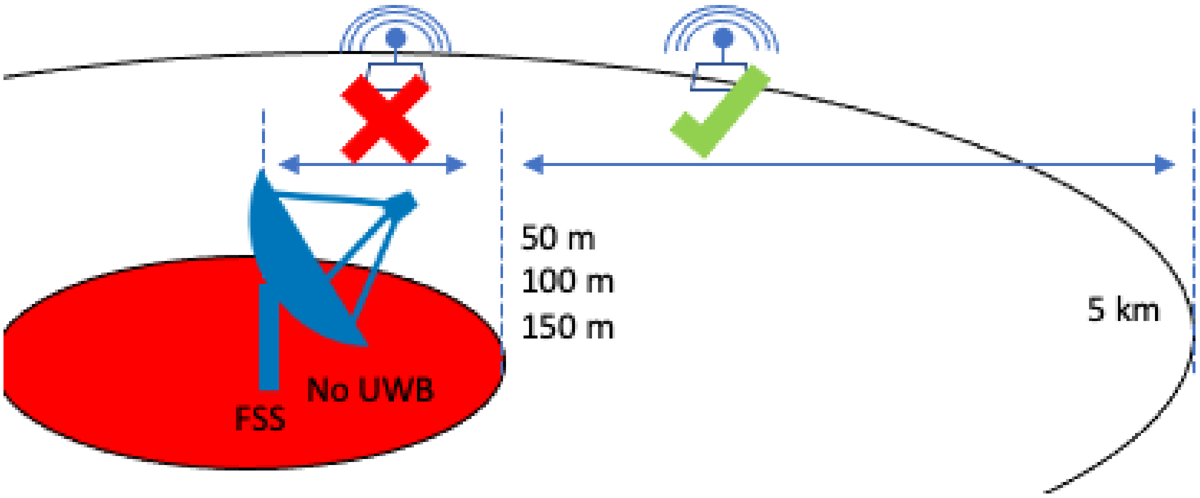

Figure 45: Illustration of the exclusion zone of FSS (rural)

In an urban environment, different sizes of exclusion zones are chosen: 30 m and 50 m (see below figure). It is assumed that the FSS is mounted on top of a high building (28.5 m). This gives sufficient clearance of the FSS antenna towards the sky, i.e. not blocked by a building.

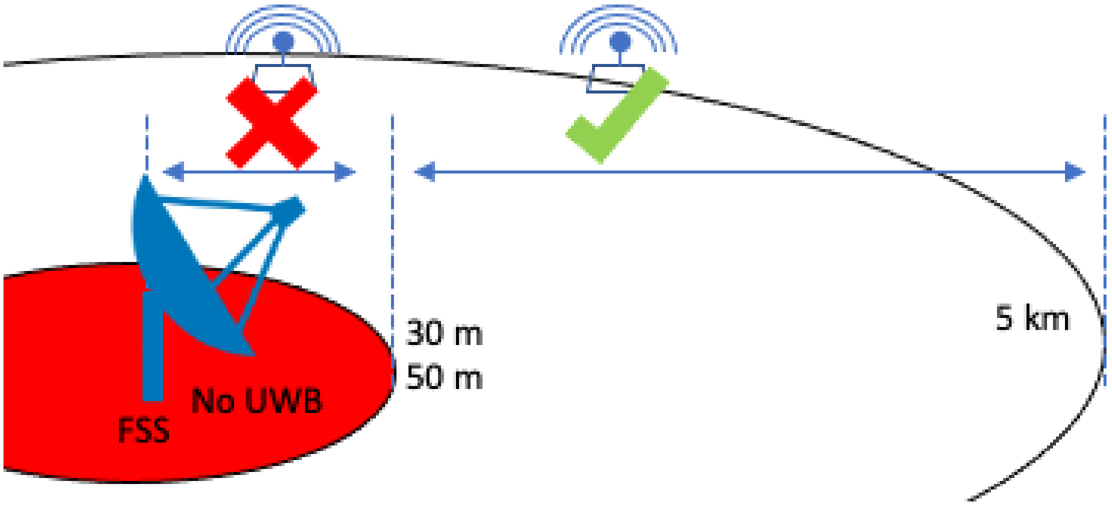

Figure 46: Illustration of the exclusion zone of FSS (urban)

5.3.2.7 Simulation Results

Simulation Scenarios

This study shows the simultaneous impact of indoor and outdoor UWB devices onto the FSS receiver. Table 52 (mean e.i.r.p. analysis) and Table 53 (peak e.i.r.p. analysis) present a summary of the scenarios that have been considered. The overall results are shown in terms of the inverse CDF of the I/N to be able to assess the long-term and short-term interference criterion.

Table 52: Summary of the simulation scenarios for mean e.i.r.p. analysis

Scenario	Description	Remarks
Scenario M-r1	UWB: ▪ Rural environment ▪ Exclusion zone: 50 m FSS: ▪ 10 degree elevation angle	Scenario_UWB_FSS_mean_r1 baseline rural with exclusion zone of 50 m
Scenario M-r2	UWB: ▪ Rural environment ▪ Exclusion zone: 100 m FSS: ▪ 10 degree elevation angle	Scenario_UWB_FSS_mean_r2 Sensitivity analysis rural with exclusion zone of 100 m
Scenario M-r3	UWB: ▪ Rural environment ▪ Exclusion zone: 150 m FSS: ▪ 10 degree elevation angle	Scenario_UWB_FSS_mean_r3 Sensitivity analysis rural with exclusion zone of 150 m
Scenario M-r4	UWB: ▪ Rural environment ▪ Exclusion zone: 50 m FSS: ▪ 5 to 85 degree elevation angle	Scenario_UWB_FSS_mean_r4 Sensitivity analysis rural with variable elevation angle (exclusion zone of 50 m)
Scenario M-u1a	UWB: ▪ Urban environment ▪ Exclusion zone: 30 m FSS: ▪ 10 degree elevation angle	Scenario_UWB_FSS_mean_u1a baseline urban with exclusion zone of 30 m
Scenario M-u1e	UWB: ▪ Urban environment ▪ Exclusion zone: 50 m FSS: ▪ 10 degree elevation angle ▪ 3 m antenna diameter	Scenario_UWB_FSS_mean_u1e Sensitivity analysis urban with exclusion zone of 50 m
Scenario M-u2	UWB: ▪ Urban environment ▪ Exclusion zone: 30 m FSS: ▪ 5 to 85 degree variable elevation angle ▪ 3 m antenna diameter	Scenario_UWB_FSS_mean_u2 Sensitivity analysis urban with variable elevation angle
Scenario M-u3	UWB: ▪ Urban environment ▪ Exclusion zone: 30 m	Scenario_UWB_FSS_mean_u3 Sensitivity analysis urban with elevation angle equivalent to Flensburg - 7E GEO satellite

	FSS: ▪ 27 degree elevation angle ▪ 3 m antenna diameter	
Scenario M-u4	UWB: ▪ Urban environment ▪ Exclusion zone: 30 m FSS: ▪ 34.5 degree elevation angle ▪ - 3 m antenna diameter	Scenario_UWB_FSS_mean_u4 Sensitivity analysis urban with elevation angle equivalent to Munich - 7E GEO satellite
Scenario M-u5a	UWB: ▪ Urban environment ▪ Exclusion zone: 30 m FSS: ▪ 10 degree elevation angle ▪ 1.4 m antenna diameter	Scenario_UWB_FSS_mean_u5a baseline urban with exclusion zone of 30 m
Scenario M-u5e	UWB: ▪ Urban environment ▪ Exclusion zone: 50 m FSS: ▪ 10 degree elevation angle ▪ 1.4 m antenna diameter	Scenario_UWB_FSS_mean_u5e Sensitivity analysis urban with exclusion zone of 50 m
Scenario M-u6	UWB: ▪ Urban environment ▪ Exclusion zone: 30 m FSS: ▪ 5 to 85 degree elevation angle ▪ 1.4 m antenna diameter	Scenario_UWB_FSS_mean_u6 Sensitivity analysis urban with variable elevation angle
Scenario M-u7	UWB: ▪ Urban environment ▪ Exclusion zone: 30 m FSS: ▪ 27 degree elevation angle ▪ 1.4 m antenna diameter	Scenario_UWB_FSS_mean_u7 Sensitivity analysis urban with elevation angle equivalent to Flensburg - 7E GEO satellite
Scenario M-u8	UWB: ▪ Urban environment ▪ Exclusion zone: 30 m FSS: ▪ 34.5 degree elevation angle ▪ 1.4 m antenna diameter	Scenario_UWB_FSS_mean_u8 Sensitivity analysis urban with elevation angle equivalent to Munich - 7E GEO satellite

Table 53: Summary of the simulation scenarios for peak e.i.r.p. analysis

Scenario	Description	Remarks
Scenario P-r1	UWB: ▪ Rural environment ▪ Exclusion zone: 50 m FSS: ▪ 10 degree elevation angle	Scenario_UWB_FSS_peak_r1 baseline rural with exclusion zone of 50 m
Scenario P-r2	UWB: ▪ Rural environment ▪ Exclusion zone: 100 m FSS: ▪ 10 degree elevation angle	Scenario_UWB_FSS_peak_r2 Sensitivity analysis with exclusion zone of 100 m
Scenario P-r3	UWB: ▪ Rural environment ▪ Exclusion zone: 150 m FSS: ▪ 10 degree elevation angle	Scenario_UWB_FSS_peak_r3 Sensitivity analysis rural with exclusion zone of 150 m
Scenario P-r4	UWB: ▪ Rural environment ▪ Exclusion zone: 50 m FSS: ▪ 5 to 85 degree elevation angle	Scenario_UWB_FSS_peak_r4 Sensitivity analysis rural with variable elevation angle (exclusion zone of 50 m)
Scenario P-u1a	UWB: ▪ Urban environment ▪ Exclusion zone: 30 m FSS: ▪ 10 degree elevation angle ▪ 3 m antenna diameter	Scenario_UWB_FSS_peak_u1a baseline urban with exclusion zone of 30 m
Scenario P-u1b	UWB: ▪ Urban environment ▪ Exclusion zone: 35 m FSS: ▪ 10 degree elevation angle ▪ 3 m antenna diameter	Scenario_UWB_FSS_peak_u1b Sensitivity analysis urban with exclusion zone of 35 m
Scenario P-u1c	UWB: ▪ Urban environment ▪ Exclusion zone: 40 m FSS: ▪ 10 degree elevation angle ▪ 3 m antenna diameter	Scenario_UWB_FSS_peak_u1c baseline urban with exclusion zone of 40 m
Scenario P-u1d	UWB: ▪ Urban environment	Scenario_UWB_FSS_peak_u1d baseline urban with exclusion zone of 45 m

	▪ Exclusion zone: 45 m FSS: ▪ 10 degree elevation angle ▪ 3 m antenna diameter	
Scenario P-u1e	UWB: ▪ Urban environment ▪ Exclusion zone: 50 m FSS: ▪ 10 degree elevation angle ▪ 3 m antenna diameter	Scenario_UWB_FSS_peak_u1e Sensitivity analysis urban with exclusion zone of 50 m
Scenario P-u2	UWB: ▪ Urban environment ▪ Exclusion zone: 30 m FSS: ▪ 5 to 85 degree elevation angle ▪ 3 m antenna diameter	Scenario_UWB_FSS_peak_u2 Sensitivity analysis urban with variable elevation angle
Scenario P-u3	UWB: ▪ Urban environment ▪ Exclusion zone: 30 m FSS: ▪ 27 degree elevation angle ▪ 3 m antenna diameter	Scenario_UWB_FSS_peak_u3 Sensitivity analysis urban with elevation angle equivalent to Flensburg - 7E GEO satellite
Scenario P-u4	UWB: ▪ Urban environment ▪ Exclusion zone: 30 m FSS: ▪ 34.5 degree elevation angle ▪ 3 m antenna diameter	Scenario_UWB_FSS_peak_u4 Sensitivity analysis urban with elevation angle equivalent to Munich - 7E GEO satellite
Scenario P-u5a	UWB: ▪ Urban environment ▪ Exclusion zone: 30 m FSS: ▪ 10 degree elevation angle ▪ 1.4 m antenna diameter	Scenario_UWB_FSS_peak_u5a baseline urban with exclusion zone of 30 m
Scenario P-u5b	UWB: ▪ Urban environment ▪ Exclusion zone: 35 m FSS: ▪ 10 degree elevation angle ▪ 1.4 m antenna diameter	Scenario_UWB_FSS_peak_u5b Sensitivity analysis urban with exclusion zone of 35 m
Scenario P-u5c	UWB: ▪ Urban environment ▪ Exclusion zone: 40 m FSS:	Scenario_UWB_FSS_peak_u5c baseline urban with exclusion zone of 40 m

	▪ 10 degree elevation angle ▪ 1.4 m antenna diameter	
Scenario P-u5d	UWB: ▪ Urban environment ▪ Exclusion zone: 45 m FSS: ▪ 10 degree elevation angle ▪ 1.4 m antenna diameter	Scenario_UWB_FSS_peak_u5d baseline urban with exclusion zone of 45 m
Scenario P-u5e	UWB: ▪ - Urban environment ▪ - Exclusion zone: 50 m FSS: ▪ - 10 degree elevation angle ▪ - 1.4 m antenna diameter	Scenario_UWB_FSS_peak_u5e Sensitivity analysis urban with exclusion zone of 50 m
Scenario P-u6	UWB: ▪ Urban environment ▪ Exclusion zone: 30 m FSS: ▪ 5 to 85 degree elevation angle ▪ 1.4 m antenna diameter	Scenario_UWB_FSS_peak_u6 Sensitivity analysis urban with variable elevation angle
Scenario P-u7	UWB: ▪ Urban environment ▪ Exclusion zone: 30 m FSS: ▪ 27 degree elevation angle ▪ 1.4 m antenna diameter	Scenario_UWB_FSS_peak_u7 Sensitivity analysis urban with elevation angle equivalent to Flensburg - 7E GEO satellite
Scenario P-u8	UWB: ▪ Urban environment ▪ Exclusion zone: 30 m FSS: ▪ 34.5 degree elevation angle ▪ 1.4 m antenna diameter	Scenario_UWB_FSS_peak_u8 Sensitivity analysis urban with elevation angle equivalent to Munich - 7E GEO satellite

RESULTS FOR SIMULTANEOUS INDOOR AND OUTDOOR OPERATION

The below figure presents the results of the mean e.i.r.p. analysis for the rural environment (i.e. FSS height of 5.5 m and dish diameter of 5.5 m). The figure shows the inverse CDF of the I/N values for 2 exclusion zones. This figure presents the impact between the baseline study (scenario M-r1) with an exclusion zone of 50 m, 100 m and 150 m. As expected, the I/N is reduced when the exclusion zone increases.

The results show that for these scenarios the resulting I/N from mean e.i.r.p. analysis is well below the short-term limit and the long-term limit.

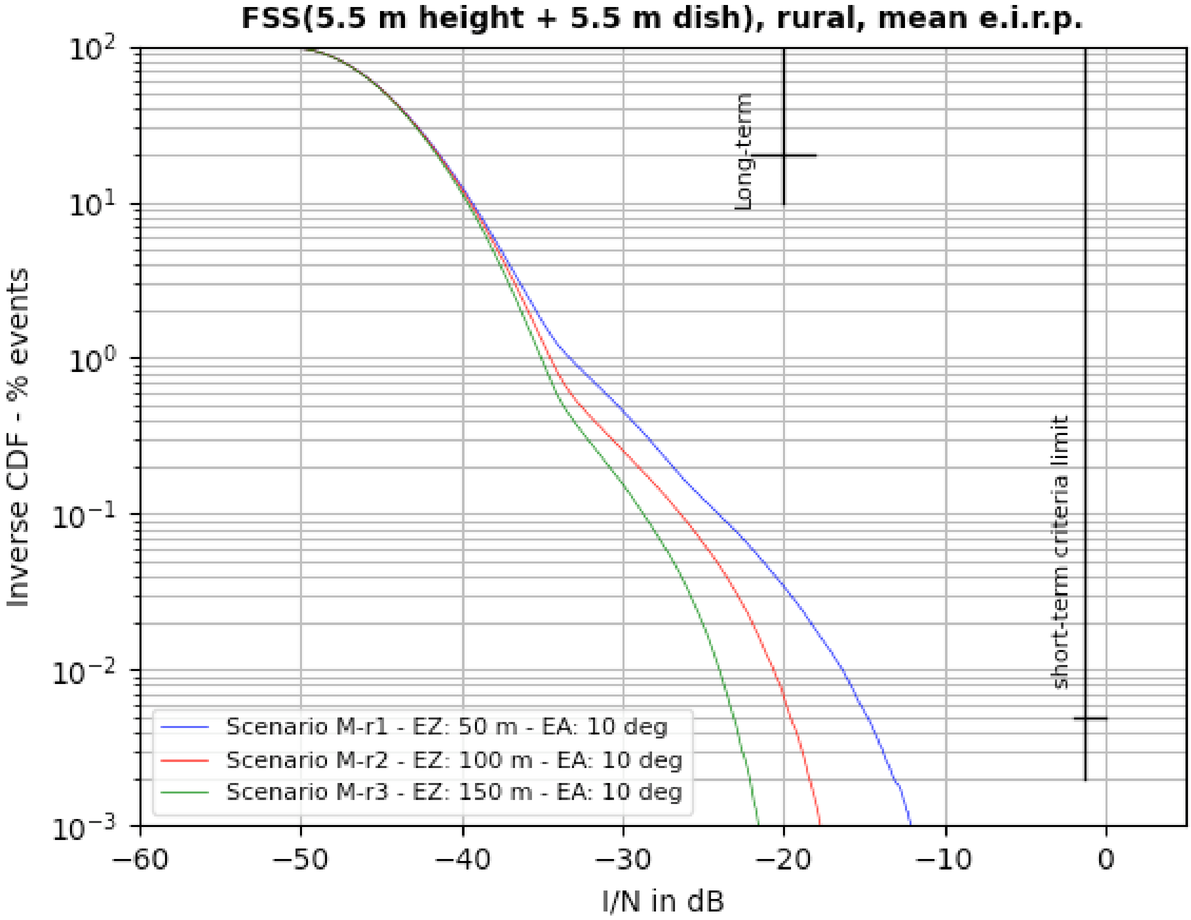

Figure 47: Results of I/N for a mean e.i.r.p. Analysis - rural environment - EZ (exclusion zone) - EA (elevation angle)

The below figure presents the results of the mean e.i.r.p. analysis for the urban environment (i.e. FSS height of 25 m and dish diameter of 3 m). Figure 50 presents the same scenarios for a smaller 1.4 m dish FSS antenna. The figures show the inverse CDF of the I/N values for 2 exclusion zones and for different elevation angles. These figures present the impact between the baseline study (scenario M-u1a and M-u5a respectively) with an exclusion zone of 30 m and elevation angle of 10 deg. As expected, the I/N is reduced when the exclusion zone increases and when the elevation angle is increased.

The results show that for these scenarios the resulting I/N from mean e.i.r.p. analysis is well below the short term limit and the long-term limit.

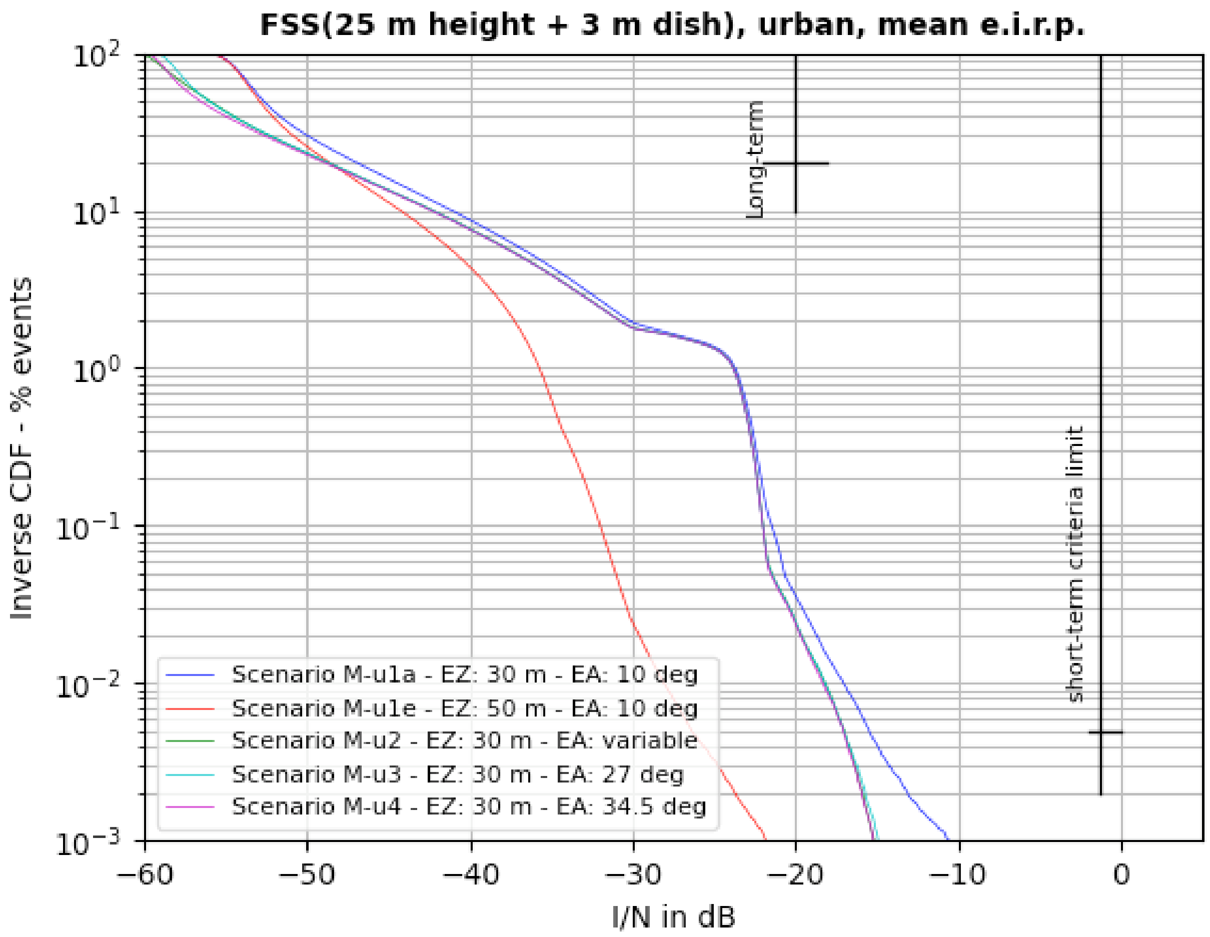

Figure 48: Results of I/N for a mean e.i.r.p. Analysis - urban environment with 3 m antenna dish EZ (exclusion zone) - EA (elevation angle)

The below Figure 49 presents the results of the peak e.i.r.p. analysis for the rural environment (i.e. FSS height of 5.5 m and dish diameter of 5.5 m). The figure shows the inverse CDF of the I/N values for 2 exclusion zones and for different elevation angles. This figure presents the impact between the baseline study (scenario P-r1) with an exclusion zone of 50 m, 100 m and 150 m. As expected, the I/N is reduced when the exclusion zone increases.

The results show that for these scenarios the resulting I/N from mean e.i.r.p. analysis is well below the short-term limit and the long-term limit.

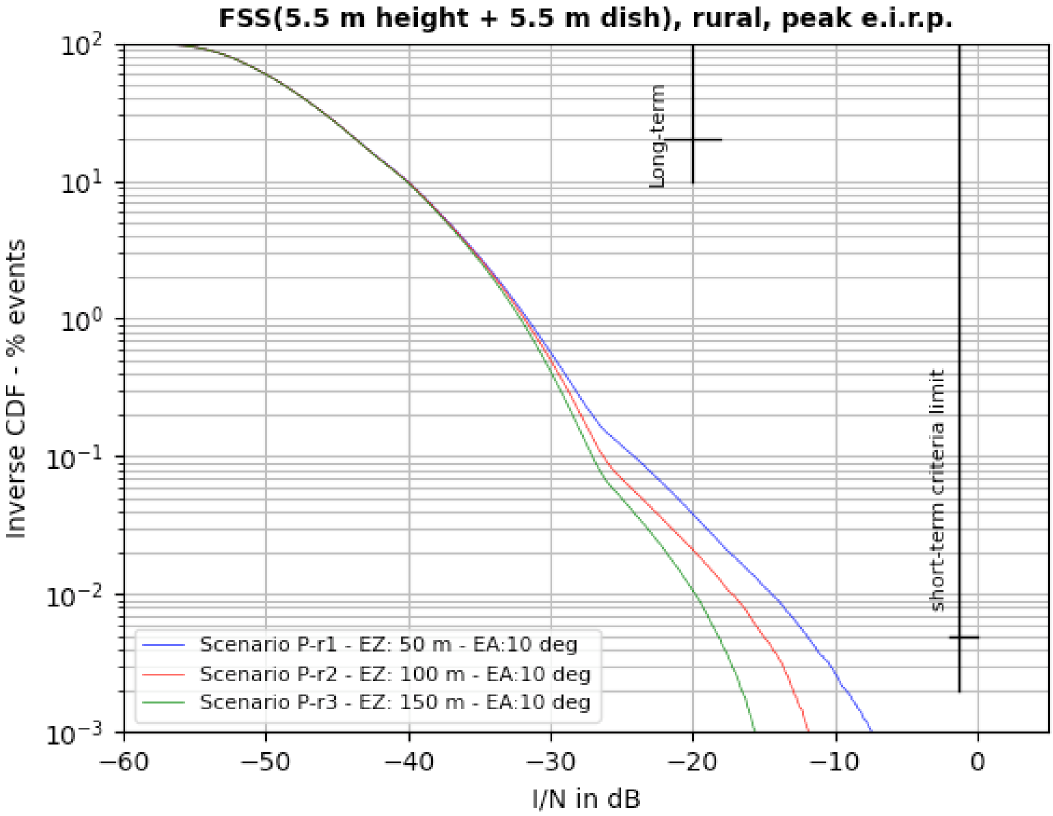

Figure 49: Results of I/N for a peak e.i.r.p. Analysis - rural environment EZ (exclusion zone) - EA (elevation angle)

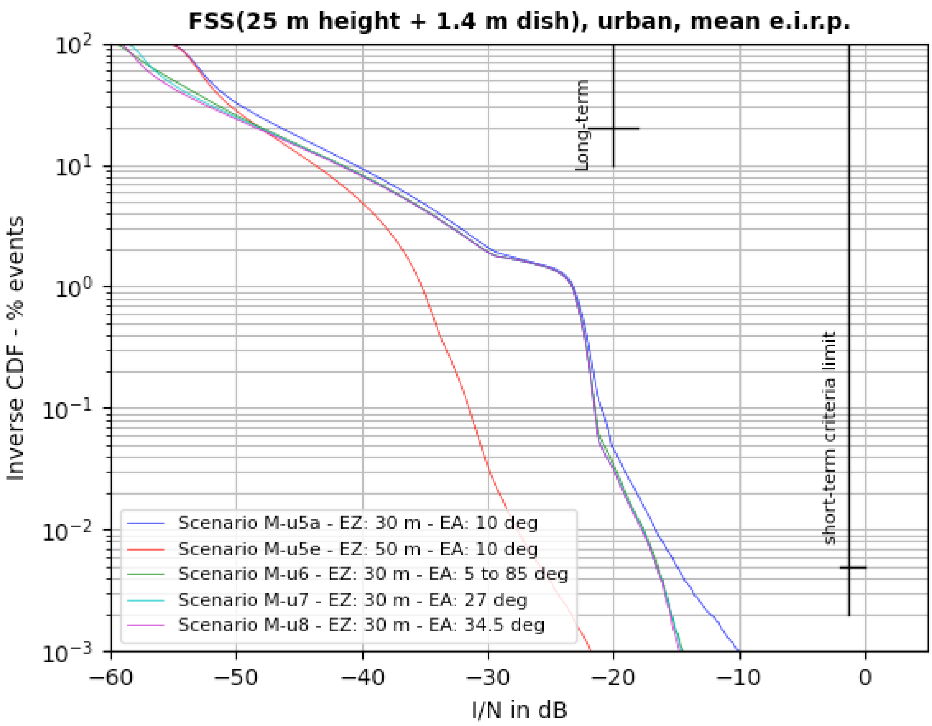

Figure 50: Results of I/N for a mean e.i.r.p. Analysis - urban environment with 1.4 m antenna dish EZ (exclusion zone) - EA (elevation angle)

The below Figure 51 presents the results of the peak e.i.r.p. analysis for the urban environment (i.e. FSS height of 25 m and dish diameter of 3 m). presents the same scenarios for a smaller 1.4 m dish FSS antenna. The figure shows the inverse CDF of the I/N values for 2 exclusion zones and for different elevation angles. This figure presents the impact between the baseline study (scenario P-u1a) with an exclusion zone of 30 m. As expected, the I/N is reduced when the exclusion zone increases and when the elevation angle is increased.

A finer granularity of the effect of the exclusion zone is presented from 30 m to 50 m with steps of 5 m.

The results show that for these scenarios the resulting I/N from mean e.i.r.p. analysis is well below the short-term limit and the long-term limit.

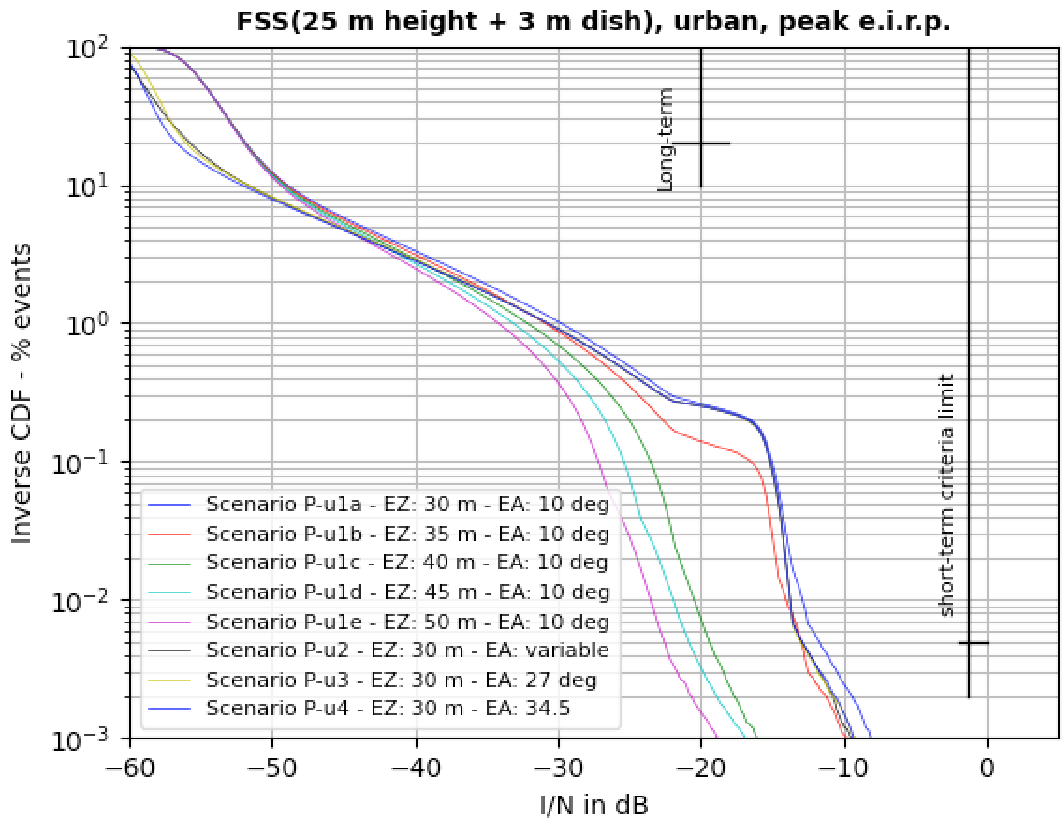

Figure 51: Results of I/N for a peak e.i.r.p. Analysis - urban environment with 3 m antenna dish EZ (exclusion zone) - EA (elevation angle)

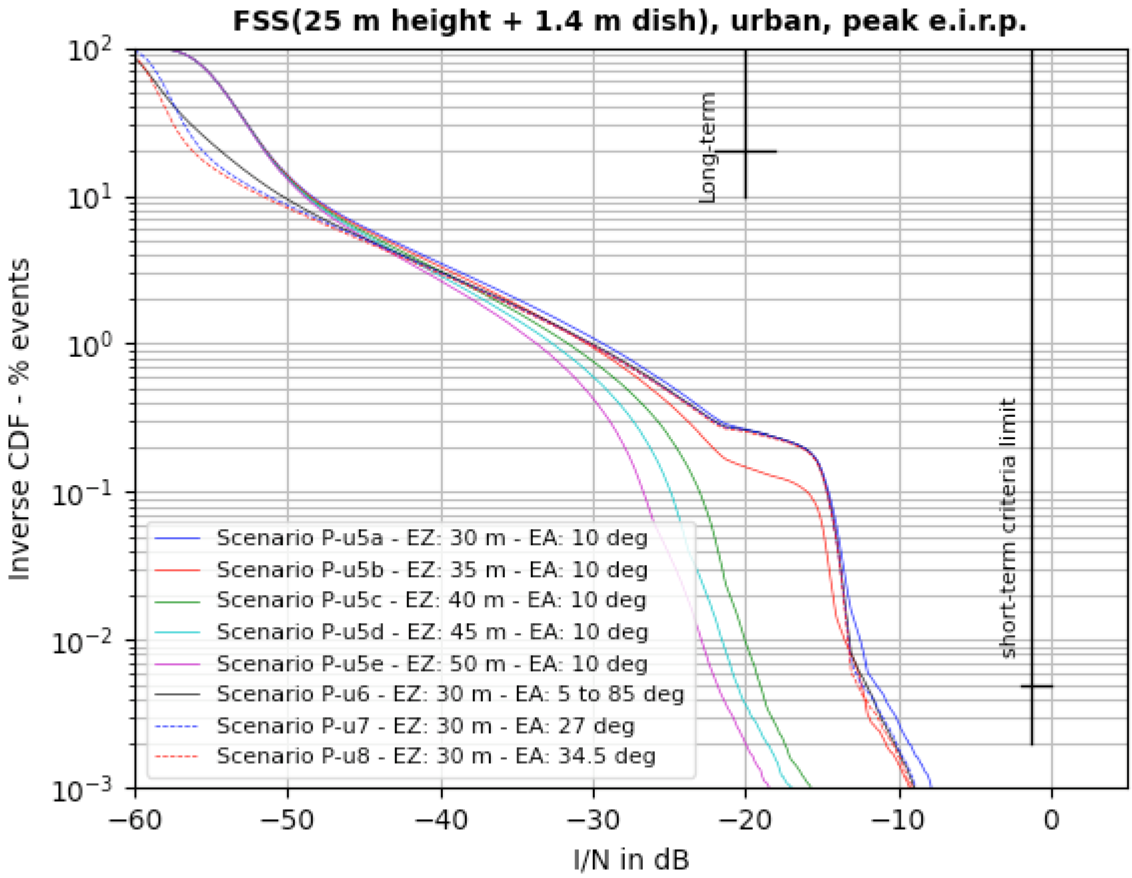

Figure 52: Results of I/N for a peak e.i.r.p. Analysis - urban environment with 1.4 m antenna dish EZ (exclusion zone) - EA (elevation angle)

5.3.2.8 Summary of the site-general Monte Carlo analysis

This contribution presents a site-general Monte Carlo simulation that assesses whether the short-term criterion for the protection of FSS is met when indoor and outdoor UWB devices are both in operation simultaneously. Also the results shows that the long-term criteria are met.

The simulations are performed using SEAMCAT.

The studies present a sensitivity analysis on the difference of FSS deployment in rural and urban environment with specific FSS height and dish antenna diameter associated to their deployment. The studies also present a sensitivity analysis on the size of the exclusion zone and elevation angle. The study analyses the impact of UWB mean and peak e.i.r.p.

Results from large number of Monte Carlo events show that the long-term and short-term interference criterion is met in all scenarios for mean and peak e.i.r.p. analysis.

5.4 RADIO ASTRONOMY IN THE BAND 6.55-6.6752 GHZ

5.4.1 Use of the band by RAS and Regulatory Status

Observations of the methanol spectral line in the RR 5.149 band, 6650.0−6675.2 MHz, are of utmost importance to radio astronomers around the world. In Europe, there are a large number of radio telescopes, which are equipped with state-of-the-art receivers to perform measurements of this spectral line and a substantial percentage of the total observing time is invested. According to footnote RR 5.149 of the Radio

Regulations, administrations are urged to take all practicable steps to protect the RAS from harmful interference in the band 6650.0−6675.2 MHz.

With RR 5.149, the ITU-R recognised the importance of methanol observations in the 6.6 GHz band. Since then, the methanol line has become extremely important for the study of star formation in its earliest stages. In fact, its detection and study in the inner parts of star forming regions is the only way for astronomers to observe star formation in its earliest stages. Methanol is also one of the few species that produce strong masers, which allows us to detect it over cosmic distances, e.g., in the core of active galaxies orbiting super-massive black holes, and thus providing insights into black hole physics and the high-energy processes in their vicinity. For this, the European VLBI Network is essential, consisting of a large number of CEPT RAS stations. VLBI observations of methanol masers are also vital in high-precision astrometry studies, which allow the determination of the spiral structure of the Milky Way with unprecedented accuracy, or provide an independent probe of the value of the famous Hubble constant.

5.4.2 Parameters used in the study

The parameters for the UWB devices used in this study are shown in section 3.5 of this Report.

The parameters for the radio astronomy station are defined in Recommendation ITU-R RA.769-2 [16] and are shown in the below table. A list of relevant CEPT RAS stations is included in Table 55.

Table 54: Radio astronomy station parameters

System Parameter	Macro Suburban Value/Description	Remarks
Integration time	2000 s	
Side lobe gain, G_r	0 dBi	According Recommendation ITU-R RA.769-2 [16], only side lobe receptions need to be considered
Threshold interference level: Recommended spectral power, $P_{lim,v}$ Spectral pfd, $S_{lim,v}$	-176 dB (mW/MHz) -228 dB (W/m²/Hz)	For spectroscopic observations: interpolated from Recommendation ITU-R RA.769-2 [16] table 2 column 9
Antenna height, h_{rt}	50 m	This height is used for generic scenarios, while for site-specific calculations the average receiving feed's height of the particular telescope is to be used.

Table 55: List of CEPT countries with RAS stations operating in the frequency band 6650−6675 MHz

RAS station	Country	Geographic longitude	Geographic latitude
Effelsberg	Germany	06° 53′ 01.0″	50° 31′ 29.4″
Wettzell		12° 52′ 38″	49° 08′ 42″
Medicina	Italy	11° 38′ 49″	44° 31′ 15″
Noto		14° 59′ 20″	36° 52′ 33″
Sardinia		09° 14′ 42″	39° 29′ 34″
Irbene	Latvia	21° 51′ 18″	57° 33′ 13″

RAS station	Country	Geographic longitude	Geographic latitude
Westerbork	Netherlands	06° 36′ 15″	52° 55′ 01″
Badary	Russia	102° 14′ 00″	51° 46′ 10″
Svetloe		29° 46′ 54″	60° 31′ 56″
Sao Zelenchukskaya		43° 47′ 15″	41° 34′ 00″
Yebes	Spain	–03° 05′ 13″	40° 31′ 28.8″
Onsala	Sweden	11° 55′ 04″	57° 23′ 35″
Bleien	Switzerland	08° 06′ 43.3″	47° 20′ 23.7″
Jodrell Bank	UK	–02° 18′ 26″	53° 14′ 10″
Pickmere		–02° 26′ 42″	53° 17′ 20″
Darnhall		–02° 32′ 09″	53° 09′ 24″
Knockin		–02° 59′ 49″	52° 47′ 26″
Defford		–02° 08′ 39″	52° 06′ 03″
Cambridge		00° 02′ 14″	52° 10′ 01″
Goonhilly*		–05° 11′ 00″	50° 03′ 02″
Chilbolton*		–01° 26′ 19″	51° 08′ 42″
Note *: Planned operations			

For single entry scenario as well as for aggregated interference scenarios, the propagation model according to Recommendation. ITU-R P.452-16 [15] and Recommendation ITU-R P.2108-0 [23] (section 3.2), including Tx clutter loss (where appropriate), is applied. The statistical clutter model of P.2108 (section 3.2) is intended mainly for urban/suburban areas and is only applicable when the transmitter (or receiver) is *within* the clutter. For all other cases, the (simpler) model of P.452 is applied. According to Recommendation ITU-R RA.1513, RAS has to accept a maximum data loss of 2%. Therefore, for the propagation model, a time-percent value of 2% is used throughout this section.

5.4.3 Interference scenarios and methodologies

5.4.3.1 General

There are two different scenarios, which will be addressed in the following. First, a generic single-entry worst-case calculation is performed to provide a brief overview about the situation. For a more realistic analysis, aggregation effects need to be taken into account. How these are carried out, depends on the use case of the UWB application and is further explained below. Aggregation calculations can also be executed as generic studies (i.e., assuming flat terrain), but also for particular RAS sites, fully accounting for topographic features. As an example, the German 100-m RAS telescope at Effelsberg is situated in a valley in the Eifel mountains and is thus fairly well shielded from interference.

5.4.3.2 Generic single-entry scenarios

Based on the UWB use cases, a number of scenarios can be thought of that may have impact on RAS operations in the 6.65 GHz band. The main parameters, which determine the level of interference at the RAS site, are the distance between Tx and Rx, and the Tx height. The latter has influence over the amount of additional clutter loss. A Tx at only 1-2 m height will be subject to significantly higher clutter loss than one high above the local clutter, which may be in direct line-of-sight. Table 56 lists some scenarios (e.g., vehicular rural or fixed installation in urban area) each associated with various UWB duty cycles, Tx heights, and clutter models that are studied. Based on the generic (flat-terrain) propagation loss according to P.452 and the used clutter model the received power is calculated and compared to the RAS threshold power level (see Table 54). The difference between the threshold and the received power is the so-called Margin. A negative margin means that the threshold has been exceeded and a violation of the Recommendation ITU-R RA.769-2 level exists. In Figure 52, the Margins for each scenario are displayed, as a function of the distance between Tx and Rx. The distance at which the curves cross the Margin-zero level is the minimal separation distance and is also included in Table 56.

Table 56: Generic single-entry scenarios and parameters.

Scenario	Clutter model	h_{tx} [m]	t_{on} [%]	Minimal separation distance [km]
Rural, vehicular in motion	None	1.5	0.5	1.5
			1.0	2.1
			5.0	5.2
Rural, vehicular in motion	P.452	1.5	0.5	0.3
			1.0	0.3
			5.0	0.7
Urban, vehicular in motion	P.2108	1.5	0.5	0.3
			1.0	0.3
			5.0	0.4
Urban, fixed installation	P.2108	5.0	0.5	0.3
			1.0	0.3
			5.0	0.4
Urban, fixed installation	None	15.0	0.5	1.5
			1.0	2.1
			5.0	5.2

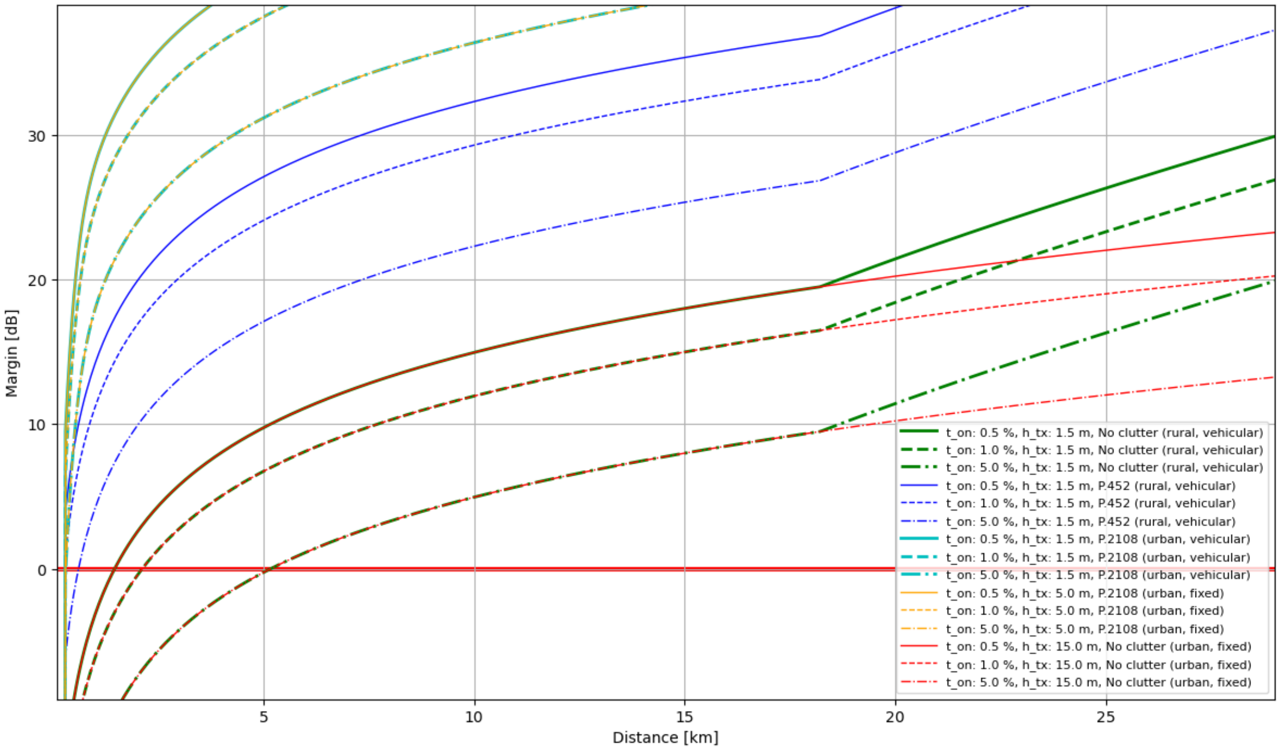

Figure 53: Margin vs. distance from RAS station for the various scenarios in Table 56

From this, it can be seen that for scenarios where the Tx is well below the clutter heights, no issue occurs. However, all applications could make use of a significant number of devices (in a given area), which could potentially increase the received power substantially. This is studied in more detail in the following sections.

5.4.3.3 Generic aggregation scenarios for fixed UWB installations

Depending on the application, fixed UWB installations will mostly be deployed to areas with high population density (urban/suburban). In particular, parking management or PACS seem unlikely in the remote environments, where the RAS stations are situated in. An exception might be outdoor logistics applications, which could be found in some industrial areas in the (larger) vicinity of a RAS telescope. Fixed vehicular applications will also be mainly deployed in high-traffic density areas, far from RAS sites. However, the counterpart of the fixed vehicular application, the UWB devices attached to vehicles may be active everywhere (with a lower activity factor). This case will be looked at in the next section.

Even with relatively high clutter losses and accounting for the fact that urban or suburban areas are at relatively large distances from most CEPT RAS stations, the large number of devices could be an issue. Therefore, in this section the separation distances are determined under the assumption that more than one device is present, i.e., 10 or 100 devices, (though not all active at the same time) and that some may be more elevated than others. For this, the Tx antenna height is randomly sampled from a uniform distribution, $h_{tx} \sim U(h_{min}, h_{max})$, for each of the devices, the total propagation loss (including clutter) is then determined for each and the total received power at the RAS Rx is determined. This calculation is repeated for different assumed Tx clutter types and activity factors (AF, $\boldsymbol{t_{on}}$). As all these parameters differ somewhat for each UWB application, distinct results are presented for all of them. It is noted that as at least some of the devices are potentially above the clutter, the model from P.2108 is not applicable and all results were obtained by using the P.452 clutter model (even for urban scenarios).

Table 57 to Table 59 list the parameters used for each of the considered UWB applications in the different scenarios (see Table 56) and Figure 55 to Figure 57 display the resulting margins, again as a function of distance. The Recommendation ITU-R RA.769-2 threshold (i.e., zero margin) is marked with a dashed red horizontal line. Based on the threshold the minimum separation distance can be derived and is also included in the corresponding tables.

Table 57: Generic aggregation for UWB parking management application assuming $h_{tx} \sim U(4\,m, 6\,m)$

t_{on} [%]	P.452 clutter zone	Device number	Minimal separation distance [km]
0.01	Sparse (rural)	10	1
		100	3
	Suburban	10	1
		100	1
	Urban	10	1
		100	1
0.05	Sparse (rural)	10	2
		100	6
	Suburban	10	1
		100	2
	Urban	10	1
		100	1
0.10	Sparse (rural)	10	3
		100	9
	Suburban	10	1
		100	2
	Urban	10	1
		100	1

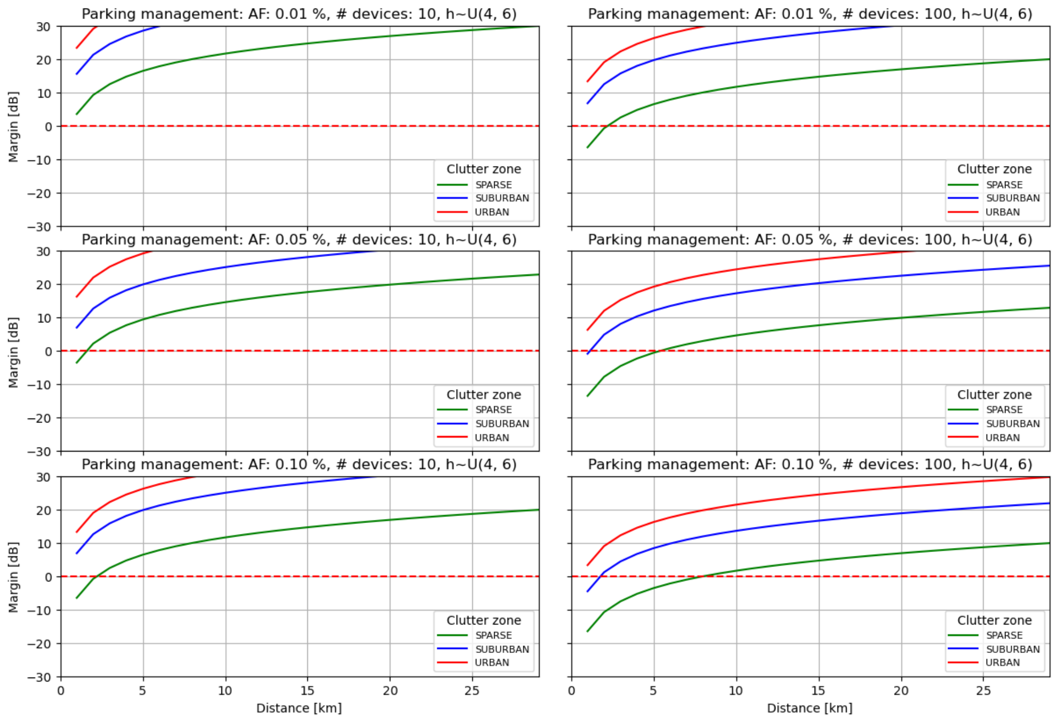

Figure 54: Margin vs. distance from RAS station for a fixed UWB parking management assuming $h_{tx} \sim U(4\,m, 6\,m)$

Table 58: Generic aggregation for UWB Outdoor logistics application assuming $h_{tx} \sim U(1\,m, 10\,m)$

t_{on} [%]	P.452 clutter zone	Device number	Minimal separation distance [km]
0.1	Sparse (rural)	10	2
		100	8
	Suburban	10	2
		100	4
	Urban	10	1
		100	1
0.3	Sparse (rural)	10	4
		100	14
	Suburban	10	3
		100	9
	Urban	10	1
		100	2
1.0	Sparse (rural)	10	7
		100	26
	Suburban	10	5
		100	2
	Urban	10	1
		100	1

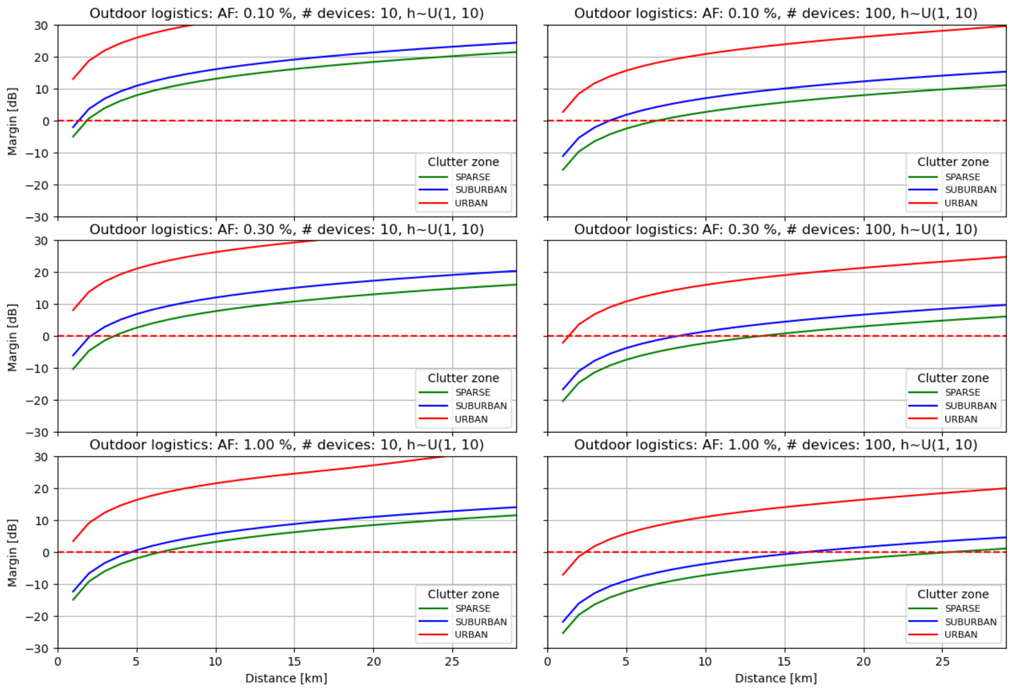

Figure 55: As Figure 54 for a fixed UWB outdoor logistics installation with $h_{tx} \sim U(1\,m, 10\,m)$

Table 59: Generic aggregation for UWB fixed vehicular application assuming $h_{tx} \sim U(1\,m, 5\,m)$

t_{on} [%]	P.452 clutter zone	Device number	Minimal separation distance [km]
0.5	Sparse (rural)	10	4
		100	13
	Suburban	10	1
		100	2
	Urban	10	1
		100	2
2.0	Sparse (rural)	10	5
		100	28
	Suburban	10	2
		100	5
	Urban	10	1
		100	4
5.0	Sparse (rural)	10	16
		100	29
	Suburban	10	2
		100	7
	Urban	10	2
		100	6

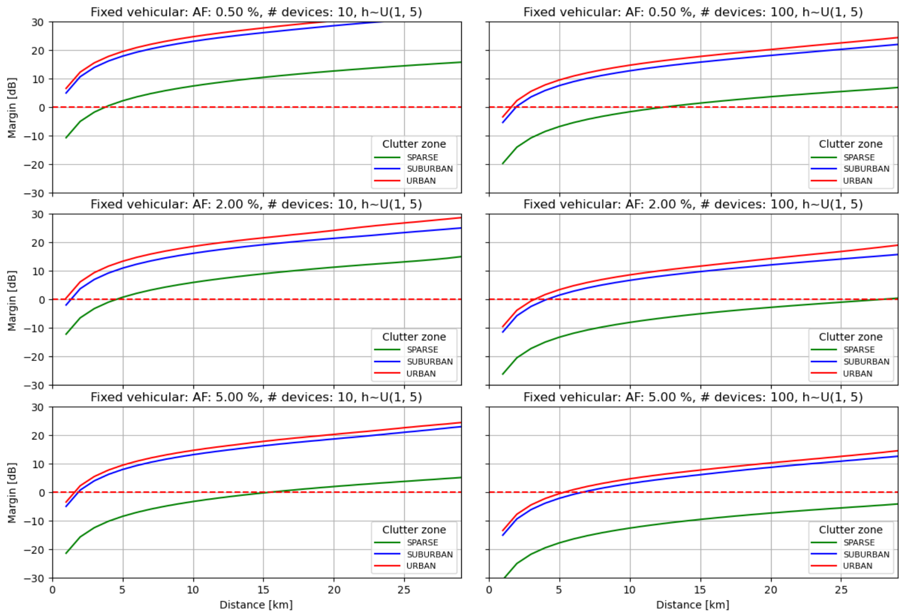

Figure 56: As Figure 54 for a fixed UWB vehicular installation with $h_{tx} \sim U(1\,m, 5\,m)$

The results show that for fixed installations, the number of devices in a given area can have a significant influence on the compatibility with the RAS, when at least a fraction of the devices is close to or even above the local clutter heights. It can be assumed that parking management applications are mostly located in urban or suburban areas. Thus, this type of application is not expected to lead to incompatibilities with the RAS. However, logistics installations may be found even in the more remote areas around RAS telescopes and for these the transmitter antenna heights could easily be above the typical clutter found in rural or suburban areas. It is noted that according to Recommendation ITU-R P.452-16 [15], the industrial clutter zone type has the same height as the urban zone. For fixed installations for vehicular UWB the typical antenna heights would be smaller than for logistics applications, however, the activity factors could be higher. Therefore, both, logistics and fixed vehicular installations may need coordination in the vicinity of a RAS station.

5.4.3.4 Site-specific aggregation for vehicular UWB devices

Vehicular UWB devices in motion need to be treated in a different manner. Although they will also be deployed in large numbers, they will not be as concentrated to one location as the fixed installation − at least in the rural environments around the RAS stations (and owing to the Tx heights for this application, urban/suburban areas can safely be excluded from analysis). To assess a realistic distribution of vehicles, road map data from OpenStreetMap[4] (OSM) is utilised, which is available under Open Database License[5]. Four example CEPT RAS stations are under study, the 100-m telescope at Effelsberg (D), which is situated in a valley in the Eifel mountains, the WSRT (NL) which is in a rather flat environment subject only to clutter loss from a small forest, the Jodrell Bank observatory (UK), which is situated in a relatively populated and developed area, and the SRT (IT), which is also situated in a mountainous area. For each of them, road map data in a box of 20 km × 20 km was queried. OSM differentiates between various road types. Table 60 lists the total length of each type of road in the area for the four stations. For simplicity, all road types other than "primary", "secondary", "tertiary" and "residential" were subsumed into a category "other". Figure 57 shows the average road length in certain distance bins (normalised to area). When interpreting the numbers, one should take into account that different types of roads will have very different traffic statistics. For example, the Effelsberg station has a rather high number of road kilometres within 2 km of the site, but the daily traffic is very low (mostly secondary and residential roads), while at Jodrell Banks primary roads are in immediate vicinity of the station.

Table 60: Total road length per road type in a box of 20 km × 20 km centred around the RAS stations. © OpenStreetMap contributors

Road type	Total length of road (per type) [km]			
	Effelsberg	WSRT	SRT	Jodrell Bank
Primary	358	346	157	426
Secondary	524	574	276	523
Tertiary	555	1011	225	948
Residential	4605	5788	1436	9445
Living street	108	34	n/a	n/a
Primary link	14	10	70	2
Secondary link	4	4	42	1
Tertiary link	1	n/a	36	6
Motorway	n/a	19	n/a	14

[4] https://www.openstreetmap.org/

[5] https://opendatacommons.org/

Road type	Total length of road (per type) [km]			
	Effelsberg	WSRT	SRT	Jodrell Bank
Trunk	n/a	48	n/a	698
Motorway link	n/a	30	n/a	19
Trunk link	n/a	22	n/a	9
Escape	2	n/a	n/a	n/a
Unclassified	138	2244	319	1404

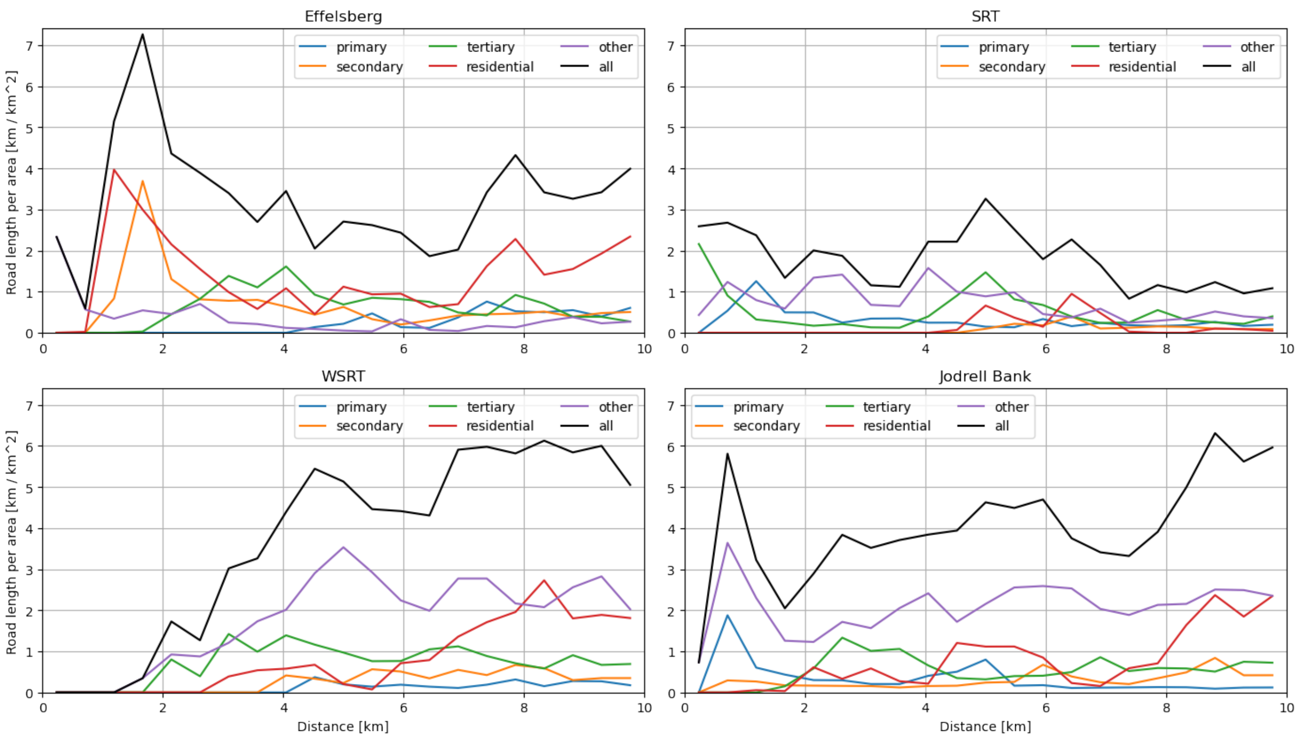

Figure 57: Road length per area per road type in distance bins around the RAS stations. © Based on OpenStreetMap

For an aggregation study, one can create samples of vehicles which follow the road distribution and also account for the different types of roads. To acknowledge the fact that traffic can be different during the day (and night) and also from day to day, the overall number of vehicles in such a sample can also be varied. In Table 61 the deployment parameters are summarised. For each of the road types, a normal distribution with a given mean and standard deviation was used to randomly sample the overall vehicle density for one realisation in the simulation. In total, the simulation was repeated 400 times to have a fair number of realisations for statistical analyses, e.g., to estimate uncertainties. In each simulation run, once the vehicle density was determined, vehicles were placed randomly onto the roads. To account for the rather long integration time of 2000 s, which is the basis of the RAS thresholds (compare RA.769), vehicular positions were sampled 200 times each (according to a time resolution of 10 s). It is noted that this approach doesn't account for the fact that vehicles are moving from one location to another in a given time, however, a full simulation of this would have been beyond the scope of this study. Figure 58 to Figure 61 show a realisation of the simulations − the one with the highest overall vehicle density − for each station. . In these maps, lines show road data, while filled dots indicate the vehicle positions. The RAS stations are in the image centres and grey circles indicate distances from the RAS station in steps of 5 km. It is noted that the grand-total highest density was in one of the simulations of the Effelsberg site, yielding a density of around 10 vehicles per km of road length, which is slightly below the maximum value in Table 6.

Table 61: Vehicle densities used for the simulation

Road type	Vehicle density (number of vehicles per kilometre 1 / km)
Primary	3.6 ± 0.9
Secondary	0.6 ± 0.15
Tertiary	0.2 ± 0.05
Residential	0.1 ± 0.025
Other	0.1 ± 0.025

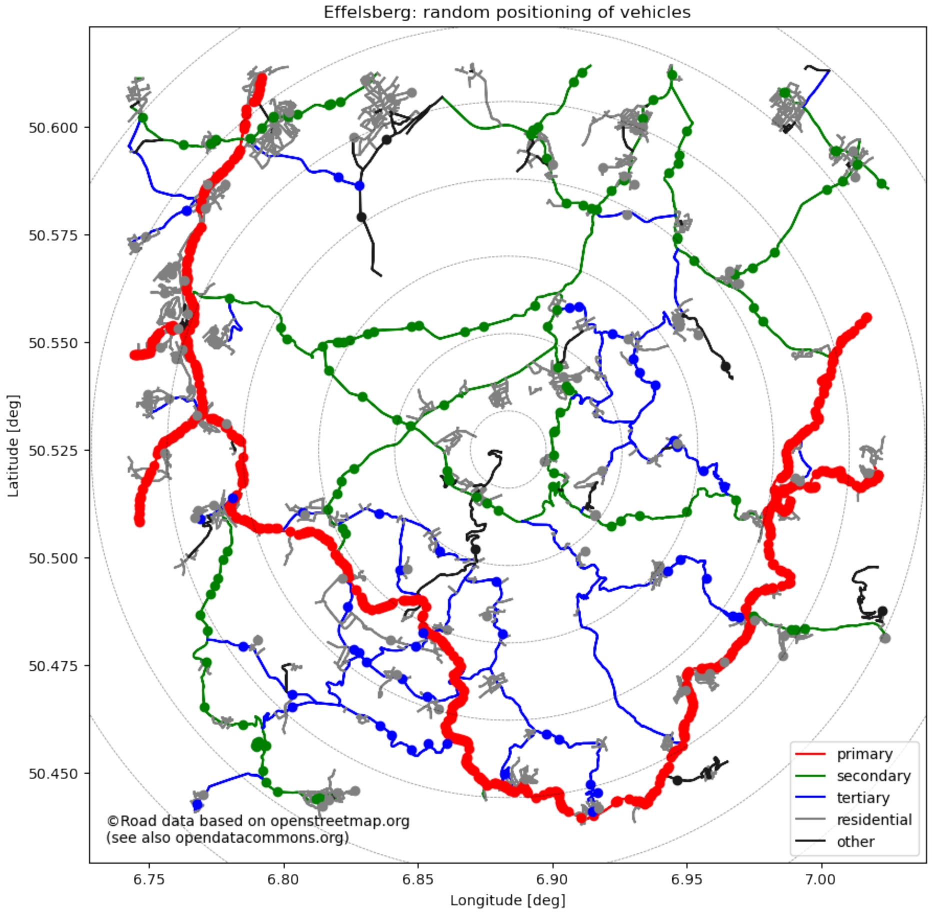

Figure 58: Random vehicle positions from the simulation around the Effelsberg station

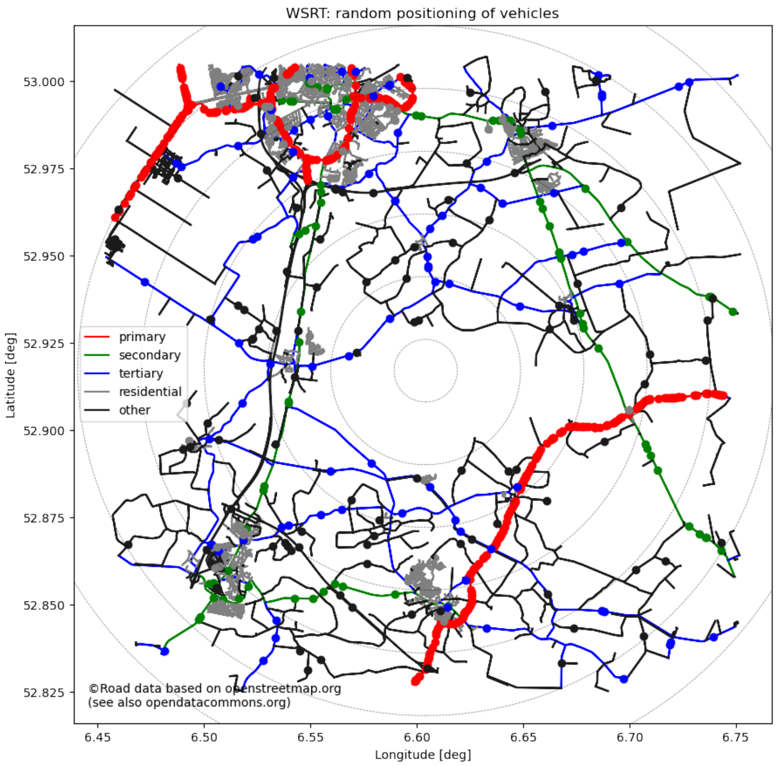

Figure 59: As Figure 58 but for the WSRT station

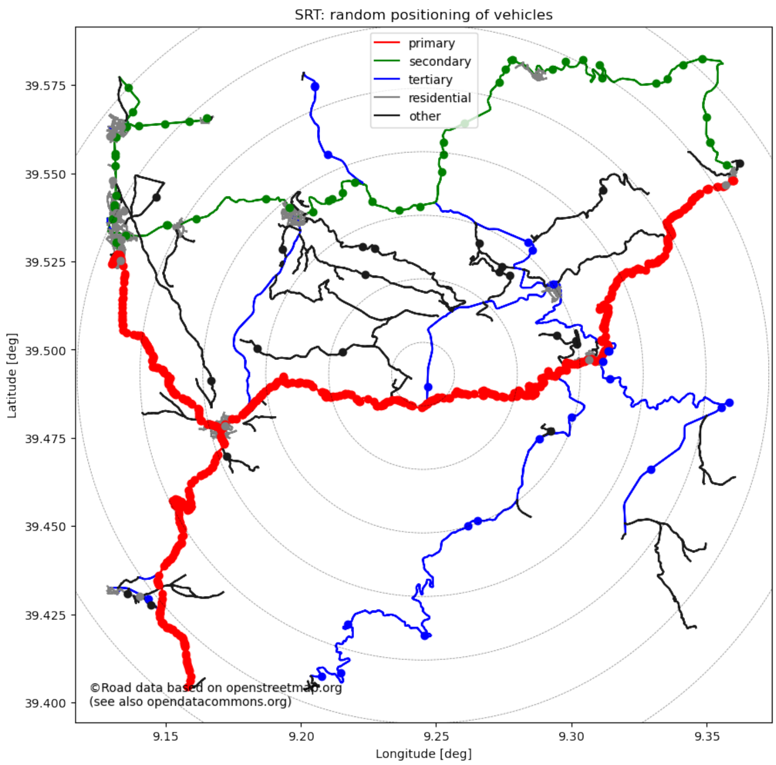

Figure 60: As Figure 58 but for the SRT station

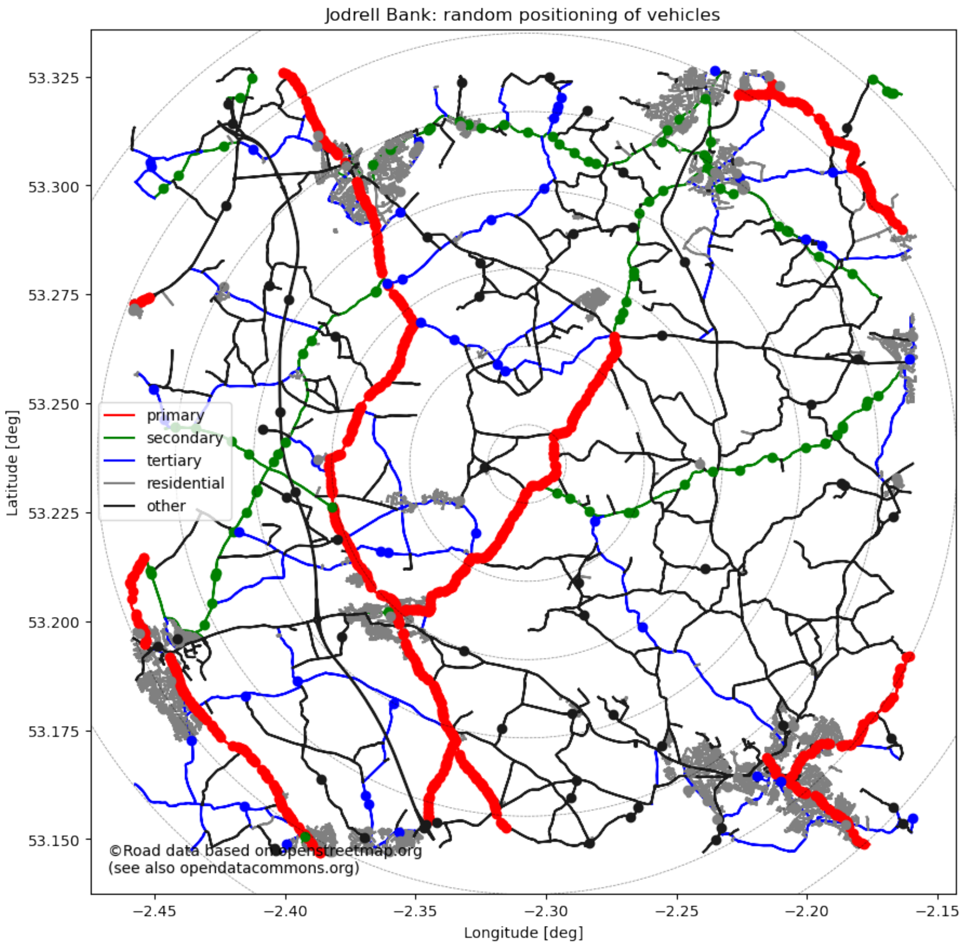

Figure 61: As Figure 58 but for the Jodrell Bank station.

Based on the location of vehicles, one can then determine the propagation loss individually. Except for Jodrell Bank observatory, terrain height profiles are based on very precise Lidar measurements[6]. For Jodrell Bank, the SRTM data [40] were used, as no Lidar data set was available at the time of this study. Furthermore, Corine Land Cover (CLC) data[7] were queried to obtain the clutter types for each position. Based on the clutter type, the clutter loss model in Recommendation ITU-R P.452, and a Tx height of 1.5 m, the clutter loss could be determined. Figure 62 to Figure 65 show the inferred clutter types around each station.

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[6] Sources for the different RAS stations used in this Report, based on a compilation by Open Data Portal, Austria:

- Effelsberg, DEU: Land Nordrhein-Westfalen (2017), DTM 1 Meter & Landesamt für Vermessung und Geobasisinformation Rhineland-Palatinate: DTM 25 Meter (DGM25) ; License: Datenlizenz Deutschland Namensnennung 2.0
- WSRT, NL: Actueel Hoogtebestand Nederland (AHN2): DTM 5 Meter
- SRT, IT: Regione Autonoma della Sardegna, Sardegna Geoportale: DTM 1 m and DTM 10 m

[7] © Corine Land Cover (CLC), https://www.copernicus.eu

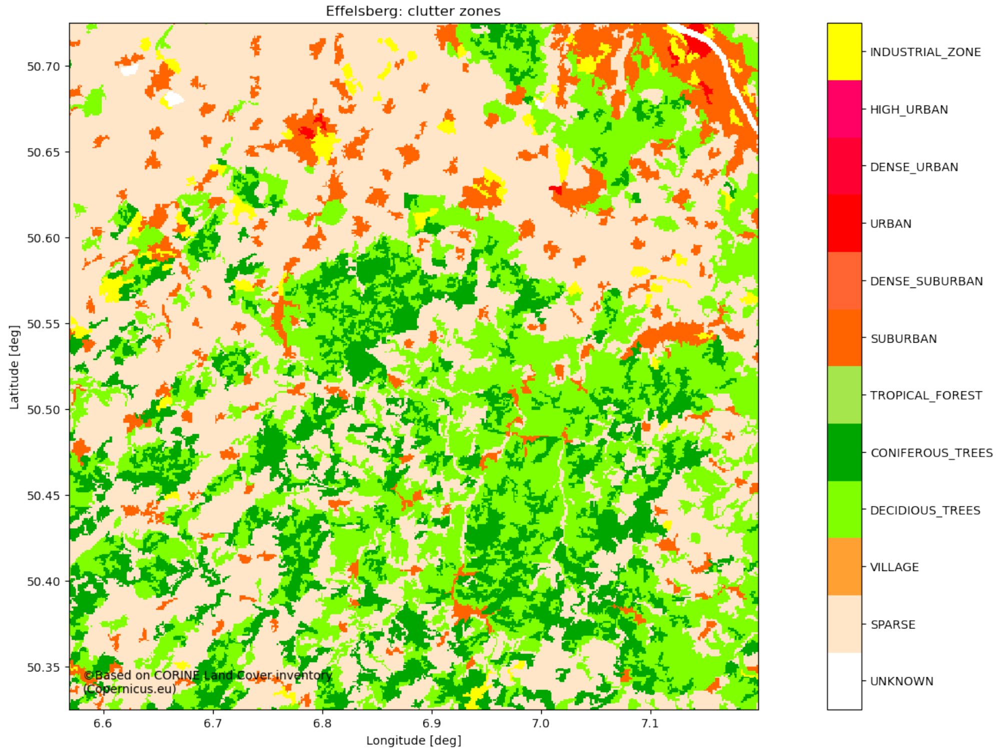


Figure 62: Clutter type zones around the Effelsberg station

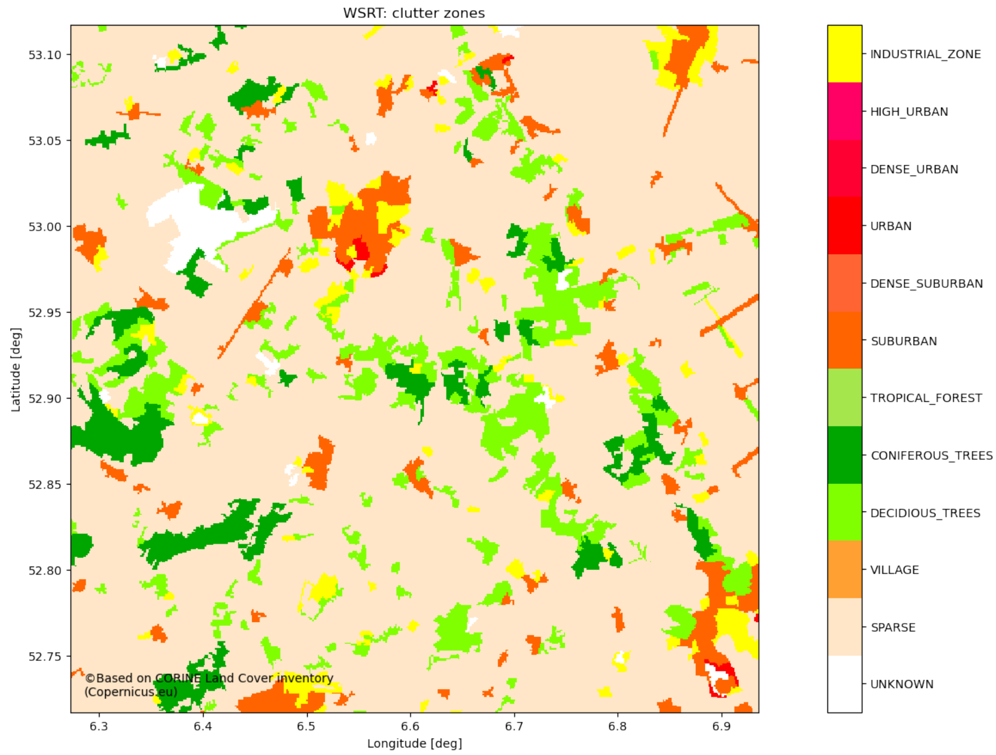


Figure 63: As Figure 62 but for the WSRT station

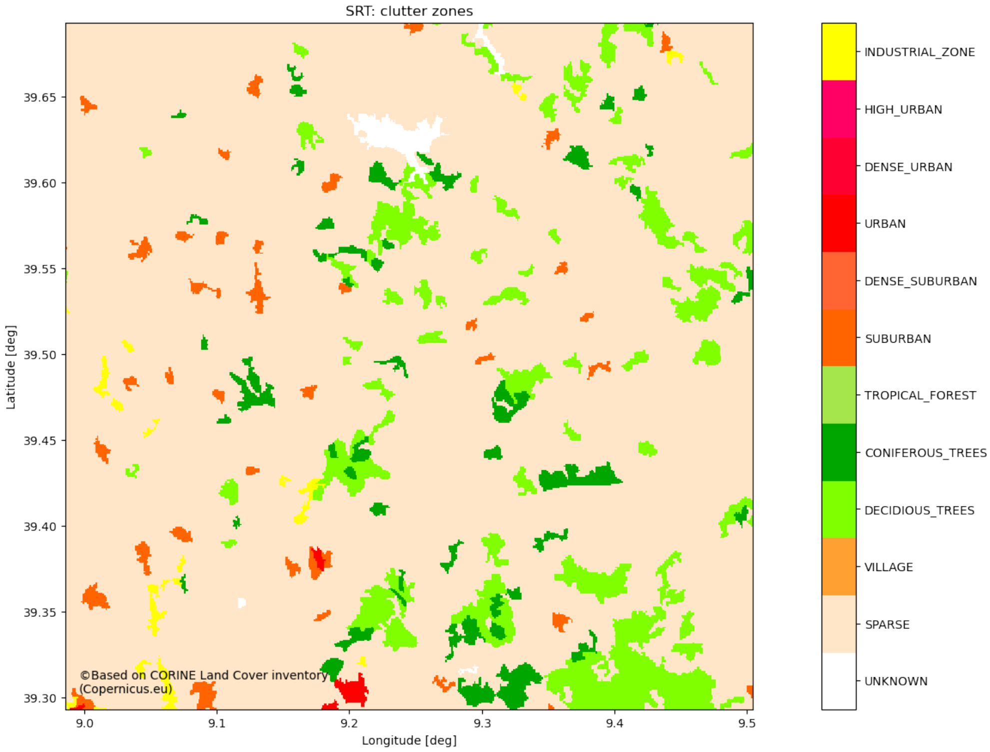


Figure 64: As Figure 62 but for the SRT station

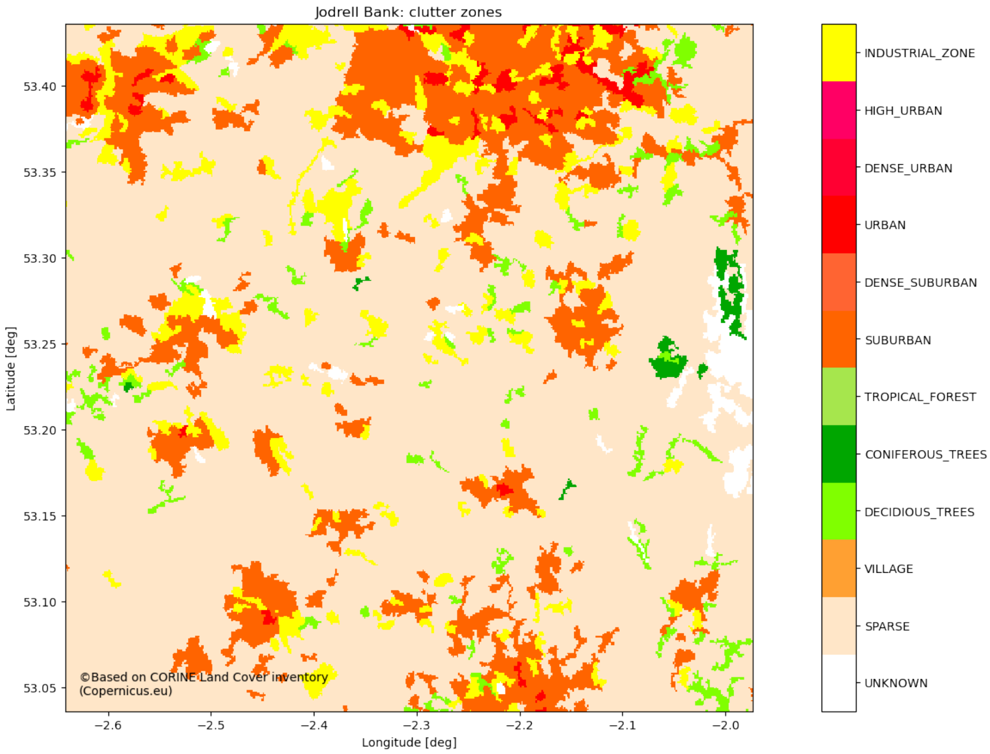


Figure 65: As Figure 62 but for the Jodrell Bank station

Accounting for an activity factor of 0.5%, the aggregated received power at the RAS station can be determined for each simulation run (averaging the powers of all time steps). As this almost always exceeds the RAS thresholds, the aggregation was repeated for a number of hypothetical exclusion zones, in which no device would be active. The results are depicted in Figure 66 to Figure 69, which show the cumulative distribution functions of the received spectral powers for the various exclusion zone radii.

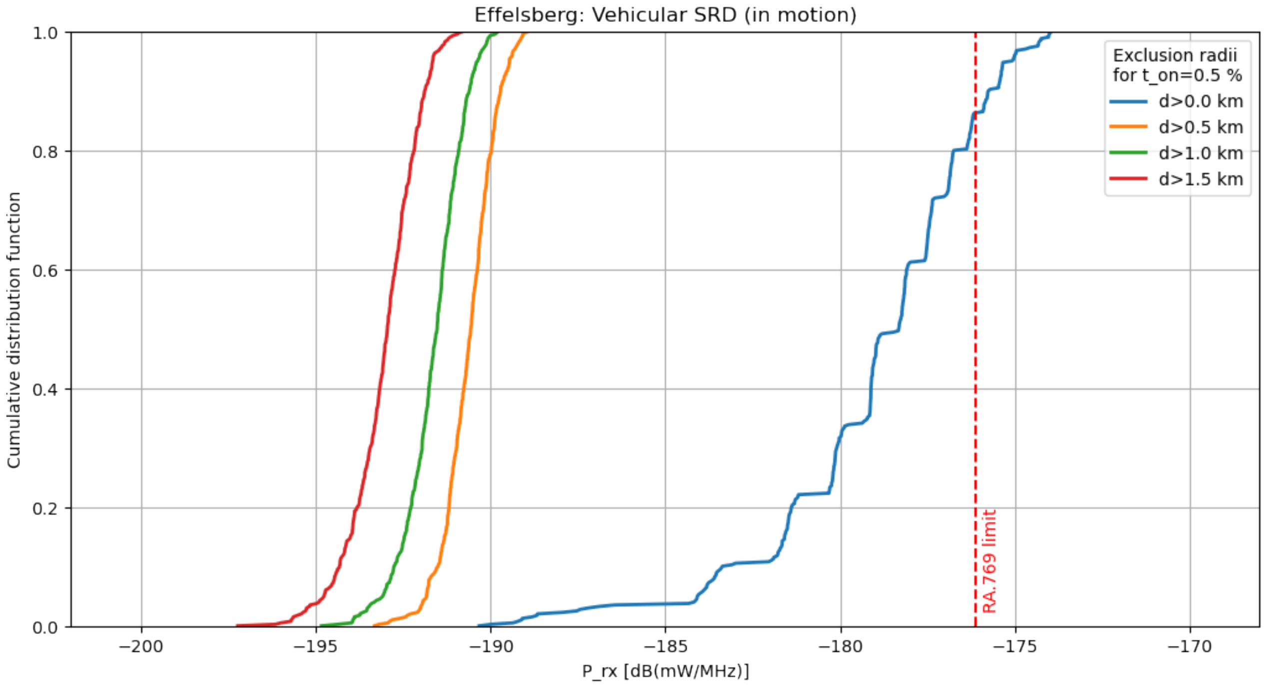


Figure 66: Results of the aggregation calculation of vehicular UWB installations in motion around the Effelsberg

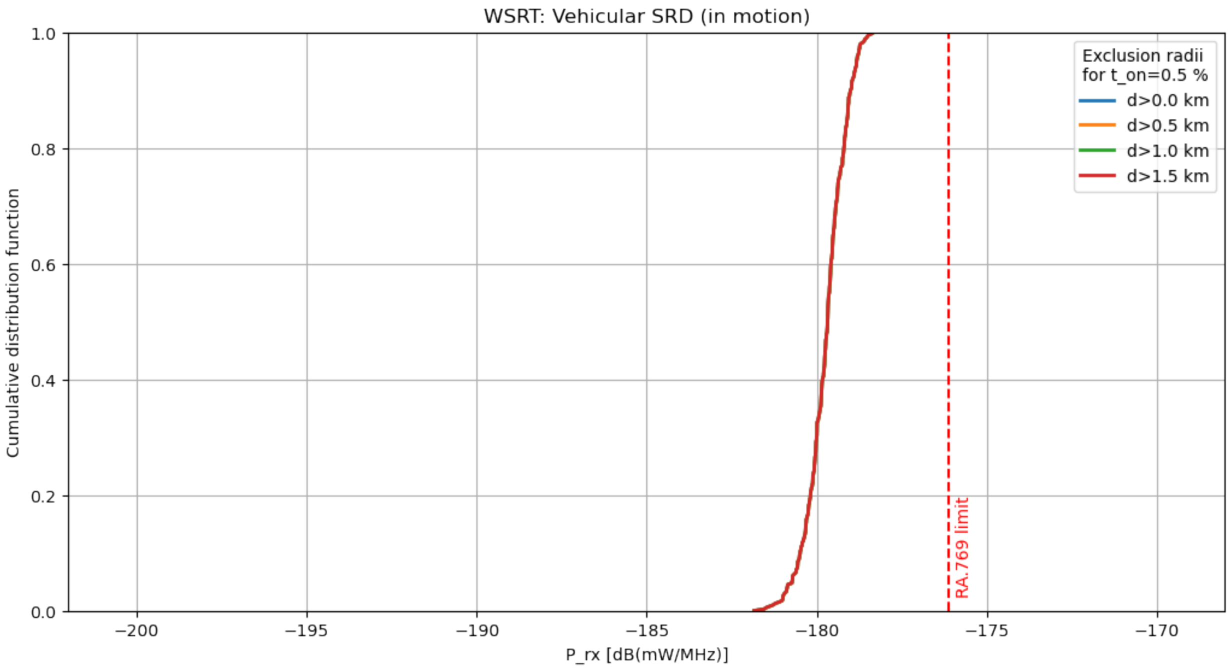


Figure 67: As Figure 66 but for the WSRT station

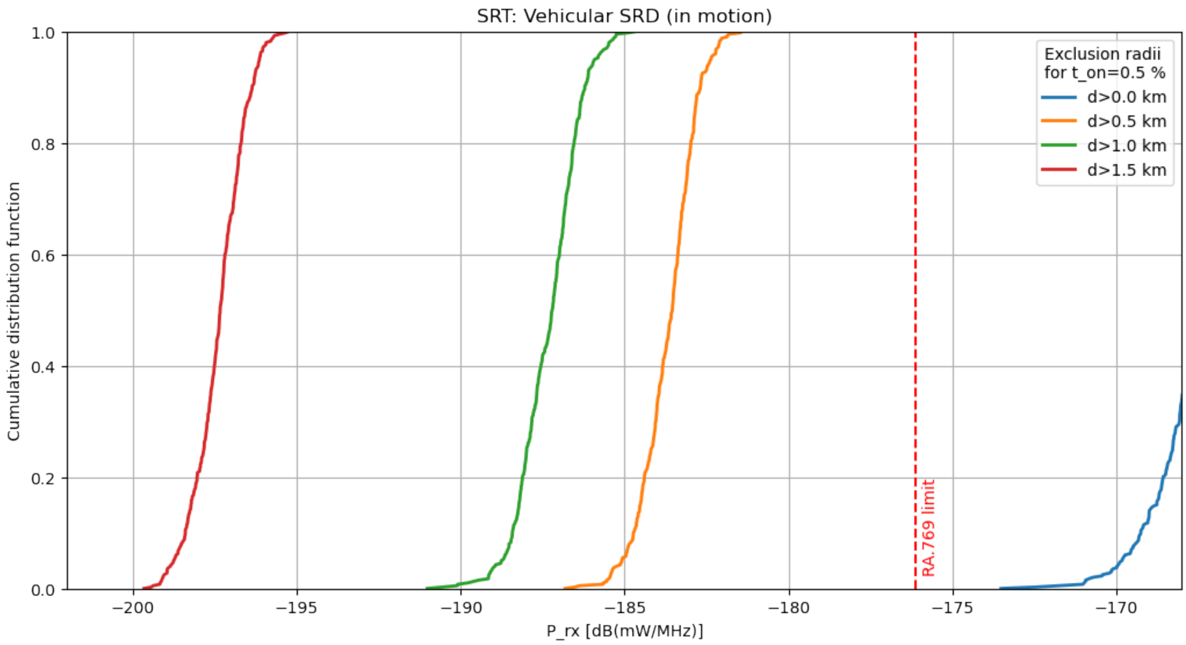


Figure 68: As Figure 66 but for the SRT station

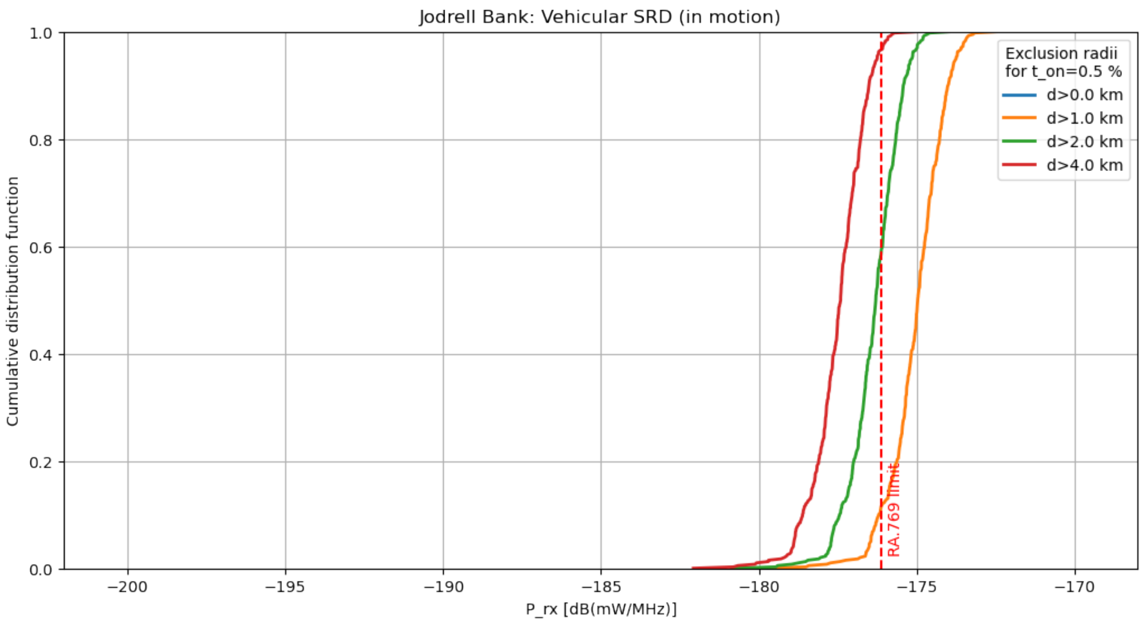


Figure 69: As Figure 66 but for the Jodrell Bank station

The results show that for UWB devices attached to vehicles compatibility with RAS is given for most sites that were studied here. This is owing to the low traffic density and the clutter conditions around the stations. In fact, RAS stations are in most cases purposefully located in remote areas for exactly this reason. A minimal separation distance of 0.5 to 1 km should suffice for adequate protection. Unfortunately, for the Jodrell Bank station the situation is somewhat worse, as there is more traffic and higher population density in the area than can be found at the other RAS sites. Here, an exclusion zone of up to 4-5 km may be needed.

5.4.4 Conclusions for the RAS

For the compatibility with the RAS, the local Tx-side clutter zone type and the Tx antenna heights play a key role. As long as (all) antennas of an installation are within the clutter, no interference at the RAS observatory is expected once the UWB device is beyond about 1 km distance. However, some of the proposed usage scenarios involve relatively high antennas, which can at least in part exceed the local clutter heights and will utilise a relatively high number density of devices and activity factors. In these cases, coordination with the RAS on a national level will be necessary in a given area around the RAS stations. Based on generic (flat-terrain) analyses, the coordination zone could be of the order of 10 km radius around a site, but local terrain and clutter properties would permit to install devices in a fair number of positions within such a coordination zone without putting RAS operations in danger.

5.5 EESS (SPACE-TO-EARTH), SRS (SPACE-TO-EARTH) AND METEOROLOGICAL-SATELLITE SERVICE (SPACE-TO-EARTH)

5.5.1 Single-entry compatibility studies

5.5.1.1 Methodology and approach used in single-entry sharing and compatibility studies

The earth stations point with a minimum elevation of 5° for EESS, and SRS (near-Earth), and 10° for SRS (Deep space). The maximum antenna gain towards the horizon is determined using this elevation angle and the relevant antenna pattern, Annex 3 of Appendix 8 of RR for EESS, and Recommendation ITU-R SA.509-3 for SRS.

The required propagation loss is then determined from the UWB e.i.r.p., the earth station antenna gain towards the horizon, and the protection criterion, with the relevant apportionment factor.

The protection criterion is taken from:

- Recommendation ITU-R SA.609-2 for SRS (Near-Earth);
- Recommendation ITU-R SA.1157-1 for SRS (Deep space);
- Recommendation ITU-R SA.1027-6 for EESS and MetSat.

The relevant apportionment factor of 20 dB should be used, as stated in Recommendation ITU-R SA.1743 [31] for SRS and Recommendation ITU-R SA.1027-6 for EESS and MetSat.

The separation distance is then calculated based on Recommendation ITU-R P.452-16 [15] using a 'flat' terrain, therefore neglecting the potential cases of an UWB transmitter being located in the earth station antenna beamwidth. No clutter loss, ITU-R P.2108-0 [23], is taken into account given that most of EESS earth stations and all SRS earth stations are located in rural areas, and that this recommendation is limited to urban and suburban areas.

The calculation is performed for a UWB with a mean e.i.r.p. of -41.3 dBm/MHz at fixed location with an antenna height of 10 m.

A similar approach is also used to address the compatibility between UWB and MetSat earth stations in the band 7750-7900 MHz.

5.5.1.2 Results for a single-entry compatibility study for EESS (space-to-Earth) in 8025-8400 MHz

The calculation is performed for an 8 m dish antenna, with an antenna height of 8 m.

Maximum antenna gains for EESS Earth stations in the 8 GHz range are typically between 54 and 60 dBi. Taking into account the minimum elevation angle, the value of 14.5 dBi is assumed for the Earth station gain towards the horizon.

Table 62: UWB and EESS(space-to-Earth) compatibility

Parameter	Value	Unit
UWB e.i.r.p.	-41.3	dBm/MHz

Parameter	Value	Unit
EESS ES antenna gain towards the horizon	14.5	dBi
EESS Protection criterion (Recommendation ITU-R SA.1027-6 [28])	-133	dBW/10 MHz
EESS Apportionment (Recommendation ITU-R SA.1027-6 [28])	20	dB
Propagation loss	106.2	dB

The required propagation loss is 106.2 dB, leading to a separation distance of 0.6 km.

5.5.1.3 Results for a single-entry compatibility study for SRS (near Earth)(space-to-Earth) in 8450-8500 MHz

The calculation is performed for the 35 m dish antenna, with an antenna height of 21 m.

Maximum antenna gains for SRS Earth stations in the 8 GHz range are typically of the order of 70 to 60 dBi. Taking into account the minimum elevation angle for SRS (near Earth), the value of 14.5 dBi is assumed for the Earth station gain towards the horizon.

Table 63: UWB and SRS (near Earth)(space-to-Earth) compatibility

Parameter	Value	Unit
UWB e.i.r.p.	-41.3	dBm/MHz
SRS ES antenna gain towards the horizon	14.5	dBi
SRS Protection criterion (Recommendation ITU-R SA.609 [30])	-216	dBW/Hz
SRS Apportionment (Recommendation ITU-R SA.1743 [31])	20	dB
Propagation loss	119.2	dB

The required propagation loss is 119.2 dB, leading to a separation distance of 3.7 km.

5.5.1.4 Results for a single-entry compatibility study for SRS (deep space)(space-to-Earth) in 8400-8500 MHz

The calculation is performed for the 35 m dish antenna, with an antenna height of 21 m.

Maximum antenna gains for SRS Earth stations (SRS ES) in the 8 GHz range are typically of the order of 70 to 60 dBi. Taking into account the minimum elevation angle for SRS (deep space), the value of 7 dBi is assumed for the Earth station gain towards the horizon.

Table 64: UWB and SRS (deep space)(space-to-Earth) compatibility

Parameter	Value	Unit
UWB e.i.r.p.	-41.3	dBm/MHz
SRS ES antenna gain towards the horizon	7	dBi
SRS Protection criterion (Recommendation ITU-R SA.1157 [29])	-221	dBW/Hz
SRS Apportionment (Recommendation ITU-R SA.1743 [31])	20	dB

Parameter	Value	Unit
Propagation loss	116.7	dB

The required propagation loss is 116.7 dB, leading to a separation distance of 2.6 km.

5.5.1.5 Results for a single-entry compatibility study for MetSat (space-to-Earth) in 7750-7900 MHz

The calculation is performed for a 3 m direct read out antenna, with an antenna height of 4 m.

Its antenna gain is 46 dBi. Taking into account the minimum elevation angle, the value of 15.4 dBi is assumed for the Earth station gain towards the horizon.

Table 65: UWB and MetSat (space-to-Earth) compatibility

Parameter	Value	Unit
UWB e.i.r.p.	-41.3	dBm/MHz
EESS ES antenna gain towards the horizon	15.4	dBi
EESS Protection criterion (Recommendation ITU-R SA.1027-6 [28])	-127	dBW/10 MHz
EESS Apportionment (Recommendation ITU-R SA.1027-6 [28])	20	dB
Propagation loss	101	dB

The required propagation loss is 101 dB, leading to a separation distance of 0.3 km.

5.5.2 Aggregate studies - general approach

5.5.2.1 Methodology

The calculations presented in the previous sections determine the required separation distance between one single UWB device operating outdoor at -41.3 dBm/MHz and EESS, MetSat and SRS Earth stations.

It is expected that the consideration of aggregate interference from multiple UWB transmitters might increase these separation distances. Thus, this section contains a number of simulations addressing the aggregated impact from UWB deployments into SRS, EESS and MetSat earth stations.

A Monte Carlo simulation is performed, whereby a number of UWB stations are randomly deployed around the victim earth station between a minimum distance, called separation distance, and this minimum distance plus 10 km. The number of UWB stations depends on the surface of this area, the density of UWB per km² as well as the activity factor. The Monte Carlo simulations have been first performed over 100000 samples. It was observed that the final results were already obtained after 10000 samples and this value was retained to speed up the simulations.

The earth stations point with a minimum elevation of 5° for EESS, and SRS (near-Earth), and 10° for SRS (Deep space). The maximum antenna gain towards the horizon is determined using the relevant antenna pattern, Annex 3 of Appendix 8 of RR for EESS, and Recommendation ITU-R SA.509-3 for SRS.

The pointing of the SRS and EESS earth stations is set at a fixed azimuth (e.g. 0° North) and at the minimum elevation defined above. The difference of azimuth between the antenna pointing and the UWB location together with the elevation of the earth station determine the antenna gain of the earth station in the direction of each UWB station.

The antenna gain of the UWB station depends on the application. An antenna discrimination of -5 dB was considered for fixed applications whereas an antenna discrimination of 0 dB was considered for vehicular applications.

The propagation loss was calculated based on Recommendation ITU-R P.452-16 [15] using a ‘flat’ terrain, therefore neglecting the potential cases of an UWB transmitter being located in the earth station antenna beamwidth. No clutter loss according to Recommendation ITU-R P.2108-0 [23] was taken into account given that most of EESS/MetSat earth stations and all SRS earth stations are located in rural areas, and that this recommendation is limited to urban and suburban areas. The percentage of time of the propagation model was set to the percentage of time associated with the protection criterion as the EESS, MetSat, SRS and UWB antenna are fixed.

The aggregate interference from the number of active UWB stations is then computed and compared to the maximum aggregate interference level as provided in the table below:

Table 66: Maximum aggregate interference level for UWB applications interfering with SRS/EESS/MetSat earth stations in the 7-8 GHz range

	SRS (near Earth)	SRS (deep space)	EESS	MetSat
Protection criteria	-216 dBW/Hz (Recommendation ITU-R SA.609-2)	-221 dBW/Hz (Recommendation ITU-R SA.1157-1)	-133 dBW/10 MHz (Recommendation ITU-R SA.1027-6)	-127 dBW/10 MHz (Recommendation ITU-R SA.1027-6)
Apportionment for non-primary applications	20 dB (Recommendation ITU-R SA.1743 [31])	20 dB (Recommendation ITU-R SA.1743)	20 dB (Recommendation ITU-R SA.1027-6)	20 dB (Recommendation ITU-R SA.1027-6)
Maximum allowable aggregate interference level	-176 dBW/MHz	-181 dBW/MHz	-163 dBW/MHz	-157 dBW/MHz

In addition, some simulations have been performed for some specific earth stations in the SRS or the EESS, where terrain is taken into account, as well as clutter according to Recommendation ITU-R P.452-16 [15].

5.5.2.2 UWB parameters used in the aggregate studies into SRS, EESS and MetSat earth stations

Based on the information provided in section 3, the UWB parameters used in these aggregate studies are summarised in the following tables.

Table 67: UWB parameters for simulations (fixed outdoor applications)

	Parking management application	Outdoor logistics	Physical access control system (PACS)	Vehicular applications fixed outdoor installations
Transmit power (e.i.r.p.)	-41.3 dBm/MHz mean e.i.r.p. power density	-41.3 dBm/MHz mean e.i.r.p. power density	-41.3 dBm/MHz mean e.i.r.p. power density	-41.3 dBm/MHz mean e.i.r.p. power density
Assumed density (Note 1)	Urban: 400 devices/km^2 Suburban: 100 device/km^2	max. 1000/km^2, in limited areas only,	Urban: 200/km^2 Suburban: 50//km^2 Rural: 10/km^2	Max. 40 devices per km of road; 400 devices per km^2, 10 km road length in 1 km^2

	Parking management application	Outdoor logistics	Physical access control system (PACS)	Vehicular applications fixed outdoor installations
	Rural: 10 devices/km^2	Urban: 50/km^2 (average over an urban area) Suburban: 100/km^2 Rural: 10/km^2		Urban: 400/km² Sub Urban: 50/km² Rural: 10/km²
Activity factor	AF: 0.05%	AF: 0.3%	AF: 0.006%	Urban AF: 5% Suburban: 2% Rural: 0.5%
Antenna heights (a.g.l)	2-10 m (5m typical)	2-10 m (5m typical)	1-3 m (typical 1.5 m)	2-10 m (5m typical)
Antenna diagram	Not available. Generally down-tilt (5 dB attenuation)	Not available. Generally down-tilt (5 dB attenuation)	See Figure 9 and Figure 10	See Figure 17, Figure 18 and Figure 19
Note 1: these densities are applicable for UWB systems operating across the 5 available 500 MHz channels in the 6-8.5 GHz range. In the aggregate calculations, they need to be adjusted to cover 1 single 500 MHz channel				

Taking into account the parameters outlined in the above table, the envisaged outdoor fixed applications can be categorised in 2 sub-classes for the purpose of these aggregated interference studies, subject to the anticipated activity factor: applications with activity factor < 0.1% (relevant for Physical access control system (PACS) and parking management applications), activity with activity factor > 0.1% (relevant for outdoor logistics applications and vehicular applications fixed outdoor installations).

Table 68: UWB parameters for simulations (vehicle installations)

	Vehicular applications, in-vehicle installations
Transmit power (e.i.r.p.)	-41.3 dBm/MHz mean e.i.r.p. power density
Assumed density (Note 1)	Urban: 1000/km² Suburban: 100/km² Rural: 25/km²
Activity factor	AF: 0.4%
Antenna heights (a.g.l)	0.5-4 m (1.5 m typical)
Antenna diagram	omnidirectional
Note 1: these densities are applicable for UWB systems operating across the 5 available 500 MHz channels in the 6-8.5 GHz range. In the aggregate calculations, they need to be adjusted to cover 1 single 500 MHz channel	

Table 69: UWB parameters for simulations (high power indoor devices)

	High power indoor devices
Transmit power (e.i.r.p.)	-31.3 dBm/MHz mean e.i.r.p. power density
Assumed density (Note 1)	Urban: 1000 to 2500 devices/km² Suburban: 100 to 250/km² Rural: 25/km²
Activity factor	AF: 1%
Antenna heights (a.g.l)	Not available
Antenna diagram	Not available
Indoor to outdoor attenuation (dB)	17
Note 1: these densities are applicable for UWB systems operating across the 5 available 500 MHz channels in the 6-8.5 GHz range. In the aggregate calculations, they need to be adjusted to cover 1 single 500 MHz channel	

Taking into account the parameters in the above table and the additional information provided in section 3 about the envisaged use case for indoor positioning applications, it is anticipated that the indoor to outdoor attenuation together with additional factors (such as body loss and clutter loss and the separation distances between indoor UWB deployments and SRS/EESS/MetSat earth stations) would provide enough mitigation to avoid interference from the specific UWB indoor deployments considered in this Report to SRS/EESS/MetSat earth stations. This scenario is therefore not addressed in these aggregated interference assessments.

Since most of EESS/MetSat earth stations and all SRS earth stations are located in rural areas, the aggregate studies performed in the following sections are focussed on UWB deployments in rural areas.

5.5.3 Generic aggregate studies for UWB fixed outdoor applications

These studies are performed based on Recommendation ITU-R P.452-16 [15] using a 'flat' terrain, without consideration of clutter.

5.5.3.1 Aggregate interference from UWB fixed outdoor applications into SRS (near Earth) earth stations (generic case)

The following figure provides the cumulative distribution function of the aggregate interference values from the simulated UWB deployments into the SRS (near Earth) earth station in the 4 following cases:

- UWB applications (PACS and parking management), separation distance (exclusion around the earth station) of 100 m;
- UWB applications (outdoor logistics applications and vehicular applications fixed outdoor installations), separation distance (exclusion around the earth station) of 100 m;
- UWB applications (PACS and parking management), separation distance (exclusion around the earth station) of 2 km;
- UWB applications (outdoor logistics applications and vehicular applications fixed outdoor installations), separation distance (exclusion around the earth station) of 2 km.

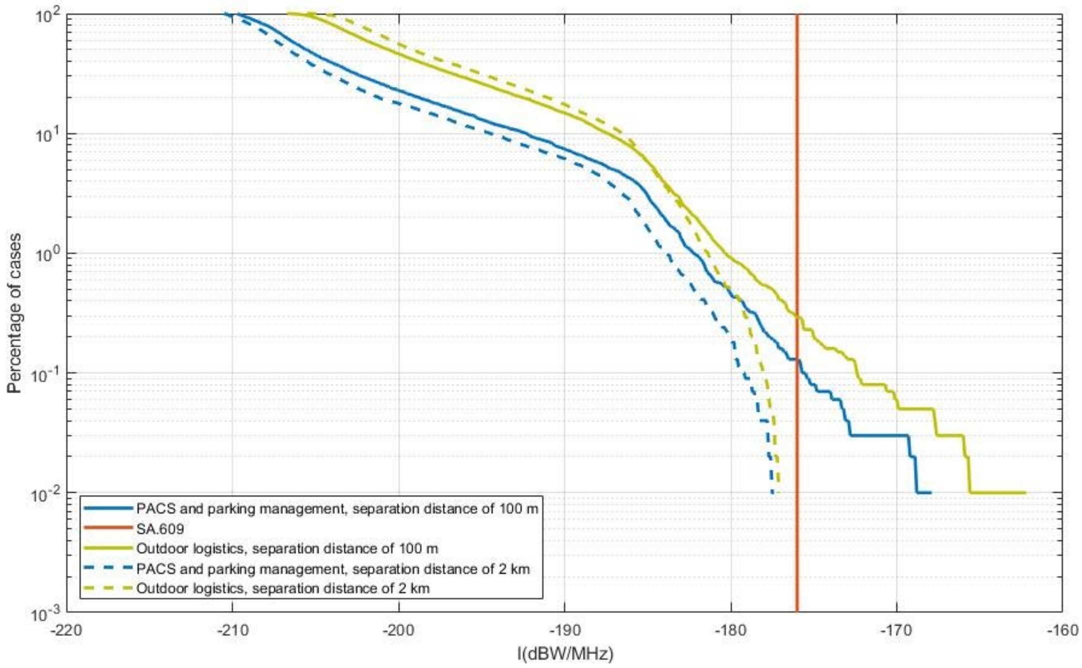


Figure 70: Aggregate interference from UWB fixed outdoor applications deployments into SRS (near Earth) earth stations

For the two types of UWB fixed outdoor deployments considered in this study, the maximum allowable aggregate interference level (-176 dBW/MHz) is exceeded in approximately 0.1% to 0.3% of the simulated samples, when considering a 100 m separation distance between any UWB transmitter and the SRS earth station.

With an increase of the separation distance to 2 km between any UWB transmitter and the SRS earth station, there is no longer any excess of the maximum allowable aggregate interference level.

5.5.3.2 Aggregate interference from UWB fixed outdoor applications into SRS (deep space) earth stations (generic case)

The following figure provides the cumulative distribution function of the aggregate interference values from the simulated UWB deployments into the SRS (deep space) earth station in the 4 following cases:

- UWB applications (PACS and parking management), separation distance (exclusion around the earth station) of 100 m;
- UWB applications (outdoor logistics applications and vehicular applications fixed outdoor installations), separation distance (exclusion around the earth station) of 100 m;
- UWB applications (PACS and parking management), separation distance (exclusion around the earth station) of 1.5 km;
- UWB applications (outdoor logistics applications and vehicular applications fixed outdoor installations), separation distance (exclusion around the earth station) of 1.5 km.

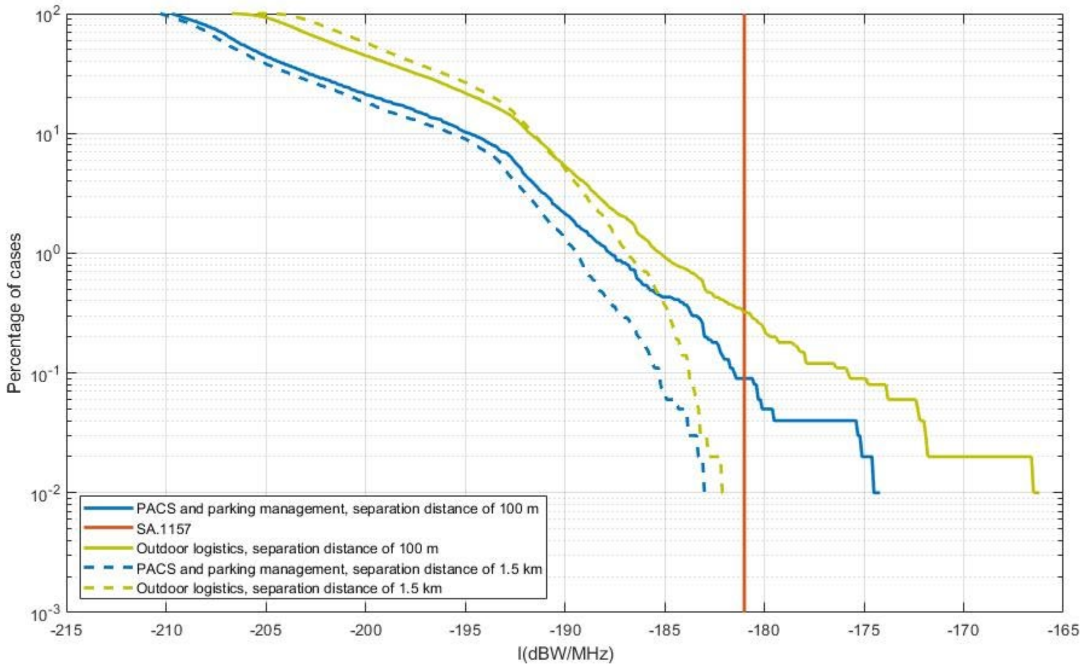


Figure 71: Aggregate interference from UWB fixed outdoor applications deployments into SRS (deep space) earth stations

For the two types of UWB fixed outdoor deployments considered in this study, the maximum allowable aggregate interference level (-181 dBW/MHz) is exceeded in approximately 0.1% to 0.3% of the simulated samples, when considering a 100 m separation distance between any UWB transmitter and the SRS earth station.

With an increase of the separation distance to 1.5 km between any UWB transmitter and the SRS earth station, there is no longer any excess of the maximum allowable aggregate interference level.

5.5.3.3 Aggregate interference from UWB fixed outdoor applications into EESS earth stations (generic case)

The following figure provides the cumulative distribution function of the aggregate interference values from the simulated UWB deployments into the EESS earth station in the 2 following cases:

- UWB applications (PACS and parking management), separation distance (exclusion around the earth station) of 100 m;
- UWB applications (outdoor logistics applications and vehicular applications fixed outdoor installations), separation distance (exclusion around the earth station) of 100 m.

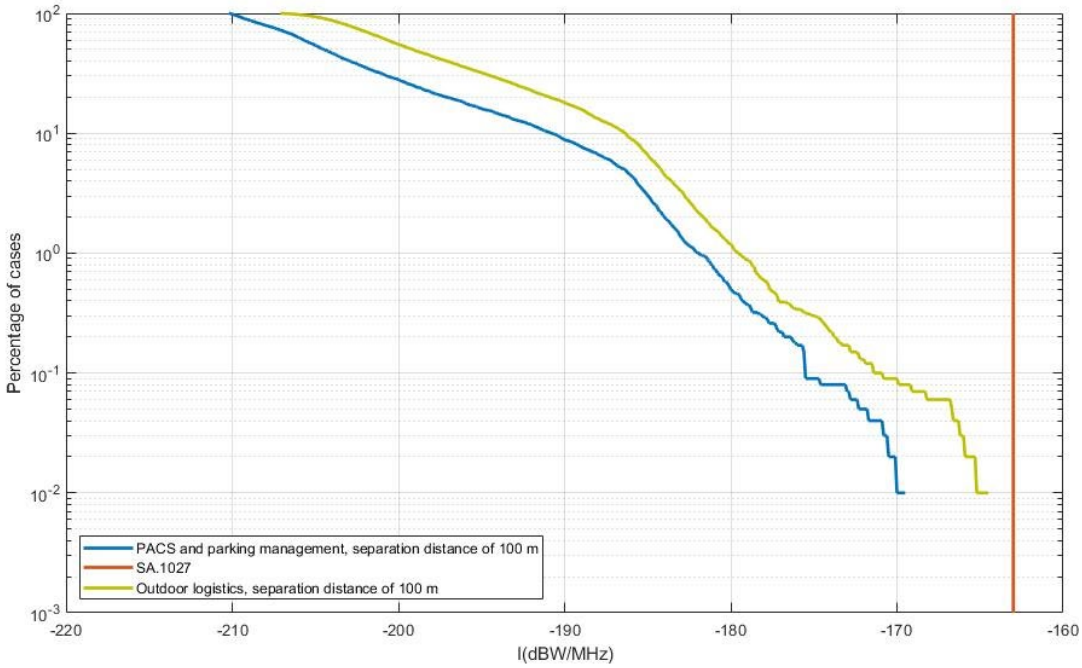


Figure 72: Aggregate interference from UWB fixed outdoor applications deployments into EESS earth stations

For the two types of UWB fixed outdoor deployments considered in this study, the maximum allowable aggregate interference level (-163 dBW/MHz) is not exceeded when considering a 100 m separation distance between any UWB transmitter and the EESS earth station.

5.5.3.4 Aggregate interference from UWB fixed outdoor applications into MetSat earth stations (generic case)

The following figure provides the cumulative distribution function of the aggregate interference values from the simulated UWB deployments into the MetSat earth station in the 2 following cases:

- UWB applications (PACS and parking management), separation distance (exclusion around the earth station) of 100 m;
- UWB applications (outdoor logistics applications and vehicular applications fixed outdoor installations), separation distance (exclusion around the earth station) of 100 m.

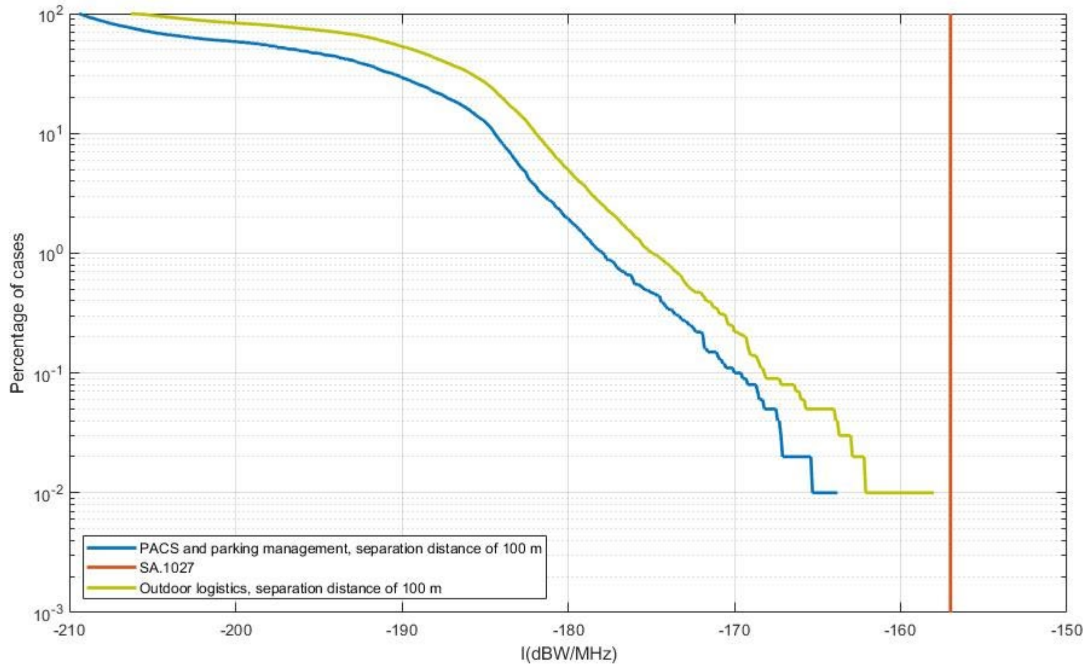


Figure 73: Aggregate interference from UWB fixed outdoor applications deployments into MetSat earth stations

For the two types of UWB fixed outdoor deployments considered in this study, the maximum allowable aggregate interference level (-157 dBW/MHz) is never exceeded, when considering a 100 m separation distance between any UWB transmitter and the MetSat earth station.

5.5.3.5 Conclusions for the analysis of the aggregate interference from UWB fixed outdoor applications into SRS/EESS/MetSat earth stations (generic case)

In the case of UWB fixed outdoor applications, the calculations of aggregated interference into SRS/EESS/MetSat earth stations, assuming flat terrain around the Earth stations, show that the SRS/EESS/MetSat protection criteria are met with the application of the following minimal separation distances between the concerned earth stations and any UWB fixed outdoor installation:

- 2 km around SRS earth station for near Earth SRS missions and 1.5 km for deep space SRS missions;
- 100 m around EESS and MetSat earth station.

5.5.4 Generic aggregate studies for UWB vehicle installations

These studies are performed based on Recommendation ITU-R P.452-16 [15] using a ‘flat’ terrain, without consideration of clutter.

5.5.4.1 Aggregate interference from UWB vehicle installations into SRS (near Earth) earth stations (generic case)

The following figure provides the cumulative distribution function of the aggregate interference values from the simulated UWB vehicle installation deployments into the SRS (near Earth) earth station in the 2 following cases:

- separation distance (exclusion around the earth station) of 100 m;
- separation distance (exclusion around the earth station) of 10 km.

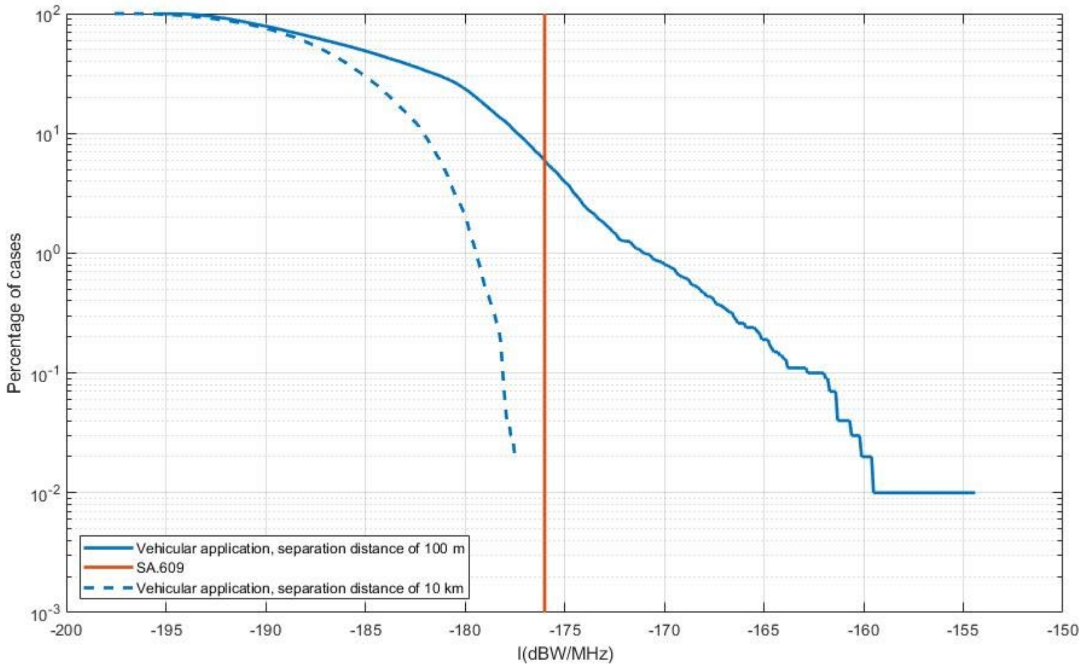


Figure 74: Aggregate interference from UWB vehicle installations deployments into SRS (near Earth) earth stations

For the UWB vehicle installations deployments considered in this study, the maximum allowable aggregate interference level (-176 dBW/MHz) is exceeded in approximately 6% of the simulated snapshots, when considering a 100 m separation distance between any UWB transmitter and the SRS earth station.

With an increase of the separation distance to 10 km between any UWB vehicle installations transmitter and the SRS earth station, there is no longer any excess of the maximum allowable aggregate interference level.

5.5.4.2 Aggregate interference from UWB vehicle installations into SRS (deep space) earth stations (generic case)

The following figure provides the cumulative distribution function of the aggregate interference values from the simulated UWB vehicle installation deployments into the SRS (deep space) earth station in the 2 following cases:

- separation distance (exclusion around the earth station) of 100 m;
- separation distance (exclusion around the earth station) of 8 km.

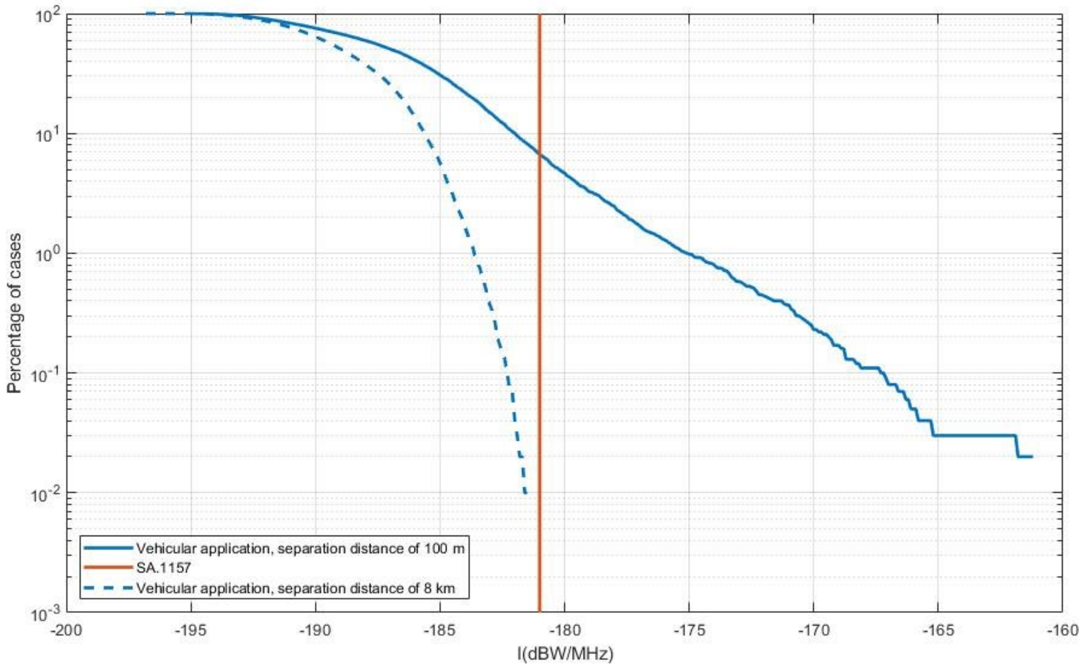


Figure 75: Aggregate interference from UWB vehicle installations deployments into SRS (deep space) earth stations

For the UWB vehicle installations deployments considered in this study, the maximum allowable aggregate interference level (-181 dBW/MHz) is exceeded in approximately 7% of the simulated snapshots, when considering a 100 m separation distance between any UWB transmitter and the SRS earth station.

With an increase of the separation distance to 8 km between any UWB vehicle installations transmitter and the SRS earth station, there is no longer any excess of the maximum allowable aggregate interference level.

5.5.4.3 Aggregate interference from UWB vehicle installations into EESS earth stations (generic case)

The following figure provides the cumulative distribution function of the aggregate interference values from the simulated UWB vehicle installation deployments into the EESS earth station in the 2 following cases:

- separation distance (exclusion around the earth station) of 100 m;
- separation distance (exclusion around the earth station) of 700 m.

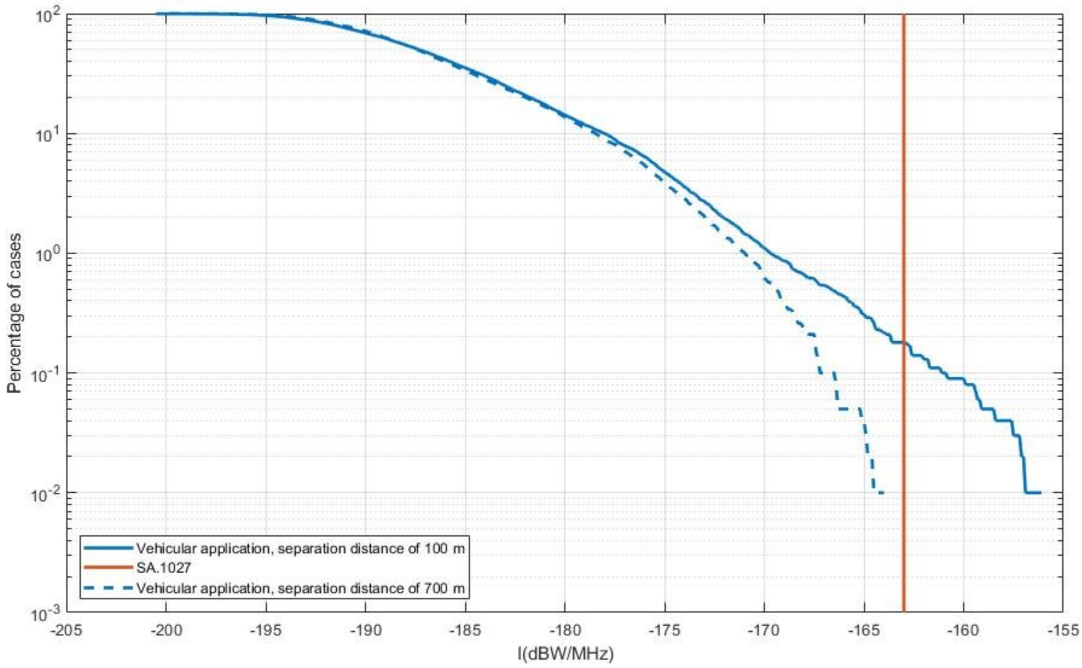


Figure 76: Aggregate interference from UWB vehicle installations deployments into EESS earth stations

For the UWB vehicle installations deployments considered in this study, the maximum allowable aggregate interference level (-163 dBW/MHz) is exceeded in approximately 0.1% of the simulated snapshots, when considering a 100 m separation distance between any UWB transmitter and the EESS earth station.

With an increase of the separation distance to 700 m between any UWB vehicle installations transmitter and the EESS earth station, there is no longer any excess of the maximum allowable aggregate interference level.

5.5.4.4 Aggregate interference from UWB vehicle installations into MetSat earth stations (generic case)

The following figure provides the cumulative distribution function of the aggregate interference values from the simulated UWB vehicle installation deployments into the MetSat earth station in the 2 following cases:

- separation distance (exclusion around the earth station) of 100 m;
- separation distance (exclusion around the earth station) of 400 m.

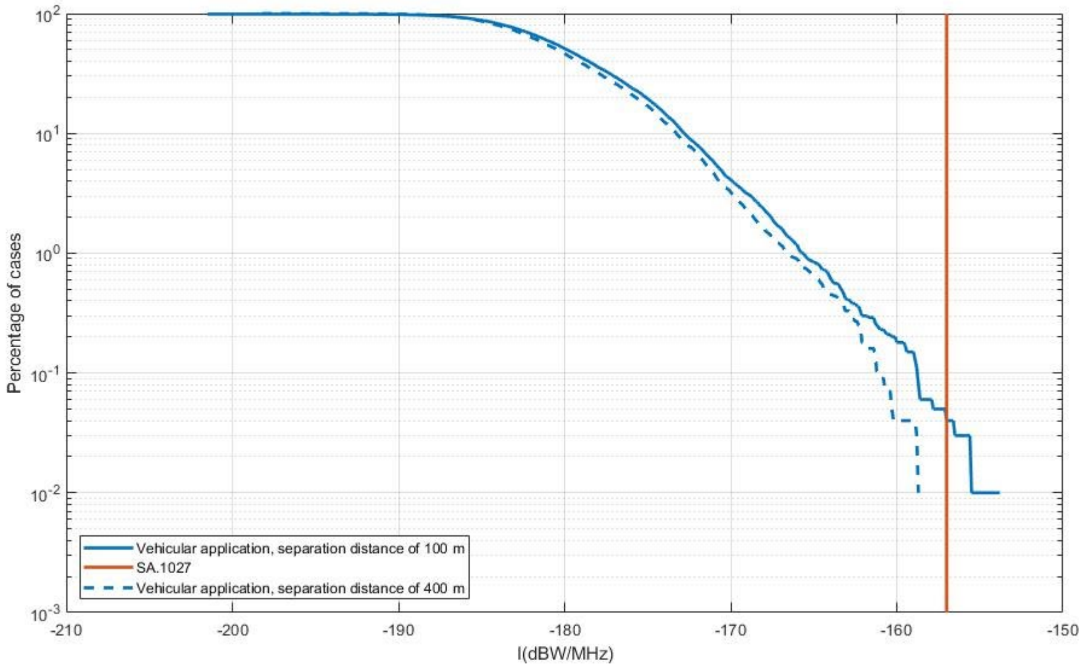


Figure 77: Aggregate interference from UWB vehicle installations deployments into MetSat earth stations

For the UWB vehicle installations deployments considered in this study, the maximum allowable aggregate interference level (-157 dBW/MHz) is exceeded in approximately 0.06% of the simulated snapshots, when considering a 100 m separation distance between any UWB transmitter and the MetSat earth station.

With an increase of the separation distance to 400 m between any UWB vehicle installations transmitter and the MetSat earth station, there is no longer any excess of the maximum allowable aggregate interference level.

5.5.4.5 Conclusions for the analysis of the aggregate interference from UWB vehicle installations into SRS/EESS/MetSat earth stations (generic case)

In the case of UWB vehicle installations, the calculations of aggregated interference into SRS/EESS/MetSat earth stations, assuming flat terrain around the Earth stations, without consideration of clutter, show that the SRS/EESS/MetSat protection criteria are met with the application of the following minimal separation distances between the concerned earth stations and any UWB vehicle installation:

- 10 km around SRS earth station for near Earth SRS missions and 8 km for deep space SRS missions;
- 700 m around EESS earth station;
- 400 m around MetSat earth station.

Since these required separation distances are quite significant for UWB vehicle installations, site-specific analyses are considered in the next section in order to take into account the effect of terrain and clutter.

5.5.5 Site specific aggregate studies for UWB vehicle installations

In this section, aggregate calculations are performed for UWB vehicle installations around specific SRS or EESS earth stations, taking into account the terrain surrounding the earth station as well as the possibility of clutter at either the earth station level or UWB level.

The clutter, if any, is modelled according to Recommendation ITU-R P.452-16 [15]. This Recommendation defines several clutter heights as well as typical separation distances from the station considered (which may be the receiving or transmitting station according to the case). Clutter has been considered only for the SRS analyses, and applied at the vehicular UWB station level, considering the clutter category given in Table 5. This results in an additional 17 dB attenuation.

Table 70: Assumptions on clutter (Recommendation ITU-R P.452-16 [15])

Clutter (ground-cover) category	Nominal height, ha (m)	Nominal distance, dk (km)
High crop fields Park land Irregularly spaced sparse trees Orchard (regularly spaced) Sparse houses	4	0.1

5.5.5.1 *Site specific study of the aggregate interference from UWB vehicle installations into SRS earth stations*

The two following figures display the cumulative distribution function of the aggregate interference values from the simulated UWB vehicle installation deployments into the SRS earth station (deep space) operated by ESA in Cebreros (Spain), without and with consideration of clutter respectively. In both cases, the minimum separation distance between the earth station and any UWB vehicle installation transmitter has been set up so that the aggregate interference complies with the maximum allowable aggregate interference level (-181 dBW/MHz) for SRS (deep space).

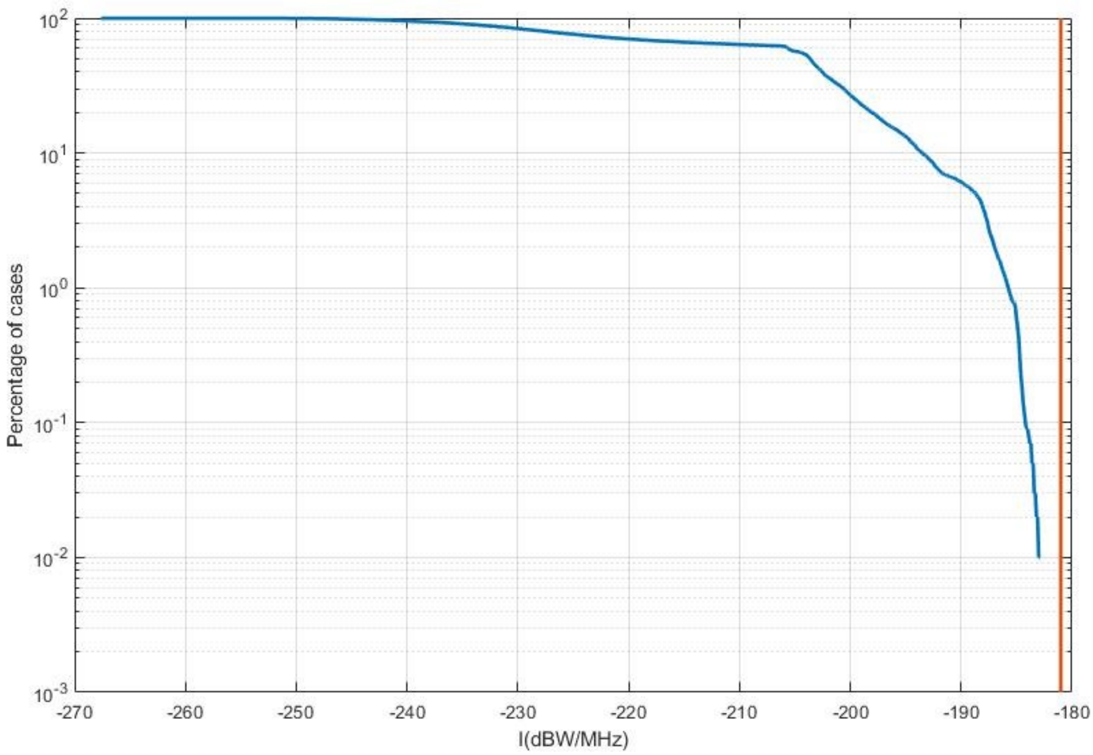


Figure 78: Vehicle installations vs the ESA deep space earth station in Cebreros without clutter, separation distance of 5 km

A separation distance of 5 km is required for this case, taking into account terrain without additional clutter.

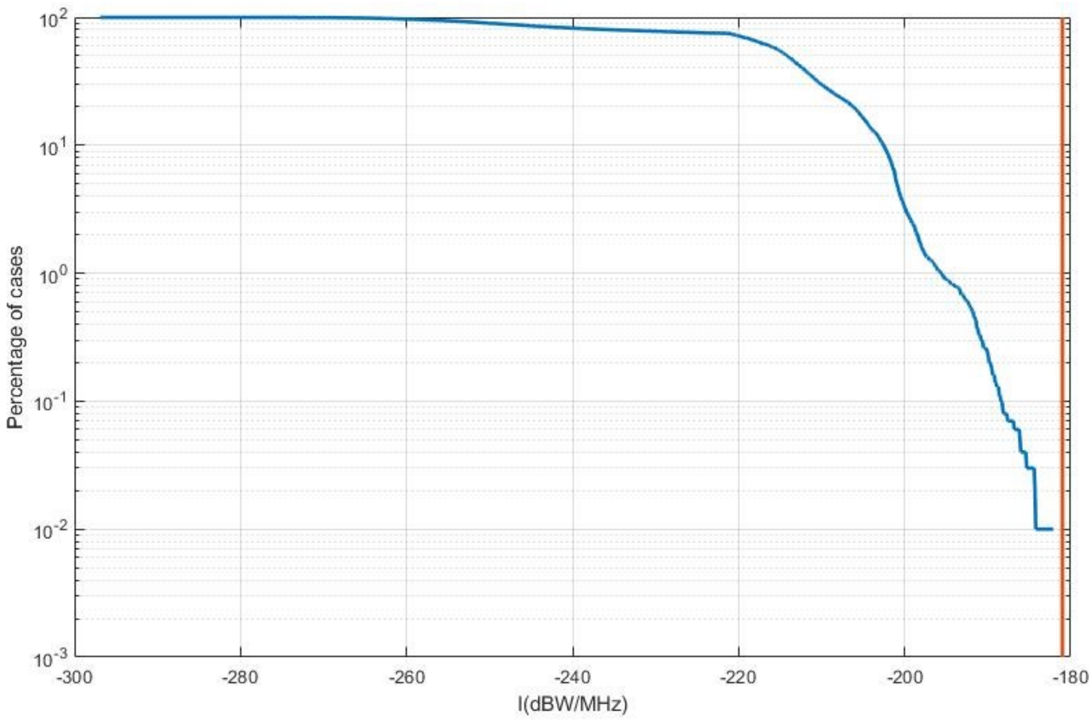


Figure 79: Vehicle installations vs the ESA deep space earth station in Cebreros with clutter (17 dB) applied to the UWB station, separation distance of 300 m

A separation distance of 300 m is required for this case, taking into account terrain with additional clutter around the UWB station.

Similar results are obtained for the SRS Near Earth case.

5.5.5.2 Site specific study of the aggregate interference from UWB vehicle installations into EESS or MetSat earth stations

The following figure displays the cumulative distribution function of the aggregate interference values from the simulated UWB vehicle installation deployments into the EESS earth station operated in Weilheim (Germany), without consideration of additional clutter. The minimum separation distance between the earth station and any UWB vehicle installation transmitter has been set up so that the aggregate interference complies with the maximum allowable aggregate interference level (-163 dBW/MHz) for EESS.

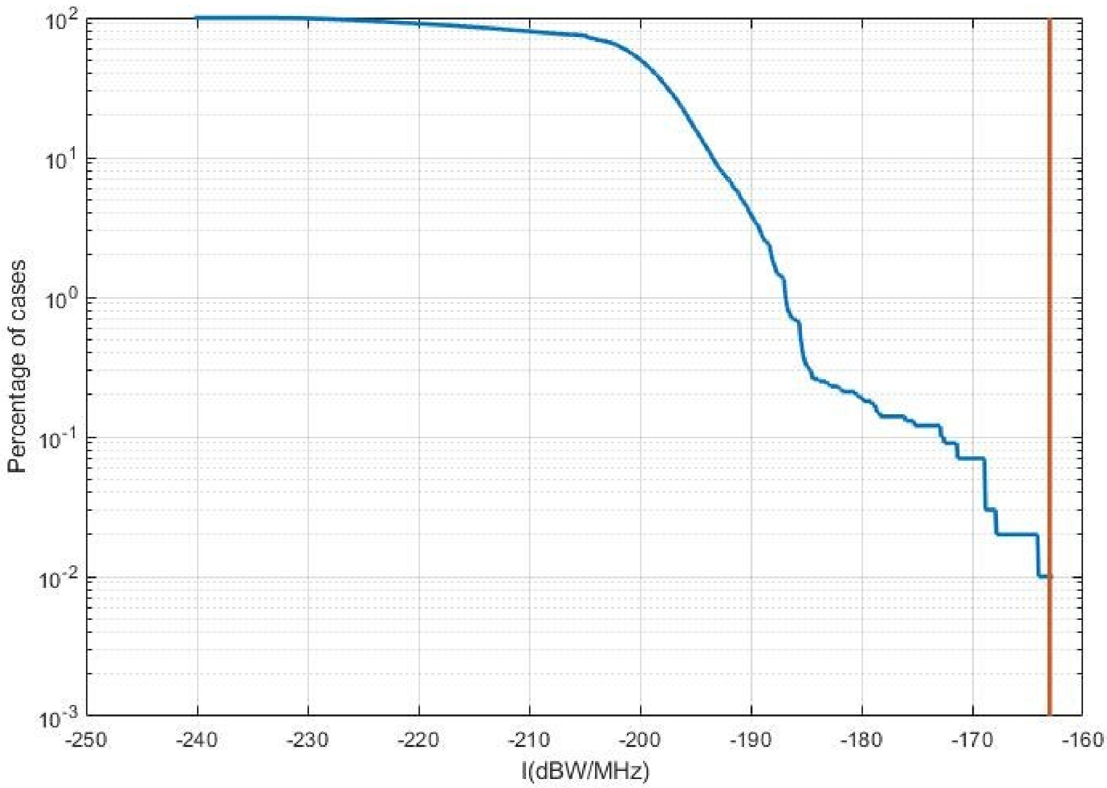


Figure 80: Vehicle installations vs the DLR EESS earth station in Weilheim without clutter

A separation distance of 500 m is required for this case, taking into account terrain without additional clutter, consistent with the value found for flat terrain.

5.5.6 Conclusions for the studies on UWB aggregate interference into EESS/SRS/MetSat earth stations

In the case of UWB fixed outdoor applications, the calculations of aggregated interference into SRS/EESS/MetSat earth stations, assuming flat terrain around the Earth stations, without consideration of clutter, show that the SRS/EESS/MetSat protection criteria are met with the application of the following minimal separation distances between the concerned earth stations and any UWB fixed outdoor installation:

- 2 km around SRS earth station for near Earth SRS missions and 1.5 km for deep space SRS missions;
- 100 m around EESS and MetSat earth station.

In the case of UWB vehicle installations, the calculations of aggregated interference into SRS/EESS/MetSat earth stations, assuming flat terrain around the Earth stations, without consideration of clutter, show that the SRS/EESS/MetSat protection criteria are met with the application of the following minimal separation distances between the concerned earth stations and any UWB vehicle installation:

- 10 km around SRS earth station for near Earth SRS missions and 8 km for deep space SRS missions;
- 700 m around EESS earth station;
- 400 m around MetSat earth station.

Additional site specific simulations have been performed for UWB vehicles installations to assess the impact of considering terrain and clutter on the required separations distances. These simulations show that the consideration of terrain and clutter, as appropriate, leads to significantly lower separation distances:

- 5 km around the SRS earth station located in Cebreros (Spain), when considering terrain without additional clutter;
- 300 m around the SRS earth station located in Cebreros (Spain), when considering terrain with additional clutter (17 dB) around the UWB stations;

- 500 m around the EESS station located in Weilheim (Germany) when considering terrain without additional clutter.

In the case of UWB indoor positioning applications, it is anticipated that the indoor to outdoor attenuation together with additional factors (such as body loss and clutter loss and the separation distances between indoor UWB deployments and SRS/EESS/MetSat earth stations) would provide enough mitigation to avoid interference from the specific UWB indoor deployments considered in this Report to SRS/EESS/MetSat earth stations. This scenario was therefore not addressed in these aggregated interference assessments.EESS (EARTH-TO-SPACE), SRS (EARTH-TO-SPACE) and METEOROLOGICAL-SATELLITE SERVICE (EARTH-TO-SPACE)

No studies were performed in the context of this ECC Report on the impact from UWB systems into EESS (Earth-to-space), SRS (Earth-to-space) and MetSat (Earth-to-space). This is justified by the following factors:

- Taking into account the large distance between the Earth and SRS spacecraft, and the extremely low UWB e.i.r.p. compared to SRS Earth stations e.i.r.p., no impact from UWB systems is expected into SRS spacecraft receivers;
- The absence of the use of the band 7190-7250 for EESS (Earth-to-space) and 8175-8215 MHz for MetSat (Earth-to-space) by European satellite systems.

5.6 EESS (PASSIVE) USED UNDER RR NO. 5.458 (6425-7250 MHZ)

5.6.1 Single-entry analysis

Taking into account the information provided in section 4.6 and considering the UWB technical and operational characteristics Table 71 assesses the impact from one single UWB device into EESS (passive). The total available interference margins in the EESS (passive) footprint are provided in the last row of Table 71.

Table 71: Single entry interference from UWB into EESS (passive) and available interference margin

Parameter name	units	Logistics and Parking and Vehicular fixed outdoor installations	Physical access control systems	In-vehicle installations	Indoor applications
Max. Tx e.i.r.p. spectral density	dBm/MHz	-41.30	-41.30	-41.30	-31.30
	dBW/200 MHz	-48.29	-48.29	-48.29	-38.29
Additional mitigation (antenna down-tilt)	dB	5	0	0	0
Indoor to outdoor attenuation	dB	0	0	0	17
Max. Tx e.i.r.p. spectral density towards EESS (passive)	dBW/200 MHz	-53.29	-48.29	-48.29	-55.29
Max. interference allowable level (with apportionment)	dBW/200 MHz	-179	-179	-179	-179

Parameter name	units	Logistics and Parking and Vehicular fixed outdoor installations	Physical access control systems	In-vehicle installations	Indoor applications
EESS (passive) antenna gain	dBi	51.5	51.5	51.5	51.5
Free space losses	dB	171.43	171.43	171.43	171.43
Atmospheric attenuation	dB	0.08	0.08	0.08	0.08
Max. Tx e.i.r.p. for 1 UWB outdoor on surface in the EESS (passive) footprint	dBW/200 MHz	-58.99	-58.99	-58.99	-58.99
Total available interference margin on surface in the EESS footprint in 200 MHz	dB	-5.70	-10.70	-10.70	-3.70

For a single UWB device operating 100% of the time with maximum transmit e.i.r.p. spectral density of -41.3 dBm/MHz as in the table above, the resulting negative margin is -10.70 dB, as in the case of the physical access control systems and in-vehicle installations. Considering in particular the fact that logistics, parking and vehicular fixed outdoor installations may have an additional mitigation of 5 dB to account for the antenna down-tilting, this margin is still negative but increases to -5.70 dB. For indoor applications with an e.i.r.p. spectral density of -31.3 dBm/MHz, the negative margin is -3.70 dB, taking into account a 17 dB indoor-to-outdoor attenuation.

This single-entry analysis, resulting in negative margins, considers a certain number of worst-case assumptions. The next sub-section is assessing the aggregate impact from potential UWB deployments within the EESS (passive) footprint with more representative assumptions.

5.6.2 Aggregate-effect impact

5.6.2.1 Assumptions and mitigation factors

For a more realistic interference scenario, the effects of clutter should be considered. As defined in Recommendation ITU-R P.2108-0 [23], clutter refers to “objects, such as buildings or vegetation, which are on the surface of the Earth but not actually terrain”. This effect consists of an additional loss, which can be added to the free-space basic transmission loss[8].

The Recommendation ITU-R P.2108-0 [23], as per its paragraph 3.3, provides a statistical distribution of Earth-space and Aeronautical clutter loss not exceeded for percentage locations for angles of elevation between 0 and 90 degrees and it is applicable to the frequency range from 10 to 100 GHz in urban and suburban environments. This in-force recommended model is currently under revision by JSWG 3J-3K-3M and CG 3K-3M-12 to expand its applicability, including to sub-10 GHz frequency-bands.

In the absence of a model recommended for sub-10 GHz frequency-bands, but aiming to account for this effect, in the spirit of compromise the hypothesis of extrapolating the model is considered.

[8] Definition of “free-space basic transmission loss” is given in Recommendation ITU-R P.341-7.

The extrapolation of ITU-R P.2108-0 [23] model in the sub-10 GHz frequency-range, for 50% pf the locations and for the case of an elevation angle of 35 degrees is depicted in the following figure.

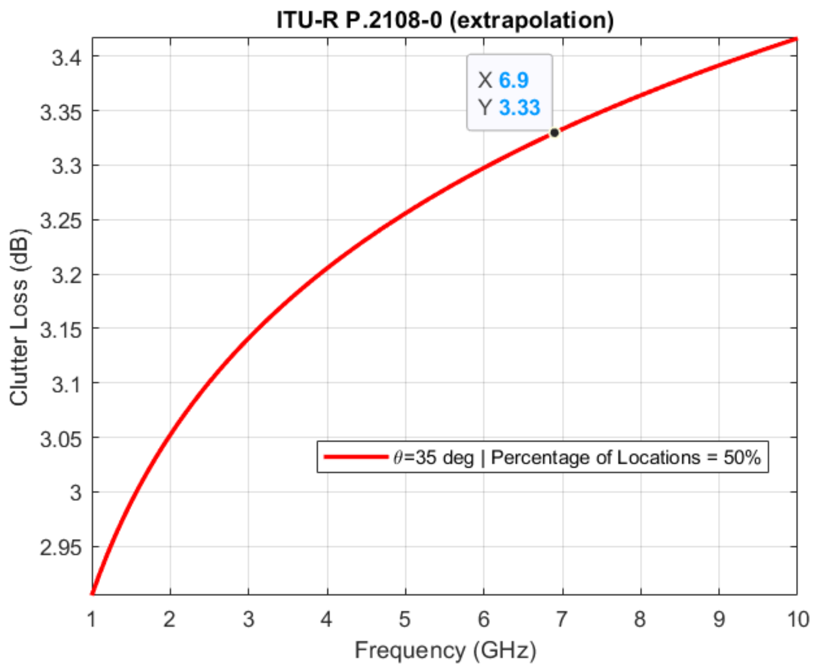


Figure 81: Clutter loss for 50% of the locations and elevation angle of 35 degrees in the sub-10 GHz frequency-range

The full cumulative distribution of clutter loss at 6.925 GHz for an elevation angle of 35 degrees is in the following figure.

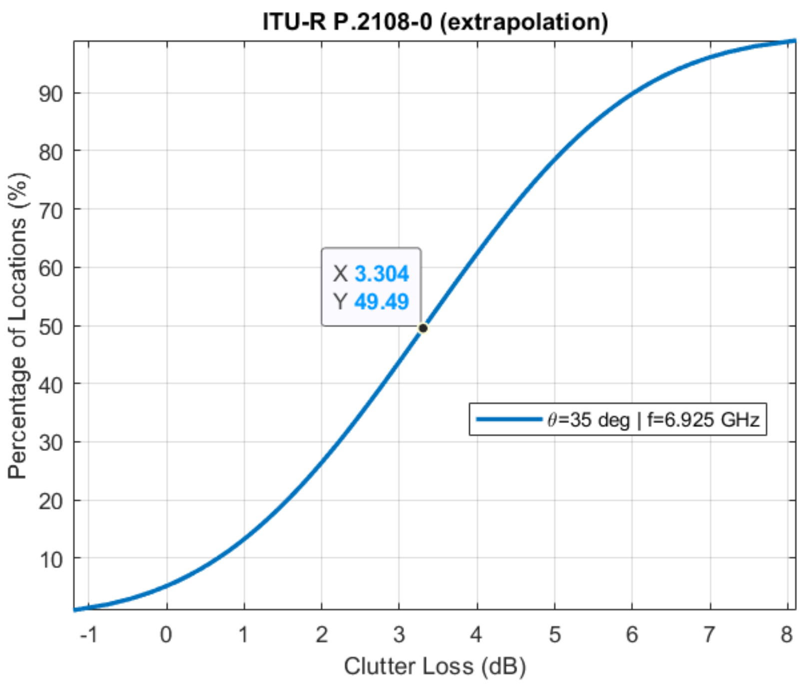


Figure 82: Cumulative distribution of clutter loss not exceeded for 6.925 GHz and elevation angle of 35 degrees

Based on these results, it is considered appropriate to take for this study an extrapolated value for 50% of the locations of 3.3 dB.

In addition, one may assume the UWB antennas do not have the main lobe pointing towards the satellite, so an average antenna discrimination of 3 dB may be considered as an additional mitigation for the calculation of aggregate interference.

Finally, considering that any UWB system is expected to operate within a 500 MHz channel in the 6-8.5 GHz frequency range, it can be assumed that only 20% of the total number of UWB devices would operate in channels overlapping with the EESS receiver bandwidth. Thus, an additional mitigation of 7 dB may be considered to derive the total number of UWB transmitters. For this consideration to describe a realistic spectrum sharing scenario, the regulation should impose consistently a maximum allowable UWB operating bandwidth of 500 MHz.

5.6.2.2 Calculations of aggregate interference

Given the UWB devices activity factors and densities provided in section 3.4, and considering the EESS(passive) footprint size (164 km^2 for the CIMR EESS (passive) sensor), the aggregate interference margins for each application, after the aggregation effect of all of its corresponding devices, are those presented in the following tables for UWB deployments in rural, suburban and urban areas. These aggregate interference margins are calculated, taking as a basis, the single-entry margins provided in the previous section, with the additional consideration of UWB deployment assumptions (activity factors and densities) and the assumption and mitigation factors described in the previous sub-section.

The results for the parking management applications are in Table 72.

Table 72: Available aggregate interference margins for the parking management applications

Parking management	Rural	Suburban	Urban
Total available interference margin on surface in the EESS footprint in 200 MHz (dB)	-5.70		
Clutter loss (dB)	0.0	3.3	3.3
Antenna discrimination (dB)	3.00		
Apportionment of devices (dB)	7.00		
Typical max. activity factor(%)	0.05%		
Devices density (#/km^2)	10	10	10
Margin for aggregate interference of individual application (dB)	5.16	-1.54	-7.56

As it is possible to see, the margin for rural areas is positive, while those for urban and suburban areas are negative.

The results for the logistics applications are in the following table:

Table 73: Available aggregate interference margins for the outdoor logistics applications

Outdoor logistics	Rural	Suburban	Urban
Total available interference margin on surface in the EESS footprint in 200 MHz (dB)	-5.70		
Clutter loss (dB)	0.0	3.3	3.3

Outdoor logistics	Rural	Suburban	Urban
Antenna discrimination (dB)	3.00		
Apportionment of devices (dB)	7.00		
Typical max. activity factor(%)	0.30%		
Devices density (#/km²)	10	100	50
Margin for aggregate interference of individual application (dB)	-2.62	-9.32	-6.31

As it is possible to see, all margins are negative.

The results for the physical access control systems are in the following table:

Table 74: Available aggregate interference margins for the physical access control systems

Physical access control	Rural	Suburban	Urban
Total available interference margin on surface in the EESS footprint in 200 MHz (dB)	-10.70		
Clutter loss (dB)	0.0	3.3	3.3
Antenna discrimination (dB)	3.00		
Apportionment of devices (dB)	7.00		
Typical max. activity factor(%)	0.006%		
Devices density (#/km²)	10	50	200
Margin for aggregate interference of individual application (dB)	9.37	5.68	-0.34

As it is possible to see, the margins for rural and suburban areas are positive and it is negative for urban areas.

The results for the fixed outdoor installations of vehicular applications are in the following table:

Table 75: Available aggregate interference margins for the fixed outdoor installations of vehicular applications

Vehicular fixed outdoor installations	Rural	Suburb	Urban
Total available interference margin on surface in the EESS footprint in 200 MHz (dB)	-5.70		
Clutter loss (dB)	0.0	3.3	3.3
Antenna discrimination (dB)	3.00		
Apportionment of devices (dB)	7.00		
Typical max. activity factor(%)	0.5	2.0	5.0
Devices density (#/km²)	10	50	400
Margin for aggregate interference of individual application (dB)	-4.84	-14.55	-27.56

As it is possible to see, all margins are negative.

The results for the in-vehicle installations are in the following table:

Table 76: Available aggregate interference margins for in-vehicle installations

In-vehicle installations	Rural	Suburb	Urban
Total available interference margin on surface in the EESS footprint in 200 MHz (dB)	-10.70		
Clutter loss (dB)	0.0	3.3	3.3
Antenna discrimination (dB)	3.00		
Apportionment of devices (dB)	7.00		
Typical max. activity factor(%)	0.4	0.5	1.0
Devices density (#/km^2)	25	100	1000
Margin for aggregate interference of individual application (dB)	-12.85	-16.54	-29.55

As it is possible to see, all margins are negative.

The results for the indoor applications are in the following table:

Table 77: Available aggregate interference margins for indoor applications

Indoor applications	Rural	Suburb	Urban
Total available interference margin on surface in the EESS footprint in 200 MHz (dB)	-3.70		
Clutter loss (dB)	0.0	3.3	3.3
Antenna discrimination (dB)	3.00		
Apportionment of devices (dB)	7.00		
Typical max. activity factor (%)	1.00		
Devices density (#/km^2)	25	250	2500
Margin for aggregate interference of individual application (dB)	-9.83	-16.53	-26.53 29.14

As it is possible to see, all margins are negative.

5.6.3 Comparison with the existing UWB regulation

5.6.3.1 Introduction

The existing generic UWB regulation in ECC Decision(06)04 [45] provides the possibility for operating devices in the frequency-range of 6-8.5 GHz with maximum mean e.i.r.p. spectral density of -41.3 dBm/MHz without any restriction in Duty cycle nor application, with the exception of devices and infrastructure used at a fixed outdoor location or connected to a fixed outdoor antenna, devices installed in flying models, aircraft and other aviation and devices installed in road and rail vehicles.

This generic use is not limited to indoor use cases. In the regulation an average activity factor of *AF* = 5% is assumed for these generic use cases.

In the baseline compatibility investigation covered in the ECC Report 64 [5] a density of up to 10000 devices/km^2 is taken as the baseline. Out of these devices, 20% are considered to be operated outdoor (see ECC Decision (06)04, considering j [45]). These regulated UWB devices already create a potential interference risk into the EESS passive sensors.

In the following tables the resulting interference effect have been investigated using the same methodology as used for the evaluation of the interference effects of the applications proposed in this Report.

5.6.3.2 Single Entry interference

Table 78: Single entry interference from UWB into EESS (passive) and available interference margin based existing generic UWB regulation in ECC Decision(06)04 [45] and ECC Report 64[5]

Parameter name	units	Outdoor usage	Indoor usage
Max. Tx e.i.r.p. spectral density	dBm/MHz	-41.30	-41.30
	dBW/200 MHz	-48.29	-48.29
Additional mitigation (antenna down-tilt)	dB	0	0
Indoor to outdoor attenuation	dB	0	17
Max. Tx e.i.r.p. spectral density towards EESS (passive)	dBW/200 MHz	-48.29	-65.29
Max. interference allowable level (with apportionment)	dBW/200 MHz	-179.00	-179.00
EESS (passive) antenna gain	dBi	51.5	51.5
Free space losses	dB	171.43	171.43
Atmospheric attenuation	dB	0.08	0.08
Max. allowable Tx e.i.r.p. for 1 UWB outdoor on surface in the EESS (passive) footprint	dBW/200 MHz	-58.99	-58.99
Total available interference margin on surface in the EESS footprint in 200 MHz	dB	-10.70	6.30

For a single UWB device operating 100% of the time with maximum transmit e.i.r.p. spectral density of -41.3 dBm/MHz as in the table above, the resulting negative margin is -10.70 dB, as in the case of an outdoor usage as per existing regulation.

Indoor applications operating as per existing regulation, with an e.i.r.p. spectral density of -41.3 dBm/MHz, and considering a 17 dB indoor-to-outdoor attenuation, present a positive interference margin of 6.30 dB.

This single-entry analysis considers a certain number of worst-case assumptions. The next sub-section is assessing the aggregate impact from potential UWB deployments within the EESS (passive) footprint with more representative assumptions.

5.6.3.3 Aggregated interference

Table 79: Available aggregate interference margins generic UWB regulation outdoor based on ECC Decision(06)04[45] and ECC Report 64[5]

In-vehicle installations	Rural	Suburb	Urban
Total available interference margin on surface in the EESS footprint in 200 MHz (dB)	-10.70		
Clutter loss (dB)	0.0	3.3	3.3
Antenna discrimination (dB)	3.00		
Apportionment of devices (dB) not considered in ECC Report 64	0.00		
Considered activity factor (%) in ECC Decision (06)04 considering j)	5.0	5.0	5.0
Devices density (#/km^2) used in ECC Report 64	20	200	2000
Margin for aggregate interference of individual application (dB)	-29.85	-36.55	-46.55

Table 80: Available aggregate interference margins generic UWB regulation indoor based on ECC Decision (06)04 [45] and ECC Report 64[5]

Indoor applications	Rural	Suburb	Urban
Total available interference margin on surface in the EESS footprint in 200 MHz (dB)	+6.30		
Clutter loss (dB)	0.0	3.3	3.3
Antenna discrimination (dB)	3.00		
Apportionment of devices (dB) not considered in ECC Report 64	0.0		
Considered activity factor (%) in ECC Decision (06)04 considering j)	5.00		
Devices density (#/km^2) used in ECC Report 64	80	800	8000
Margin for aggregate interference of individual application (dB)	-18.87	-25.57	-35.57

As it is possible to see, all margins are negative.

The deterioration of the interference margin into the passive sensor caused by the applications presented in this Report will be, in general, smaller than the deterioration caused by generic UWB devices, operating based on the existing regulation for generic UWB devices in ECC Decision (06)04 [45] and the related assumed activity factors and device densities in ECC Report 64 [5].

6 CONCLUSION

6.1 OVERVIEW

The applications that are investigated in this Report are used for radiodetermination and location tracking, tracing and data acquisition. They operate in the field of logistics and traffic management, home security applications and access control, indoor positioning applications and vehicular applications.

Study results presented in this Report evaluate whether compatibility with incumbent system in the band 6.0 GHz to 8.5 GHz could be achieved, when UWB devices are operating with -41.3 dBm/MHz either as fixed installations or in road vehicles and whether a limited number of indoor devices can operate with an increase TX power of up to -31.3 dBm/MHz.

In order to adequately assess the compatibly situation, the future use cases have been analysed and, where necessary, appropriate mitigation factors have been identified. It can be stated that in contrast to the originally assumed use cases in ECC Report 64 [5] the deployment of UWB has mainly focused on location tracking and low data rate communications based on IEEE802.15.4z [44] standards rather than the assumed high and ultra-high data rate systems based on e.g. the ECMA 368 [49] standard or ETSI TS 102 455 [48]. Since the completion of ECC Report 64 in 2005, such high and ultra-high data rate UWB systems did not materialise. Rather, WAS/RLAN systems became the dominant technologies for high and ultra-high data rate transmissions. This leads to a significant reduction of the assumed activity factors.

Furthermore, today’s technology can provide several operational channels also in the band between 6.0 GHz and 8.5 GHz which can be taken into account in the band apportionment and thus reducing the density of devices in a potential victim band further.

These effects have mainly been taken into account in the aggregation investigations.

In this Report, the peak power effect of UWB devices have been investigated for the first time in more detail, especially in the fixed service investigations.

The different types of applications and their parameters studied in this Report are summarised in the Table below.

Table 81: Summary of the applications and their parameters

Application	Assumed Density	Activity factor	Transmit Power (e.i.r.p.)
Fixed outdoor application			
Parking management application	Urban: max. 40 devices/km or 400 devices/ km^2 Suburban: 100 device/ km^2 Rural: 10 devices/ km^2	AF: 0.05%	-41.3 dBm/MHz mean e.i.r.p. power density in 1 ms 0 dBm/50 MHz (Max), peak e.i.r.p. power
Outdoor logistics	Outdoor logistics: max. 1000/km^2 Urban: 50/ km^2 Suburban: 100/ km^2 Rural: 10/km^2	AF: 0.3%	-41.3 dBm/MHz mean e.i.r.p. power density in 1 ms 0 dBm/50 MHz (Max), peak e.i.r.p. power
Physical access control system (PACS)	Urban: 200/km^2 Suburban: 50/km^2 Rural: 10/km^2	AF: 0.006%	-41.3 dBm/MHz mean e.i.r.p. power density in 1 ms 0 dBm/50 MHz (Max), peak e.i.r.p. power

Application	Assumed Density	Activity factor	Transmit Power (e.i.r.p.)
Vehicular applications fixed outdoor installations	Max. 40 devices per km of road; 400 devices per km², 10 km road length in 1 km² Urban: 400/km² Sub Urban: 50/km² Rural: 10/km²	Urban AF: 5% Suburban: 2% Rural: 0.5%	-41.3 dBm/MHz mean e.i.r.p. power density in 1 ms 0 dBm/50 MHz (Max), peak e.i.r.p. power
General vehicular outdoor applications for ITS			
Vehicular applications, vehicle installations	6000 per km² max. (10 3-lane roads two directions dense traffic), typical 1000 per km² Urban: 1000/km² Suburban: 100/km² Rural: 25/km²	AF: 1% max AF typical: 0.4% AF: 0.04% for V2V	-41.3 dBm/MHz mean e.i.r.p. power density in 1 ms 0 dBm/50 MHz (Max), peak e.i.r.p. power
High power indoor devices			
Indoor systems with higher power	Urban: 1000 to 2500 devices/km² Suburban: 100 to 250/km² Rural: 25/km²	AF: 1%	-31.3 dBm/MHz mean e.i.r.p. power density in 1 ms 10 dBm/50 MHz (Max), peak e.i.r.p. power

Due to the mentioned additional mitigation factors the overall interference potential of the applications investigated in this Report is lower than the interference potential of the already regulated generic UBW devices based on ECC Decision (06)04 [45].

This Report outlines that the three following factors are key in assessing the compatibility between UWB devices with relaxed conditions as described in section 0.1, and incumbents systems across the band 6-8.5 GHz:

- Reduced densities of UWB devices compared to the ones considered in ECC Report 64 [5];
- Consideration of use cases associated with low data rate and low activity factors as the one considered in ECC Decision (06)04;
- Ability for UWB devices to spread, on an aggregate basis, across a number of possible operational channels.

For each considered application, the assumed device density taken into account in the studies, is described in Table 1. It was noted that if the deployment densities assumed in this report are exceeded, further studies on additional mitigation techniques may be required in order to ensure coexistence with outdoor stations of radiocommunication services.

For fixed outdoor installations, coexistence would be possible[9] based on the following assumptions:

- Maximum mean e.i.r.p. power of -41.3dBm/MHz, peak power in 50 MHz of 0 dBm;
- Maximum height of 10 m;
- Directive antennas are down tilted to provide additional attenuation of 5dB for parking management, outdoor logistics and fixed vehicular applications;
- Omnidirectional antennas for data acquisition for authentication / access control (PACS);

[9] It is noted that for these installations, in a few specific geometrical cases with low probability, single-interference studies have shown that separation distances are more than 1 km.

- Duty Cycle < 5% per second (see Table 4).

For indoor installations (both fixed installations and portable devices), coexistence would be possible based on the following assumptions:
- Maximum mean e.i.r.p. power of -31.3 dBm/MHz, peak power in 50 MHz of 10 dBm;
- Duty Cycle < 5% per second (see Table 3);
- Networked/controlled operation.

For vehicular applications coexistence would be possible based on the following assumptions:
- Maximum mean e.i.r.p. power of -41.3 dBm/MHz, peak power in 50 MHz of 0 dBm;
- Maximum height of 4 m;
- Omnidirectional antennas;
- Duty Cycle < 1% per second (see Table 5).

6.2 FIXED SERVICE (FS)

MCL calculations show a maximum separation distance of 11226 m for the outdoor line of sight scenario. Taking into account vertical geometries this distance can be reduced to 10965 m.

For outdoor NLOS scenarios the maximum separation distance is 1484 m. Taking into account vertical geometries this distance can be reduced to 250 m. That behaviour can be explained by using a suburban/urban clutter model, adding minimum 16.7 dB attenuation for distances greater than 250 m.

Outside of the FS main lobe, the minimum separation distance is about 50 m without applying any clutter.

Additional results leading to smaller distances than shown above, covering also indoor scenarios, peak power scenarios and a FS antenna scenario with lower peak gain are included in ANNEX 2.

For the indoor high-power UWB applications, a geometrical minimum required separation distance for aggregated propagation effects study was performed with indoor high-power UWB using the geometrical approach where the effective FS antenna gain is calculated based on the relative position of the UWB device compared to the FS receiver. Recommendation ITU-R P.452 was used to model propagation losses, Recommendation ITU-R P.2109 [36] to model building entry losses, and Recommendation ITU-R P.2108 [23] for clutter losses. All the propagation losses were aggregated into one statistical loss, which was used to determine the minimum separation distance at different percentiles p. Four different scenarios were considered consisting of two types of buildings, traditional and thermally efficient, and two types of propagation conditions. The first considers propagation losses and building entry losses, and another one considers clutters losses besides propagation losses and building entry losses. The overall CDF of the losses was computed and evaluated for p = 1%, p = 10%, and p = 50%, where p represents the percentile of the overall losses. The results assuming no clutter and traditional buildings span from 0.25 km to 25.5 km, whereas for thermally efficient buildings they span from 0 km to 19.75 km. The results assuming clutter and traditional buildings span from 0 km to 0.26 km, whereas for thermally efficient buildings they span from 0 km to 0.25 km.

Two Monte Carlo studies were carried out. Results from a large number of Monte Carlo events show that the percentage of events for which the short-term threshold (I/N = 19 dB) is not exceeded for more than $4.5 \cdot 10^{-5}$% (which was used as a proxy for short-term protection criterion). The long-term threshold (I/N = -20 dB) is not exceeded for more than 1.7%, which is below 20%. Although there are no clear guidelines given in the regulatory literature regarding the allowed exceedance time for the peak power criterion, considering that the other 2 examined criteria are met, it can be assumed that this criterion is also met.

A simultaneous assessment of RLAN and UWB systems has not been done. Given that the significantly lower interference levels of UWB compared to RLAN, a significant increase of the overall impact is not expected.

It is noted that the simulations carried out used space- and time-based distributions for calculating a percentage of interference[10]. Therefore, results are in terms of time-space percentage and not in terms of time percentage only. This needs to be taken into account in the interpretation of results.

6.3 FIXED SATELLITE SERVICE (FSS)

MCL calculations show a maximum separation distance of 25386 m from the FSS receiver for the LOS scenario. Taking into account vertical geometries and the corresponding elevation angles this distance can be reduced to 156 m, even without taking clutter into account.

For NLOS scenarios the maximum separation distance is 1428 m from the FSS receiver. Taking into account vertical geometries this distance can be reduced to 156 m.

Outside of the FSS main beam, the minimum separation distance is about 34 m without applying any clutter.

The MCL calculations included in this Report are based on the assumption of a FSS systems operating in dense urban environments. The compatibility studies take into account the FSS antenna patterns for an elevation of 10° and the relative heights of 20 m between the FSS antenna and the UWB devices. Different dish sizes have been considered. Only the outdoor UWB deployment has been taken into account.

For all dish sizes above 3 m, the minimum separation distance in main beam direction of the FSS is 30 m in the considered urban environment. For smaller antenna dish sizes this distance increases to 190 m for a dish size of 1.8 m and 250 m for a dish size of 1.2 m in the considered urban environment.

MCL calculations for FSS systems operating in rural environment have not been considered.

Aggregate interference studies using Monte-Carlo methodology show that the long term and short-term interference criterion is met in all scenarios for mean and peak e.i.r.p. based on a sensitivity analysis on the difference of FSS deployment in rural and urban environment with specific FSS height and dish antenna diameter associated to their deployment as well as on the size of the exclusion zone and elevation angle.

6.4 RADIO ASTRONOMY SERVICE (RAS)

For the investigation of any potential compatibility issues between UWB and RAS, an extensive analysis has been performed taking into account single entry scenarios and aggregation scenarios with the focus on outdoor deployments.

For the compatibility with the RAS, the local Tx-side clutter zone type and the Tx antenna heights play a key role. As long as (all) antennas of an installation are within the clutter, no interference at the RAS observatory is expected once the UWB device is beyond about 1 km distance. However, some of the proposed usage scenarios involve relatively high antennas, which can at least in part exceed the local clutter heights and will utilise a relatively high number density of devices and activity factors. In these cases, coordination with the RAS on a national level will be necessary in a given area around the RAS stations. Based on generic (flat-terrain) analyses, the coordination zone could be of the order of 10 km radius around a site, but local terrain and clutter properties would permit to install devices in a fair number of positions within such a coordination zone without putting RAS operations in danger.

The results for the vehicular-to-vehicular case show that for UWB devices attached to vehicles compatibility with RAS is given for most sites that were studied here. This is owing to the low traffic density and the clutter conditions around the stations. In fact, RAS stations are in most cases purposefully located in remote areas for exactly this reason. A minimal separation distance of 0.5 km to 1 km should suffice for adequate protection. Unfortunately, for the Jodrell Bank station the situation is somewhat worse, as there is more traffic and higher population density in the area than can be found at the other RAS sites. Here, an exclusion zone of up to 4-5 km may be needed. Taking into account that the considered activity factor of 0.4% in the V2V investigation is

[10] There are ongoing studies within ECC to provide a methodology on how to derive “short term” protection criteria for FS for any sharing and compatibility studies. The results were not yet available at the time of publication of this report

significantly higher than the assumed activity factor for this kind of application (AF ≤ 0.04%) this exclusion or control zone could be changed when the real AFs are taken into account.

6.5 SPACE SCIENCE SERVICES

6.5.1 EESS (SPACE-TO-EARTH), SRS (SPACE-TO-EARTH) AND METEOROLOGICAL-SATELLITE SERVICE (SPACE-TO-EARTH)

The single-entry studies included in the Report show mitigation distances between 300 m and 3600 m for a UWB device operating with 100% duty cycle and assuming a LoS path towards the installations.

In addition, aggregated interference investigations have been performed, taking into account the UWB applications deployments assumed in this Report. The calculations of aggregated interference into SRS/EESS/MetSat earth stations, assuming flat terrain around the Earth stations, without consideration of clutter, show that the SRS/EESS/MetSat protection criteria are met with the application of the following minimal separation distances between the concerned earth stations and any UWB application:

- For UWB fixed outdoor installation:
  - 2 km around SRS earth station for near Earth SRS missions and 1.5 km for deep space SRS missions;
  - 100 m around EESS and MetSat earth station.
- For UWB vehicle installation
  - 10 km around SRS earth station for near Earth SRS missions and 8 km for deep space SRS missions;
  - 700 m around EESS earth station;
  - 400 m around MetSat earth station.

Additional site specific simulations have been performed for UWB vehicles installations to assess the impact of considering terrain and clutter on the required separations distances. These simulations show that the consideration of terrain and clutter, as appropriate, leads to significantly lower separation distances:

  - 5 km around the SRS earth station located in Cebreros (Spain), when considering terrain without additional clutter;
  - 300 m around the SRS earth station located in Cebreros (Spain), when considering terrain with additional clutter (17 dB) around the UWB stations;
  - 500 m around the EESS station located in Weilheim (Germany) when considering terrain without additional clutter.

In the case of UWB indoor positioning applications, it is anticipated that the indoor to outdoor attenuation together with additional factors (such as body loss and clutter loss and the separation distances between indoor UWB deployments and SRS/EESS/MetSat earth stations) would provide enough mitigation to avoid interference from the specific UWB indoor deployments considered in this Report to SRS/EESS/MetSat earth stations. This scenario was therefore not addressed in these aggregated interference assessments.

6.5.2 EESS (EARTH-TO-SPACE), SRS (EARTH-TO-SPACE) AND METEOROLOGICAL-SATELLITE SERVICE (EARTH-TO-SPACE)

No impact from UWB systems is expected into EESS, SRS and MetSat spacecraft receivers in the context of the ECC Report.

6.5.3 EESS(PASSIVE) USED UNDER RR NO. 5.458 (6425-7250 MHZ)

The spectrum sharing studies with EESS passive sensors in the band 6425 MHz to 7250 MHz show negative interference margin for most of the proposed applications and corresponding interference scenarios considered in this Report. This applies to both the single-entry and the aggregate interference calculations.

However, the degradation of the radio environment experienced by EESS passive sensors caused by the applications presented in this Report is expected to be generally smaller than that caused by the operation of generic UWB devices based on the existing regulation in ECC Decision (06)04 and the related assumed activity factors and device densities in ECC Report 64 [5].

ANNEX 1: ECA TABLE 6-8.5 GHZ

Frequency band	Allocations	Applications
5925.000-6700.000	Fixed Fixed-Satellite (Earth-to-space) Earth Exploration-Satellite (passive)	ESV Radiodetermination Radio astronomy FSS Earth stations Passive sensors (satellite) Fixed UWB
6700.000-7075.000	Fixed Earth Exploration-Satellite (passive) Fixed-Satellite (Earth-to-space) (space-to-Earth)	Feeder links UWB PMSE Fixed Passive sensors (satellite) FSS Earth stations Radiodetermination
7075.000-7145.000	Fixed Earth Exploration-Satellite (passive)	Radiodetermination Passive sensors (satellite) Fixed PMSE UWB
7145.000-7190.000	Fixed Mobile Space Research (deep space) (Earth-to-space) Space Operation (Earth-to-space)	Radiodetermination UWB PMSE Fixed
7190.000-7235.000	Fixed Space Research (Earth-to-space) Mobile Earth Exploration-Satellite (Earth-to-space)	Fixed PMSE UWB Radiodetermination Passive sensors (satellite)
7235.000-7250.000	Fixed Earth Exploration-Satellite (Earth-to-space) Space Research (Earth-to-space)	Passive sensors (satellite) Radiodetermination UWB PMSE Fixed
7250.000-7300.000	Fixed Fixed-Satellite (space-to-Earth) Mobile	Fixed PMSE UWB Radiodetermination MSS Earth stations Land military systems Satellite systems (military)
7300.000-7375.000	Fixed Fixed-Satellite (space-to-Earth)	Satellite systems (military) Land military systems

Frequency band	Allocations	Applications
	Mobile except aeronautical mobile	MSS Earth stations Radiodetermination UWBs PMSE Fixed
7375.000-7450.000	Fixed Fixed-Satellite (space-to-Earth) Mobile except aeronautical mobile Maritime Mobile-Satellite (space-to-Earth)	Fixed PMSE Radiodetermination UWB MSS Earth stations Land military systems Satellite systems (military)
7450.000-7550.000	Maritime Mobile-Satellite (space-to-Earth) Fixed Fixed-Satellite (space-to-Earth) Meteorological-Satellite (space-to-Earth) Mobile except aeronautical mobile	Land military systems Weather satellites Satellite systems (military) Radiodetermination UWB PMSE Fixed
7550.000-7750.000	Fixed Fixed-Satellite (space-to-Earth) Mobile except aeronautical mobile Maritime Mobile-Satellite (space-to-Earth)	PMSE UWB Fixed Radiodetermination Land military systems Satellite systems (military)
7750.000-7900.000	Fixed Meteorological-Satellite (space-to-Earth) Mobile except aeronautical mobile	Weather satellites Radiodetermination Fixed UWB PMSE
7900.000-8025.000	Fixed Mobile Fixed-Satellite (Earth-to-space)	PMSE Fixed UWB Radiodetermination MSS Earth stations Satellite systems (military) Land military systems
8025.000-8175.000	Fixed-Satellite (Earth-to-space) Earth Exploration-Satellite (space-to-Earth) Fixed Mobile	Land military systems Land mobile Satellite systems (military) Radiodetermination Earth exploration-satellite UWB

Frequency band	Allocations	Applications
		PMSE Fixed
8175.000-8215.000	Earth Exploration-Satellite (space-to-Earth) Fixed Meteorological-Satellite (Earth-to-space) Mobile Fixed-Satellite (Earth-to-space)	Fixed PMSE UWB Earth exploration-satellite Radiodetermination Satellite systems (military) Land military systems Land mobile
8215.000-8400.000	Fixed-Satellite (Earth-to-space) Earth Exploration-Satellite (space-to-Earth) Fixed	Satellite systems (military) Land military systems Radiodetermination Earth exploration-satellite Radio astronomy UWB PMSE Fixed
8400.000-8500.000	Fixed Space Research (space-to-Earth) Radiolocation	PMSE Fixed UWB Radiodetermination Space research

ANNEX 2: SURFACE PLOTS FOR MCL EVALUATIONS

A2.1 INTRODUCTION

In the following section, MCL calculations are evaluated over a two-dimensional surface contour plot, representing the scenarios given in Table 5. The receiver is placed at the position (0,0), directed to the right. For all the respective points on the surface, the impact of an UWB device on the receiver is evaluated, taking into account the antenna patterns. The red contour shows the two dimensional separation distance. The coloured areas highlight the amount to which the results lie above or below the criterion *I/N*. The parameters used and also the results are noted on the plots, respectively. Propagation models were used as described in the body of the Report.

Peak radius results represent the maximum range of interference coming from the height level of the UWB device, when a constant ground level of 0 m is assumed. This is usually located in the main lobe direction.

Circle radius results represent the minimum range of interference coming from the height level of the UWB device, when a constant ground level of 0 m is assumed. This is usually located in the back lobe area.

A2.2 PLOTS FS COMPATIBILITY

The below table gives an overview of the total six scenarios, including the one shown in the body of the Report.

Scenario 1 and 2 describe the "UWB outdoor" scenario. Scenario 1 used a FS link with higher peak gain, Scenario 2 with lower peak gain.

Scenario 3 and 4 describe the "UWB indoor" scenario. Scenario 3 used a FS link with higher peak gain, Scenario 4 with lower peak gain.

Scenario 5 and 6 describe "UWB peak outdoor" scenario. Scenario 5 used a FS link with higher peak gain, Scenario 6 with lower peak gain.

Table 82: Overview of MCL scenarios for FS compatibility studies

Parameter	Scenario 1/2 "UWB mean outdoor"	Scenario 3/4 "UWB indoor"	Scenario 5/6 "UWB peak outdoor"
Frequency	6.0 GHz		
FS Antenna Pattern	Recommendation ITU-R F.699		
UWB Antenna Pattern mitigation	5 dB / 0 dB		
UWB Antenna height	5 m		
FS Antenna height	25 m		
FS antenna gain	46.6 dBi / 38.7 dBi		
FS Feeder loss	2 dB / 1.3 dB		
FS Receiver Noise Figure	4 dB		
UWB e.i.r.p. max	-41.3 dBm/MHz	-31.3 dBm/MHz	-17 dBm/MHz
Clutter Loss (P.2108 [23])	Not used, 1%, 10%, 50%, 90%		

Parameter	Scenario 1/2 "UWB mean outdoor"	Scenario 3/4 "UWB indoor"	Scenario 5/6 "UWB peak outdoor"
Building entry loss	0 dB	>= 16.6 dB, depending on vertical angle	0 dB
Polarisation loss	0 dB		
Body loss	0 dB		
Protection criterion I/N	-20 dB	-20 dB	5 dB

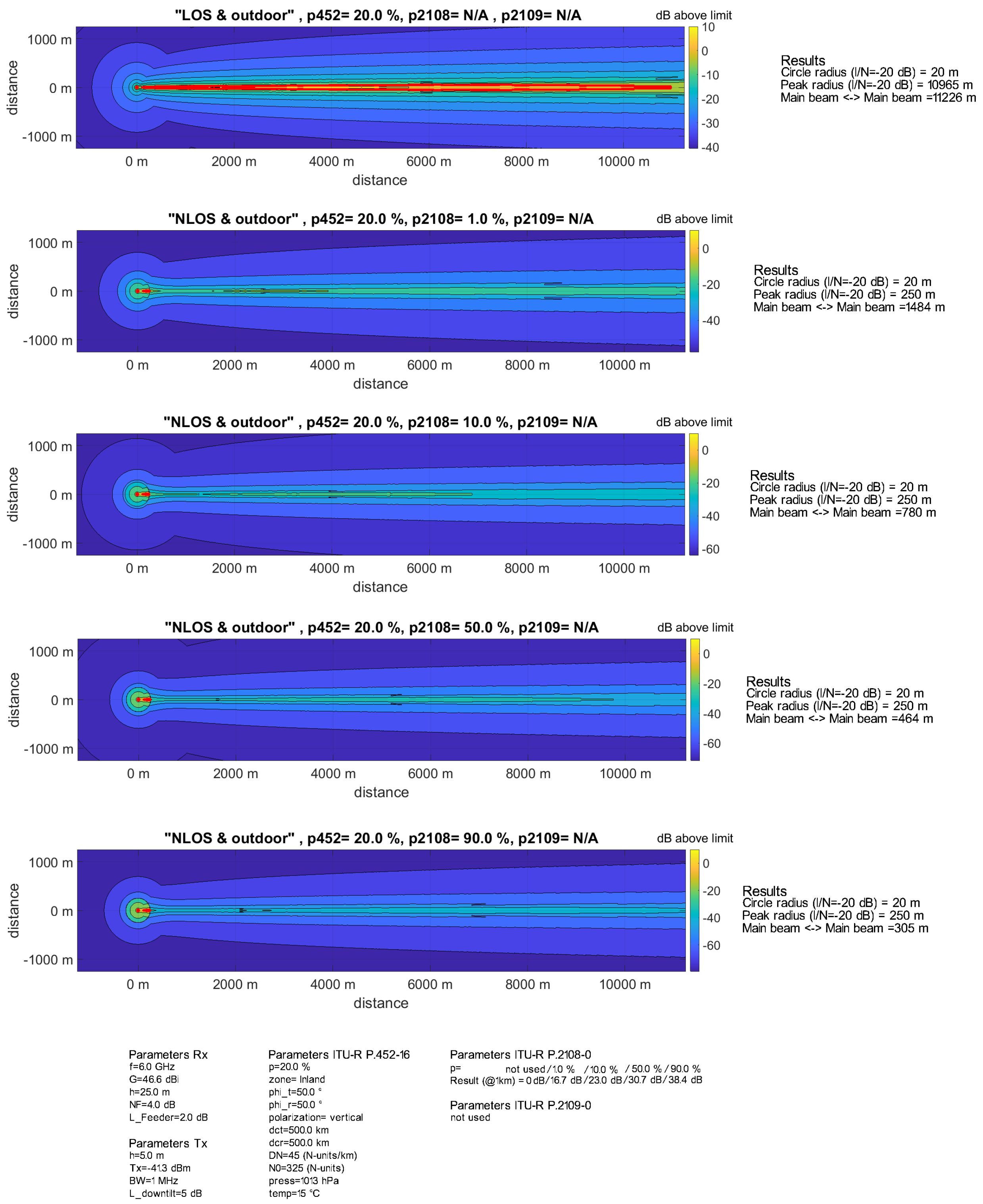


Figure 83: Scenario 1 "UWB Outdoor, FS high gain", variation of Clutter probability

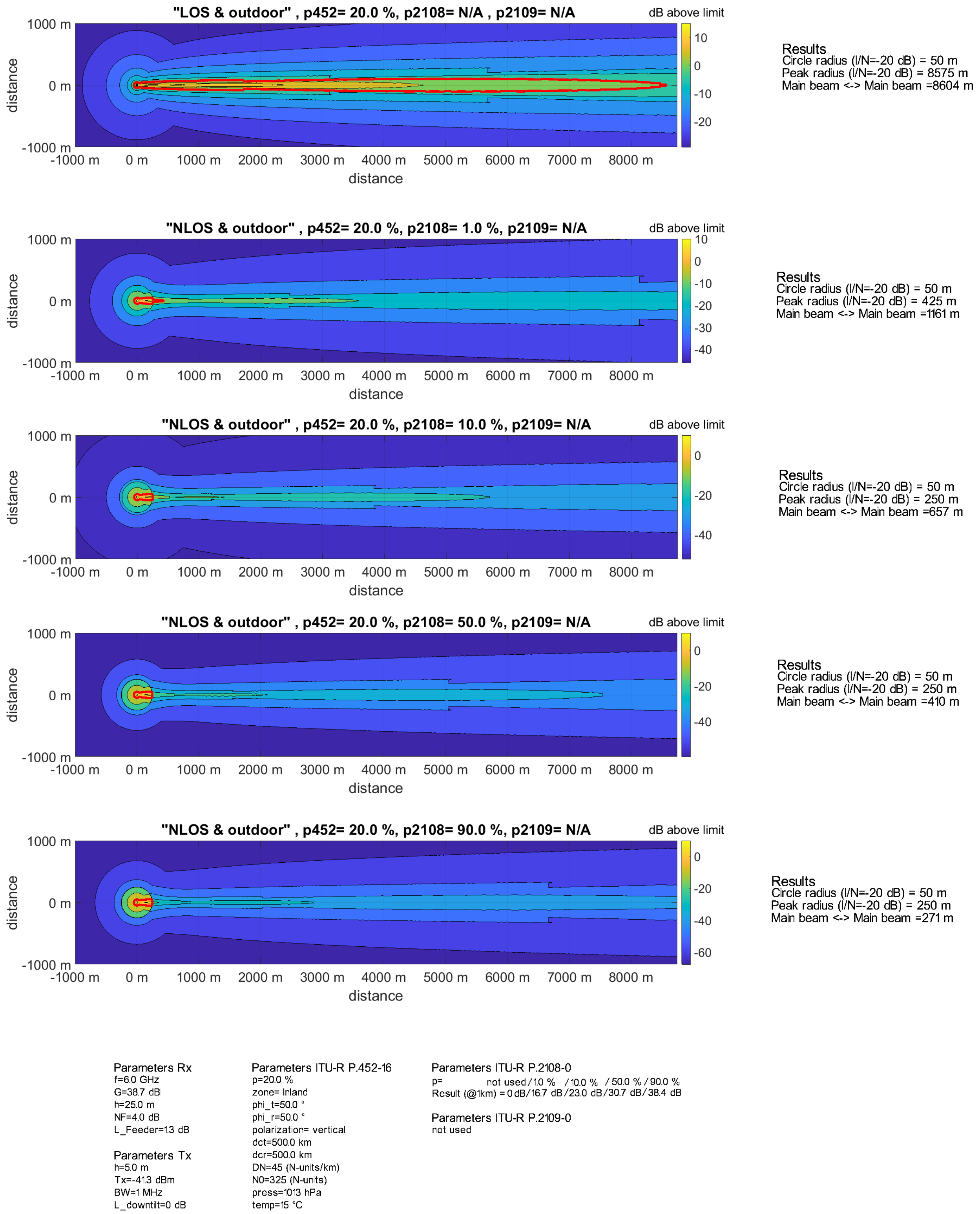


Figure 84: Scenario 2 "UWB Outdoor, FS low gain", variation of Clutter probability

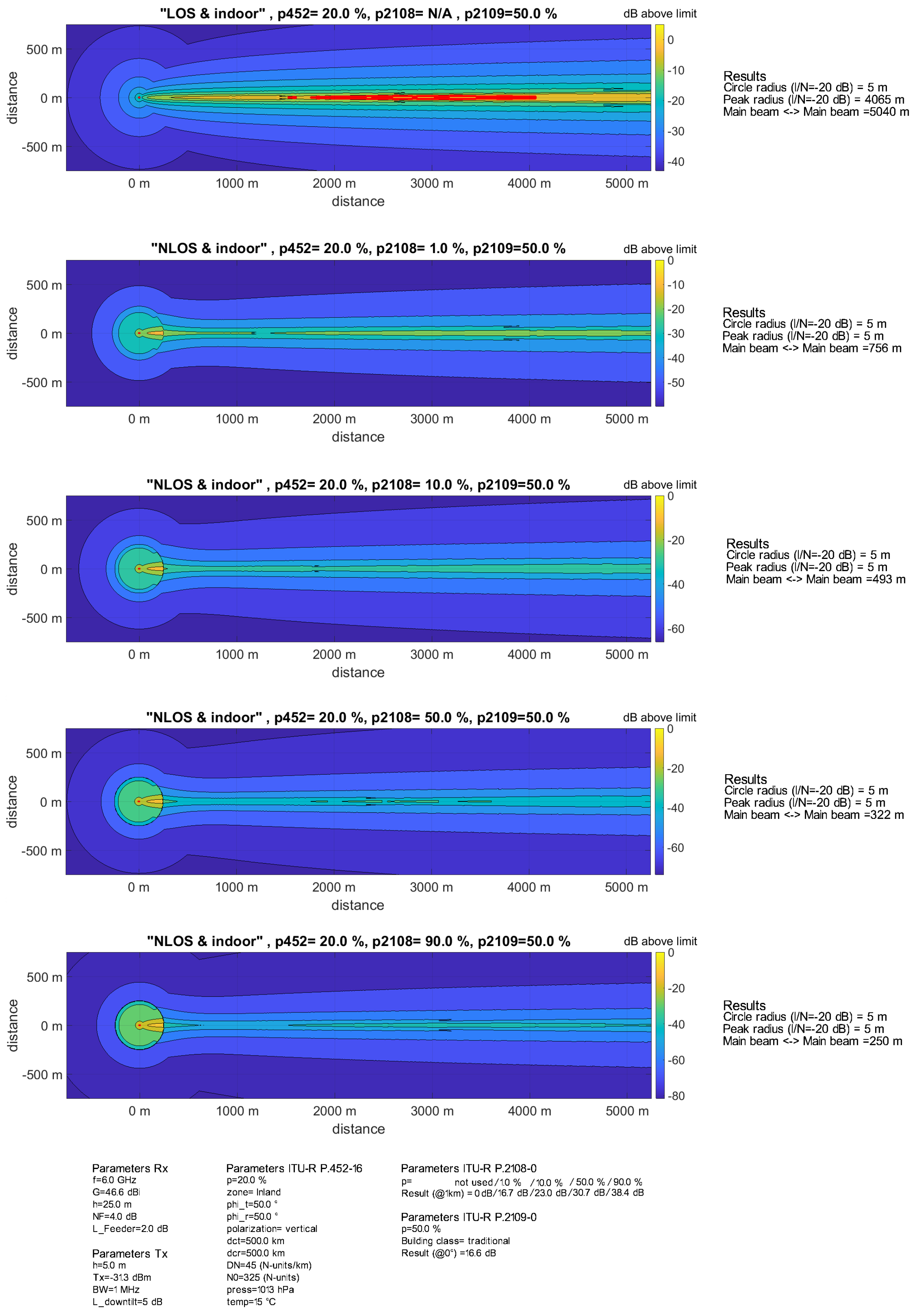


Figure 85: Scenario 3 "UWB Indoor, FS high gain", variation of Clutter probability

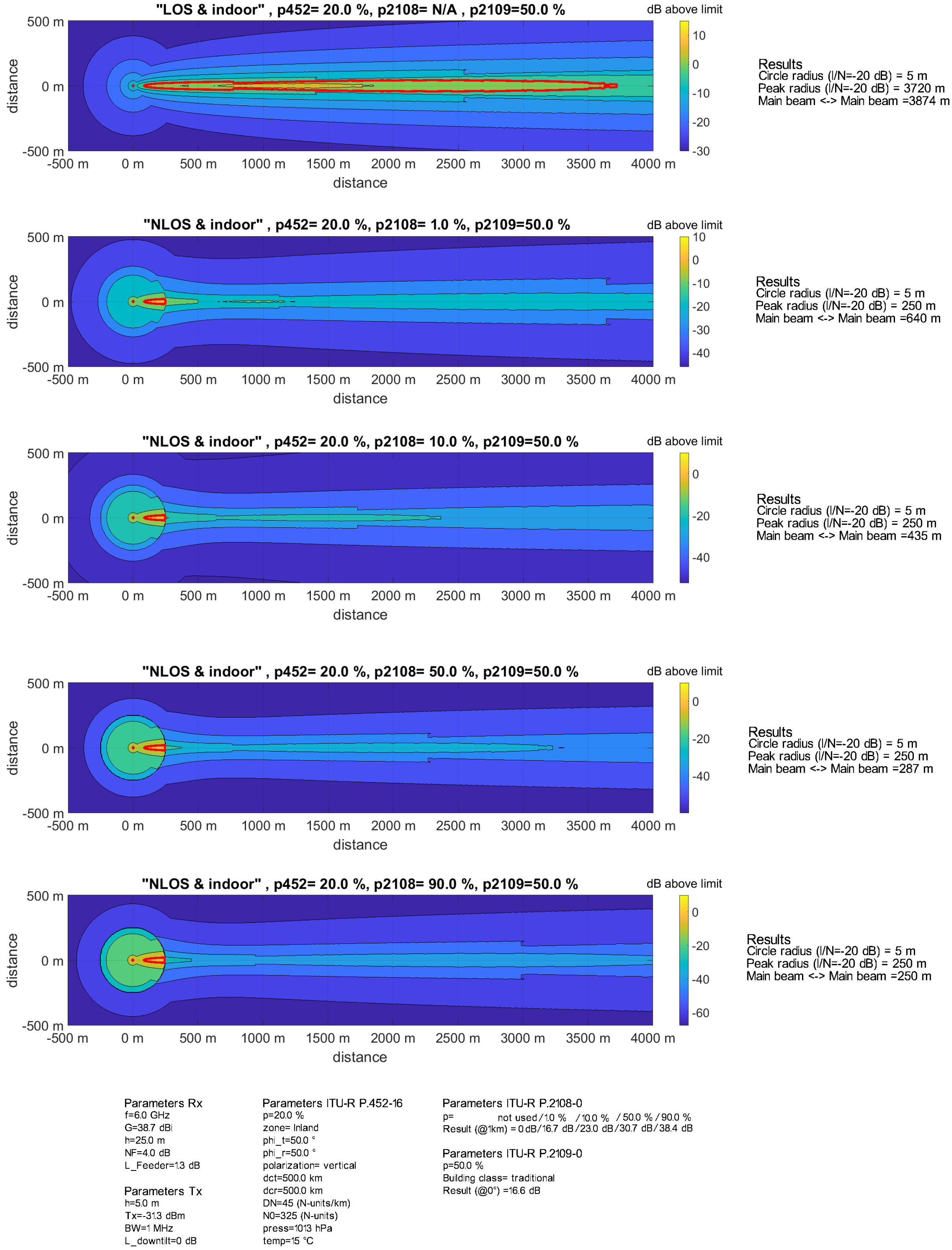


Figure 86: Scenario 4 "UWB Indoor, FS low gain", variation of Clutter probability

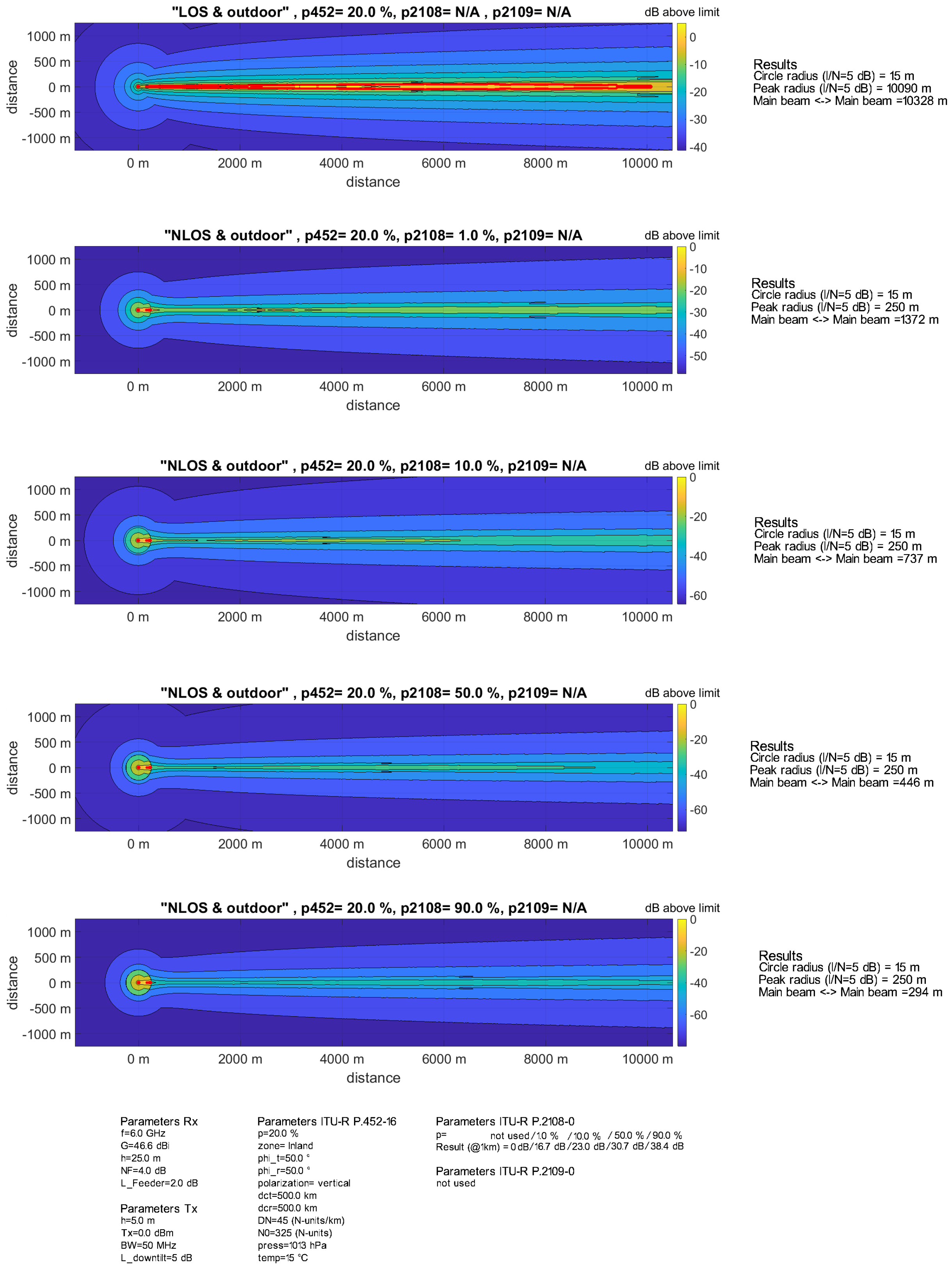


Figure 87: Scenario 5 "UWB peak Outdoor, FS high gain", variation of Clutter probability

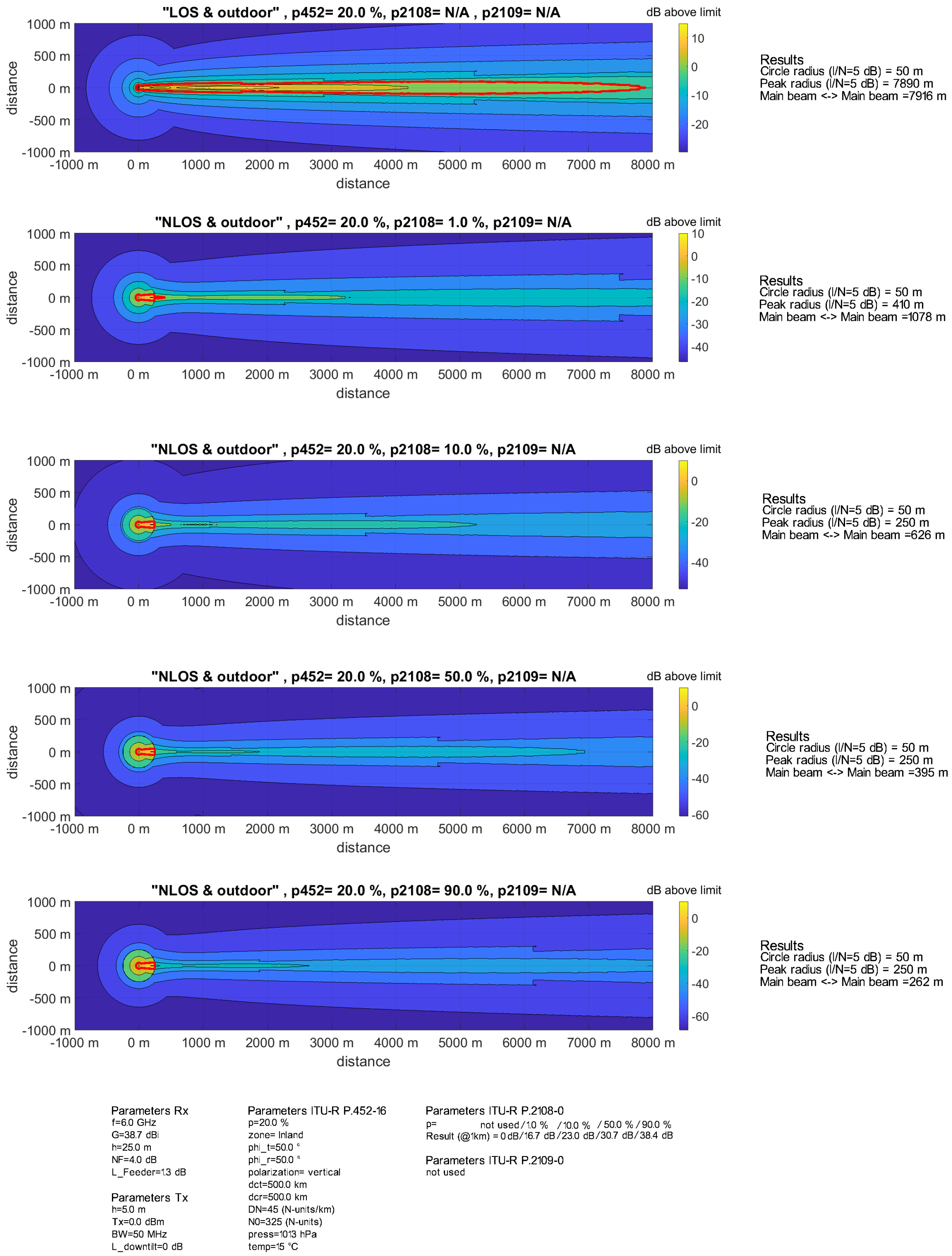


Figure 88: Scenario 6 "UWB peak Outdoor, FS low gain", variation of Clutter probability

A2.3 PLOTS FSS COMPATIBILITY

The below table gives an overview of the total six scenarios, including the one shown in the body of the Report.

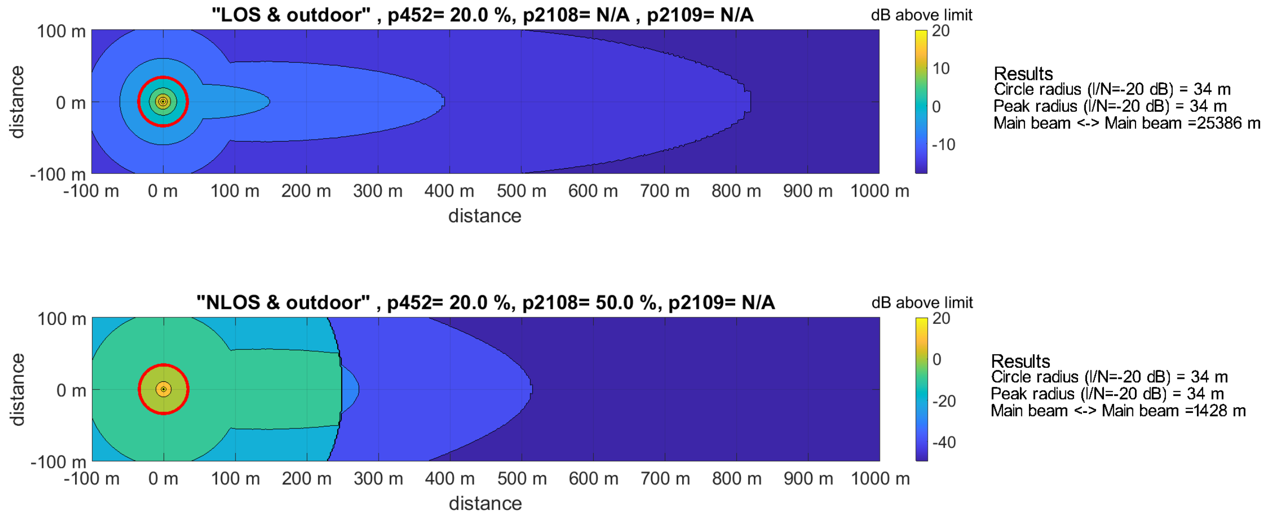
Scenario 1 and 2 describe the "UWB outdoor" scenario. Scenario 1 used a FSS link with higher peak gain, Scenario 2 with lower peak gain.

Scenario 3 and 4 describe the "UWB indoor" scenario. Scenario 3 used a FSS link with higher peak gain, Scenario 4 with lower peak gain.

Scenario 5 and 6 describe "UWB peak outdoor" scenario. Scenario 5 used a FSS link with higher peak gain, Scenario 6 with lower peak gain.

Table 83: Overview of MCL scenarios for FSS

Parameter	Scenario 1/2 "UWB mean outdoor"	Scenario 3/4 "UWB indoor"	Scenario 5/6 "UWB peak outdoor"
Frequency	7.575 GHz		
FSS Antenna Pattern	RR Appendix-7 (WRC-07)		
UWB Antenna Pattern mitigation	5 dB	0 dB	5 dB
UWB Antenna height	5 m		
FSS Antenna height	25 m		
FSS maximum antenna gain	49.2 dBi / 31.5 dBi		
FSS antenna gain horizon	4 dBi / 12.2 dBi		
FS Feeder loss	2 dB		
FSS Receiver Noise Figure	0.95 dB / 1.5 dB		
UWB e.i.r.p. max	-41.3 dBm/MHz	-31.3 dBm/MHz	-17 dBm/MHz
Clutter Loss (P.2108 [23])	[Not used, 50%]		
Building entry loss	0 dB	>= 16.6 dB, depending on vertical angle	0 dB
Polarisation loss	0 dB		
Body loss	0 dB		
Protection criterion I/N	-20 dB	-20 dB	5 dB



Parameters Rx
f=7.575 GHz
uptilt=10.0 °
Gmax=49.2 dBi
Ghor=4.0 dBi
D=9.0 m
h=25.0 m
NF=0.9 dB
L_Feeder=2.0 dB

Parameters Tx
h=5.0 m
Tx=-41.3 dBm
BW=1 MHz
L_downtilt=5 dB

Parameters ITU-R P.452-16
p=20.0 %
zone= Inland
phi_t=50.0 °
phi_r=50.0 °
polarization= vertical
dct=500.0 km
dcr=500.0 km
DN=45 (N-units/km)
N0=325 (N-units)
press=1013 hPa
temp=15 °C

Parameters ITU-R P.2108-0
p= not used / 50.0 %
Result (@1km) = 0 dB / 31.6 dB

Parameters ITU-R P.2109-0
not used

Figure 89: Scenario 1 "UWB mean Outdoor, FSS high gain", variation of Clutter probability

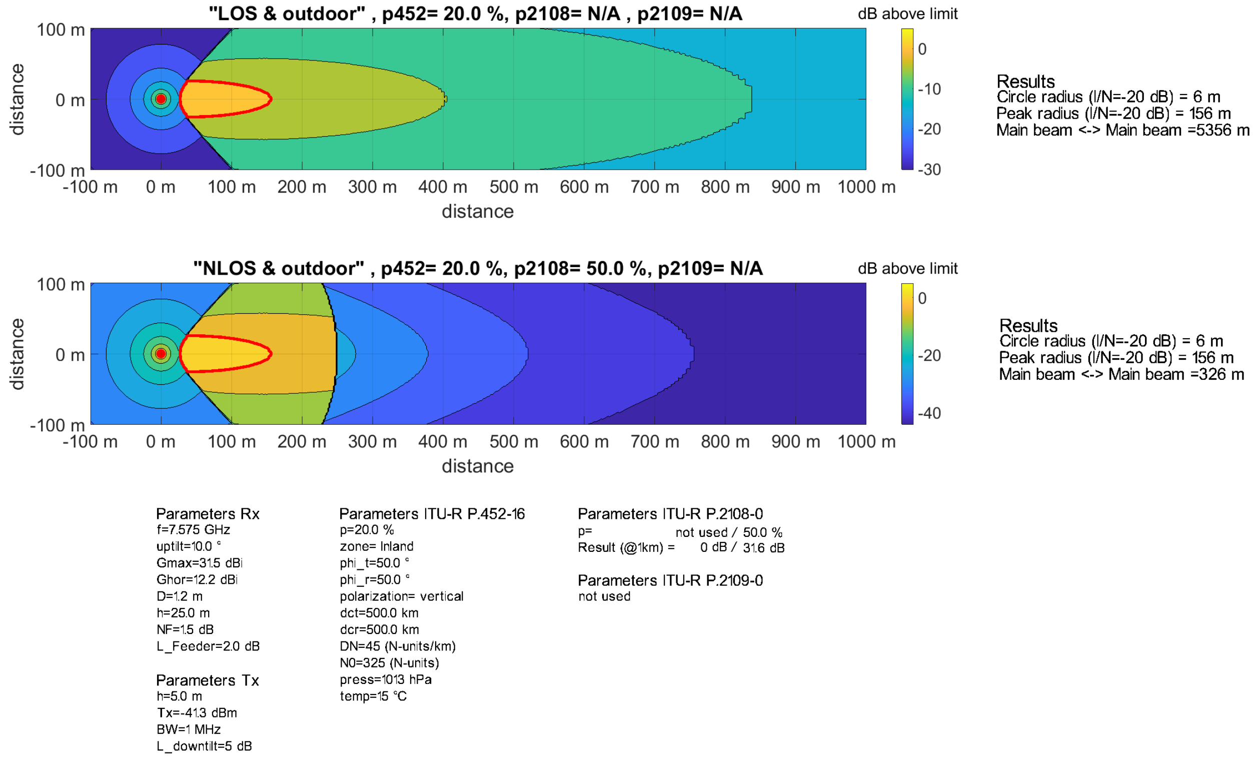


Figure 90: Scenario 2 "UWB mean Outdoor, FSS low gain", variation of Clutter probability

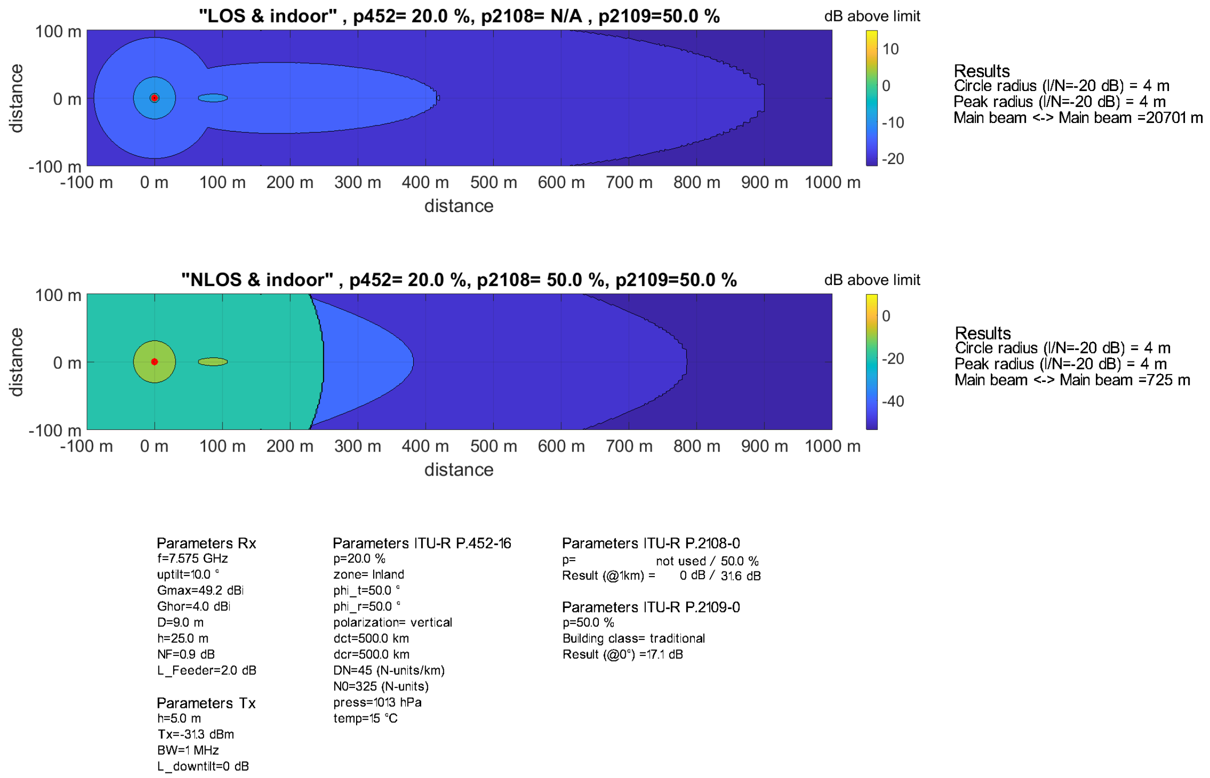


Figure 91: Scenario 3 "UWB Indoor, FSS high gain", variation of Clutter probability

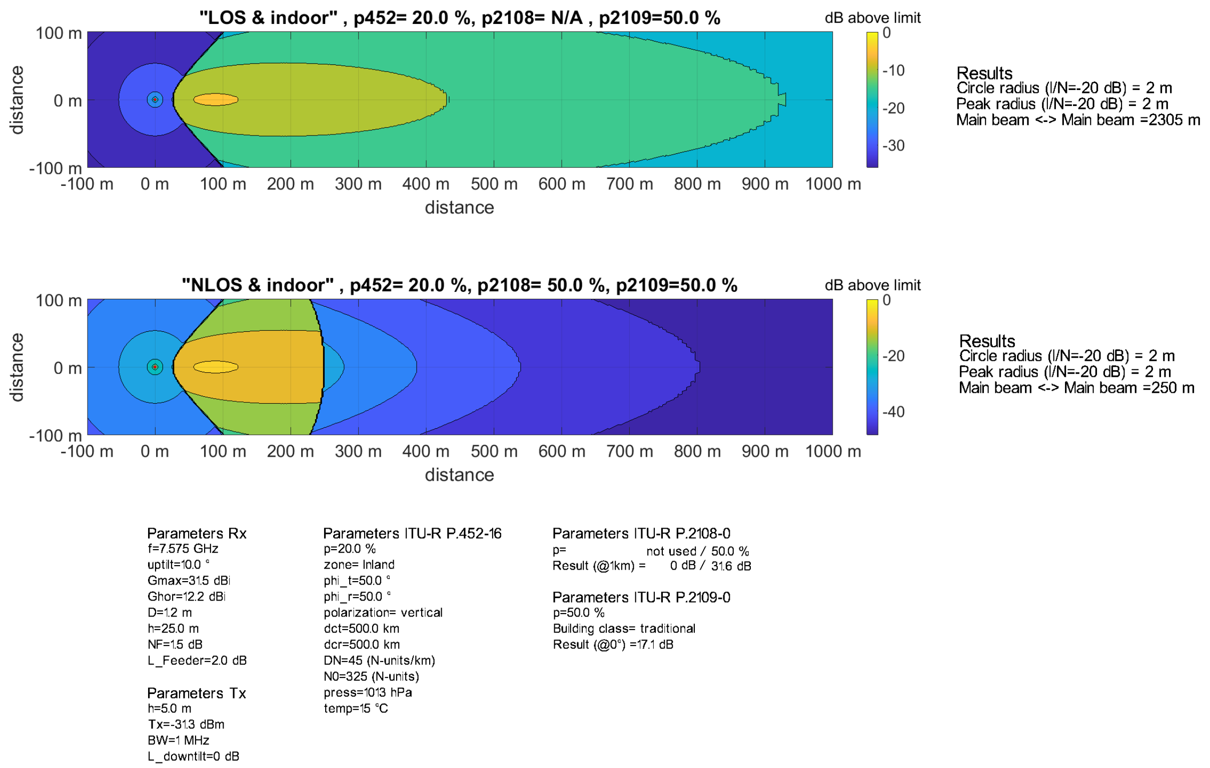


Figure 92: Scenario 4 "UWB Indoor, FSS low gain", variation of Clutter probability

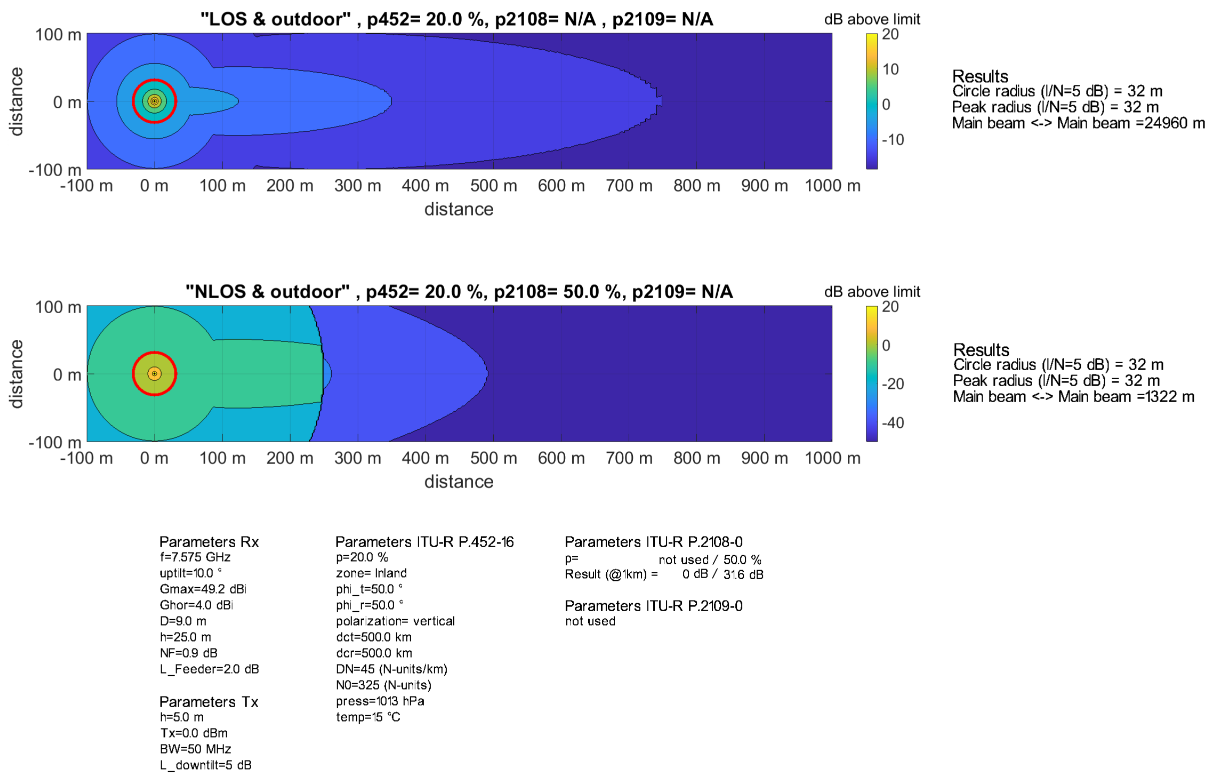


Figure 93: Scenario 5 "UWB peak Outdoor, FSS high gain", variation of Clutter probability

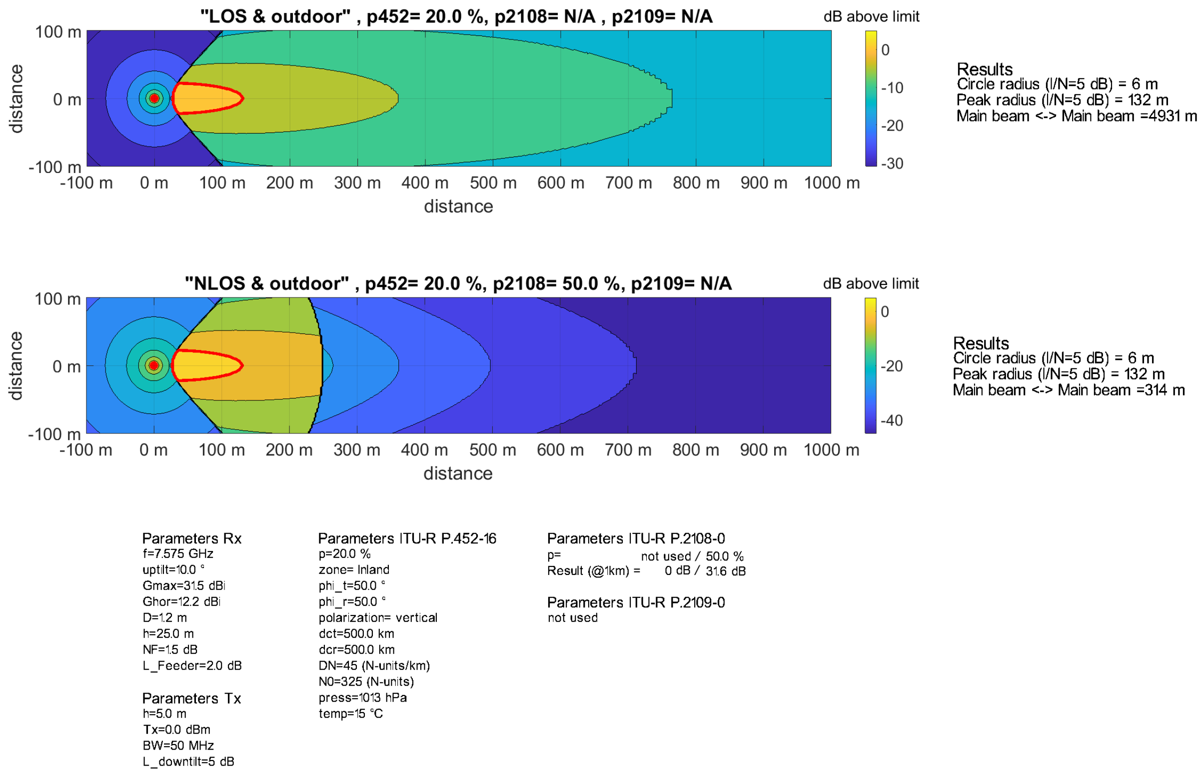


Figure 94: Scenario 6 "UWB peak Outdoor, FSS low gain", variation of Clutter probability

ANNEX 3: FS PEAK POWER CONSIDERATIONS

A3.1 INTRODUCTION

In the UWB regulation world-wide typically two TX powers are regulated:

1 Maximum mean power density in dBm/MHz e.i.r.p. (typically -41.3 dBm/MHz) and

2 Maximum peak power in dBm/50 MHz e.i.r.p. (typically 0 dBm/50 MHz)

Both values have to be fulfilled in order to be compliant with the UWB regulatory framework.

The first rule dictates the maximum mean Power Spectral Density (PSD), i.e., the radiated power within a given bandwidth when averaged over 1 ms:

$$PSD_{mean} \leq -41.3 \text{ dBm / MHz (74 nW per MHz)} \quad (6)$$

The second rule imposes a limit on how strong a single pulse can be transmitted. It basically limits the power of the UWB signal to 0 dBm when passing it through a filter of a bandwidth of 50 MHz:

$$PSD_{peak} \leq 0 \text{ dBm / 50 MHz (1mW in 50 MHz)} \quad (7)$$

Assuming 500 MHz of bandwidth (pulse duration t_p equal to 2 ns), we obtain a maximum average power of 37 μW by multiplying the 500 MHz of bandwidth with the maximum spectral density of 74 nW/MHz.

The mean power and the peak power are interrelated and mainly connected by the pulse repetition rate of the UWB signal. For frequency hopping signal the dwell time can be taken to describe this interrelation.

A 3.2 PEAK POWER IN THE TIME DOMAIN

A 3.2.1 Derivation

The first rule (mean power limitation to -41.3 dBm/MHz) states that the maximum PSD_{mean} has to be averaged over at most 1 ms, which translates into 37 nJ of transmitted energy in 1 ms. This means that during one millisecond, we could theoretically send just one very strong pulse with a maximum full band peak power depending on the pulse duration t_p. Taking this theoretical ideal numerical case above with t_p equal to 2 ns and P_{TX} equal to 37 μW (-14.3 dBm in 500 MHz) yields a full band peak power of 18 W (+42.7 dBm) as shown in Figure 95. This pulse would then have a pulse duty cycle of 2 ns/1 ms = 0.0002% and a flat peak power spectrum in the complete 500 MHz operation frequency range.

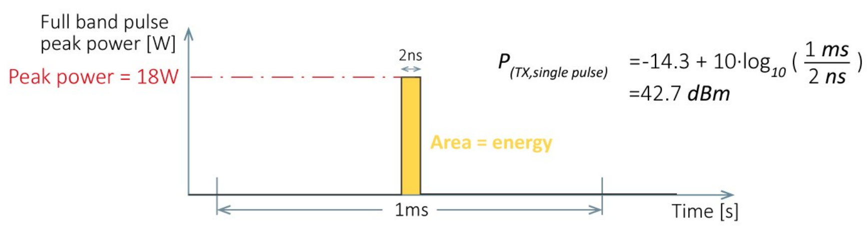


Figure 95: Example peak power without peak power limit definition [37]

The second rule (peak power limit of 0 dBm/50 MHz) however limits the instantaneous pulse peak power to a value that shall not exceed 0 dBm when passing the signal through a 50 MHz bandwidth filter (i.e., 10% of the energy of the original 500 MHz wide signal but 10 times higher duration). This translates into a full band signal peak power of +20 dBm [38], which is 22.7 dB lower than when only the first rule is applied. Therefore, to comply with both rules and maximize the transmitted energy per pulse, we can transmit around 186 (=

10(+22.7/10)) pulses of +20 dBm (500 MHz bandwidth). Therefore, the mean pulse repetition rate of transmission becomes 1 ms /186 pulses = 5.3 µs = 186 kHz [38].

Worldwide any UWB regulation strictly limit the amount of pulse energy (yellow area in figures) that can be sent during 1 ms in a given spectrum band. In Figure 96, a comparison of these considerations is given for a low rate (LRP) and a high rate (HRP) UWB system.

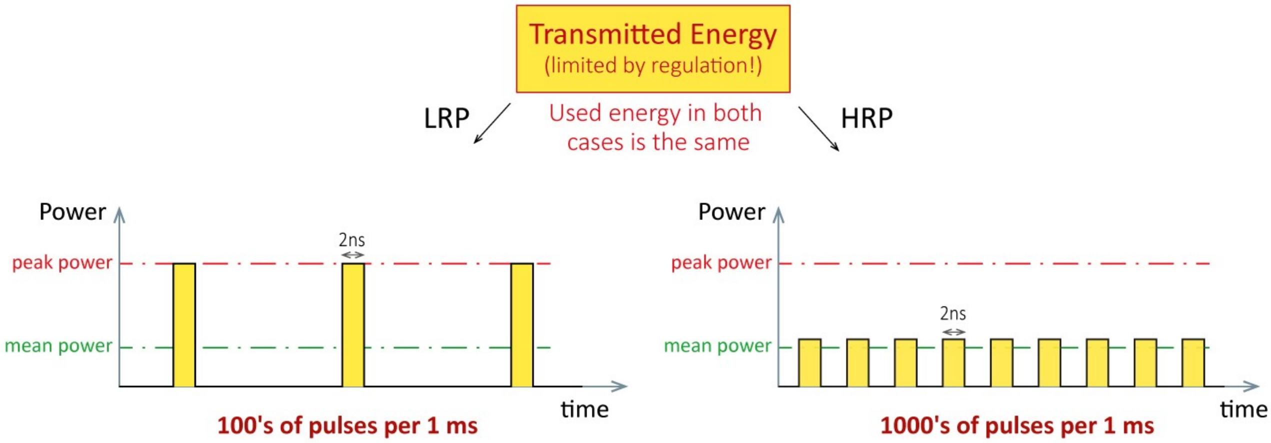


Figure 96: Comparison of low rate (LRP) and high rate (HRP) UWB [37]

Increasing the number of pulses sent in 1 ms leads to a reduction of the pulse peak power.

As mentioned above for a low rate UWB system with a repetition rate $R \leq$ 186 kHz and an ideal flat bandwidth of 500 MHz each pulse of 2 ns duration can reach the peak power limit of 0 dBm/50 MHz.

In a typical FS system with 25 MHz bandwidth this would lead to an interference power P_i of [38]:

$$\text{Pi} = 0\,\text{dBm}/50\,\text{MHz} * 20\log(25\,\text{MHz}/50\,\text{MHz}) = -6\,\text{dBm}/25\,\text{MHz} \quad (8)$$

The corresponding pulse duty cycle (*PDC*) in 500 MHz is:

$$\text{PDC}_{500\text{MHz}} = 1.86 * 105 * 2\text{ns}/1\text{s} = 0.0372\% \quad (9)$$

If one now filters this signal with a 25 MHz bandpass filter the duration of the pulse will increase by the factor 500 MHz/25 MHz = 20. The pulse duty cycle in 25 MHz $\text{PDC}_{25\text{MHz}}$ and in 30 MHz $\text{PDC}_{30\text{MHz}}$ is given by:

$$\text{PDC}_{25\text{MHz}} = 1.86 * 105 * 2\text{ns} * 20/1\text{s} = 0.744\% \quad (10)$$

$$\text{PDC}_{30\text{MHz}} = 1.86 * 105 * 2\text{ns} * 16{,}67/1\text{s} = 0.62\% \quad (11)$$

In Figure 97, the behaviour of a pulse in the time domain using different resolution band widths (RBW) is depicted. It can be seen that the pulse width in time domain increases by a decrease of the RBW of the measurement equipment. This effect is equivalent to the behaviour of a RX filter with a specific bandwidth.

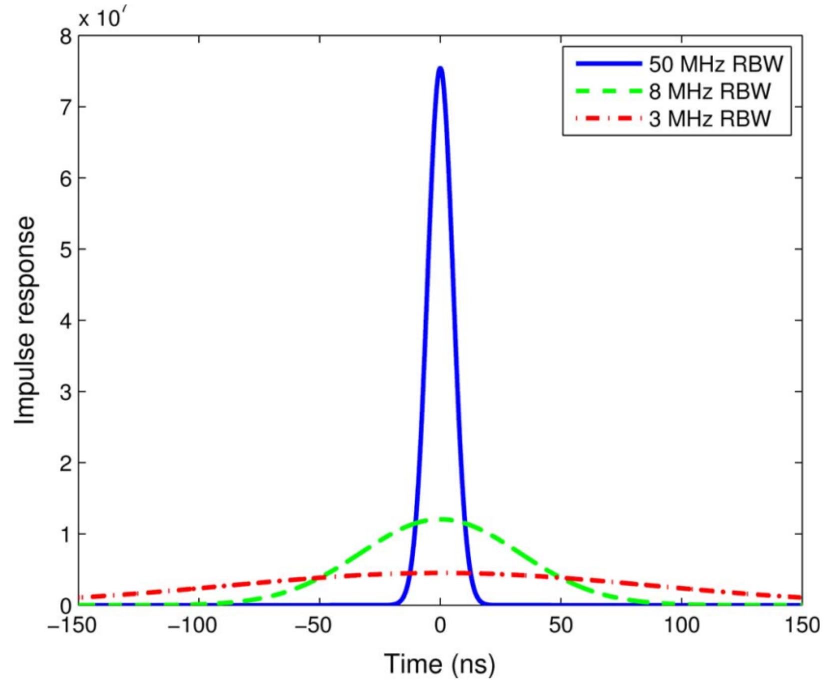


Figure 97: Impulse response in time domain using different filters/resolution band width (RBW) [39]

We can also calculate the maximum peak power density in 30 MHz:

$$PSD_{peak\_30\ MHz} = 0\ dBm/50\ MHz * 20log10(30\ MHz\ /50\ MHz) = -4.4\ dBm/30\ MHz \quad (12)$$

For any given band of 30 MHz bandwidth in the operational frequency range (OFR) of the UWB devices this is the maximum peak power level under the assumption that the peak power is constant over the complete OFR of the UWB and the pulse of 2 ns duration is synchronously received at the FS filter input. For real signals both conditions will not be true, neither the peak power is constantly distributed over the OFR nor all pulses will be synchronised with the FS receiver. A typical peak power spectrum is given in Figure 98 taken from [39].

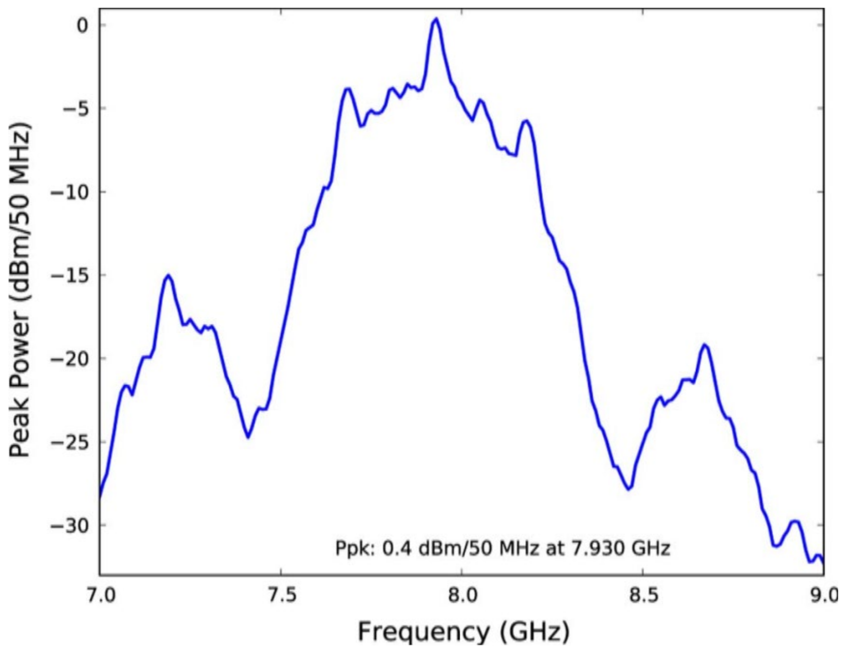


Figure 98: Measured peak power for a complete IEEE 802.15.4a signal [39]

It can be recognised that the peak power limit if 0 dBm/50 MHz is only reached at a specific frequency in the overall OFR.

A. 3.2.2 Short-term interference level range calculation:

The noise floor of an FS system in 30 MHz including 5 dB noise figure is -94.2 dBm.

Thus, the threshold of short-term interference would be -75.2 dBm for an I/N of +19 dB.

Based on that the required pathloss or minimum coupling loss (MCL) from UWB device with an omnidirectional antenna towards an FS receiver with 0 dBi antenna gain in direction of the UWB device can be calculated as follows:

$$75.2\ \text{dBm} - 4.4\ \text{dBm (UWB peak power in 30 MHz)} = 70.8\ \text{dB} \quad (13)$$

This MCL value of 70.8 dB corresponds to LoS separation distance of 12.7 m. If we now assume a down tilt fixed UWB antenna with 5 dB as given in the use case section this value would decrease to 7.1 m.

With this required pathloss (70.8 dB) between the UWB device and the FS antenna, the FS TX with a TX power of 28 dBm into the antenna will generate an interference level of around -42 dBm in the UWB receiver. Taking into account this higher level of interference the UWB system will not correctly operate.

A3.2.3 Peak criterion

In order to take into account the peak power in the calculation we have to take the limit given in Report ITU-R SM.2057 [25]

$$\text{Ip50/Na50} = +5\ \text{dB} \quad (14)$$

With a noise power of N_{a50} = -97 dBmin 50 MHz and a noise figure *NF* of 5 dB the effective noise level in an FS receiver with 50 MHz bandwidth is

$$\text{Na50\_eff} = -92\ \text{dBm} \quad (15)$$

If one now takes the given threshold of $I_{p50}/N_{a50} \leq +5$ dB the interference threshold I_{p50} at the FS receiver is -87 dBm peak.

The required pathloss for a 0d Bm peak power in 50 MHz is 87 dB. This translates into a LoS mitigation distance of 90 m for an assumed 0 dBi FS antenna gain towards the UWB device and including a 5 dB down tilt antenna to around 50 m.

Assuming a 25 MHz bandwidth FS receiver the peak power limit is:

$$I_{p25}/N_{a25} \leq +2\ \text{dB} \quad (16)$$

Note 1:

- $I_{p25} = I_{p50} - 20\log10(50/25) = I_{p50} - 6$ dB
- $N_{a25} = N_{a50} - 10\log10(50/25) = N_{a50} - 3$ dB
- $I_{p25}/N_{a25} = I_{p25}$ [dB] - N_{a25} [dB] = I_{p50} [dB] – 6 dB - N_{a50} [dB] + 3 dB = I_{p50} [dB] - N_{a50} [dB] - 3 dB = 2 dB

Based on the assumption that the noise decreases with 10log and the peak power effect with 20log the criterion I_{p25}/N_{a25} = +2d B is valid.

Including a noise figure NF of 5 dB as above the effective noise level at the FS receiver is:

$$\text{Na25\_eff} = -95\ \text{dBm} \quad (17)$$

Taking the Interference threshold of I_{p25}/N_{a25} ≤ +2 dB we get the peak interference limit of -93 dBm/25 MHz peak. Now this leads to a MCL of 87 dB between the FS receiver and the UWB transmitter. This is the same value as in 50 MHz.

A.3.3 Summary and conclusion

Typical UWB system are limited to the TX energy of 37nJ in 1 ms by set of regulations limiting the mean e.i.r.p. power in 1 MHz during 1 ms (-41.3 dBm/MHz) and the peak e.i.r.p. power in 50 MHz (0 dBm/50 MHz).

The consideration related to peak power interference of pulse based UWB systems into a FS system has to be split into two main parts:

- Long-term interference with a time probability of below 20% and
- Short-term interference with a time probability of below $4.5*10^{-5}$%

For both criterions mean I_a/N_a limits are defined for the mean power levels:

- long-term: I/N ≤ -20 dB;
- short-term: I/N ≤ +19 dB.

For the peak power limits for the long-term criterion ITU-R SM.2057 [25] sets a limit of I_{p50}/N_{a50} ≤ +5 dB for aggregated peak power interference. This level corresponds to a peak power limit of 0 dBm/50 MHz.

For the short-term interference criterion, a detailed signal structure of a UWB pulse system operating with the peak limit (peak limited systems) have to be considered, see [25], annex 2, clause 1.1.1.2. These peak limited systems have a very low peak duty cycle *PDC* of 0.0372% in 500 MHz. This has to be taken into account in the aggregation simulations.

The peak power energy is not continuously distributed over the OFR of the UWB device, see Figure 98 and will have a different distribution for different UWB devices and operational modes. Not all devices in a given area will operate in the peak power limited mode. In the aggregated peak power simulations only the ideal pulses with a flat power distribution are considered.

ANNEX 4: LIST OF REFERENCES

[1] ETSI TR 103 314 V1.1.1 (2016-07): “System Reference document (SRdoc);Short Range Devices (SRD) using Ultra Wide Band (UWB); Technical characteristics for SRD equipment using Ultra Wide Band Sensor technology (UWB) based on amended mitigation techniques for UWB”

[2] ETSI TR 103 416 V1.1.1): Short Range Devices (SRD) using Ultra Wide Band (UWB); Technical characteristics and spectrum requirements for UWB based vehicular access systems for operation in the 3,4 GHz to 4,8 GHz and 6 GHz to 8,5 GHz frequency ranges

[3] ETSI TR 102 495 V1.2.1: “Electromagnetic compatibility and Radio spectrum Matters (ERM) - System Reference Document - Short Range Devices (SRD) - Technical characteristics for SRD equipment using Ultra Wide Band Sensor technology (UWB) - Part 5: Location tracking applications type 2 operating in the frequency bands from 3,4 GHz to 4,8 GHz and from 6 GHz to 8,5 GHz for person and object tracking and industrial applications”

[4] EC Decision 2019/785/EU of 14 May 2019 on the harmonisation of radio spectrum for equipment using ultra-wideband technology in the Union and repealing Decision 2007/131/EC, May 2019

[5] ECC Report 64: “The protection requirements of radiocommunications systems below 10.6 GHz from generic UWB applications”, approved February 2005

[6] CEPT Report 45: Report from CEPT to the European Commission in response to the Fifth Mandate to CEPT on ultra-wideband technology to clarify the technical parameters in view of a potential update of Commission Decision 2007/131/EC, approved June 2013

[7] ECC Report 170: " Specific UWB applications in the bands 3.4-4.8 GHz and 6-8.5 GHz Location Tracking Applications for Emergency Services (LAES), location tracking applications type 2 (LT2) and location tracking and sensor applications for automotive and transportation environments (LTA)", approved October 2011

[8] Recommendation ITU-R F.758-6: System parameters and considerations in the development of criteria for sharing or compatibility between digital fixed wireless systems in the fixed service and systems in other services and other sources of interference

[9] Recommendation ITU-R SF.1650-1: “The minimum distance from the baseline beyond which in-motion earth stations located on board vessels would not cause unacceptable interference to the terrestrial service in the bands 5 925-6 425 MHz and 14-14.5 GHz”

[10] Recommendation ITU-R F.699-7: “Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to about 70 GHz”

[11] Recommendation ITU-R F.1245-2: Mathematical model of average and related radiation patterns for line-of-sight point-to-point fixed wireless system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 GHz to about 70 GHz

[12] Recommendation ITU-R SF.1006: “Determination of the interference potential between earth stations of the fixed-satellite service and stations in the fixed service:”

[13] Recommendation ITU-R F.1094: “Maximum allowable error performance and availability degradations to digital fixed wireless systems arising from radio interference from emissions and radiations from other sources”

[14] Recommendation ITU-R S. 1432: “Apportionment of the allowable error performance degradations to fixed-satellite service (FSS) hypothetical reference digital paths arising from time invariant interference for systems operating below 30 GHz”

[15] Recommendation ITU-R P.452-16: “Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz”

[16] Recommendation ITU-R RA.769-2: “Protection criteria used for radio astronomical measurements”

[17] Recommendation ITU-R P.525-3: “Calculation of free-space attenuation”

[18] Recommendation ITU-R F.383-9, “Radio-frequency channel arrangements for high-capacity fixed wireless systems operating in the lower 6 GHz (5 925 to 6 425 MHz) band”

[19] Recommendation ITU-R F.384-11, “Radio-frequency channel arrangements for medium- and high-capacity digital fixed wireless systems operating in the 6 425-7 125 MHz band”

[20] ECC Report 302: “Sharing and compatibility studies related to Wireless Access Systems including Radio Local Area Networks (WAS/RLAN) in the frequency band 5925-6425 MHz”, approved 2019

[21] Project HIGHTS Deliverable 2.1 (March 2015): "Use cases and Application Requirements"

[22] ETSI STF565: “Specifications for the definition of the cooperative ITS Vulnerable Road Users (VRU) service”, https://portal.etsi.org/stf.aspx?tbid=595&SubTB=595

[23] Recommendation ITU-R P.2108-0, “Prediction of clutter loss”

[24] ECC Report 316: "Sharing studies assessing short-term interference from Wireless Access Systems including Radio Local Area Networks (WAS/RLAN) into Fixed Service in the frequency band 5925-6425 MHz”, approved May 2020

[25] ITU-R Report SM.2057: "Studies related to the impact of devices using ultra-wideband technology on radiocommunication services", 2005

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