



# 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

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## 0 EXECUTIVE SUMMARY

This Report contains sharing and compatibility studies between WAS/RLAN systems and existing incumbent systems in the 5925-6425 MHz band and adjacent bands, in line with the EC Mandate on 6 GHz [1].

Studies have been performed in order to assess sharing and compatibility scenarios for WAS/RLANs in the 5925-6425 MHz band and identify technical conditions that would enable coexistence between existing usages and WAS/RLAN systems without constraining incumbent uses in CEPT countries, in the band 5925-6425 MHz and adjacent to that band.

The studies rest on an agreed set of inputs including parametric inputs and distributions which are detailed in Sections 3 and 4 of the Report. The Report covers sharing and compatibility scenarios based on models of 2025 deployments.

Section 5 of the Report addresses modelling issues, methodologies and approaches that are common to all studies. This includes agreed propagation and loss models on terrestrial paths and earth-to-space paths.

Sections 6-11 of the Report set out the study results for each sharing and compatibility system. Each of these Sections is summarised below. Note that the detailed descriptions of specific elements of each study are provided in a separate annex.

### 0.1 SHARING BETWEEN WAS/RLAN AND FS

In order to investigate sharing potential between WAS/RLAN and FS, both Minimum Coupling Loss (MCL) and Monte Carlo analyses were performed.

In the first study (A), based on an MCL approach, two different types of areas have been identified where a single WAS/RLAN could possibly exceed the protection criterion: a circular area which has a relatively small radius and a peak area which has a relatively large extent down the boresight. This keyhole shaped area is due to the FS antenna pattern (see ITU-R Recommendation F.699 [37]).

Sensitivity analyses have taken into account different WAS/RLAN e.i.r.p. density levels, indoor and outdoor deployments, population density types, FS and WAS/RLAN antenna heights, FS antenna gains and building types. The short term interference was not assessed in this study.

For the long term protection threshold  $I/N = -10$  dB, which relates to co-primary status for mobile service as given in the ECA table [2], the range of required separation distances has been calculated:

- Circle distances are found to be varying from 43 m to 4017 m, peak distances are found to be varying from 48 m to 40400 m.

For the long term protection threshold  $I/N = -20$  dB, which relates to the systems that do not have a co-primary status, the range of required separation distances has been calculated:

- Circle distances are found to be varying from 72 m to 4017 m, peak distances are found to be varying from 103 m to 47100 m.

Sensitivity analyses showed that reduction of the power density level or indoor use are examples of measures that can be taken to reduce the calculated separation distances.

MCL calculations have revealed critical scenarios, but did not allow final conclusions to be made about the statistical likelihood of occurrence of these scenarios. Therefore, a statistical approach based on Monte Carlo studies was carried out.

A second study (B) looking at providing results for a statistical approach, analysed the publicly available population of fixed links in United Kingdom (UK) and the Netherlands. The results of this Monte Carlo study show that the long term interference criterion is met ( $I/N = -10$  dB not exceeded for more than 20% of time). Furthermore, Fractional Degradation in Performance (FDP) was assessed in study B, the results show

that although the FDP < 10%, which is a complementary protection criterion, was exceeded for some of the links studied in the UK, some of the scenarios seemed to lead to interference events that were highly improbable, but may occur as a result of the parameters of the Monte Carlo simulations that were carried out. It is assumed that these situations would be unlikely to occur. However, if only indoor deployment with a maximum e.i.r.p. of 200 mW is considered, the studies showed that all but 2 cases of FDP exceedances were resolved. Under those conditions, the study considered sharing to be feasible.

A third study (C) assessed two sets of complementary simulations based on three existing FS receivers in France. First, an interference coverage mapping approach studied the geographical area from where a WAS/RLAN (indoor 250 mW and outdoor 1 W) would exceed the interference threshold of  $I/N = -10$  dB. It indicated that allowing outdoor WAS/RLAN operating with an e.i.r.p. of 1 W would create interference from a large area around the FS link, depending on the terrain profile. However, when restricting the usage to indoor only utilizing an e.i.r.p. up to 250 mW the possible interfering area is substantially reduced, bringing the interference area within close proximity to the FS receiver. These simulations also showed that when WAS/RLANs are within close proximity of some FS receivers, the short term protection threshold of 19 dB is exceeded (even in the indoor case). In terms of time percentage, this appears to be more critical compared with the long term protection criterion. Indeed, considering the WAS/RLAN 2% RF activity factor, the short term protection threshold for an access point situated within this area will be exceeded more than the  $4.5 \cdot 10^{-4}\%$  tolerated value, given that the conditions modelled in the static analysis persist over time. A complementary statistical study based on a Monte Carlo approach, using the WAS/RLAN parameters distributions described in this Report, indicated that the I/N value of -10 dB was not exceeded for more than 20% of the time as advised by Recommendation ITU-R F.758 [33] for the long term protection criterion. The short term protection criterion was exceeded for two of the three studied links, the number of iterations performed in the study did not allow the assessment of the short term protection criterion for the third studied link.

## 0.2 SHARING BETWEEN WAS/RLAN AND FSS

Studies have been performed in order to assess compatibility and coexistence scenarios for WAS/RLANs and the FSS in the 5925-6425 MHz band and identify technical conditions allowing to enable coexistence between existing usages and WAS/RLAN systems without constraints to the incumbents in CEPT countries.

Studies assumed a representative set of FSS satellites with coverage over Europe.

Two studies were conducted to assess aggregate interference from WAS/RLAN into FSS receivers in space, assuming WAS/RLAN deployment models in Europe by 2025. Study A employs a Monte Carlo methodology involving stochastic inputs to the WAS/RLAN deployment model for the Mid scenario, while study B delivers a static analysis based on average values for the Low, Mid and High scenarios detailed in the Report in Table 13. The number of instantaneously transmitting WAS/RLANs within the FSS receive bandwidth used in the simulations are given in Table 76. The statistical study A has shown that the obtained level is consistent over the Monte Carlo runs.

Studies show that the calculated levels of interference are highly sensitive to some WAS/RLAN parameters and assumptions in the study, including but not limited to the RF activity factor of WAS/RLAN devices.

Study A considers the Mid scenario for a representative set of FSS satellites. The results show that the protection criterion of  $I/N = -10$  dB is satisfied with more than 8.5 dB of margin available in all cases. Service apportionment was not taken into account. The margins found in study A show that sharing is feasible on the basis of the technical parameters agreed for FSS and WAS/RLAN systems for the Mid scenario, with no constraints on WAS/RLAN deployment or operations.

Study B also considers a representative set of existing FSS satellites (as well as a potential future satellite) and the WAS/RLAN deployment model in Europe by 2025 in accordance with Low, Mid and High scenarios. For the studies that were carried out using agreed Low, Mid and High WAS/RLAN deployment numbers with other agreed baseline parameters, the results showed that no instances of excess interference were found to the FSS receivers studied. However, for the most sensitive satellite case in the High scenario the calculated levels of interference were close to the FSS protection criteria used in this study (i.e. -13.5 dB, including 3 dB service apportionment), with the smallest margin equal to 0.5 dB when assuming a BEL (14 dB) for normal building types only.

As part of Study B additional analysis looked at the sensitivity of the results by increasing the proportion of outdoor WAS/RLAN usage above the agreed baseline parameter (up to 5%). The results showed that for the High scenario that aggregate interference was sometimes close to or exceeded the interference threshold slightly for the most sensitive satellites studied. These results highlight the risk of excess interference should higher power outdoor usage increase beyond that specified in the agreed baseline parameters. This concern and potential risk could be addressed by controlling the usage of higher power WAS/RLAN devices operating outdoors.

Considering coexistence conditions for uncontrolled WAS/RLAN use, taking steps such as limiting the use to indoor only deployment and/or introducing an e.i.r.p. limit, would help further ensuring long term protection of FSS space stations from aggregate interference from WAS/RLAN devices in the band 5925-6425 MHz.

### **0.3 COMPATIBILITY BETWEEN WAS/RLAN AND ROAD-ITS**

One adjacent-band compatibility study, using the MCL methodology, was conducted to assess the impact of WAS/RLAN out-of-band (OoB) emission on Road-ITS below 5925 MHz, considering a protection criterion of  $I/N = -6$  dB. WAS/RLAN deployment scenarios of indoor, outdoor (fixed AP and portable device) and in-vehicle were studied. The results of this compatibility study show that, depending on the scenario, the WAS/RLAN OoB emissions below 5925 MHz should meet a limit between -69 dBm/MHz and -36 dBm/MHz for the main-lobe case and between -59 dBm/MHz and -26 dBm/MHz for the side-lobe case. The scenario where the ITS antenna is integrated inside the vehicle resulted in the most stringent requirement. However, it is noted that this scenario is unlikely to occur since the ITS antennas are usually installed outside the vehicle. The indoor usage scenario results in the least stringent requirement for WAS/RLAN OoB emissions below 5925 MHz.

### **0.4 SHARING AND COMPATIBILITY BETWEEN WAS/RLAN AND CBTC**

A first study, using the MCL methodology, assesses the adjacent band coexistence between WAS/RLAN and Communication based train control (CBTC) below 5935 MHz, both WAS/RLAN OoB and in-band emissions were studied. Different scenarios taking into account both indoor only (inside a building) and outdoor (fixed AP and portable device) were studied. The indoor usage scenario results in the least stringent requirement for WAS/RLAN OoB and in-band emissions.

The study shows that, if considering an indoor only WAS/RLAN operation, a density of OoB WAS/RLAN emission of -29 dBm/5 MHz is sufficient to ensure the CBTC operation.

When comparing the results achieved assuming WAS/RLAN operation starting at 5940 MHz and 5935 MHz, it is found that the WAS/RLAN operation above 5940 MHz is less restrictive for the WAS/RLAN emissions. In that case, an in-band e.i.r.p. of 21.5 dBm/20 MHz for indoor WAS/RLAN usage in adjacent channels (restricted to the first 20 MHz WAS/RLAN) would fulfil the CBTC blocking requirement for the three studied CBTC technologies.

Concerning the portable device in adjacent channels, studies show that a density of OoB WAS/RLAN emission of -42 dBm/5 MHz and an e.i.r.p. density of 4.7 dBm/20 MHz (WAS/RLAN first channel starting at 5940 MHz) are sufficient to ensure the CBTC operation.

Another study, also using the MCL methodology, investigated the impact of WAS/RLAN devices coexisting in the same frequency band as the Copenhagen S-train CBTC system. The results present the required minimum distance between the WAS/RLAN device and CBTC receiver to avoid the interference from the WAS/RLAN device. This distance ranges from 180 to 600 m. If S-train and WAS/RLAN share the same frequency band, it is very probable that WAS/RLAN devices will be present within these distances. Dedicated mitigations techniques, to be locally applied, may need to be defined.

## **0.5 COMPATIBILITY BETWEEN WAS/RLAN AND RADIO ASTRONOMY SERVICE**

The number of Radio Astronomy Service (RAS) sites in Europe observing in this frequency range is small, possibly around 19. The local environment of each site is very well understood. Compatibility between WAS/RLAN and those sites could be addressed on a case-by-case basis at national level.

An I/N threshold can be used to derive a contour around the RAS site following applicable ITU-R Recommendations and taking into account the details of the site and possibly the typical observation schedule. The contours, which can be considered as a coordination zone or exclusion zone, represent a zone which needs to be managed by the regulator.

## **0.6 COEXISTENCE BETWEEN WAS/RLAN AND ULTRA WIDE BAND (UWB) SYSTEMS**

A minimum coupling loss study of a range of e.i.r.p. levels (from 0 dBm to 30 dBm) has shown that an individual WAS/RLAN interferer between 30 m and 946 m away, respectively, causes more than 3 dB sensitivity reduction in UWB communications and location tracking systems. For UWB sensing applications, the equivalent distances range from 7 m to 212 m.

Aggregate interference evaluations with Monte Carlo simulations show that when taking the WAS/RLAN RF activity factor into account, the probability that the sensitivity reduction to UWB communications and location tracking devices exceeds 3 dB ranges from 0.0024% to 3.3% depending on the scenario considered. For UWB sensing devices, the probability that the sensitivity reduction is more than 3 dB varies from 0.042% to 1.7%.

The introduction of WAS/RLANs as specified in this report could have an impact on the applications and users of studied UWB systems that can only operate over the frequency range under study in this Report.

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## LIST OF ABBREVIATIONS

<b>Abbreviation</b>	<b>Explanation</b>
<b>3GPP</b>	Third generation partnership project
<b>5G</b>	Fifth generation
<b>agl</b>	Above ground level
<b>AP</b>	Access point
<b>BEL</b>	Building entry loss
<b>BS</b>	Base station
<b>CBTC</b>	Communication based train control
<b>CCDF</b>	Complementary Cumulative Distribution Function
<b>CDF</b>	Cumulative distribution function
<b>CEPT</b>	European Conference of Postal and Telecommunications Administrations
<b>CET</b>	Central European time
<b>C/I</b>	Carrier to interferer ratio
<b>C/(I+N)</b>	Carrier to interference plus noise ratio
<b>CLC</b>	Corine land cover
<b>CS</b>	Channel spacing
<b>CSMA/CA</b>	Carrier Sense Multiple Access/Collision Avoidance
<b>CSV</b>	Comma separated values
<b>CTS</b>	Clear to send
<b>DSSS</b>	Direct Sequence Spread Spectrum
<b>e.i.r.p.</b>	Effective isotropically radiated power
<b>ECA</b>	European common allocation
<b>ECC</b>	Electronic Communications Committee
<b>EET</b>	Eastern European time
<b>ERC</b>	Electronic Radiocommunications Committee
<b>ESOB</b>	Earth Station on-board Vessel
<b>ETSI</b>	European Telecommunications Standards Institute
<b>EST</b>	Eastern standard time
<b>EU</b>	European Union
<b>FDP</b>	Fractional Degradation Performance
<b>FSS</b>	Fixed-Satellite Service
<b>FS</b>	Fixed Service
<b>FSPL</b>	Free Space Path Loss

<b>Abbreviation</b>	<b>Explanation</b>
<b>GDP</b>	Gross domestic product
<b>Gbps</b>	Gigabits per second
<b>GPWv4</b>	Gridded Population of the World V4
<b>HD</b>	High definition
<b>HTS</b>	High throughput satellites
<b>JRC</b>	Joint Research Centre of the European Commission
<b>IEEE</b>	Institute of Electrical and Electronics Engineers
<b>IMT</b>	International Mobile Telecommunications
<b>I/N</b>	Interferer to noise ratio
<b>IoT</b>	Internet of things
<b>ITS</b>	Intelligent transport systems
<b>ITU</b>	International Telecommunication Union
<b>LAA</b>	Licensed Assisted Access
<b>LAT</b>	Latitude
<b>LON</b>	Longitude
<b>Mbps</b>	Megabits per second
<b>MAC</b>	Medium access control
<b>MCL</b>	Minimum coupling loss
<b>MFCN</b>	Mobile/Fixed Communications Networks
<b>MIMO</b>	Multiple input and multiple output
<b>MSK</b>	Moscow standard time
<b>NASA</b>	National Aeronautics and Space Administration
<b>NLOS</b>	Non line of sight
<b>NR</b>	New radio
<b>LAA</b>	Licensed assisted access
<b>LAT</b>	Latitude
<b>LON</b>	Longitude
<b>LOS</b>	Line of sight
<b>LTE</b>	Long term evolution
<b>MERLIN</b>	Multi-Element Radio-Linked Interferometer Network
<b>OBU</b>	On board unit
<b>Ofcom</b>	Office of communications (United Kingdom)
<b>OFDM</b>	Orthogonal Frequency-Division Multiplexing
<b>OoB</b>	Out of band
<b>OTA</b>	Over the air

<b>Abbreviation</b>	<b>Explanation</b>
<b>PER</b>	Packet error rate
<b>pdf</b>	Power flux density
<b>PP</b>	Point-to-point
<b>PR</b>	Protection ratio
<b>PSD</b>	Power spectrum density
<b>QAM</b>	Quadrature amplitude modulation
<b>QPSK</b>	Quadrature phase-shift keying
<b>RAS</b>	Radio Astronomy Service
<b>RLAN</b>	Radio local area networks
<b>Rx</b>	Receiver
<b>RF</b>	Radio frequency
<b>RMS</b>	Root mean square
<b>RSU</b>	Road side unit
<b>RTS</b>	Request to send
<b>SEDAC</b>	Socioeconomic Data and Applications Center
<b>SNR</b>	Signal to noise ratio
<b>SNIR</b>	Signal to noise plus interferer ratio
<b>TDMA</b>	Time division multiple access
<b>STA</b>	Wi-Fi station
<b>STO</b>	Semi-automated train operation
<b>Tx</b>	Transmitter
<b>TU</b>	Train unit
<b>UK</b>	United Kingdom
<b>UN</b>	United Nations
<b>UTC</b>	Coordinated universal time
<b>UTO</b>	Unattended train operation
<b>UWB</b>	Ultra-wide band
<b>VLBI</b>	Very Long Baseline Interferometry
<b>WAS</b>	Wireless access systems
<b>WET</b>	Western European time
<b>Wi-Fi</b>	Wireless fidelity
<b>TCC</b>	Traffic control centre
<b>TD-LTE</b>	Time division LTE

## 1 INTRODUCTION

This Report studies the technical feasibility of the introduction of low power wireless access systems including radio local area networks (WAS/RLANs) in the frequency band 5925-6425 MHz under a non-protected basis, ensuring certainty of continued operation, development and protection of existing incumbent services. The work is related to the EC Mandate on WAS/RLAN in the 5925-6425 MHz band [1] with the aim of exploring the availability of additional spectrum for the provision of internet-based services with increased data capacity and speed.

The Report contains sharing and compatibility studies assessing the interference from WAS/RLANs into the following services and applications:

- Fixed Service (FS) links operating in the band 5925-6425 MHz;
- Fixed-Satellite Service (FSS), Earth-to-space links operating in the band 5925-6425 MHz;
- Road-Intelligent Transport Systems (ITS) operating in the lower adjacent band below 5925 MHz;
- Communication Based Train Control (CBTC) systems operating in the lower adjacent band below 5935 MHz and in the band 5925-5975 MHz;
- Radio Astronomy in the frequency band 6650.0-6675.2 MHz;
- Ultra-Wide Band applications in the frequency band 5925-6425 MHz.

## 2 ALLOCATIONS AND APPLICATIONS IN THE BAND 5925-6425 MHz AND ADJACENT BANDS

### 2.1 FREQUENCY BAND ALLOCATION AND USE

Table 1 provides an extract of the current European Common Allocation (ECA) Table (ERC Report 25 [2]) in the 5925-6425 MHz band. In the first column it shows that the ITU-R Radio Regulations contain among others a primary mobile service allocation in Region 1 for this band.

**Table 1: European Common Allocation Table for the frequency band 5925-6700 MHz**

RR Region 1 Allocations and Footnotes applicable to CEPT	European Common Allocations and ECA Footnotes	ECC/ERC harmonisation measure	Applications	Standards	Notes
FIXED 5.457 FIXED-SATELLITE (EARTH-TO-SPACE) 5.457A 5.457B MOBILE 5.457C 5.149 5.440 5.458	FIXED FIXED-SATELLITE (EARTH-TO-SPACE) Earth Exploration-Satellite (passive) 5.149 5.440 5.458 MOBILE	ECC/DEC/(05)09	ESV	EN 301 447	Within the band 5925-6425 MHz
		ECC/DEC/(05)09	FSS Earth stations	EN 301 443	Priority for civil networks
		ECC/REC/(14)06 ERC/REC 14-01 ERC/REC 14-02	Fixed	EN 302 217	Point-to-point
			Passive sensors (satellite)		For sea surface temperature, sea surface wind speed and soil moisture measurements
			Radio astronomy		Spectral line observations (e.g. methanol line), VLBI
		ECC/DEC/(11)02 ERC/REC 70-03	Radio-determination applications	EN 302 372 EN 302 729	Within the band 4500-7000 MHz for TLPR application and 6000-8500 MHz for LPR applications
		ECC/DEC/(06)04 ECC/DEC/(12)03	UWB applications	EN 302 065	Generic UWB as well as UWB on-board aircraft regulation within the band 6.0-8.5 GHz

Note 1: According to the ECO Frequency Information System (EFIS, [www.efis.dk](http://www.efis.dk)), sixteen CEPT administrations have a primary mobile allocation and two CEPT administrations have a secondary mobile allocation in this band.  
 Note 2: The text of the footnotes of the ITU Radio Regulations can be found in the ECA Table <https://www.efis.dk/views2/compare-allocations.jsp>

Table 2 is an extract of the ECA Table for the frequency band 5850-5925 MHz.

Table 2: European Common Allocation Table for the frequency band 5850-5925 MHz

RR Region 1 Allocation and footnotes applicable to CEPT	European Common Allocation and ECA Footnotes	ECC/ERC harmonisation measure	Applications	Standards	Notes
FIXED FIXED-SATELLITE (EARTH-TO-SPACE) MOBILE 5.150	FIXED FIXED-SATELLITE (EARTH-TO-SPACE) MOBILE 5.150	ECC/REC/(06)04	BFWA	EN 302 502	Within the band 5725-5875 MHz
		ECC/DEC/(15)03	DA2GC	EN 303 339 EN 303 316	Within the band 5855-5875 MHz
			FSS Earth stations	EN 301 443	Priority for civil networks
			ISM		Within the band 5725-5875 MHz
		ECC/DEC/(08)01 ECC/REC/(08)01 ERC/REC 70-03	ITS	EN 302 571	Within the bands 5875-5925 MHz and 5855-5875 MHz. Traffic safety applications within the band 5875-5905 MHz
		ECC/REC/(17)03	MBR	EN 303 276	Within 5852-5872 MHz and 5880-5900 MHz
		ERC/REC 70-03	Non-specific SRDs	EN 300 440	Within the band 5725-5875 MHz
		ERC/REC 70-03	Radiodetermination applications	EN 302 372	Within the band 4500-7000 MHz for TLPR application
		ERC/REC 70-03	WIA	EN 303 258	Within the band 5725-5875

## 2.2 DEPLOYMENT OF OTHER SERVICES/APPLICATIONS BY CEPT ADMINISTRATIONS

### 2.2.1 Urban Rail Systems (CBTC)

CEPT Report 71 [87] shows in its Annex 1, Table 2b, the use of CBTC systems in 5.9 GHz bands (lines already deployed or under construction) and in Table 3, the series of planned projects. The listed projects are in Austria, Belgium, Denmark, France, Germany and Spain.

Communication Based Train Control (CBTC) systems are used in some metropolitan cities in France (5915-5935 MHz), Denmark (5925-5975 MHz) and Spain (5905-5925 MHz).

### 2.2.2 Radio astronomy

The frequency band 6650.0-6675.2 MHz is important for observations of methanol ( $\text{CH}_3\text{OH}$ ). This transition of methanol is a very powerful cosmic maser found exclusively in regions where massive stars form. It is widely observed in Europe using single dishes, Multi-Element Radio-Linked Interferometer Network (MERLIN) interferometry and Very Long Baseline Interferometry (VLBI).

Furthermore, at 6030 MHz and at 6035 MHz excited-OH (Hydroxyl; the main transition of Hydroxyl is the 1667 MHz and 1665 MHz lines, also significant for Radio Astronomy studies) is observed in a maser state and also in absorption, organised in star-forming regions. These regions provide valuable information on the physical parameters, including the elusive magnetic fields of the environment where the massive star is forming, at a stage before the visible light can emerge through the dust.

The Radio Regulations footnote **5.149** includes the band 6650-6675.2 MHz but does not include 6030 MHz and 6035 MHz.



**3 WAS/RLAN IN THE 6 GHZ FREQUENCY RANGE**

**3.1 TECHNICAL CHARACTERISTICS OF WAS/RLAN IN THE BAND 5925-6425 MHZ**

**3.1.1 Transmitter Output Power / Radiated Power**

WAS/RLAN devices used in different applications will have different power levels and will be associated with different technologies. Based on current market share projections, the dominant technology is likely to be IEEE 802.11-based. For the 6 GHz band, industry is seeking to introduce a new category of equipment - low power outdoor access points that would be deployed in use cases adjacent to enterprises. The power distribution in Table 3 reflects this new category and use case.

Unlicensed LTE technologies (Licensed Assisted Access, MulteFire and 5G New Radio) are not yet deployed in numbers sufficient to project their impact on the interference environment, but are subject to the same power limits as other short range devices. Most devices are expected to use e.i.r.p. levels lower than the maximum limit for various reasons such as power consumption and transmit power control. Devices that serve as base stations may transmit at the higher power level than the devices that serve as mobile stations. The maximum transmit power of mobile station devices based on Licensed Assisted Access (LAA) is 250 mW. The transmit power level of LAA, MulteFire and 5G New Radio (NR) mobile station devices is generally lower than the maximum power level due to the power control mechanism, where actual transmit power is a function of the receiver sensitivity or the desired signal to noise plus interferer ratio (SNIR) at the receiver and the path loss between the mobile station and the base station.

To develop the statistical WAS/RLAN e.i.r.p. in Table 3, typical use cases were identified, peak e.i.r.p. was assigned, busy hour operating ratios were assigned and an equal weight was assigned to all values in the E-plane using the distributions outlined in Tables and Figures of ANNEX 1.

*3.1.1.1 Typical WAS/RLAN use cases and associated peak e.i.r.p.*

The seven typical use cases for WAS/RLAN are:

- Indoor Enterprise AP/small cell, Indoor Consumer AP/small cell and Indoor High Performance Gaming Router;
- Indoor/outdoor Client/STA;
- Outdoor High Power AP/small cell, Outdoor Low Power AP/small cell.

Based on the proposed technical parameters from ETSI TR 103 524 [3], a peak e.i.r.p. of 30 dBm (1 W) was assigned as a maximum allowed value for indoor high performance AP and high power outdoor AP segments. Table 3 provides the peak power for these seven use cases.

**Table 3: Peak e.i.r.p. of various WAS/RLAN use cases**

Parameter	Indoor	Indoor	Indoor	Indoor / Outdoor	Outdoor	Outdoor
	Enterprise AP/small cell	Consumer AP/small cell	High Performance Gaming Router	Client/STA	High Power AP/small cell	Low Power AP/small cell
Conducted Power (dBm)	13.5	12.5	18.6	12	21.6	14
Peak Antenna Gain (dBi)	4.1	5.3	5.3	3.5	5.3	5.3

Parameter	Indoor	Indoor	Indoor	Indoor / Outdoor	Outdoor	Outdoor
MIMO Gain (dB)	6.0	6.0	6.0	3.0	3.0	4.8
Total Peak e.i.r.p. (dBm)	23.6	23.8	29.9	18.5	29.9	24.1
Note: Conducted power, peak antenna gain and MIMO gain are examples representative of the total peak e.i.r.p. shown.						

### 3.1.1.2 Busy hour weights

To determine the worst-case time of interference into incumbent systems, busy hours for corporate, public and home usage were studied. Results showed that home usage was the heaviest and, therefore, busy hours were assumed to be 7:00 pm-11:00 pm local time. That resulted in a busy hour across Europe of 7:00 pm-8:00 pm UTC-1 (for details see ANNEX 3).

Table 4 provides busy hour weights for indoor use cases (corporate, public and residential) in different environments (urban, suburban and rural) and Table 5 provides busy hour weights for outdoor use cases.

**Table 4: Busy hour weights for various WAS/RLAN indoor use cases**

User Type	Urban			Suburban			Rural		
	Corp	Pub	Res	Corp	Pub	Res	Corp	Pub	Res
Client/STA	50%	50%	25%	50%	50%	25%	50%	50%	25%
Enterprise AP/small cell	50%	50%	0%	50%	50%	0%	50%	50%	0%
Consumer AP/small cell	0%	0%	70%	0%	0%	70%	0%	0%	70%
High Performance Gaming Router	0%	0%	5%	0%	0%	5%	0%	0%	5%
Total (Indoor)	100%	100%	100%	100%	100%	100%	100%	100%	100%

**Table 5: Busy hour weights for various WAS/RLAN outdoor use cases**

Device Type	Urban	Suburban	Rural
Outdoor High Power AP/small cell	20%	20%	20%
Outdoor Low Power AP/small cell	30%	30%	30%
Outdoor Client/STA	50%	50%	50%
Total (outdoor)	100%	100%	100%

### 3.1.1.3 WAS/RLAN isotropic antenna patterns for modelling purposes

For modelling purposes, isotropic antenna models for H-plane and E-plane are used for both indoor and outdoor deployments of WAS/RLANs. This is more conservative than using directional or sectoral antennas for both mobile stations and base stations because the direction of any individual antenna is unknown.

Wi-Fi APs and small cell base stations typically use downward-tilted, e.g. ceiling-mounted units, or horizontal emissions patterns, which would reduce the interference to satellites. However, for the simplicity of the

modelling and for reducing the run duration of Monte Carlo simulations, this Report considers a conservative model and uses omnidirectional antenna patterns with an equivalent average gain.

The e.i.r.p. E-plane (elevation) patterns for the seven typical use cases for indoor and outdoor WAS/RLANs are shown in Figure 90 through Figure 95 in ANNEX 1. The tables next to the elevation patterns are for illustrative purposes only.

#### 3.1.1.4 Weighted average e.i.r.p. of WAS/RLAN devices

Combining busy hour weights with the seven typical antenna models from ANNEX 1 and assuming equal probability for each of the antenna patterns results in the weighted e.i.r.p. distributions in Table 6 and Table 7 below, considering 98% of the WAS/RLAN devices are indoors and 2% outdoors (see section 3.2.4).

**Table 6: WAS/RLAN power distribution for indoor use case (98%)**

Indoor Use Case	Weight	Weighted e.i.r.p. distribution (mW)						Total
		1000	250	100	50	13	1	
Client/STA	26.32%	0.00%	0.00%	1.82%	12.03%	12.47%	0.00%	26.32%
Enterprise AP/small cell	2.63%	0.00%	1.06%	0.90%	0.58%	0.09%	0.01%	2.63%
Consumer AP/small cell	66.31%	0.00%	7.90%	2.76%	11.20%	38.94%	5.51%	66.31%
High Performance Gaming Router	4.74%	0.71%	0.2%	0.73%	1.97%	0.97%	0.16%	4.74%
Subtotal	100.00%	0.71%	9.15%	6.21%	25.79%	52.47%	5.68%	100.00%

**Table 7: WAS/RLAN power distribution for outdoor use case (2%)**

Outdoor Use Case	Weight	Weighted e.i.r.p. distribution (mW)						Total
		1000	250	100	50	13	1	
High Power AP/small cell	20%	2.99%	0.83%	3.05%	8.37%	4.10%	0.66%	20.00%
Low Power AP/small cell	30%	0.25%	3.41%	1.33%	5.73%	16.87%	2.41%	30.00%
Client/STA	50%	0.00%	0.00%	3.46%	22.85%	23.68%	0.00%	50.00%
Subtotal	100.00%	3.24%	4.24%	7.84%	36.95%	44.65%	3.07%	100%

Table 8 has the percentages of indoor and outdoor devices that transmit at a certain e.i.r.p. level that are used in the study. This results in weighted average e.i.r.p. of 17.48 dBm (55.98 mW) for indoor WAS/RLANs, 18.76 dBm (75.16 mW) for outdoor WAS/RLANs and 17.51 dBm (56.33 mW) for combined indoor/outdoor WAS/RLANs.

**Table 8: Power distribution of WAS/RLAN devices**

Tx e.i.r.p. Power	1000 mW	250 mW	100 mW	50 mW	13 mW	1 mW	all
Indoor	0.71%	9.15%	6.21%	25.79%	52.47%	5.68%	100%
Outdoor	3.24%	4.24%	7.84%	36.95%	44.65%	3.07%	100%
Weighted average e.i.r.p. (98% and 2%)	7.60 mW	22.63 mW	6.24 mW	13.01 mW	6.80 mW	0.06 mW	56.33 mW

### 3.1.2 WAS/RLAN antenna heights

The antenna height depends on the regions where users are located and can be modelled as following for different deployment zones. To determine WAS/RLAN source height distributions, first building height distributions were required as shown in Table 9 below.

**Table 9: Building heights probability (Source [4][5])**

		Building height probability									
		Urban indoor			Suburban indoor			Rural indoor			All Outdoor
Building story	Height (m)	Corp	Public	Home	Corp	Public	Home	Corp	Public	Home	
1	1.5	69%	69%	60%	69%	69%	60%	70%	70%	70%	95%
2	4.5	21%	21%	30%	21%	21%	30%	25%	25%	25%	2%
3	7.5	7%	7%	7%	7%	7%	5%	5%	5%	5%	2%
4	10.5	0.7%	0.7%	0.7%	0.7%	0.7%	5%	0%	0%	0%	0.5%
5	13.5	0.58%	0.58%	0.58%	0.58%	0.58%	0%	0%	0%	0%	0%
6	16.5	0.5%	0.5%	0.5%	0.5%	0.5%	0%	0%	0%	0%	0%
7	19.5	0.43%	0.43%	0.43%	0.43%	0.43%	0%	0%	0%	0%	0%
8	22.5	0.35%	0.35%	0.35%	0.35%	0.35%	0%	0%	0%	0%	0%
9	25.5	0.28%	0.28%	0.28%	0.28%	0.28%	0%	0%	0%	0%	0%
10	28.5	0.2%	0.2%	0.2%	0.2%	0.2%	0%	0%	0%	0%	0%

Building height type probability must then be recast into the probability of WAS/RLAN presence on each floor of a multi-story building. From the raw data on building heights, the probability of WAS/RLAN location by floor is calculated, see Table 10. For taller buildings, the random assignment of a WAS/RLAN to the 10<sup>th</sup> floor increases the probability of WAS/RLANs at heights on floors one-through nine by 10% of the 10 story building type probability. Stated differently, once a WAS/RLAN is present on the top floor, the combined distribution is weighted heavily to lower floors. For example, the likelihood that a WAS/RLAN will be on the first floor in an urban environment is the sum as follows:

*WAS/RLAN on 1st Floor Probability = 1 Story Building Probability + 2 Story Building Probability/2 Floors ... +10 Story Building Probability/10 Floors*

**Table 10: WAS/RLAN source height distribution**

Build- ing Story	Height (m)	Urban indoor			Suburban indoor			Rural indoor			Out- door
		Corp	Public	Home	Corp	Public	Home	Corp	Public	Home	
1	1.5	82.35%	82.35%	77.85%	82.35%	82.35%	77.92%	84.17%	84.17%	84.17%	95.00%
2	4.5	13.35%	13.35%	17.85%	13.35%	13.35%	17.92%	14.17%	14.17%	14.17%	2.00%
3	7.5	2.85%	2.85%	2.85%	2.85%	2.85%	2.92%	1.67%	1.67%	1.67%	2.00%
4	10.5	0.52%	0.52%	0.52%	0.52%	0.52%	1.25%	0.00%	0.00%	0.00%	0.50%
5	13.5	0.36%	0.36%	0.36%	0.36%	0.36%	0.00%	0.00%	0.00%	0.00%	0.00%
6	16.5	0.24%	0.24%	0.24%	0.24%	0.24%	0.00%	0.00%	0.00%	0.00%	0.00%
e	19.5	0.16%	0.16%	0.16%	0.16%	0.16%	0.00%	0.00%	0.00%	0.00%	0.00%
8	22.5	0.09%	0.09%	0.09%	0.09%	0.09%	0.00%	0.00%	0.00%	0.00%	0.00%
9	25.5	0.05%	0.05%	0.05%	0.05%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%
10	28.5	0.02%	0.02%	0.02%	0.02%	0.02%	0.00%	0.00%	0.00%	0.00%	0.50%
Total		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

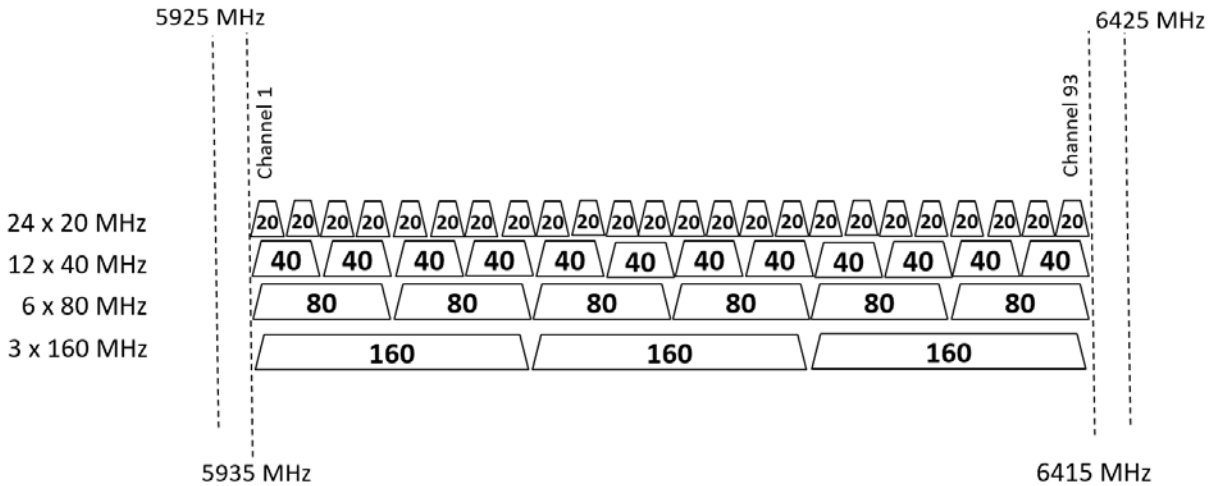
For outdoor deployments, the addition of a low power outdoor category changes the building story height distribution, as low power outdoor devices would be attached no higher than one story above the ground (e.g. loading docks and outdoor patios). The base station device height, therefore, changes to predominantly 1.5 m, with a few devices at 4.5 m, 7.5 m, 10.5 m and 27.5 m for urban, suburban and rural market deployment zones. For outdoor deployments, omnidirectional model for a base station device is not adequate. A commonly used reference model for the outdoor 3D antenna element pattern is given in [8].

### 3.1.3 Operating frequency

Where the channel number increment is 5 MHz, the Nominal Centre Frequencies ( $f_{cn}$ ) for a Nominal Channel Bandwidth of 20 MHz are defined by the following formula, where  $g$  = channel number from Table 11:

$$f_{cn(g)} = 5\,940 + (g \times 5) \text{ MHz}, \quad \text{where } 1 \leq g \leq 93$$

IEEE 802.11ax compliant equipment is envisaged to use simultaneous transmissions on more than one Operating Channel with a Nominal Channel Bandwidth of 20 MHz. Figure 1 below shows an example of a channel plan. This channel plan is indicative and does not take into account coexistence studies with applications below 5 935 MHz (like Road-ITS and CBTC).



**Figure 1: Example band plan with 5 MHz channel number increment**

The WAS/RLAN channel set from IEEE 802.11ax Draft 3.0 [6] given in Table 11, starting at 5940 MHz with 5 MHz channel number increment is not the final channel set for Europe.

**Table 11: Channel set with 5 MHz channel number increment**

Channel width	# of channels	Channel set
20 MHz	24	1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61, 65, 69, 73, 77, 81, 85, 89 and 93
40 MHz	12	3, 11, 19, 27, 35, 43, 51, 59, 67, 75, 83 and 91
80 MHz	6	7, 23, 39, 55, 71 and 87
160 MHz	3	15, 47 and 79

The equipment compliant with the existing LTE-LAA standard [7] can support combined channel bandwidth via carrier aggregation up to 32 component carriers (including at least one primary component carrier anchored in a licensed band), where each component carrier can have a bandwidth of 1.4, 3, 5, 10, 15 or 20 MHz. Such configurations, among others, will be potentially used in the coming 3GPP 5G NRU standard [91], too.

**3.1.4 Bandwidth**

The 6 GHz band will be greenfield operation for all WAS/RLAN systems and is expected to be used for high data-rate applications. Correspondingly, more common deployment of 80 MHz and 160 MHz devices is expected while lower bandwidth operation, such as 20 MHz and 40 MHz might also be used. Table 12 shows a prediction for the distribution of WAS/RLAN channel bandwidths used in 6 GHz band.

**Table 12: Bandwidth distribution [3]**

Channel bandwidth	20 MHz	40 MHz	80 MHz	160 MHz
WAS/RLAN device percentage	10%	10%	50%	30%

### 3.1.5 WAS/RLAN performance characteristics

As WAS/RLANs were not previously designed to operate in the 5925-6425 MHz frequency range (i.e. RF components such as power amplifiers and filters are not tuned to these frequencies), so only modern devices, which operate at extremely high efficiencies are expected in the band. For example, the IMT-2020 peak spectral efficiency requirement for indoor hotspot in the downlink is 30 bits/s/Hz (the average is 9 bits/s/Hz). The next generation of WAS/RLAN technology standardised by IEEE, which is expected in 2020, IEEE 802.11ax, and the 3GPP based 5G New Radio will have peak spectral efficiencies that greatly exceed this requirement. For example, IEEE 802.11ax has a peak throughput of 60 bits/s/Hz for both uplink and downlink. Based on this and the demand for larger channels, it is expected that new 6 GHz WAS/RLAN technology will deliver an average throughput rate of 1 Gbps as achieved in current 5 GHz technology.

### 3.2 WAS/RLAN DEPLOYMENT MODEL

This section sets out a busy hour deployment model for WAS/RLAN in Europe. The vast majority of licence exempt wireless traffic per person occurs during the busy hours 19:00-23:00 local time [9]. For a conservative and simplified analysis, this model focused on video consumption in the residential environment, as this has a higher projected data rate demand per person than the corporate and public hotspot environments. Annex A3.5 provides further explanation of the data rate demand.

Table 13 summarises the WAS/RLAN deployment model and specifies the total number of instantaneously transmitting devices within Europe during the busy hour. To address uncertainties, Table 13 includes parametric inputs (Low, Mid and High) for the busy hour factor and the market adoption factor. Therefore, Low, Mid and High values of instantaneously transmitting devices are given.

**Table 13: Summary of the WAS/RLAN deployment model**

	Low	Mid	High
Total CEPT population 2025	768 589 000		
Wireless devices operating in licence exempt spectrum (remainder operating in licence spectrum)	90%		
Busy Hour factor	50%	62.7%	62.7%
6 GHz factor (6GHz / (6GHz + 5GHz +2.4GHz))	48.17%		
Market Adoption factor (6 GHz capable devices)	25%	32%	50%
RF Activity factor per person	1.97%		
Instantaneously transmitting WAS/RLAN devices	820 521	1 317 034	2 057 866

#### 3.2.1 Elaboration of WAS/RLAN deployment model parameters

These studies are based on inputs and contributions that are evidence-based or with a strong supporting rationale including earlier study work. The following subsections set-out an explanation of inputs to the WAS/RLAN deployment model summarised in Table 13. Detailed material can be found in ANNEX 3.

##### 3.2.1.1 Total population of Europe projected for 2025

The total population of Europe projected for 2025 was based on CEPT member countries located in the WET, CET, EET and EST/MSK time zones [10]. The majority of the European population resides in these four time zones and at 20:00 CET, all four time zones experience busy hour traffic conditions.

Annex A3.1 provides further detail including a table of the human populations per CEPT member country and a time zone map covering these time zones.

Studies of interference incident to FSS receivers consider FSS footprints that extend beyond the bounds of the four time zones WET, CET, EET and EST/MSK. In the absence of detailed information about WAS/RLAN deployment outside Europe, these WAS/RLAN densities per inhabitant beyond Europe are divided by four. This is consistent with earlier studies in ITU-R Working Party 5A and accounts for assumed differences in gross domestic product (GDP), telecoms infrastructure and client deployment. In effect, this approach assigns average European traffic conditions to these populations since the busy hour to average traffic ratio in Europe is predicted to be 4.4 in 2025 [11]. In order to support studies of WAS/RLAN interference into incumbent receivers, the spatial distribution of WAS/RLANs through the human population is modelled using the Gridded Population of the World V4 (GPWv4) data from NASA's Socioeconomic Data and Applications Center (SEDAC) [12]. Further explanation is given in Annex A3.2.

#### *3.2.1.2 Percentage of operation in license exempt spectrum*

The percentage of wireless devices operating in license exempt spectrum (remainder operating in license spectrum) is set at 90%. This is a conservative estimate of the percentage of data transmitted over wireless devices operating in license exempt spectrum with the remaining 10% assumed to be operating under licensed conditions.

#### *3.2.1.3 Busy hour factor*

Parametric inputs of 50% and 62.7% for the busy hour factor have been used. This factor describes the percentage of WAS/RLAN devices involved in busy hour. There is some uncertainty and a parametric input is considered appropriate.

These busy hour factor inputs were used in the 5 GHz WAS/RLAN studies [32] and ITU-R Joint Task Group (JTG) 4-5-6-7 considered 62.7% to be the average busy hour factor over urban, suburban and rural areas.

#### *3.2.1.4 6 GHz factor*

The 6 GHz factor is the percentage of WAS/RLAN devices utilising the 6 GHz frequency band. This is given by the ratio of spectrum available at 6 GHz to that available across the 6, 5 and 2.4 GHz frequency bands (500 MHz / 1038 MHz).

#### *3.2.1.5 Market adoption factor*

Parametric inputs of 25%, 32% and 50% were used for the market adoption factor; that is, the percentage of devices capable of operation at 6 GHz. The low input of 25% assumes a slow adoption of 6 GHz equipment, the Mid input of 32% is based on actual market projections and the High value of 50% assumes rapid adoption of 6 GHz technology. A rationale for the 32% input value is given in Annex A3.3.

#### *3.2.1.6 Radio frequency RF activity factor*

This radio frequency (RF) activity factor is given per person during the busy hour. An RF activity factor of 1.97% per person was used in this study and the RF activity factor measurements for streaming video are provided in ANNEX 7.

#### *3.2.1.7 Total number of instantaneously transmitting devices*

The total number of instantaneously transmitting devices is given by the product of all other inputs in Table 13. Low, Mid and High estimates are obtained.



### 3.2.2 Assignment of populations to urban, suburban and rural environments

The total population of Europe has been assigned to urban, suburban and rural environments as follows:

- Urban: 50%;
- Suburban: 27%;
- Rural: 23%.

### 3.2.3 Busy hour data rate in the residential environment

It is assumed that the data rate demand during the busy hour is based on high definition (HD) video streaming in the residential environment since this offers the most conservative model for the sharing and compatibility studies. Assuming nearly everyone is consuming HD video with no down-time, leads to an average throughput of 4.44 Mbps (2.0 Gbytes/hour). Further explanation is provided in Annex A3.5.

### 3.2.4 Number of WAS/RLANs operating indoors and outdoors

To estimate indoor versus outdoor deployments actual historical and projected shipment data was used for outdoor Wi-Fi sales and LTE-based small cells. Combining the forecast for small cell and Wi-Fi devices for the outdoor market gives 1% of total units worldwide in 2021, and then doubling this for 2025 leads to a conservative ratio for indoor vs. outdoor WAS/RLANs (98% and 2% respectively). Further explanation is given in Annex A3.6.

Considering the total outdoor usage of 2% and the e.i.r.p. distribution given in Table 7, the number of instantaneously transmitting outdoor WAS/RLANs with e.i.r.p. levels between 250 mW and 1 W used in the simulations can be derived using the same methodology from Table 13, as shown in Table 14 below.

**Table 14: Summary of the WAS/RLAN deployment model for outdoor usage**

	Low	Mid	High
Total CEPT population 2025 used for WAS/RLAN calculations (Table 13)	768 589 000		
Total CEPT WAS/RLAN population 2025 used for outdoor calculations	2% of 768 589 000 = 15 371 780		
Wireless devices operating in licence exempt spectrum outdoor	90% (13 834 602)		
Busy Hour factor	50%	62.7%	62.7%
6 GHz factor (6 GHz / (6 GHz + 5GHz +2.4 GHz))	48.17%		
Market Adoption factor (6 GHz capable devices)	25%	32%	50%
RF Activity factor per person	1.97%		
Number of simultaneously transmitting WAS/RLANs outdoor	16 410	26 341	41 157
Higher power outdoor WAS/RLAN e.i.r.p. distribution (percentage in accordance with Table 7)			
1000 mW (3.24%)	531	853	1 333
250 mW (4.24%)	695	1116	1745

### 3.2.5 Busy Hour time zone considerations

A time zone adjustment model was used to determine the number of active inhabitants, which varies over the different time zones, when a busy hour population is distributed over a large geographical area. The model is based on findings from [14] which showed that transitions between active and non-active times in typical human activity patterns are rather steep (see Figure 2).

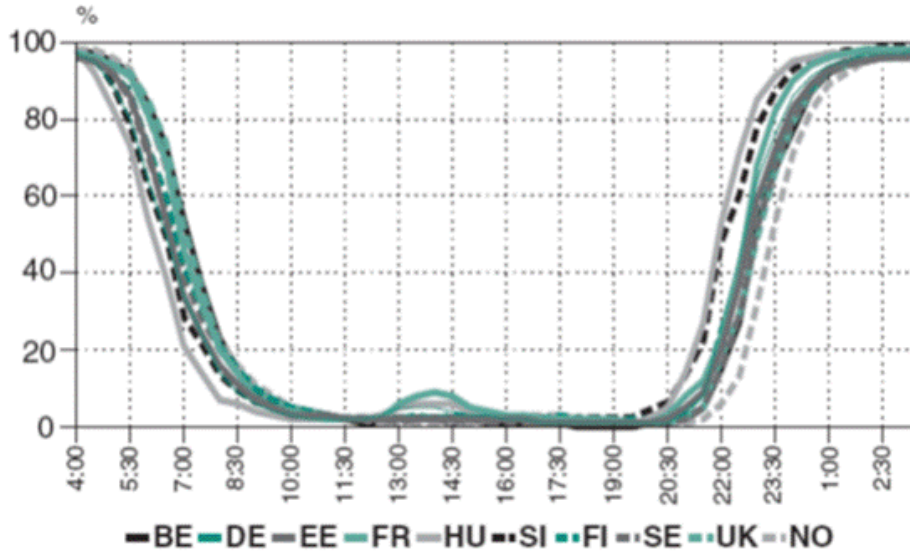


Figure 2: Sleep: Daily rhythm of persons aged 20 to 74 on weekdays [14]

While activity patterns vary between countries this variation is essentially limited to the hour that people wake up and go to bed. These hours vary only by up to one hour, not only within Europe (as shown above) but globally (see Figure 3).

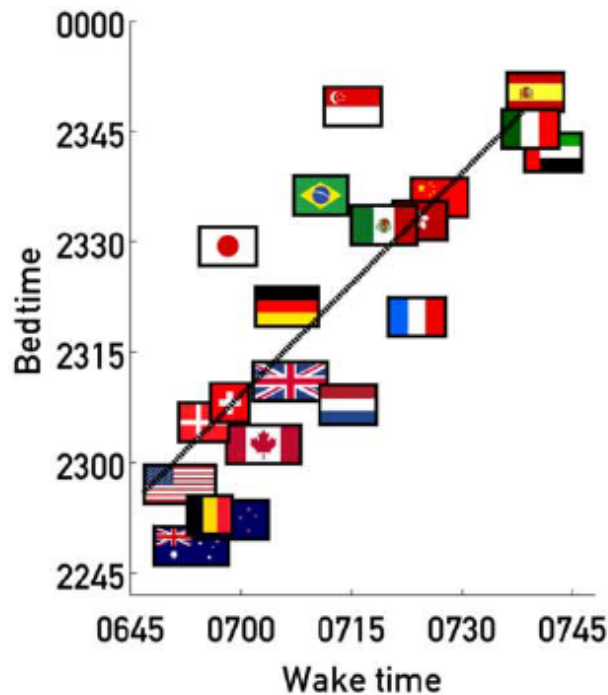


Figure 3: Wake and bed times in 20 surveyed countries [15]

Based on the above information, the number of persons that are active globally at the time of the busy hour in a specific time zone, i.e. for a specific longitude, was calculated. As reference zone and time, UTC+1 and 8 pm were chosen. It must be noted that "active" here does not mean that people are actively using WAS/RLAN or the Internet but simply that they are not sleeping. For WAS/RLAN sharing studies, the WAS/RLAN market factors and busy hour patterns in the countries/regions within the respective time zones are taken into account.

### 3.2.5.1 Population distribution by time zone

A list of the world's countries and the corresponding time zone information was obtained from [16]. There are, however, several countries representing a considerable share of the world's population that span several time zones. These are: Australia, Brazil, Canada, Democratic Republic of the Congo, France, Indonesia, Kazakhstan, Kiribati, Mexico, Federated States of Micronesia, Russia and the United States of America.

Owing to its overseas territories, France is the country with the largest number of time zones. As the majority of the country's population is concentrated in the UTC+1 zone, the other territories have not been considered in this calculation.

For all other multi-time zone countries with the exception of Micronesia and Kiribati detailed information on population distribution per time zone was collected from a variety of sources [17]-[30]. The two aforementioned countries which both span two time zones were placed in the UTC+11 and UTC+12 zones, respectively. The resulting error is negligible; overall, more than 99.9% of the global population has been accounted for in their actual time zones.

The total and active population figures shown below were calculated for the year 2025, based on the latest available forecasts provided by the United Nations [31]. The following modifications of the UN source data were made in Table 16:

- EU Member State Cyprus was moved from the 'Asia' to the 'Europe' category;
- The population of Russia in time zones UTC+6 and beyond was moved from the 'Europe' to the 'Asia' category.

The active share of the population for each hour of the day was derived from [14] and applied to the populations in the various time zones.

The resulting values for total and active populations per time zone are presented in Table 15, whereas the resulting values for total and active populations by continent are shown in Table 16. These tables provide calculations of the active population for a specific example, i.e. the start of the busy hour (8 pm.) in the UTC+1 time zone.

**Table 15: Total and active population per time zone assuming UTC+1 as reference time zone**

Time zone	Total population	Active share of population	Active (awake) population
UTC-11:00	321 811	82%	263 885
UTC-10:00	1 643 483	93%	1 528 439
UTC-09:00	617 375	99%	611 201
UTC-08:00	64 341 715	99%	63 698 298
UTC-07:00	44 143 670	99%	43 702 234
UTC-06:00	276 929 769	99%	274 160 472
UTC-05:00	316 882 373	99%	313 713 549
UTC-04:30	77 428 606	99%	76 654 320

Time zone	Total population	Active share of population	Active (awake) population
UTC-04:00	73 524 210	99%	72 788 968
UTC-03:30	548 421	99%	542 937
UTC-03:00	260 247 765	99%	257 645 287
UTC-02:00	3 085	99%	3 054
UTC-01:00	601 854	99%	595 835
UTC	304 449 308	99%	301 404 815
UTC+01:00	898 136 074	99%	889 154 713
UTC+02:00	607 728 530	95%	577 342 104
UTC+03:00	666 518 917	80%	533 215 133
UTC+03:30	86 729 781	60%	52 037 869
UTC+04:00	43 615 175	35%	15 265 311
UTC+05:00	310 916 346	17%	52 855 779
UTC+05:30	1 473 178 946	12%	176 781 474
UTC+05:45	31 813 598	11%	3 499 496
UTC+06:00	204 262 928	10%	20 426 293
UTC+06:30	57 001 494	3%	1 710 045
UTC+07:00	435 985 694	2%	8 719 714
UTC+08:00	1 686 163 103	2%	33 723 262
UTC+09:00	212 898 187	4%	8 515 927
UTC+09:30	2 150 802	6%	129 048
UTC+10:00	35 652 955	10%	3 565 295
UTC+11:00	1 357 748	40%	543 099
UTC+12:00	6 407 310	70%	4 485 117
Total	8 182 201 033	46%	3 789 282 973

**Table 16: Total and active population by continent assuming UTC+1 as reference time zone**

Region	Population (2025)	Active (awake) population
Africa	1 517 706 140	1 401 175 213
Asia	4 825 636 804	647 528 091
Europe (note 1)	721 026 895	669 240 042
Latin America	691 493 304	684 578 371
Northern America	382 428 768	378 505 871
Oceania	43 909 122	8 255 386
Grand Total	8 182 201 033	3 789 282 973

Region	Population (2025)	Active (awake) population
Note 1: The population of Europe in 2025 has been calculated on the basis of the 2018 edition of the UN World Population Prospects. It includes Europe plus EU Member State Cyprus and minus the territories of the Russian Federation in time zones beyond UTC+5. Therefore, the calculated value differs from the one presented in Table 13.		

For studies involving FSS, the reference time zone considered is related to the coverage areas considered from the satellite in a given orbital position.

## 4 SERVICES AND APPLICATIONS IN THE 6 GHZ FREQUENCY RANGE

### 4.1 FIXED SERVICE (FS)

#### 4.1.1 FS system parameters and assumptions

The technical characteristics of point-to-point (PP) Fixed Service (FS) links are summarised in Table 17 for the lower 6 GHz band and in Table 18 for the upper 6 GHz band. The characteristics are derived from Recommendation ITU-R F.758 [33] and Report ITU-R F.2326 [34]:

- 1 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";
- 2 Report ITU-R F.2326-0: "Sharing and compatibility study between indoor International Mobile Telecommunication small cells and fixed service stations in the 5925-6425 MHz frequency band" [34].

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

- 1 Recommendation ITU-R F.383-9: "Radio-frequency channel arrangements for high-capacity fixed wireless systems operating in the lower 6 GHz (5925-6425 MHz) band" [35];
- 2 Recommendation ITU-R F.384-11: "Radio-frequency channel arrangements for medium- and high-capacity digital fixed wireless systems operating in the 6425-7-125 MHz band" [36];
- 3 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" [37], with peak side-lobe levels appropriate for single-entry interference studies;
- 4 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" [38], with average side-lobe levels appropriate for aggregate interference studies.

**Table 17: 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 [37] Recommendation ITU-R F.1245 for aggregate interference [38]	
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 $1 \times 10^{-6}$ BER (dBW/MHz)	-112.5	-110.5
Nominal long term interference power density (dBW/MHz)	-139 + I/N	-140 + I/N
Protection requirement (dB)	I/N = -10 and -20 (Recommendation ITU-R F.758: Table 4) [33]	
Link Length (km)	Between 10 and 80 (Mode: 40)	
<p>Note: This Report studies interference protection criteria of I/N = -10 dB and I/N = -20 dB to reflect that fifteen CEPT administrations have a mobile allocation with a primary status in this band and one CEPT administration has a mobile allocation with a secondary status</p> <p>* Where a typical value (Mode) is provided, it is to be taken as indicative within the range specified and further sensitivity analysis may be required on a case-by-case basis to assess a given interference potential due to the variations within the range specified. The typical values are based on Recommendation ITU-R F.758-6 [33] and Report ITU-R F.2326-0 [34]</p>		

**Table 18: 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
Tx output power range (dBW)	Between -15 and 3 (Mode*: -2)

Parameter	Value
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 [37] Recommendation ITU-R F.1245 for aggregate interference [38]
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 $1 \times 10^{-6}$ BER (dBW/MHz)	-113
Nominal long term interference power density (dBW/MHz)	$-139.5 + I/N$
Protection requirement (dB)	$I/N = -10$ and $-20$ (Recommendation ITU-R F.758: Table 4) [33]
Link Length (km)	Between 10 and 80 (Mode: 40)
<p>Note: This Report studies interference protection criteria of <math>I/N = -10</math> dB and <math>I/N = -20</math> dB to reflect that 15 CEPT administrations have a mobile allocation with a primary status in this band and one CEPT administration has a mobile allocation with a secondary status</p> <p>* Where a typical value (Mode) is provided, it is to be taken as indicative within the range specified and further sensitivity analysis may be required on a case-by-case basis to assess a given interference potential due to the variations within the range specified. The typical values are based on Recommendation ITU-R F.758-6 and Report ITU-R F.2326-0.</p>	

#### 4.1.2 Fixed Service Point-to-Point narrow channels use in the band

In addition to the characteristics outlined in section 4.1.1 for the FS with 40 and 29.65 MHz, it has to be noted that ECC Recommendation (14)06 [39] provides options for administrations to implement Fixed Service Point-to-Point narrow channels (3.5 MHz, 1.75 MHz, 0.5 MHz, 0.25 MHz and 0.025 MHz) in the guard bands and centre gaps of the lower 6 GHz (5925 to 6425 MHz) and upper 6 GHz (6425-7125 MHz). Details of these options can be consulted in the Annexes of ECC Recommendation (14)06.

#### 4.1.3 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 4 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 [40], 5 December 2017, Embedded Excel file "Draft Revised ECC Rep 173 - Below and Above 50 GHz in 2016.xlsw".



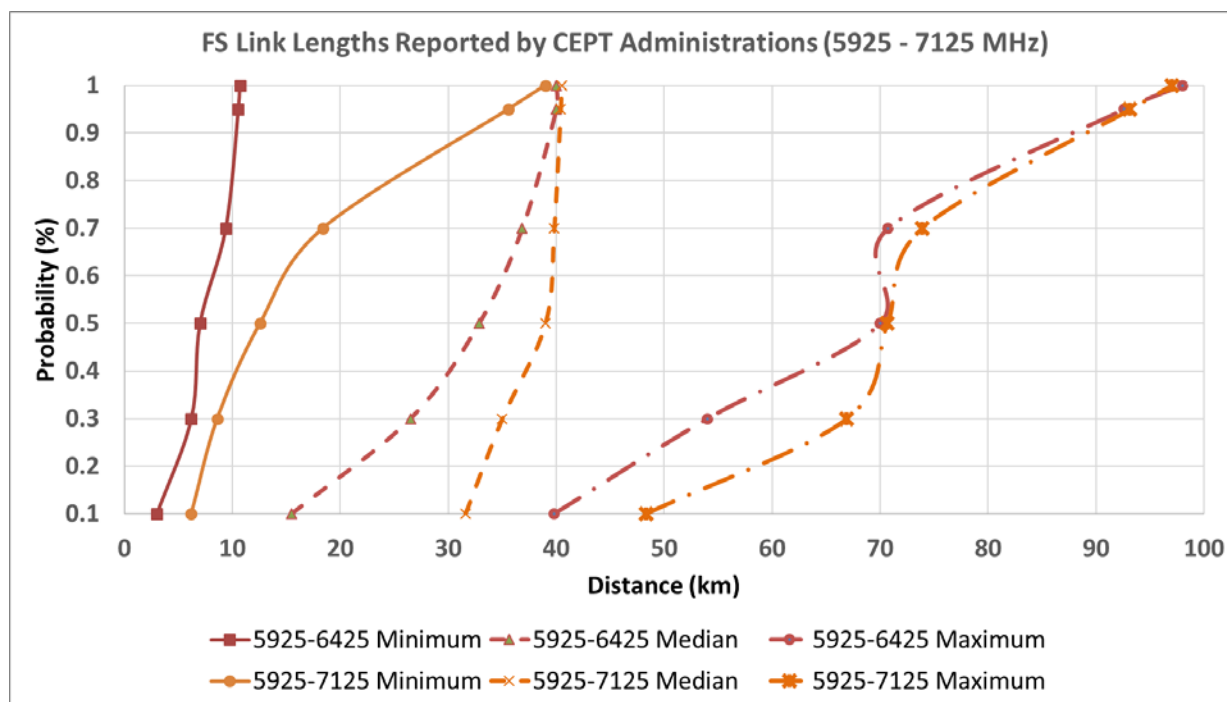


Figure 4: FS Link Lengths Reported by CEPT administrations (5925-7125 MHz)

## 4.2 FIXED SATELLITE SERVICE (FSS), EARTH-TO-SPACE

### 4.2.1 FSS system parameters and assumptions

The technical characteristics of Fixed Satellite Service (FSS) transmitters are summarised in Table 19. They are based on the following Recommendations and Reports relevant for the assessment of interference in this Report:

- 1 ECC Report 244: "Compatibility studies related to WAS/RLANs in the 5725-5925 MHz band", January 2016 [32];
- 2 Recommendation ITU-R S.672-4: "Satellite antenna radiation pattern for use as a design objective in the fixed-satellite service employing geostationary satellites" [41], this Recommendation needs  $G_m$ ,  $L_s$  and other parameters for the radiation pattern to be defined, otherwise, measured radiation patterns are to be used;
- 3 Recommendation ITU-R S.465-5: "Reference radiation pattern of earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31 GHz" [42];
- 4 Recommendation ITU-R S.524-9: "Maximum permissible levels of off-axis e.i.r.p. density from earth stations in geostationary-satellite orbit networks operating in the fixed-satellite service transmitting in the 6 GHz, 13 GHz, 14 GHz and 30 GHz frequency bands" [43];
- 5 Recommendation ITU-R S.1432-1: "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" [44];
- 6 Recommendation ITU-R S.1587-3: "Technical characteristics of earth stations on board vessels (ESV) communicating with FSS satellites in the frequency bands 5925-6425 MHz and 14-14.5 GHz which are allocated to the fixed-satellite service" [45];

- 7 Recommendation ITU-R S.731: "Reference earth-station cross-polarised radiation pattern for use in frequency coordination and interference assessment in the frequency range from 2 to about 30 GHz" [46].

**Table 19: Typical FSS Transmitter (Earth Station) parameters in the frequency range 5925-6425 MHz**

Parameter	Typical value
Range of operating frequencies (MHz)	5925-6425
Antenna diameters (m)	1.2, 1.8, 2.4, 3.0, 4.5, 8, 16 and 32
Antenna reference pattern	Recommendation ITU-R S.465 [42]
Range of emission bandwidths (MHz)	0.040-72
Earth station deployment	All regions, in all locations (rural, suburban and urban)
Earth station e.i.r.p. density towards the horizon	In accordance with RR No. <b>21.8</b> and Recommendation ITU-R S.524-9 [43]
Minimum earth station antenna elevation angle (degrees)	5

#### 4.2.2 FSS protection criteria

Taking into account the large coverage area of the Fixed Satellite receive beams in the band 5925-6425 MHz, emissions from a large number (i.e. several hundred millions) of WAS/RLAN Access Points (APs) are to be considered, so that the interference to the FSS space station is characterised by the average aggregate interference from WAS/RLAN APs. Therefore, any interference scenario in the Earth-to-space direction is considered on a time invariant basis and the protection criteria to be applied should be based on an I/N value of -10.5 dB, where N refers to the thermal noise, in line with Recommendation ITU-R S.1432-1. This value does not include apportionment, if any, of the allowable interference into FSS between other (than FSS) co-primary services, apportionment has to be considered on a case-by-case basis.

#### 4.2.3 FSS deployment

FSS deployments can be found in 5925-6425 MHz where earth stations in the Earth-to-space uplink direction operate only to satellites in geostationary orbits. The frequency band 5925-6425 MHz is where all of the currently operating satellites (e.g. INTELSAT and SES) have received transponders. Table 20 provides details of the selection of satellites that have been taken as representative of those requiring protection in the visible portion of the geostationary orbit from Europe. In these frequency bands, the satellite beams cover very large areas of the Earth (using global, hemispherical, zonal or regional beams).

It should be understood as representative characteristics to conduct sharing studies independently of the lifetime of the particular satellites being analysed. Indeed, even if a particular satellite reaches the end of its lifetime, it will be replaced for an equivalent satellite that allows continuing providing fixed-satellite service in the relevant service area. It should be noted that the band 5925-6425 MHz is extensively used by FSS satellite networks worldwide and that currently about 180 satellites are in orbit using this band.

**Table 20: FSS satellite parameters for sharing studies**

Satellite	Sub-satellite longitude	Maximum Receive Gain (dBi)	Receiving Thermal Noise Temperature (K)	Figure of merit (dB/K) (using thermal noise)	Receiving System Noise Temperature (K)	Figure of merit (dB/K) (using system noise)
A	5° West	20.3	595	-7.44		
B	14° West	26.5	1200			
C	31.5° West	32.8	700			
D	3° East	22.9	316	-2.09		
E	27.5° West	34.2	565.76	6.67	832	5.00
F	53° East	26.5	1200			
I	359° East	28.67	340.68	3.35	501	1.67
J	40.5° West	22	190	-0.8		
K	22° West	28.2	190	5.4		
L	20° West	31.8	250	7.8		
M	50.5° East	32.4	250	8.4		
N	57° East	27.9	190	5.1		
O	5° East	32.5	700			
P	47.5° West	20	190	-2.8		
Q	37.5° West	30.5	190	7.7		
R	60° East	37.29	201.28	14.25	296	12.58
R'	5° East	37.29	201.28	14.25	296	12.58
T	34.5° West	39.90	224.4	16.39	330	14.71
U	8° West	27.2	428	0.88		
V	10° East	24.2	412	-1.94		
W	66° East	27.86	357	2.33	525	0.66
Y	45° West	31.04	298.52	6.29	439	4.62
Z	72° East	28.33	252.96	4.30	372	2.62

### 4.3 ROAD-INTELLIGENT TRANSPORT SYSTEMS (ITS) IN THE ADJACENT BAND

Technical characteristics of Road-ITS systems are outlined in Section 8.

### 4.4 COMMUNICATION BASED TRAIN CONTROL SYSTEMS (CBTC)

Technical characteristics of CBTC systems are outlined in Section 9.

#### **4.5 RADIO ASTRONOMY**

Technical characteristics for the Radio Astronomy Service are outlined in Section 10.

#### **4.6 ULTRA WIDE BAND (UWB) SYSTEMS**

Technical characteristics of UWB systems are outlined in Section 11.

## 5 METHODOLOGY AND APPROACH USED IN SHARING AND COMPATIBILITY STUDIES

### 5.1 METHODOLOGY

This Report has embraced both MCL and Monte Carlo simulation methodologies [80]. With MCL, a set of assumptions are used to derive the loss required on the interference path in order that an interferer does not violate a predetermined interference protection criterion. Violations of the criterion indicate that additional losses are required on the interference path. Monte Carlo analyses can be used to assess the same interference criterion considered using the MCL methodology. However, because Monte Carlo will deliver results that include the probability of their occurrence, simulation runs often involve tens of thousands of instances. The results can be presented in the form of an interference graph or complementary cumulative distribution function (CDF); that is a graph showing the probability that the interference criterion is reached or exceeded during the simulation. This allows for all simulated events to be viewed within the context of the overall sample space studied.

### 5.2 PROPAGATION MODELS

#### 5.2.1 Terrestrial paths

When analysing interference into FS stations from a deployment of a large number of WAS/RLANs across a large geographical area, any simulation must model the variations in interference path morphologies that exist. The interference in this case is statistical and as such the propagation models should be stochastic, taking into account the large variation in parameters, geometries and morphologies expected.

These morphologies have several different aspects. FS stations and WAS/RLANs are installed and used in urban, suburban and rural areas. The FS links are designed to be line of sight (LOS) and, therefore, the path from transmitter to receiver is always above obstructions, including terrain and nearby buildings. Finally, WAS/RLANs are used at ground level and in upper floors of buildings, indoors and outdoors, such that the interference paths, through clutter, are from WAS/RLANs below rooftop to FS stations above rooftop.

To model these interference paths and to account for the resulting different morphologies, this sharing and compatibility study used the propagation and clutter models listed below.

For indoor WAS/RLAN usage, Recommendation ITU-R P.2109 [47] is used for computing indoor-to-outdoor interference path propagation losses as described in Section 5.4.

For near-in, out to 1 km, propagation loss including clutter, WINNER II (WII) [52] was used for suburban and urban areas.

For propagation loss beyond 1 km in suburban and urban areas, Recommendation ITU-R P.452 [48] with terrain data was used in combination with Recommendation ITU-R P.2108 [49]. ITU-R P.2108 is a suburban/urban endpoint clutter model used for long distance paths with the WAS/RLAN in the clutter field and makes the assumption the signal propagates out of the clutter field over rooftops.

For rural area propagation, Recommendation ITU-R P.452 with terrain data including rural endpoint clutter model was used. By default, the rural clutter morphology is assumed to be village centre since WAS/RLANs are generally used within buildings. If the location is dominated by trees, a rural tree clutter morphology is assumed, instead<sup>1</sup>.

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<sup>1</sup> The European Environment Agency's Corine Land Cover (CLC) raster database is used to categorise locations with deciduous trees, mixed tree forest and coniferous trees.

The Recommendation ITU-R P.452 assumes that for each rural clutter category there is an average clutter height and distance from the clutter. From this geometry an elevation angle is calculated to the top of the clutter. If the interference path elevation angle is above the elevation angle to the clutter, then there is no clutter loss. Otherwise Recommendation ITU-R P.452 is used to calculate the clutter loss. Additionally, no clutter loss is added for cases where the distance from the WAS/RLAN to the FS station is less than 10 times the distance from the WAS/RLAN to the clutter.

### 5.2.1.1 Discussion of propagation models selected for terrestrial paths

The following was considered in recommending WINNER II (WII) over Recommendation ITU-R P.1411 [53], for propagation loss out to 1 km in urban and suburban areas.

- The Winner II model is based on measurements up to 6 GHz and is valid out to 5 km. The model is widely used and was developed by curve fitting a large number of measurements. It is reasonable to assume WII is valid up to 6.425 GHz, which is of interest here. WII macro cell models are applicable to propagation scenarios where the FS station is above rooftop and the WAS/RLANs are below rooftop and assume that both the FS station and WAS/RLAN are in the same clutter field. Even though WII is applicable out to 5 km, a conservative recommendation is to only use the model out to 1 km. This is the recommendation in Recommendation ITU-R P.1411 and is consistent with Recommendation ITU-R P.2108, Section 3.2, where median clutter is effectively constant beyond 1 km. Clutter fields in urban and suburban areas can be greater than 1 km, however, not every clutter path is expected to be that long.
- Additionally, it was determined that the WII non line of sight (NLOS) Urban and Suburban models match the Extended Hata (Cost-Hata or eHata) model at 2 GHz where their frequencies overlap. The eHata model, based on Okumura's extensive measurements, is widely accepted (in the frequency range from 1500 to 2000 MHz). The WII model thus makes a reasonable extension from the eHata model.
- The Recommendation ITU-R P.1411 is a ratified near-in clutter model that covers the frequency band of interest. It includes detailed site-specific models and derived site general models. A drawback of ITU-R P.1411 is that it does not provide a means with which to assess the relative likelihood of whether LOS or NLOS conditions prevail, which is a critical aspect of clutter modelling. In contrast, the WII model provides formulations for estimating the probability of LOS.
- Thus, the empirically-based WII model provides a stochastic view that is more appropriate for performing a statistical analysis that captures the variation of parameters over many different morphologies. Additionally, the Recommendation ITU-R P.1411 model's lack of a LOS prediction method shows a lack of cohesion and pronounced discontinuity across the LOS and NLOS formulations. This property makes it difficult to apply when conducting a broad statistical analysis of clutter.
- In this Report, WINNER II LOS probabilities are implemented using the following pseudocode:
  - a) Place each WAS/RLAN on Earth randomly according to population density
  - b) For each WAS/RLAN, calculate the distance to the FS:  $d$
  - c) For each WAS/RLAN, calculate  $p_{\text{LOS}}$  which is a function of distance  $d$  and the environment (WAS/RLAN can be in Urban, Suburban or Rural environment)
  - d) For each WAS/RLAN, generate a random number  $r = \text{rand}(1)$  with a uniform distribution over the interval  $[0, 1]$ 
    - if  $r < p_{\text{LOS}}$ : calculate path loss using LOS equation
    - else: calculate path loss using NLOS equation
  - e) repeat for all FSs
- While the WINNER II model indicates that WAS/RLAN antenna height may be adjusted, it does not observe any specific hard upper-bound. To address this ambiguity, one has to turn to one of the WINNER II model's predecessors, the eHata model, as mentioned above. In applying the WINNER II model, the range of valid WAS/RLAN antenna heights is assumed to be at least up to 10 m, which is the

upper bound of the applicable eHata model range. For WAS/RLANs above 10 m, a conservative assumption is to simply assume that the probability of a LOS path is equal to one. Alternatively, 3GPP (3GPP TR 36.873 [54]) defines 3D macro cell models where the probability of LOS paths is calculated for WAS/RLAN antenna heights up to 22.5 m. Although the 3GPP models are geometrically based the probability of a LOS path may still be valid;

### 5.2.1.2 References and information on implementation

- 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":
  - A reference MATLAB implementation available on ITU-R Study Group 3 web page [82];
  - A reference Excel implementation available on ITU-R Study Group 3 web page [83].
- Recommendation ITU-R P.525 [51]: "Calculation of free-space attenuation";
- Recommendation ITU-R P.1411 [53]: "Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz)," The model includes clutter loss and is not to be combined with the clutter loss model of Recommendation ITU.R P.2108-0;
- WINNER II path loss model, developed by IST-WINNER II project [52], supports LOS and NLOS propagation conditions and, unlike Recommendation ITU-R P.1411, it provides the LOS probabilities. This model includes clutter loss and as such, it is not to be combined with the clutter loss model of Recommendation ITU-R P.2108-0.

## 5.2.2 Earth-to-air paths

For indoor WAS/RLAN usage, Recommendation ITU-R P.2109 is used for computing indoor-to-outdoor interference path propagation losses as described in Section 5.4.

For suburban and urban propagation areas, local end-point clutter is added using Recommendation ITU-R P.2108, Section 5.3 (for Earth-to-space paths). It accounts for the elevation angles from the transmitters to the satellites.

To estimate rural clutter loss, Recommendation ITU-R P.452 was used with WAS/RLANs deployed predominately in village centres. Recommendation ITU-R P.452 assumes that in village centres clutter height is 5 m and the distance to the clutter is 0.07 km which equals an angle of 2.86 degrees for a WAS/RLAN with 1.5 m height. Therefore, in the simulations, when the rural WAS/RLAN height is 1.5 m, a clutter loss of 18.4 dB was added when the look angle to the FSS receiver was  $\leq 2.86$  degrees. When rural WAS/RLAN heights are above 1.5 m, the clutter loss is assumed to be negligible and is not calculated.

For each WAS/RLAN, a 4/3 earth model is used to determine whether the satellite is in view or over the horizon. WAS/RLANs for which the satellite is not in view are considered to contribute no interference. The path loss is computed using Free Space Path Loss (FSPL), per Recommendation ITU-R P.619-3 [57], from the WAS/RLAN position to the satellite orbital slot. Atmospheric loss, which is small, was ignored in this calculation.

### 5.2.2.1 References and information on implementation

- Recommendation ITU-R P.525: "Calculation of free-space attenuation" [51];
- Recommendation ITU-R P.528: "Propagation curves for aeronautical mobile and radionavigation services using the VHF, UHF and SHF bands" [56];
- Recommendation ITU-R P.619: "Propagation data required for the evaluation of interference between stations in space and those on the surface of the Earth" [57];
- Recommendation ITU-R P.2041: "Prediction of path attenuation on links between an airborne platform and Space and between an airborne platform and the surface of the Earth" [55].

### 5.3 CLUTTER LOSS

Recommendation ITU-R P.2108 [49] is used to predict clutter loss. Recommendation ITU-R P.2108 is valid only for urban/suburban areas. Therefore, in this Report, rural clutter loss is modelled using Recommendation ITU-R P.452 [48], Section 4.5, which defines clutter loss for rural environment not covered by Recommendation ITU-R P.2108. By default, the rural clutter morphology is assumed to be village centre since WAS/RLANs are generally used within buildings. If the location is dominated by trees, rural tree clutter morphology is assumed, instead. The European Environment Agency's Corine Land Cover (CLC) raster database [50] is used to categorise locations with deciduous trees, mixed tree forest and coniferous trees.

The Recommendation ITU-R P.452 model assumes that for each rural clutter category there is an average clutter height and distance from the clutter. From this geometry an elevation angle is calculated to the top of the clutter. If the interference path elevation angle is above the elevation angle to the clutter, then there is no clutter loss. Otherwise Recommendation ITU-R P.452 is used to calculate the clutter loss. Additionally, no clutter loss is added for cases where the distance from the WAS/RLAN to the FS station is less than 10 times the distance from the WAS/RLAN to the clutter.

A reference Excel implementation of Recommendation ITU-R P.2108-0 "Prediction of clutter loss" is available on ITU-R Study Group 3 web page [84].

### 5.4 BUILDING ENTRY LOSS

For indoor WAS/RLAN usage, Recommendation ITU-R P.2109 is used for computing indoor-to-outdoor interference path propagation losses. Two types of buildings are defined in this Recommendation: traditional and thermally efficient. Building entry losses through thermally efficient buildings are higher than traditional buildings. The model assumes 70% of buildings are traditional and 30% of buildings are thermally efficient.

A reference Excel implementation of Recommendation ITU-R P.2109: "Prediction of building entry loss" is available from ITU-R Study Group 3 web page [85].

### 5.5 POLARISATION MISMATCH

For aggregate interference studies an average 3 dB loss may be applied where the following assumptions are valid:

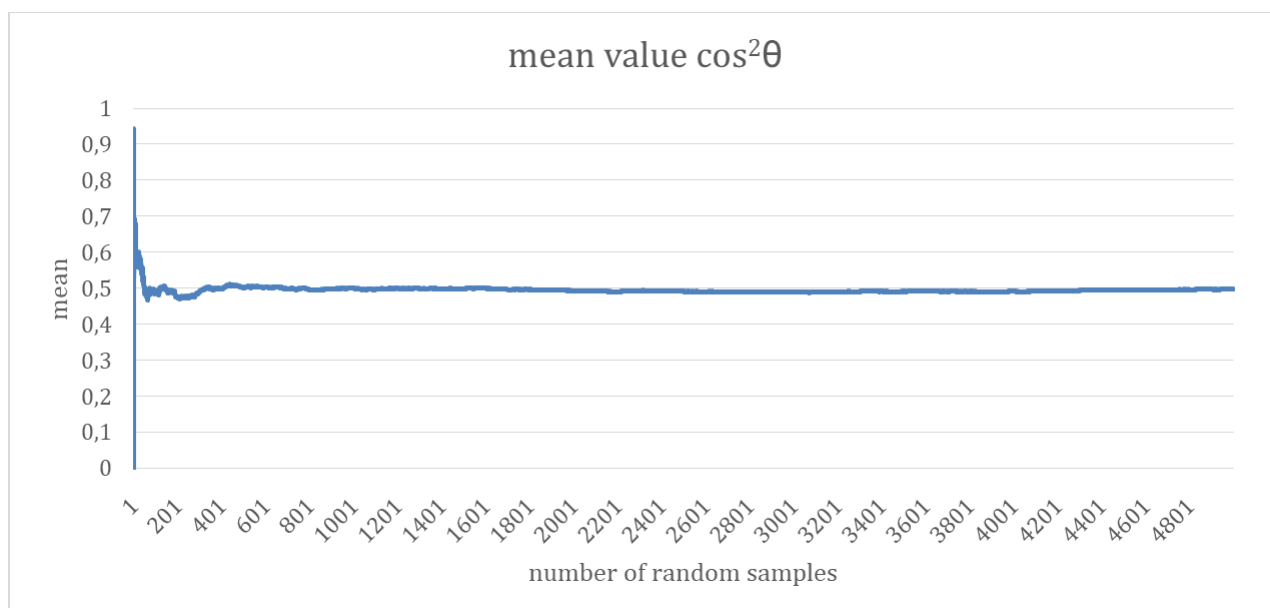
- a) The aggregate interference results from a large number of contributions from emission of WAS/RLAN access points and terminals of similar interference levels;
- b) No single source of interference (or small number of sources with the same polarisation angle at the victim receiver) dominates the calculation;
- c) The victim receiver has a polarizing filter of any kind.

In cases where these assumptions do not apply, a study may use any value considered appropriate. Each aggregate interference assessment study should indicate what level of polarisation discrimination was applied in the study together with the underlying rationale for the assumptions made.

For single entry interference, where the calculation is dominated by one source, a worst case loss of 1.5 dB should be assumed for main-lobe to main-lobe coupling and a loss of 0 dB in other cases.

When considering how many WAS/RLANs constitutes a large number in this context, it is worth noting that the average value of 0.5 is approached very quickly as the number of randomly orientated interferers increase. Figure 5 below shows the results of one simulation of 5000 samples.





**Figure 5: The mean value of  $\cos^2\theta$  as a function**

The value oscillates around 0.5 and the mean value converges towards 0.5 quickly. In this case, after 100 samples the value is 0.483627142, after 1000 samples it is 0.508790695, after 5000 samples the value is 0.501666179.

For 100+ interferers it is safe to assume a polarisation loss of 3 dB.

### 5.5.1 Applicability to WAS/RLAN - FSS studies

The FSS uplink receiver, in all cases studied, sees many sources of interference. Therefore, the minimum value for polarisation coupling loss to be applied in WAS/RLAN into FSS uplinks is 3 dB.

#### 5.5.1.1 Arguments for randomness of WAS/RLAN polarisation as seen from the satellite

This section demonstrates why assumption b) is considered to be a very good approximation:

- 1 WAS/RLAN devices use linear polarisation, but polarisation mismatch is a known problem in WAS/RLAN networks;
- 2 APs may have a fixed plane of polarisation, but this is not consistent from AP to AP and depends on many factors including AP orientation. As all our studies to date are assuming that AP orientation cannot be assumed to be consistent, this will lead to a range of polarisation planes even in the AP reference frame;
- 3 WAS/RLAN user devices have no fixed orientation in the vast majority of cases - phones, phablets, tablets and laptops are all subject to user movement and, therefore, change in polarisation plane in the earth reference frame;
- 4 Scattered energy from WAS/RLAN, e.g. from indoor to outdoor or from local clutter, is depolarised;
- 5 From the satellite point of view, the situation is subject to an additional layer of variation. For example, an AP that has horizontal polarisation in the earth reference frame will be seen differently by the satellite when at different locations on the surface of the earth. When considering continental and hemispheric beams this leads to a very large variation.

### 5.5.2 Applicability to WAS/RLAN - FS Studies

The situation for WAS/RLAN to FS links is less straightforward. Depending on the details of the scenario modelled, it is conceivable that the interference level is dominated by a few WAS/RLAN devices. However, the main beam of an FS receiver could equally see many WAS/RLAN at similar interference levels.

Therefore, in the case of FS links the value for polarisation loss should be assessed on a case-by-case basis and should be either 1.5 dB or 3 dB as a minimum. The 1.5 dB minimum applies in the case of single interferer dominance into the FS main lobe; the 3 dB applies to aggregate cases.

## 5.6 BODY LOSS

RF signal attenuation that is caused by the human body is typically taken into account in sharing studies with mobile client devices. A fixed body loss value of 4 dB is applied in Monte Carlo simulations when the modelled WAS/RLAN device is a client, while body loss is assumed to be non-existent for Access Point devices. The percentage of client devices is given as 26.32% and 50% for indoor and outdoor deployments, respectively, in Section 3.1.1.4. Hence, the following methodology is applied in the Monte Carlo analysis:

- a) For indoor devices, apply 4 dB additional loss for 26.32% of the devices (clients)
- b) For outdoor devices, apply 4 dB additional loss for 50% of the devices (clients)

For analyses that use the percentages of different e.i.r.p. values directly in the model, Table 21 can be used. This table is obtained by using the original e.i.r.p. weight tables and scaling the client power by 4 dB (corresponding to a linear factor of 2.5). Hence, the original value of 100 mW is considered under the new category of 40 mW, 50 mW is considered under the new category of 20 mW and 13 mW is considered under the new category of 5 mW.

**Table 21: Percentage of devices e.i.r.p. considering body loss**

Power (mW)	1000	250	100	50	13	1	40	20	5	Total
Indoor percentage	0.71%	9.16%	4.39%	13.75%	40.00%	5.68%	1.82%	12.03%	12.47%	100.0%
Outdoor percentage	3.24%	4.24%	4.38%	14.10%	20.97%	3.07%	3.46%	22.85%	23.68%	100.0%

## 6 SHARING BETWEEN WAS/RLAN AND FIXED SERVICE

### 6.1 INTRODUCTION

This Section contains the results of three complementary studies (Study A, B and C) of the interference from WAS/RLAN to FS networks.

Study A is a minimum coupling loss (MCL) analysis which looks at a range of FS parameters and WAS/RLAN parameters to define a maximum single-entry interference scenario, in a smooth-earth model.

The MCL study does not consider how the interference values vary with time nor how likely it is to find WAS/RLANs deployed at the specific locations needed to drive the interference levels above the threshold. It does not consider the real-world distribution of WAS/RLAN e.i.r.p. and RF activity factor or the significant off-boresight discrimination from real antennas. Nor does it consider the aggregation of interference from the population of WAS/RLANs.

Therefore, Monte Carlo analyses in Studies B and C have also been conducted to determine whether short term and long term protection criteria were met.

Both MCL and Monte Carlo studies applied only far-field antenna radiation patterns without taking into account any near-field effects.

Each study is described below in detail.

### 6.2 STUDY A: MCL ANALYSIS OF INTERFERENCE FROM WAS/RLAN INTO FS

#### 6.2.1 Introduction

It is assumed that an FS station is the victim receiver and a WAS/RLAN AP is the interfering transmitter. In this single interferer analysis, the system parameters provided in previous sections are taken into account and the horizontal distances are determined at which the protection thresholds of  $I/N = -10$  dB and  $I/N = -20$  dB are exceeded. The short term protection threshold  $I/N = 19$  dB was not assessed in this study.

With the aim to visualise the critical areas around the FS station MCL calculations are done for different angles between both systems.

The following MCL formula is used:

$$P_{\text{TxEIRP}} - L_{\text{Path}} - L_{\text{Clutter}} - L_{\text{BuildingEntry}} + G_{\text{Rx}} \leq 10 \log(kT_0B) + NF_N + \frac{I}{N}$$

where:

- $P_{\text{TxEIRP}}$  is the e.i.r.p. of the WAS/RLAN transmitter;
- $L_{\text{Path}}$  is the attenuation caused by the path of transmission;
- $L_{\text{Clutter}}$  is the attenuation caused by obstacles in the path of transmission;
- $L_{\text{BuildingEntry}}$  is the attenuation caused by walls when the WAS/RLAN transmitter is located inside a building;
- $G_{\text{Rx}}$  is the antenna gain of the FS receiver in the direction of the WAS/RLAN transmitter;
- $NF_N$  is the noise figure of the FS receiver;
- $\frac{I}{N}$  is the protection criterion.

In this analysis, the interfering power and the received power are normalised to 1 MHz.

Four scenarios are analysed:

- Urban scenario with WAS/RLAN devices located indoors with e.i.r.p. power densities:
  - $1000 \text{ mW} / 20 \text{ MHz} = 17 \text{ dBm/MHz}$ ;
  - $250 \text{ mW} / 20 \text{ MHz} = 11 \text{ dBm/MHz}$ .
- Urban scenario with WAS/RLAN devices located outdoors with e.i.r.p. power densities:
  - $1000 \text{ mW} / 20 \text{ MHz} = 17 \text{ dBm/MHz}$ ;
  - $25 \text{ mW} / 20 \text{ MHz} = 1 \text{ dBm/MHz}$ ;
  - $25 \text{ mW} / 94 \text{ MHz} = -6 \text{ dBm/MHz}$ .
- Rural scenario with WAS/RLAN devices located indoors with e.i.r.p. power densities:
  - $1000 \text{ mW} / 20 \text{ MHz} = 17 \text{ dBm/MHz}$ ;
  - $250 \text{ mW} / 20 \text{ MHz} = 11 \text{ dBm/MHz}$ .
- Rural scenario with WAS/RLAN devices located outdoors with e.i.r.p. power densities:
  - $1000 \text{ mW} / 20 \text{ MHz} = 17 \text{ dBm/MHz}$ ;
  - $25 \text{ mW} / 20 \text{ MHz} = 1 \text{ dBm/MHz}$ ;
  - $25 \text{ mW} / 94 \text{ MHz} = -6 \text{ dBm/MHz}$ .

In addition to this sensitivity analysis, which considers different power density levels, another sensitivity analysis is performed, which considers different antenna heights and building types. In the latter analysis, only antennas which are directed towards each other (that results in peak separation distances only) are analysed.

Five scenarios are analysed, each with WAS/RLAN devices transmitting with e.i.r.p. of  $1000 \text{ mW} / 20 \text{ MHz} = 17 \text{ dBm/MHz}$  and with  $240 \text{ mW} / 160 \text{ MHz} = 2 \text{ dBm/MHz}$ :

- Urban scenario with outdoor WAS/RLAN devices at Tx height of 1.5 m:
  - Rx heights of 10 m, 25 m, 40 m and 55 m.
- Urban scenario with indoor (traditional building) WAS/RLAN devices at Tx height of 1.5 m:
  - Rx heights of 10 m, 25 m, 40 m and 55 m.
- Urban scenario with indoor (thermally efficient building) WAS/RLAN devices at Tx height of 1.5 m;
  - Rx heights of 10 m, 25 m, 40 m and 55 m.
- Urban scenario with indoor (traditional building) WAS/RLAN devices at Tx height of 4.5 m;
  - Rx heights of 10 m, 25 m, 40 m and 55 m.
- Urban scenario with indoor (thermally efficient building) WAS/RLAN devices at Tx height of 4.5 m;
  - Rx heights of 10 m, 25 m, 40 m and 55 m.

## 6.2.2 Propagation model

A comparison of propagation models is given in ANNEX 4. This Section gives a short summary of this comparison.

For urban scenarios from 0 m to 1000 m, the model described in Recommendation ITU-R P.1411-9 [53] is used with line of sight (LOS) conditions. From 1000 m, the model described in Recommendation ITU-R P.452-16 [48] is used with non-line of sight (NLOS) conditions. The model described in Recommendation ITU-R P.2108-0 [49] is added for clutter losses.

For rural scenarios from 0 m to 4017 m, the model described in Recommendation ITU-R P.452-16 is used with LOS conditions. From 4017 m, the same model is used with NLOS conditions. The clutter losses from Recommendation ITU-R P.452 are added.

For indoor scenarios, building entry loss according to the model described in Recommendation ITU-R P.2109-0 is added to all constellations. The difference between the indoor and outdoor scenarios in this

study is in the building entry loss of about 17 dB (for a traditional building type) and about 32 dB (for a thermally-efficient building type).

### 6.2.3 Parameters

The basis of the MCL calculations is the set of parameters derived from previous sections. For the parameters given by distributions, values are taken which have maximum impact on the FS receiver for defining the worst case scenario. These parameters are listed in Table 22.

It may happen that the combination of parameters for one of these scenarios is not valid (e.g. antenna height in combination with antenna gain).

With  $I/N = -10$  dB and  $I/N = -20$  dB there are two protection criteria to be considered.

Antenna heights were chosen according to the description of the WINNER II project. It is also assumed that this vertical separation distance assures that there is no WAS/RLAN device inside of the first Fresnel zone of the FS link.

**Table 22: MCL parameters**

Parameter	Value	Comment
Frequency	6.175 GHz	Centre frequency of the proposed band
FS Antenna Pattern	Recommendation ITU-R F.699 [37]	The elevation angle is assumed to be 0° for calculations
WAS/RLAN Antenna Pattern	Isotropical	Simplified assumption for single interferer case. e.i.r.p. values are used.
WAS/RLAN Antenna height	1.5 m	Taken from WINNER II description, used for power density sensitivity analysis
	1.5 m, 4.5 m	Used for antenna height sensitivity analysis
FS Antenna height	25 m	Taken from WINNER II description, used for power density sensitivity analysis
	10 m, 25 m, 40 m and 55 m	Used for antenna height sensitivity analysis
FS Maximum antenna gain	46.6 dBi	Used for power density sensitivity analysis
	38.1 dBi, 46.6 dBi,	Used for antenna height sensitivity analysis
FS Receiver Noise Figure	4 dB	Used for power density sensitivity analysis
	4 dB and 5 dB	Used for antenna height sensitivity analysis
WAS/RLAN e.i.r.p. max	14 dBm, 24 dBm and 30 dBm	Used for power density sensitivity analysis
	23.8 dBm 30 dBm	Derived peak e.i.r.p. value for consumer AP (Table 3 of the Report), used for antenna height sensitivity analysis
WAS/RLAN bandwidth min	20 MHz and 94 MHz	Used for power density sensitivity

Parameter	Value	Comment
		analysis
	20 MHz and 160 MHz	Used for antenna height and building entry loss sensitivity analysis
Building entry loss	0 if outdoor ~ 17 dB if indoor traditional ~ 32 dB if indoor thermally efficient	Recommendation ITU-R P.2109 used for indoor scenarios (BEL sensitivity analysis)
Polarisation loss	0 dB	
Body loss	0 dB	

#### 6.2.4 Results for sensitivity analysis of power density levels

MCL calculations have been done for a flat terrain profile height of 0 m. The FS receiver antenna is at a height of 25 m, is directed along the  $x$  –axis and has an elevation angle of  $0^\circ$ . The WAS/RLAN transmitter is at a height of 1.5 m and is directed toward the FS receiver. The resulting plots illustrate the threshold contours in the horizontal plane along which the WAS/RLAN transmitter causes interference to the FS receiver corresponding to  $I/N = -10$  dB and  $I/N = -20$  dB.

##### 6.2.4.1 Urban indoor scenario

Figure 6 shows the theoretical separation distance (thick blue line for  $I/N = -10$  dB, thick red line for  $I/N = -20$  dB) for the urban indoor scenario, which was described in Section 6.2.1. The parameters used can also be seen in Figure 6. For an  $I/N = -10$  dB, separation distances from 700 m up to 13 500 m can be observed. For an  $I/N = -20$  dB, the distances are between 900 m and 19 900 m. These distances are strongly dependent on the antenna pattern and again of the FS receiver. Since the NLOS model is applied for distances greater than 1000 m, contour lines are compressed here and start to form a circle.

Figure 7 shows the theoretical separation distance for the urban indoor scenario with a WAS/RLAN power density of 11 dBm/MHz.

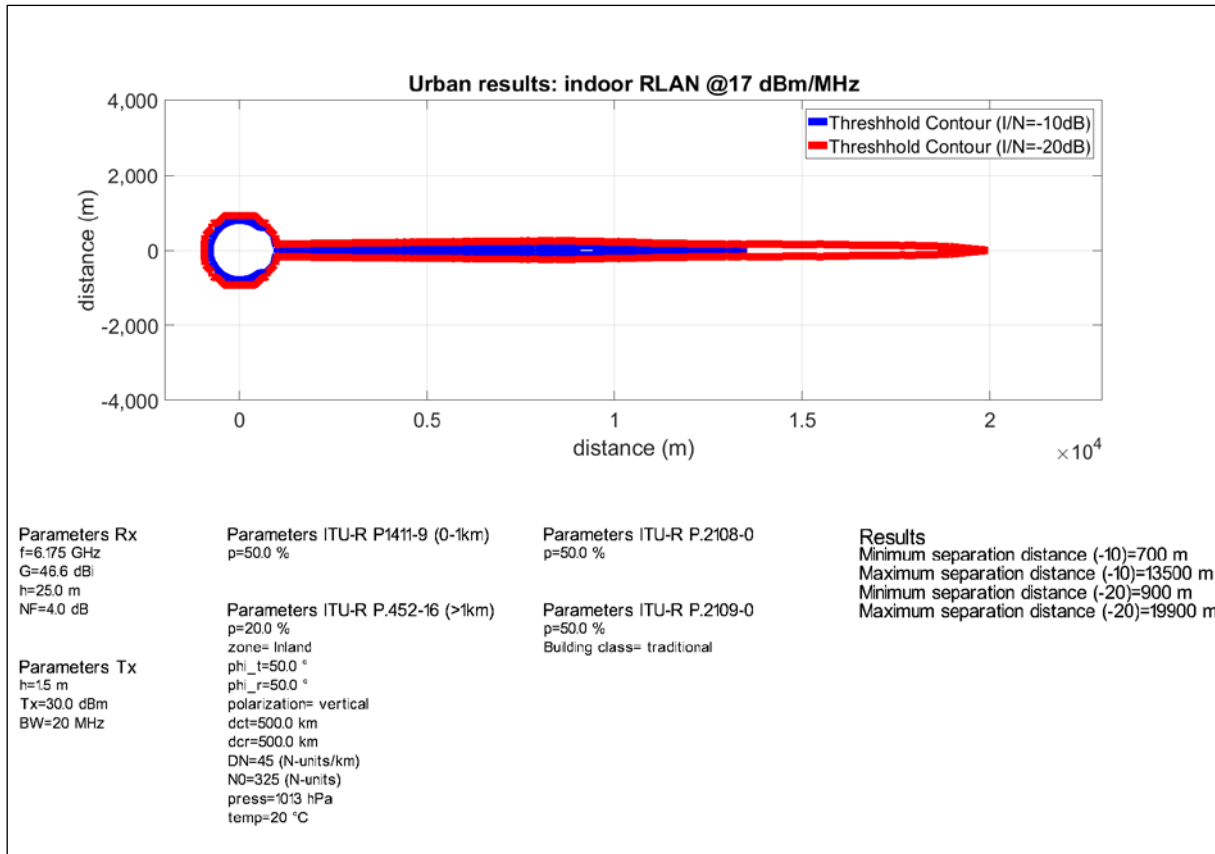


Figure 6: Urban results - indoor WAS/RLAN @ 17 dBm/MHz e.i.r.p.

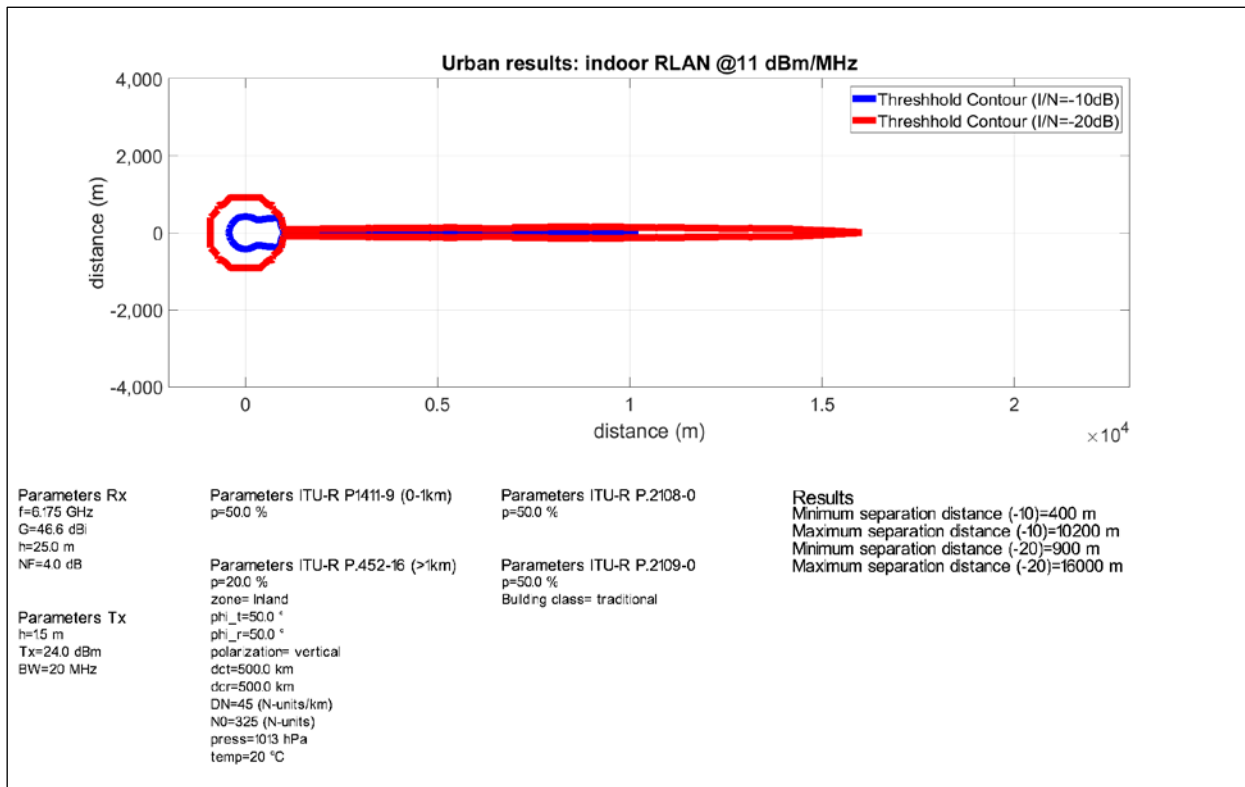


Figure 7: Urban results - indoor WAS/RLAN @ 11 dBm/MHz e.i.r.p.

6.2.4.2 Urban outdoor scenario

Figure 8 shows the theoretical separation distance (thick blue line for  $I/N = -10$  dB, thick red line for  $I/N = -20$  dB) for the urban outdoor scenario, which was described in Section 6.2.1. The parameters used are also provided in Figure 8.

For an  $I/N = -10$  dB it can be seen in that in the urban outdoor scenario separation distances range between 900 m and 24 200 m. For an  $I/N = -20$  dB, the distances are between 900 m and 31 700 m. These distances are strongly dependent on the antenna pattern and gain of the FS receiver.

Figure 9 shows the theoretical separation distance for the urban outdoor scenario with a WAS/RLAN power density of 1 dBm/MHz.

Figure 10 shows the theoretical separation distance for the urban outdoor scenario with a WAS/RLAN power density of  $-6$  dBm/MHz.

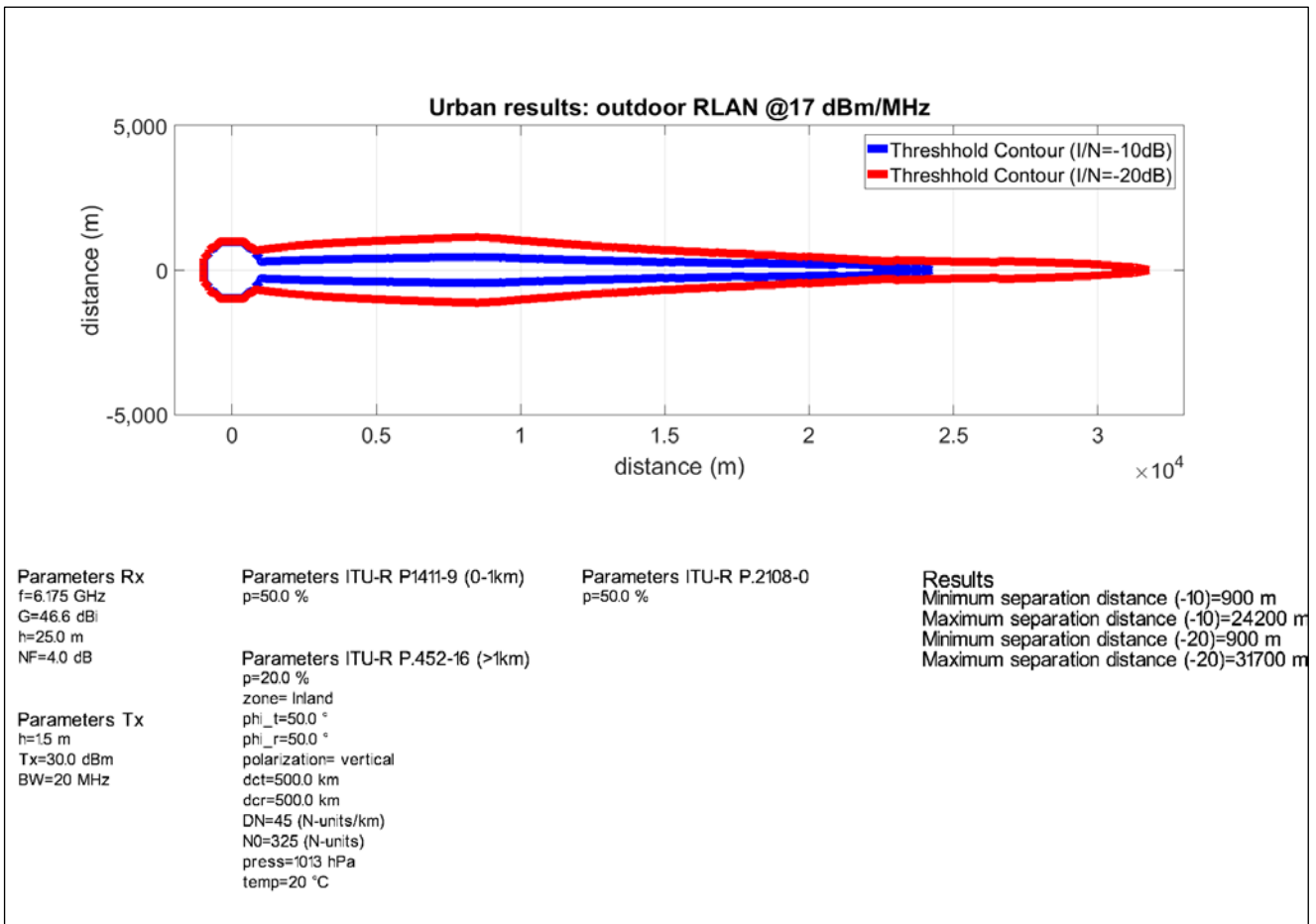


Figure 8: Urban results - outdoor WAS/RLAN @ 17 dBm/MHz e.i.r.p.



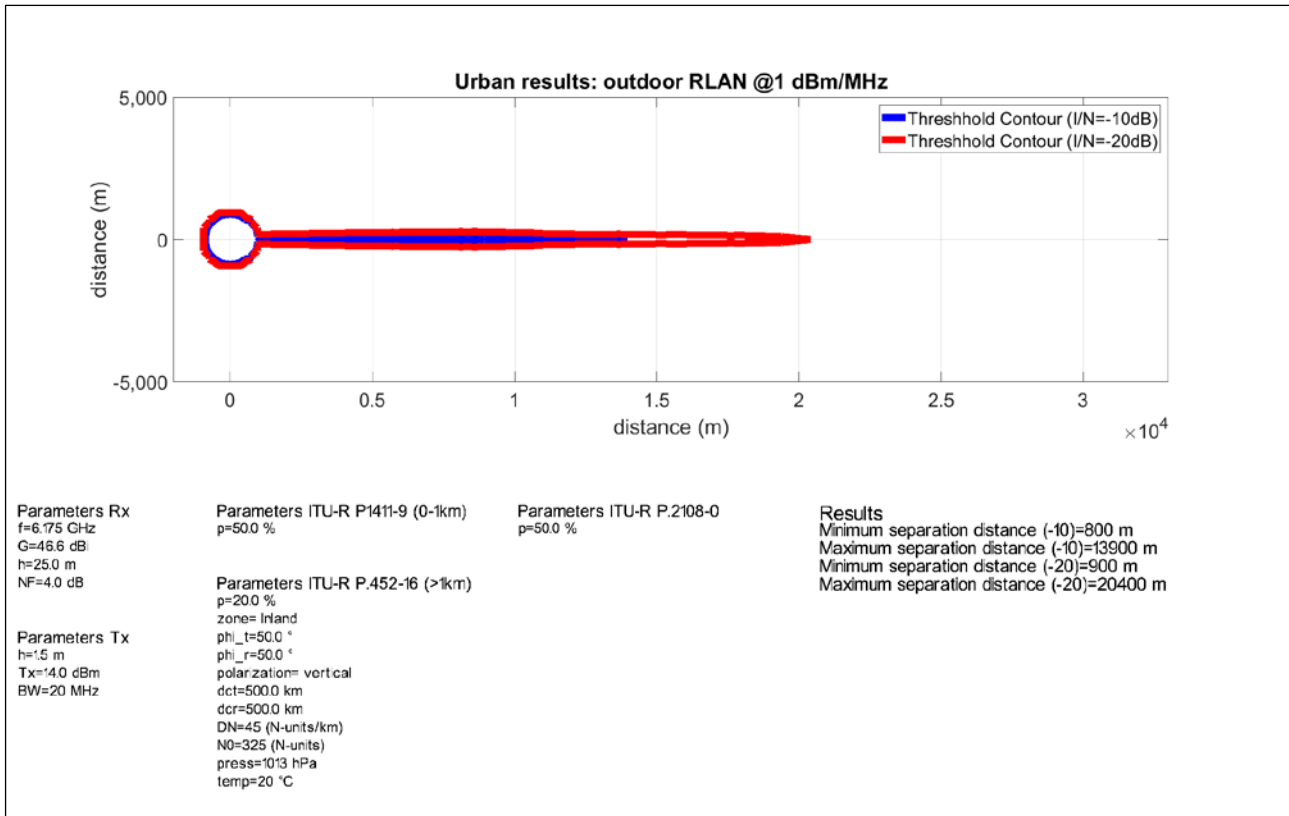


Figure 9: Urban results - outdoor WAS/RLAN @ 1 dBm/MHz e.i.r.p.

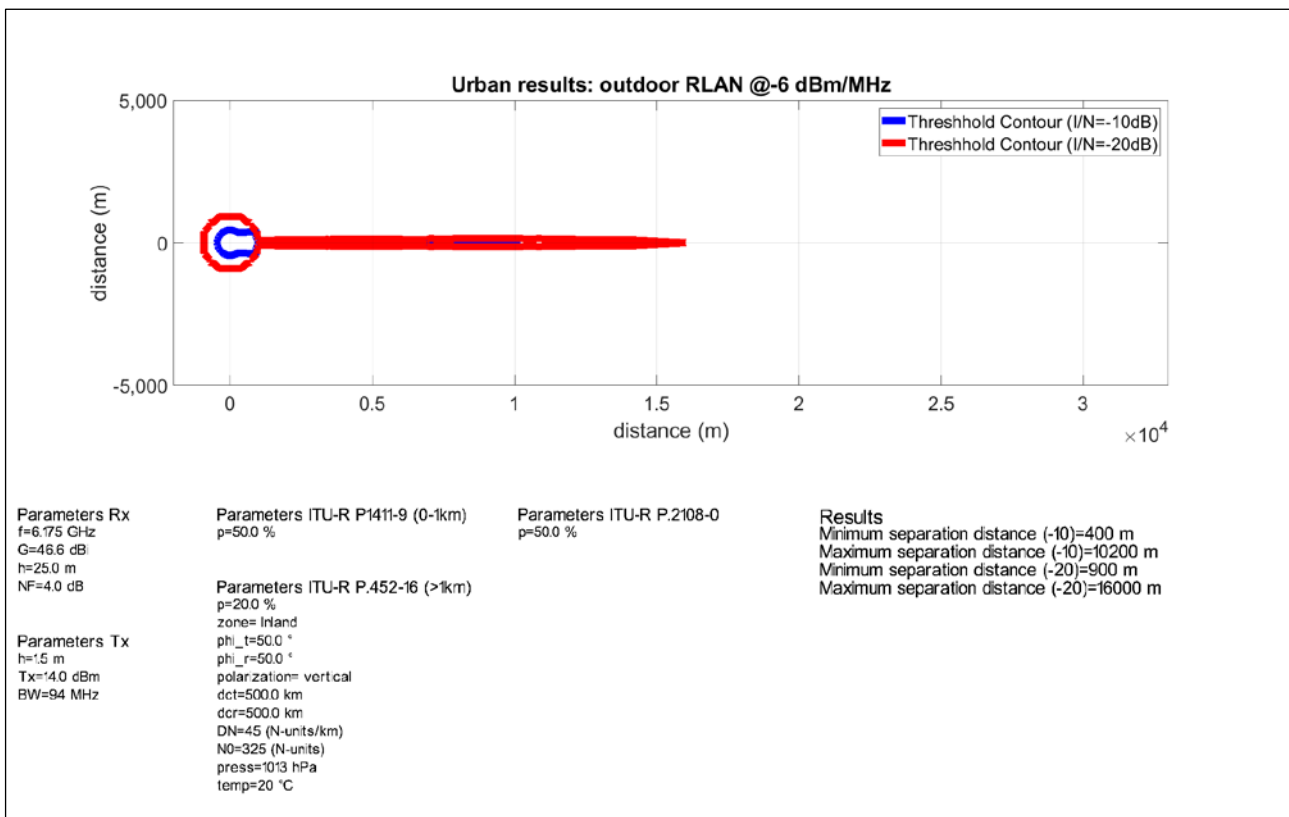


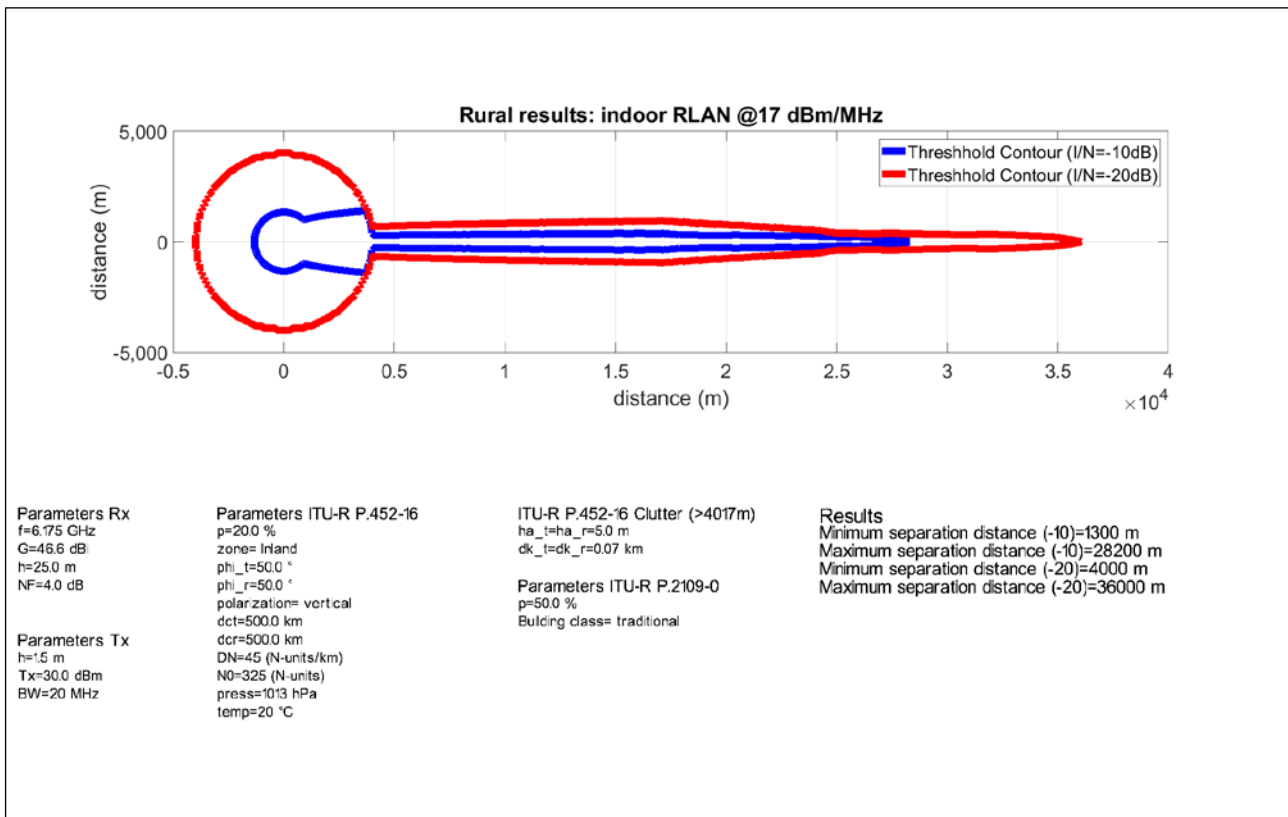
Figure 10: Urban results - outdoor WAS/RLAN @ -6 dBm/MHz e.i.r.p.

### 6.2.4.3 Rural indoor scenario

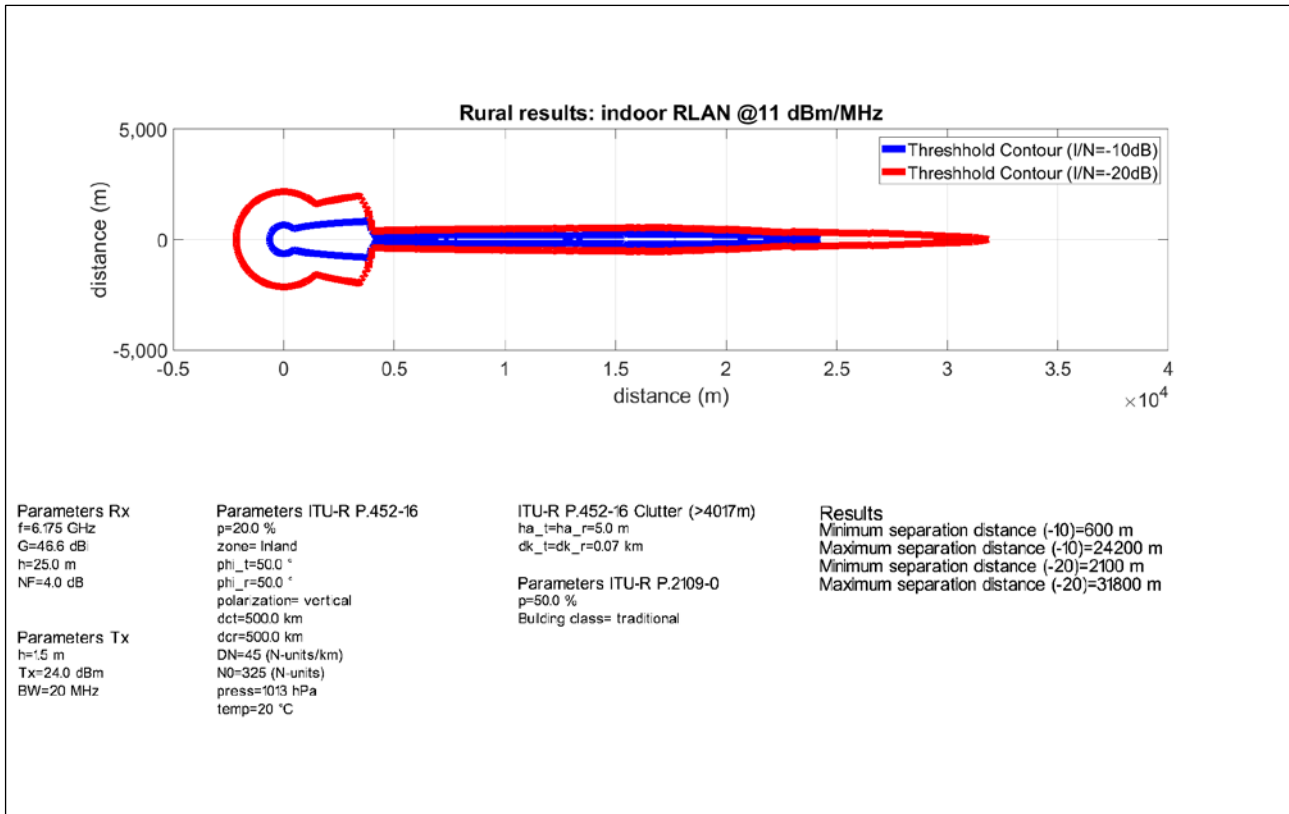
Figure 11 shows the theoretical separation distance (thick blue line for  $I/N = -10$  dB, thick red line for  $I/N = -20$  dB) for the rural indoor scenario which was described in Section 6.2.1. The used parameters are also given in Figure 11.

For an  $I/N = -10$  dB, it can be seen in Figure 11 that in the rural indoor scenario separation distances range between 1300 m up to 28 200 m. For an  $I/N = -20$  dB, the distances are between 4000 m and 36 000 m. These distances are strongly dependent of the antenna pattern of the FS receiver. As described in Section 6.2.2, the shape of the threshold contour shown in Figure 11 can be derived from the propagation model which does not have a continuous nature. For distances greater than 4017 m, additional clutter losses are introduced reducing this way the impact on the FS receiver by about 30 dB.

Figure 12 shows the theoretical separation distance for the rural indoor scenario at a WAS/RLAN power density of 11 dBm/MHz.



**Figure 11: Rural results - indoor WAS/RLAN @ 17 dBm/MHz e.i.r.p.**



**Figure 12: Rural results - indoor WAS/RLAN @ 11 dBm/MHz e.i.r.p.**

#### 6.2.4.4 Rural outdoor scenario

Figure 13 shows the theoretical separation distance (thick blue line for  $I/N = -10$  dB, thick red line for  $I/N = -20$  dB) for the rural outdoor scenario which was described in Section 6.2.1. The parameters used are also provided in Figure 13.

As described in Section 6.2.2, the shape of the threshold contour shown in Figure 13 can be derived from the propagation model which does not have a continuous nature. For distances greater than 4017 m, additional clutter losses are introduced reducing this way the impact on the FS receiver by about 30 dB. Nevertheless, for  $I/N = -10$  dB separation distances appear from 4000 m up to 40 400 m and for  $I/N = -20$  dB up to 47 100 m.

Figure 14 shows the theoretical separation distance for the rural outdoor scenario for a WAS/RLAN power density of 1 dBm/MHz.

Figure 15 shows the theoretical separation distance for the rural outdoor scenario for a WAS/RLAN power density of  $-6$  dBm/MHz.

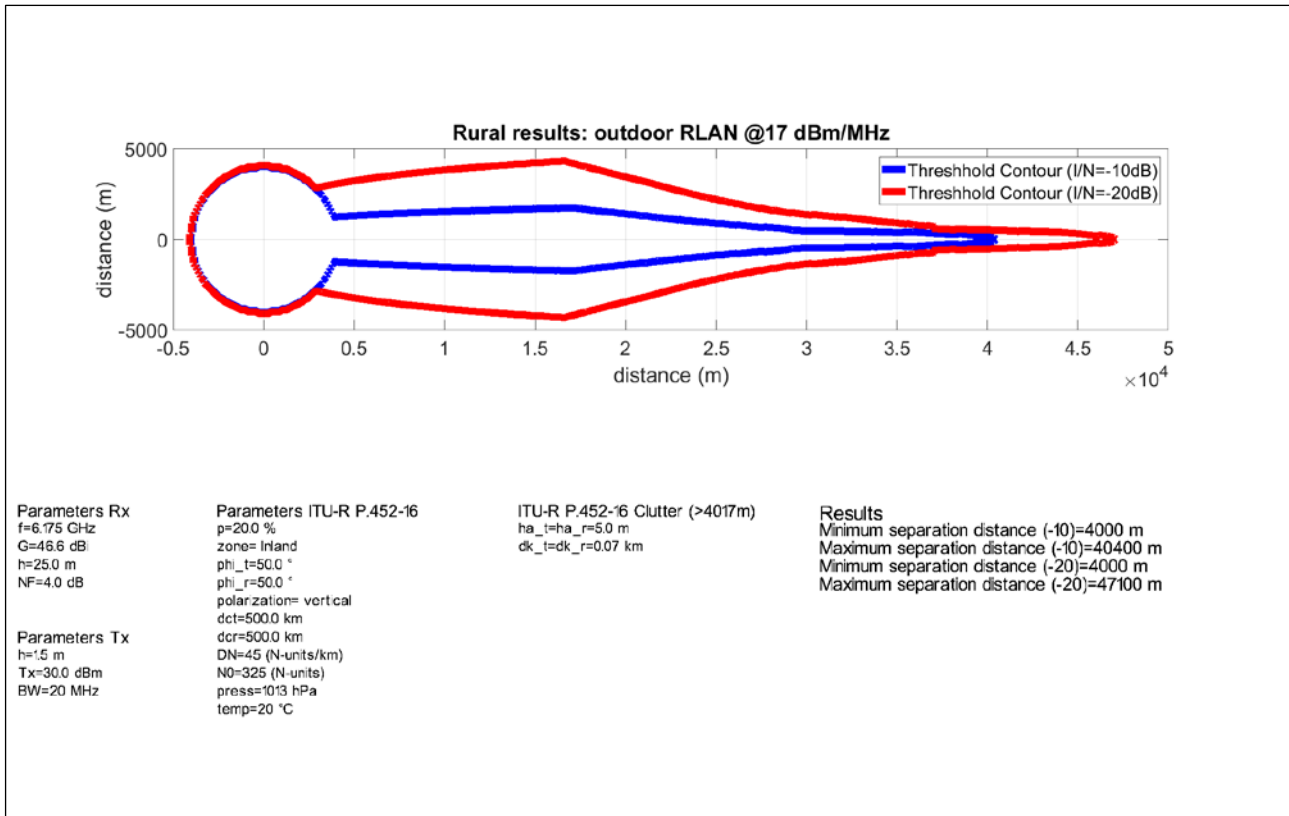


Figure 13: Rural results - outdoor WAS/RLAN @ 17 dBm/MHz e.i.r.p.

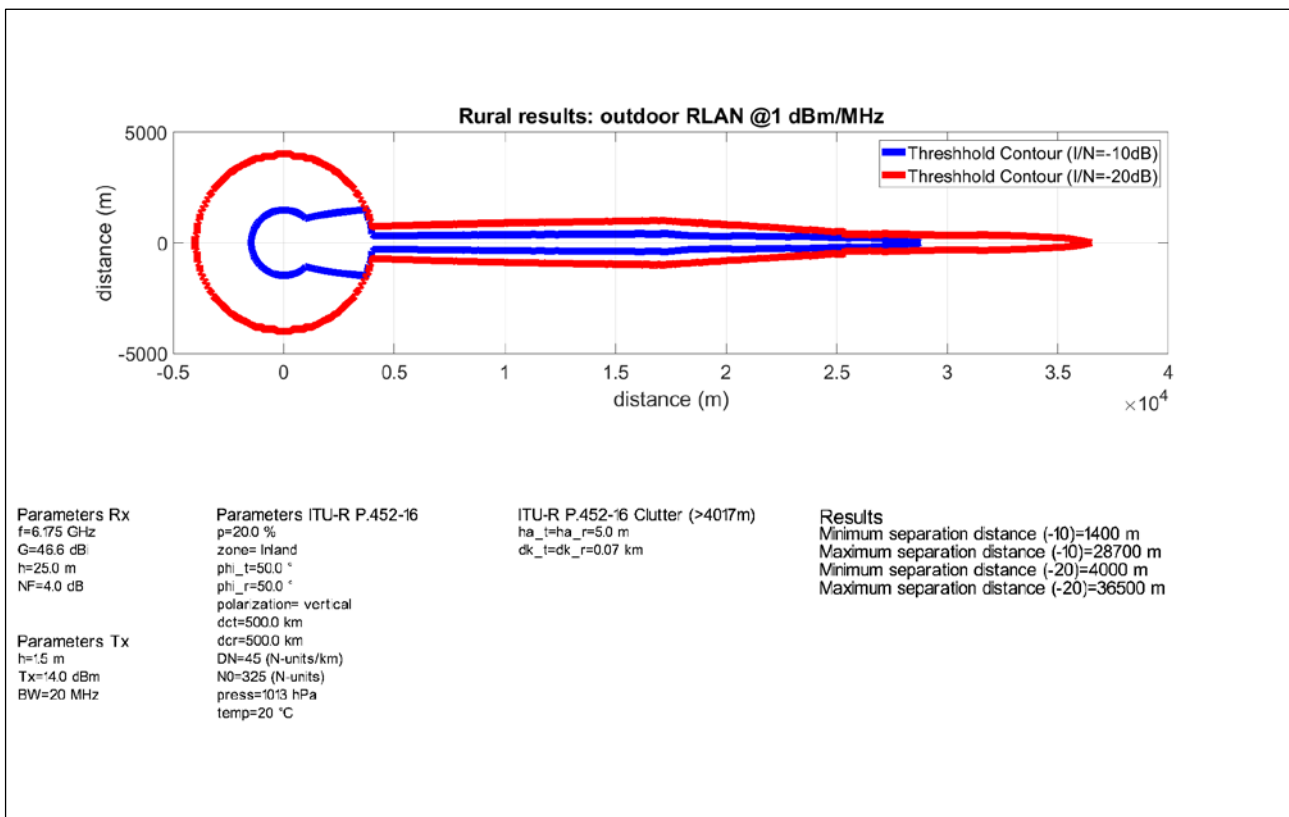


Figure 14: Rural results - outdoor WAS/RLAN @ 1 dBm/MHz e.i.r.p.

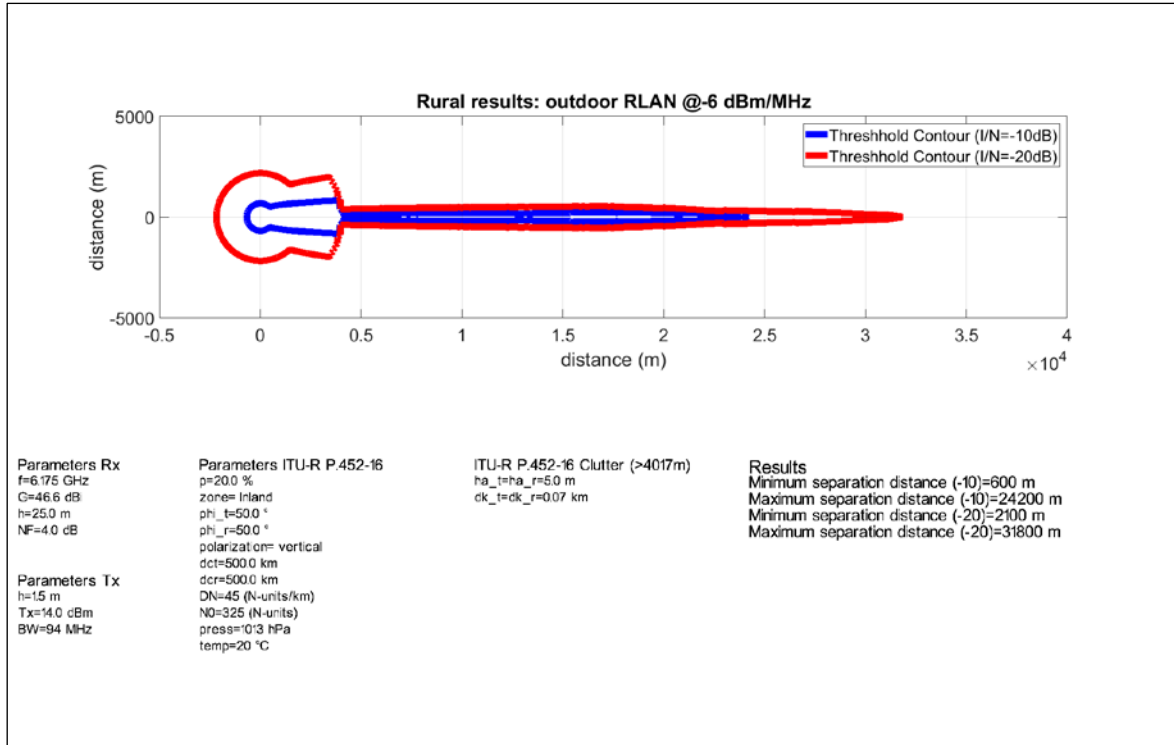


Figure 15: Rural results - outdoor WAS/RLAN @ -6 dBm/MHz e.i.r.p.

6.2.4.5 Summary of sensitivity analysis considering different power density levels

Single interferer MCL analyses have been conducted between Fixed Service and WAS/RLAN to derive the minimum separation distances between both systems as summarised in Table 23 and Table 24.

Table 23: FS MCL results for I/N = -10 dB

WAS/RLAN Scenario	Radiated power e.i.r.p.	Circle radius	Peak radius
Urban indoor	17 dBm/MHz	700 m	13 500 m
	11 dBm/MHz	400 m	10 200 m
	-20 dBm/MHz	0 m	0 m
Urban outdoor	17 dBm/MHz	1000 m (note 1)	24 200 m
	1 dBm/MHz	800 m	13 900 m
	-6 dBm/MHz	400 m	10 200 m
	-37 dBm/MHz	0 m	0 m
Rural indoor	17 dBm/MHz	1300 m	28 200 m
	11 dBm/MHz	600 m	24 200 m
	-30 dBm/MHz	0 m	0 m
Rural outdoor	17 dBm/MHz	4017 m (note 1)	40 400 m
	1 dBm/MHz	1400 m	28 700 m

WAS/RLAN Scenario	Radiated power e.i.r.p.	Circle radius	Peak radius
	-6 dBm/MHz	600 m	24 200 m
	-46 dBm/MHz	0 m	0 m

Note 1: Due to rounding and algorithms corresponding values in the figures are displayed with 900 m and 4000 m

**Table 24: FS MCL results for  $I/N = -20$  dB**

WAS/RLAN Scenario	radiated power e.i.r.p.	Circle radius	Peak radius
Urban indoor	17 dBm/MHz	1000 m (Note 1)	19 900 m
	11 dBm/MHz	1000 m (Note 1)	16 000 m
	-30 dBm/MHz	0 m	0 m
Urban outdoor	17 dBm/MHz	1000 m (Note 1)	31 700 m
	1 dBm/MHz	1000 m (Note 1)	20 400 m
	-6 dBm/MHz	1000 m (Note 1)	16 000 m
	-46 dBm/MHz	0 m	0 m
Rural indoor	17 dBm/MHz	4017 m (Note 1)	36 000 m
	11 dBm/MHz	2100 m	31 800 m
	-40 dBm/MHz	0 m	0 m
Rural outdoor	17 dBm/MHz	4017 m (Note 1)	47 100 m
	1 dBm/MHz	4017 m (Note 1)	36 500 m
	-6 dBm/MHz	2100 m	31 800 m
	-56 dBm/MHz	0 m	0 m

Note 1: Due to rounding and algorithms corresponding values in the figures are displayed with 900 m and 4000 m

### 6.2.5 Results for sensitivity analysis of antenna height levels and building entry loss

In this Section, the impact of the FS links antenna heights (10 m, 25 m, 40 m and 55 m) as well as of the WAS/RLAN location (outdoor, indoor) and WAS/RLAN antenna height (1.5 m and 4.5 m) onto the separation distances required to protect the FS receiver from WAS/RLAN interferences in a co-channel case is studied.

The following input data has been used to reflect a maximum interference scenario:

WAS/RLAN:

- e.i.r.p. = 30 dBm;
- bandwidth = 20 MHz.

Fixed Service:

- Rx gain = 46.6 dB;
- NF = 4 dB.

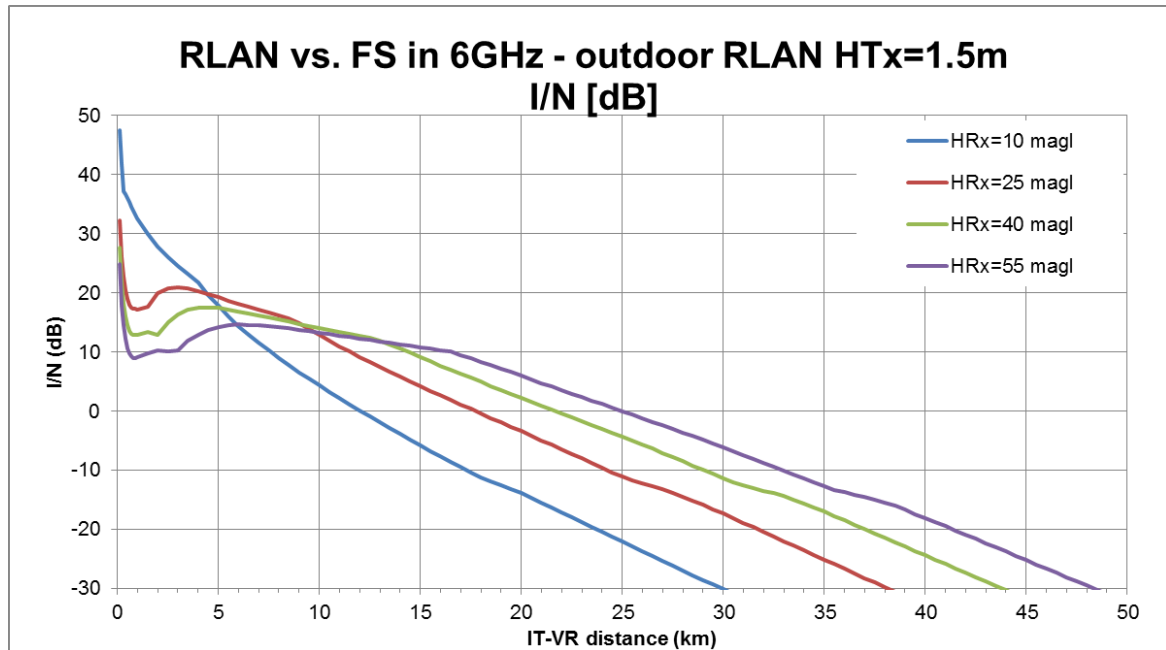


Figure 16: I/N at FS versus WAS/RLAN distance in 0° azimuth direction of FS main beam (outdoor WAS/RLAN @ 1.5 m)

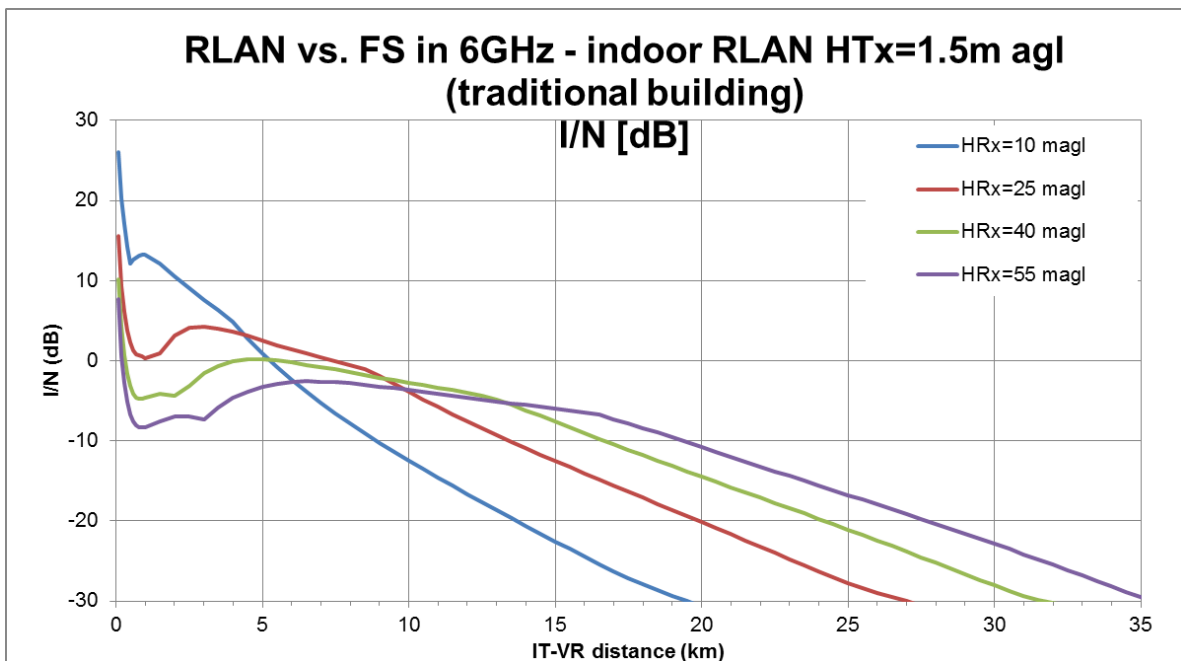


Figure 17: I/N at FS versus WAS/RLAN distance in 0° azimuth direction of FS main beam (indoor WAS/RLAN @ 1.5 m, traditional building type)

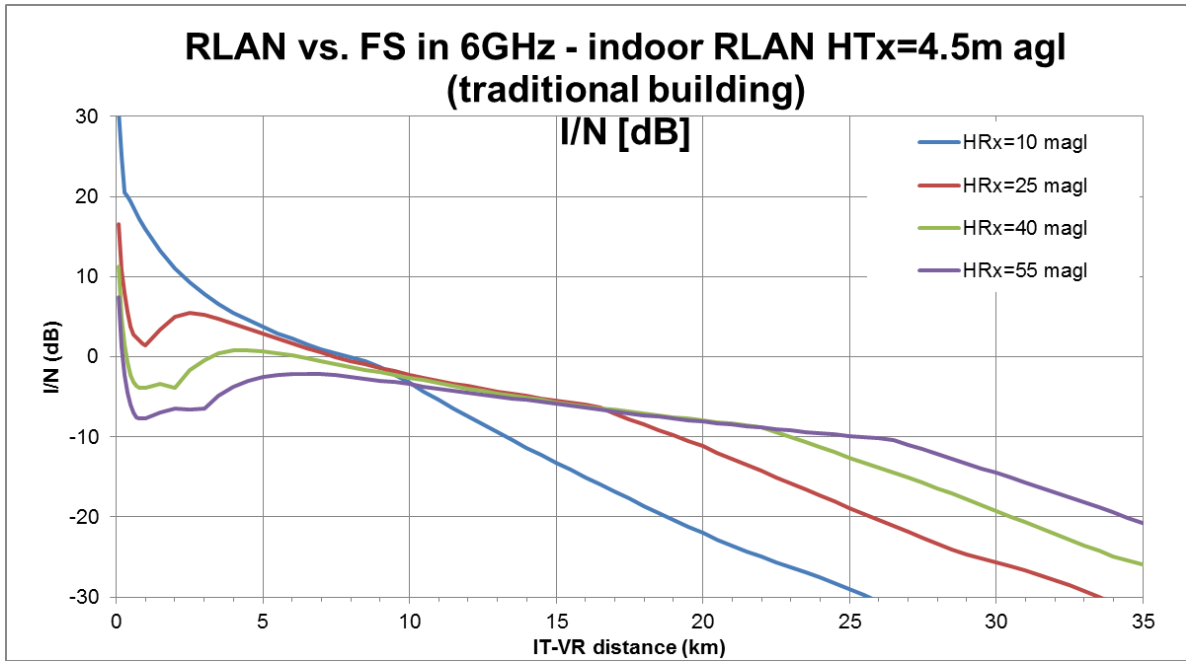


Figure 18: I/N at FS versus WAS/RLAN distance in 0° azimuth direction of FS main beam (indoor WAS/RLAN @ 4.5 m, traditional building type)

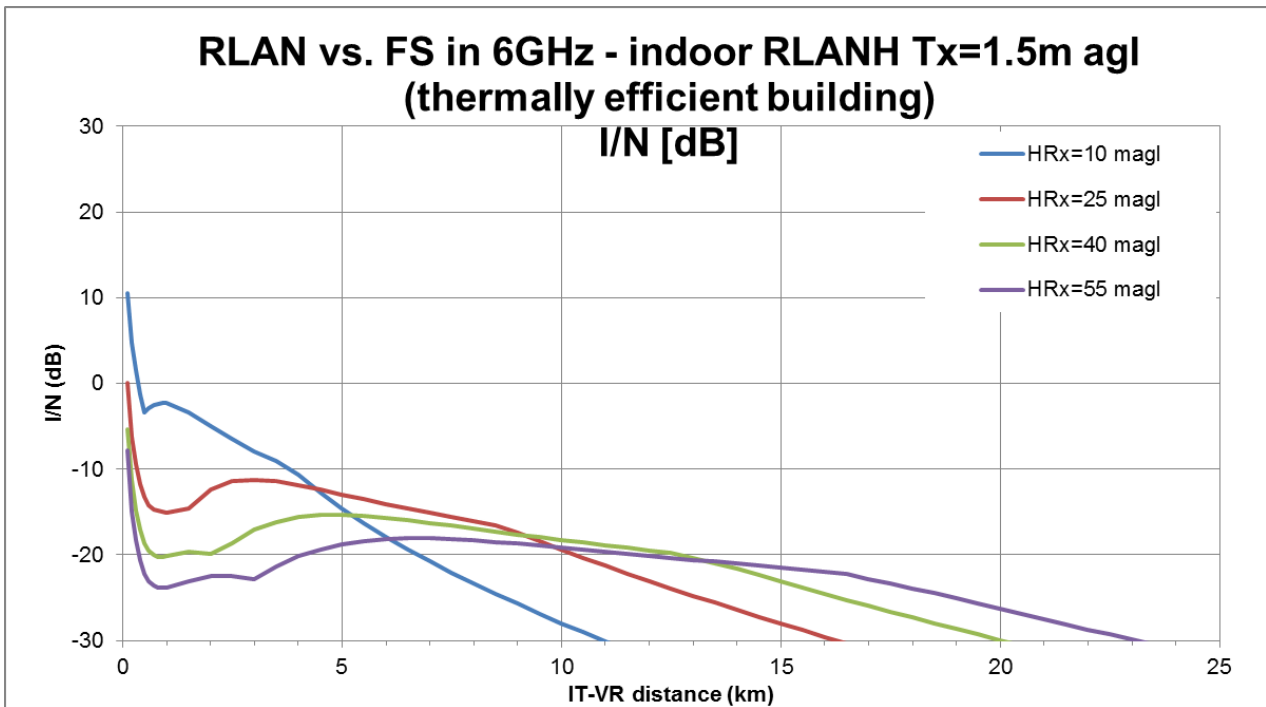
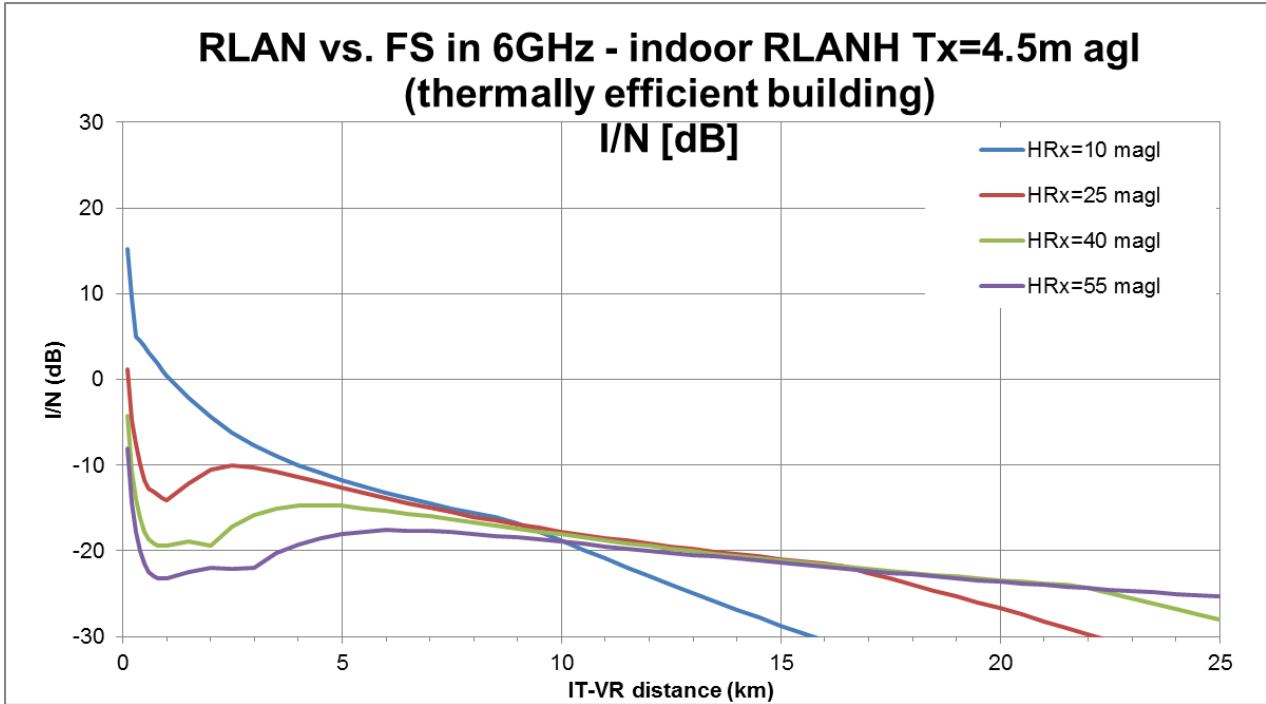


Figure 19: I/N at FS versus WAS/RLAN distance in 0° azimuth direction of FS main beam (indoor WAS/RLAN @ 1.5 m, thermally efficient building type)





**Figure 20: I/N at FS versus WAS/RLAN distance in 0° azimuth direction of FS main beam (indoor WAS/RLAN @ 4.5 m, thermally efficient building type)**

**Table 25: Summary of the results for separation distance as a function of the FS antenna height for  $I/N = -10$  dB and maximum interference scenario**

WAS/RLAN environment	$H_{Rx} = 10$ m agl (km)	$H_{Rx} = 25$ m agl (km)	$H_{Rx} = 40$ m agl (km)	$H_{Rx} = 55$ m agl (km)
Outdoor WAS/RLAN $H_{Tx} = 1.5$ m	17.3	24.2	29.0	32.9
Indoor WAS/RLAN (traditional building) $H_{Tx} = 1.5$ m	8.9	13.4	16.7	19.4
Indoor WAS/RLAN (thermally efficient buildings) $H_{Tx} = 1.5$ m	3.86	0.325	0.173	0.127
Indoor WAS/RLAN (traditional building) $H_{Tx} = 4.5$ m	13.3	19.2	23.0	25.5
Indoor WAS/RLAN (thermally efficient buildings) $H_{Tx} = 4.5$ m	4.0	0.407	0.186	0.124

As it can be seen from Table 25, the peak radii are much less when the WAS/RLAN transmitter is located indoor than when it is located outdoor as expected.

The largest distance (32.9 km) is achieved when WAS/RLAN is outdoor and the FS receiver height is at the highest studied value (55 m). Some mitigation techniques should be considered in order to avoid this kind of interference.

It should be highlighted that the case where the WAS/RLAN is outdoor would be the more problematic as the WAS/RLAN device could be anywhere and could, therefore, transmit in the direction of the main beam of the FS receiver.

Table 26 gives peak radii of the critical area for an  $I/N = -20$  dB and for a 1.5 m WAS/RLAN antenna height. The distances are higher than for an  $I/N = -10$  dB as could be expected especially for the thermal efficient building indoor case (for example 12.8 km versus 0.173 km in Table 25 for a 40 m fixed service antenna height).

**Table 26: Results for separation distance as a function of the FS antenna height for  $I/N = -20$  dB and maximum interference scenario**

WAS/RLAN environment	$H_{Rx} = 10$ m agl (km)	$H_{Rx} = 25$ m agl (km)	$H_{Rx} = 40$ m agl (km)	$H_{Rx} = 55$ m agl (km)
Outdoor WAS/RLAN $H_{Tx} = 1.5$ m	23.8	31.7	37	41.3
Indoor WAS/RLAN (traditional building) $H_{Tx} = 1.5$ m	13.7	19.9	24.2	27.7
Indoor WAS/RLAN (thermally efficient buildings) $H_{Tx} = 1.5$ m	6.72	10.4	12.8	11.8

The following input data has been used to reflect a minimum interference scenario:

WAS/RLAN:

- e.i.r.p. = 23.8 dBm;
- bandwidth = 160 MHz.

Fixed Service:

- Rx gain = 38.1 dB;
- NF = 5 dB.

**Table 27: Summary of the results for separation distance as a function of the FS antenna height for  $I/N = -10$  dB and minimum interference scenario**

WAS/RLAN environment	$H_{Rx} = 10$ m agl (km)	$H_{Rx} = 25$ m agl (km)	$H_{Rx} = 40$ m agl (km)	$H_{Rx} = 55$ m agl (km)
Outdoor WAS/RLAN $H_{Tx} = 1.5$ m	5.97	9.3	10.1	9.9
Indoor WAS/RLAN (traditional building) $H_{Tx} = 1.5$ m	1.35	0.472	0.255	0.171
Indoor WAS/RLAN (thermally efficient buildings) $H_{Tx} = 1.5$ m	0.22	0.087	0.048	0.051
Indoor WAS/RLAN (traditional building) $H_{Tx} = 4.5$ m	1.39	0.472	0.283	0.181
Indoor WAS/RLAN (thermally efficient buildings) $H_{Tx} = 4.5$ m	0.371	0.102	0.051	0.051

The minimum interference case results in required separation distances that are as low as 48 m in the case of indoor WAS/RLAN deployment for thermal efficient buildings. Note that the probability to have an indoor WAS/RLAN transmitting in the direction of the main lobe of the FS antenna would be low, as this would mean that the building would be located just between the FS transmitter and the FS receiver.

For the traditional building entry loss, even though the separation distances are a bit larger than for the thermally efficient building, they are anyway rather small compared to the outdoor case (171 m versus 9.9 km for a 55 m FS antenna).

Table 28 presents the separation distances for an  $I/N = -20$  dB and for a 1.5 m WAS/RLAN antenna height for the minimum interference case. The distances are larger than those in the case of  $I/N = -10$  dB as could be expected, but for the thermal efficient building indoor case the order of magnitude is the same as for the maximum interference case of Table 26 (for example 0.103 km in Table 28 versus 0.051 km in Table 27 for a 55 m fixed service antenna height).

**Table 28: Results for separation distance as a function of the FS antenna height for  $I/N = -20$  dB and minimum interference scenario**

WAS/RLAN environment	$H_{Rx} = 10$ m agl (km)	$H_{Rx} = 25$ m agl (km)	$H_{Rx} = 40$ m agl (km)	$H_{Rx} = 55$ m agl (km)
Outdoor WAS/RLAN $H_{Tx} = 1.5$ m	9.85	14.9	18.4	21.4
Indoor WAS/RLAN (traditional building) $H_{Tx} = 1.5$ m	4.13	4.42	4.13	3.49
Indoor WAS/RLAN (thermally efficient buildings) $H_{Tx} = 1.5$ m	0.713	0.248	0.133	0.103

Table 29 and Table 30 give the results for the minimum interference in the back lobe of the antenna. For  $I/N = -10$  dB, the lowest value is 43 metres while for  $I/N = -20$  dB, the lowest value is 72 metres. It should be noted that the lowest values found in this case are not much lower than for the peak value case (43 m versus 48 m and 72 m versus 103 m). This is because the FS antenna height is well above the height of the WAS/RLAN transmitter, therefore the FS antenna does not receive the WAS/RLAN signal in its main beam even for the peak radius case due to the antenna diagram geometry. Therefore, the higher the difference of heights between the WAS/RLAN and the FS, the smaller the difference of separation distance between the peak radius case and the circle radius case.

**Table 29: Results for separation distance as a function of the FS antenna height for  $I/N = -10$  dB and minimum interference scenario for the circle radius case**

WAS/RLAN environment	$H_{Rx} = 10$ m agl (km)	$H_{Rx} = 25$ m agl (km)	$H_{Rx} = 40$ m agl (km)	$H_{Rx} = 55$ m agl (km)
Outdoor WAS/RLAN $H_{Tx} = 1.5$ m	0.23	0.23	0.23	0.23
Indoor WAS/RLAN (traditional building) $H_{Tx} = 1.5$ m	0.097	0.097	0.096	0.10
Indoor WAS/RLAN (thermally efficient buildings) $H_{Tx} = 1.5$ m	0.055	0.055	0.044	0.05
Indoor WAS/RLAN (traditional building) $H_{Tx} = 4.5$ m	0.099	0.10	0.10	0.098

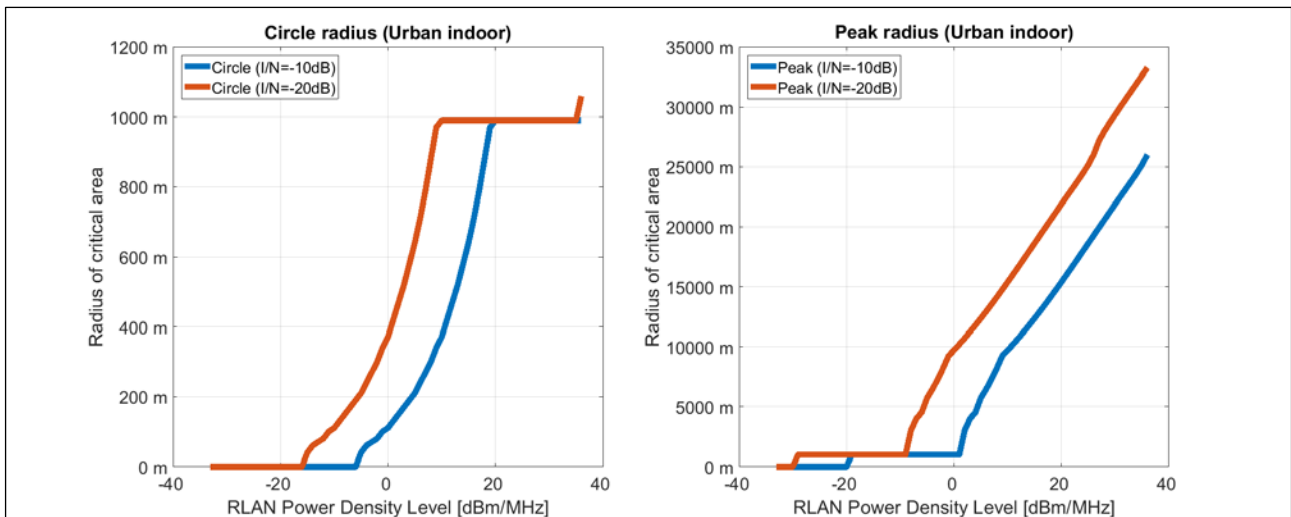
WAS/RLAN environment	$H_{Rx} = 10$ m agl (km)	$H_{Rx} = 25$ m agl (km)	$H_{Rx} = 40$ m agl (km)	$H_{Rx} = 55$ m agl (km)
Indoor WAS/RLAN (thermally efficient buildings) $H_{Tx} = 4.5$ m	0.049	0.052	0.043	0.049

**Table 30: Results for separation distance as a function of the FS antenna height for  $I/N = -20$  dB and minimum interference scenario for the circle radius case**

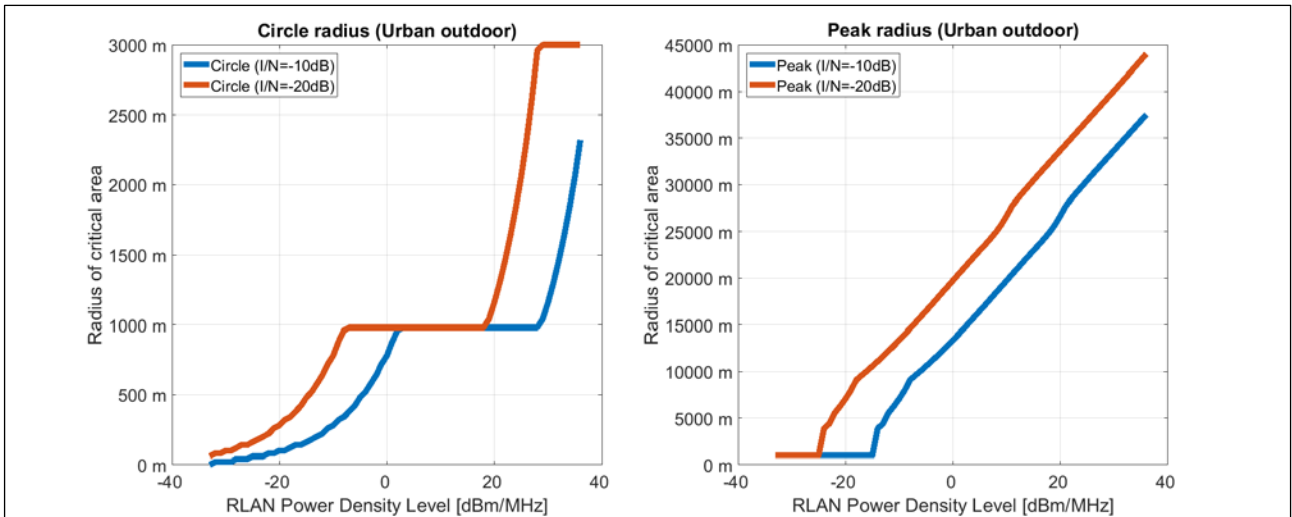
WAS/RLAN environment	$H_{Rx} = 10$ m agl (km)	$H_{Rx} = 25$ m agl (km)	$H_{Rx} = 40$ m agl (km)	$H_{Rx} = 55$ m agl (km)
Outdoor WAS/RLAN $H_{Tx} = 1.5$ m	0.40	0.39	0.39	0.39
Indoor WAS/RLAN (traditional building) $H_{Tx} = 1.5$ m	0.17	0.17	0.17	0.16
Indoor WAS/RLAN (thermally efficient buildings) $H_{Tx} = 1.5$ m	0.080	0.080	0.072	0.073

**6.2.6 Summary of MCL Analyses**

Two different types of critical areas have been shown in the MCL study: a circular area which has a relatively small radius and a peak area which has a relatively large radius. This is due to the FS antenna pattern with its high peak gain. The dependency of the radii on the transmitted WAS/RLAN power density is shown in Figure 21 for the urban indoor scenario. The dependency of the radii on the transmitted WAS/RLAN power density is shown in Figure 22 for the urban outdoor scenario. A decrease of transmitted power or an increase of bandwidth can reduce the size of critical areas.



**Figure 21: Dependency of critical radii on the WAS/RLAN power density indoors**



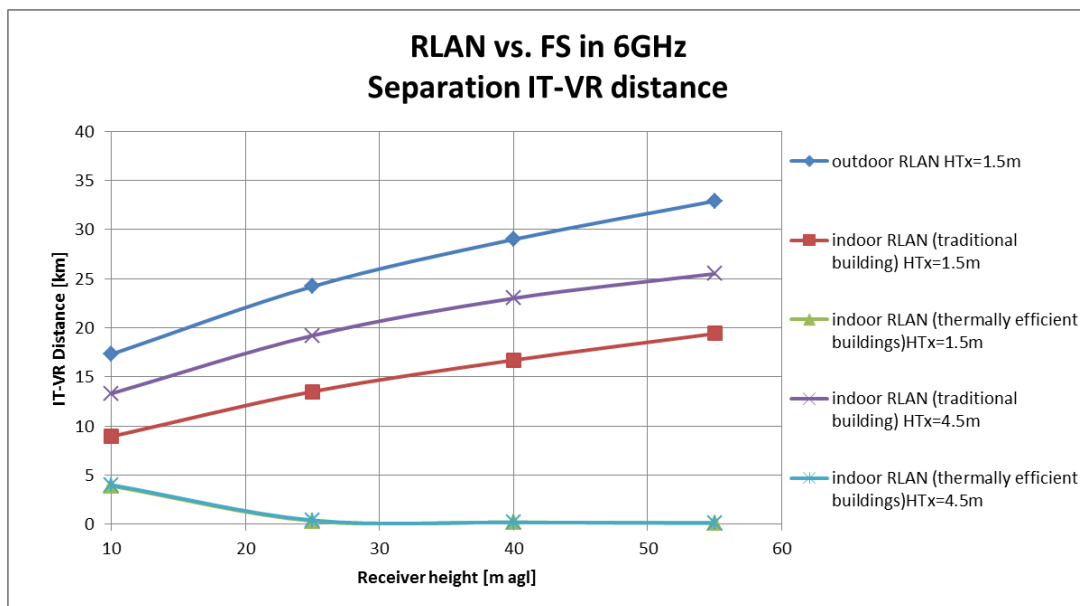
**Figure 22: Dependency of critical radii on the WAS/RLAN power density outdoors**

To achieve the same level of compatibility for outdoor WAS/RLAN devices the power density level has to be reduced by the amount of building entry loss. In this MCL study, about 17 dB (traditional building) has been used.

It was shown that for the single interferer study, rural environments are more critical for FS base stations. A lower density of WAS/RLAN devices in those environments could compensate this for aggregated cases.

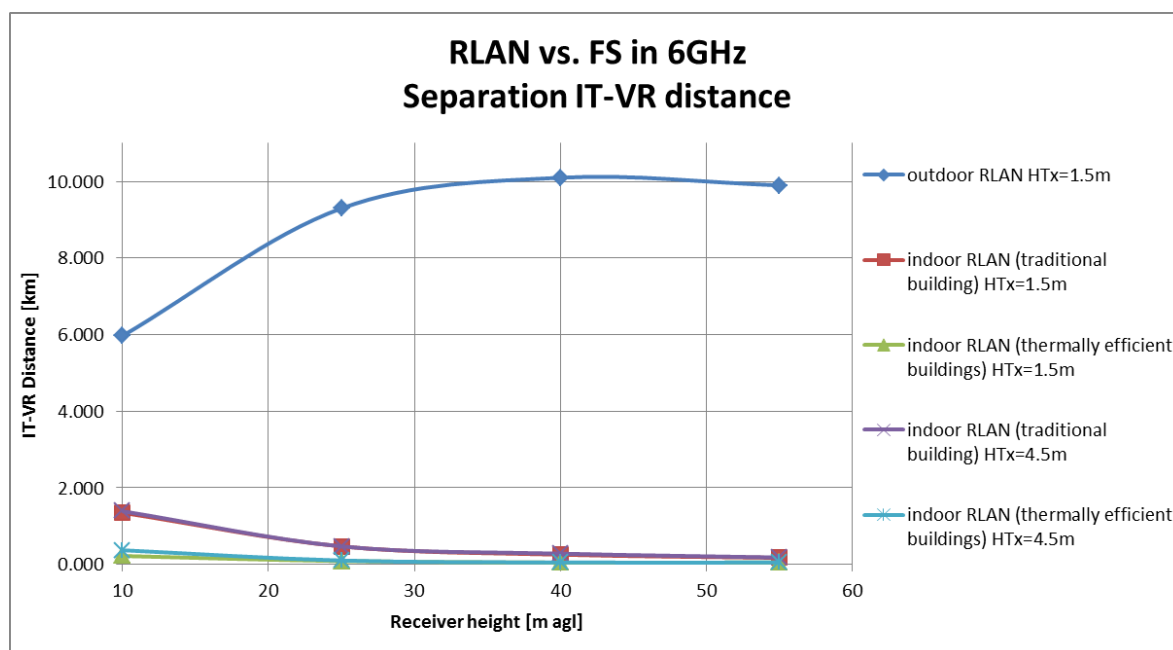
The impact from FS into WAS/RLAN has not been studied but it seems possible that WAS/RLAN devices could also suffer from occupied channels inside of the critical area. Urban areas would be the most critical environment for that because many WAS/RLAN devices would have to share smaller bandwidths when one frequency is occupied by an FS station.

Figure 23 clearly shows that the peak radius between WAS/RLAN device and FS receiver increases with the FS antenna height except for the thermally efficient building case. The peak radius nearly doubles when the FS antenna height increases from 10 m up to 55 m.



**Figure 23: Dependency of critical peak radii on the FS receiver height and WAS/RLAN environment for  $I/N = -10$  dB and maximum interference scenario**

For minimum interference constellations, Figure 24 clearly shows that the required separation distance between WAS/RLAN interfering transmitter and FS receiver increases with the FS antenna height for the outdoor WAS/RLAN case. The required separation distance increases from 6 km up to about 10 km when the FS antenna height increases from 10 m up to 55 m. For the indoor case, there is a decrease of the separation distances with the FS antenna height.



**Figure 24: Dependency of critical peak radii on the FS receiver height and WAS/RLAN environment for  $I/N = -10$  dB and minimum interference scenario**

### 6.3 STUDY B: MONTE CARLO ANALYSIS OF INTERFERENCE FROM WAS/RLAN INTO FS

The minimum coupling loss model (MCL) in study A (see section 6.2) showed separation distances between an FS and a single worst-case WAS/RLAN interference into FS. Study A has shown that long term protection threshold can be exceeded by a single WAS/RLAN device if the RF activity factor is higher than 20%. However, considering the 1.97% average RF activity factor of this single device is lower than 20%, the long term FS criterion will probably not be exceeded. Probability of an aggregation of devices, which could exceed the criterion, needs further statistical analysis. The Monte Carlo studies in the rest of this section derive probability of interference for the given set of parameters and deployments to determine whether all FS receivers are protected from WAS/RLAN interference by meeting FS defined FDP and long term protection criteria. The Monte Carlo study B was carried out on two sets of real FS data in Europe.

The United Kingdom and The Netherlands provided the FS link locations, FS system parameters and other relevant information necessary for conducting a Monte Carlo analysis to determine the aggregate  $I/N$  at each of the FS receive locations [61], [62] and [63]. Section 6.3.1 provides detail on the simulation methodology.

It should also be noted that in the UK, as a result of the implementation of Earth Stations on-board Vessels (ESOBs) in the band post WRC-03, a recommendation to increase (up to 25 dB) the fade margins used in the assignment criteria for fixed links in this band was implemented.

This interference environment was modelled for each WAS/RLAN deployment iteration by randomly distributing active WAS/RLANs using the probability distribution for population density and other relevant parameters such as centre frequency, bandwidth, e.i.r.p. and height as indicated in Section 6.3.1. Each WAS/RLAN deployment iteration was assumed to be independent.

Two-hundred-and-fifty-thousand (250 000) independent WAS/RLAN deployments were simulated for each FS station of each administration to derive statistics to determine whether:

- a) the *long term* aggregate interference of the WAS/RLANs to the FS above the interference threshold of  $I/N = -10$  dB was not exceeded more than 20% of the time (per Recommendation ITU-R F.758 [33]).
- b) the aggregate interference impact of the WAS/RLANs to the FS meets the Fractional Degradation of Performance (FDP) criteria per Recommendation ITU-R F.1094 [59]. FDP, as defined in Recommendation ITU-R F.1108-4 [64], is calculated for each FS receiver as follows:

$$FDP = \frac{1}{M} \sum_{i=1}^M (10^{(I/N)_i/10}),$$

where  $M$  is the total number of iterations of the Monte Carlo simulation and  $(I/N)_i$  is the  $I/N$  (in dB) of the  $i$ -th iteration.

### 6.3.1 Monte Carlo simulation methodology

Interference from WAS/RLAN deployments into FS receivers is analysed using a Monte Carlo simulation. The simulation has the following structure:

- 1) Data setup:
  - a. Put the FS Transmitters (Tx) and FS Receivers (Rx) link information into a database;
  - b. Create a database of antenna patterns for the FS Receivers in the simulation;
  - c. Define the simulation region and create a database of population density at points within the simulation region;
  - d. Transform population data over the simulation region to WAS/RLAN device population probability distribution over the simulation region.
- 2) Monte Carlo iterations:
  - a. Generate a random layout of WAS/RLANs using the device population probability distribution;
  - b. Generate the path loss, clutter loss, building loss values between each WAS/RLAN and FS Rx in accordance with the propagation modelling set out in Section 5.2.1. Also a random polarisation loss value is generated;
  - c. Using the FS Rx feeder loss, bandwidth and noise figure, compute the aggregate WAS/RLAN I/N at the FS Rx.
- 3) Iterate: Repeat step 2 for the total specified number of iterations. Record I/N values for each FS Rx on each iteration and write results to a file.
- 4) Use the recorded aggregate I/N values to create the I/N Complementary Cumulative Distribution Function (CCDF) or Interference Graph.

Steps 1) and 2) above are further elaborated below.

#### Step 1) Data Setup:

For all FS Rx antennas in the simulation, Ofcom UK antenna patterns (based on manufacturers' data) are used. In the absence of an Ofcom antenna pattern, Recommendation ITU-R F.1245 is used (see section 4.1.1).

As clarified in Section 3, the population density is modelled using the Gridded Population of the World V4 (GPWv4) [12] projected into 2025 according to UN expectation for Europe [10]. The matrix resolution is 30 arcseconds for both latitude and longitude coordinates. Grid points that are in the ocean or other locations that are not part of the simulation are omitted from the population density file. Each grid point is classified as being urban, suburban or rural depending on the population density value for the grid point and threshold values that are inputs to the simulation.

The population density matrix is used to produce the WAS/RLAN device population probability distribution over the simulation region. The first step is to convert population density values into population values for each grid point by multiplying the population density by the area of the 30 arcsec x 30 arcsec region centred at the grid point. These population values are then summed for each of the regions Europe, Africa and Middle East. Let PE, PA and PM be the populations of Europe, Africa and the Middle East respectively. Let

NE, NA, NM be the number of active WAS/RLAN devices in Europe, Africa and the Middle East respectively. These values are inputs to the simulation. For each grid point, the population value is converted to the average WAS/RLAN device count by multiplying by (NE/PE), (NA/PA) or (NM/PM) depending on whether the grid point is in Europe, Africa or the Middle East. This is then converted into a large discrete probability distribution function where each grid point is assigned a probability equal to the average WAS/RLAN device count at that grid point divided by the total WAS/RLAN device count. A random WAS/RLAN position is obtained by generating a random grid point using this discrete probability distribution, then selecting a location uniformly distributed over the 30 arcsec x 30 arcsec region centred at the grid point.

## Step 2) Monte Carlo iterations:

For each iteration, a random layout of active WAS/RLAN devices is generated one WAS/RLAN at a time. Each WAS/RLAN device is assigned a random longitude/latitude position generated using the device population probability distribution described above. Each WAS/RLAN device is assigned a random height, e.i.r.p. and building type using discrete probability distributions according to Table 10 and Table 8 respectively. Building types are outdoor (meaning no building attenuation) WAS/RLAN, indoor-traditional or thermally efficient (respecting a 30% thermally efficient/ 70% traditional balance). Each WAS/RLAN is assigned a random bandwidth using a discrete probability distribution as in Table 12 and a random centre frequency as in Table 11. The centre frequency is generated by considering all possible centre frequencies for the selected bandwidth and using a uniform distribution.

For each FS in the simulation, interference from all WAS/RLANs is computed and aggregated. If the distance from a WAS/RLAN to the FS Rx is larger than 150 km, the WAS/RLAN is assumed to contribute no interference to the FS Rx. Next, the FS Tx and FS Rx locations are used with the WAS/RLAN position to determine if the WAS/RLAN is inside the first Fresnel zone of the FS link. If the WAS/RLAN is in fact inside the FS' first Fresnel zone, the WAS/RLAN is ignored in the interference calculation. This is assumed to be an unlikely interference path and a poor FS link design since the FS link does not have first Fresnel zone clearance. The WAS/RLAN bandwidth and centre frequency along with the FS Rx bandwidth and centre frequency are used to compute the fraction of the WAS/RLAN bandwidth that overlaps with the FS Rx bandwidth. If there is no overlap, the WAS/RLAN is ignored in the interference calculation. To visualise the impact of those factors and the placement of WAS/RLANs within 150 km of FS Sections 6.3.2.1 and 6.3.3.1 provide more detail.

In implementation of Recommendation ITU-R P.452, time percentages (p) between 0.01% and 100% are generated randomly. However, since P.452 is only defined for time percentages up to 50%, when the generated value is greater than 50%, this time percentage is set to 50%.

A random building entry loss is computed using Recommendation ITU-R P.2109-0 and the building type and elevation angle from the WAS/RLAN to the FS Rx. Random path loss and path clutter values are generated using the specified path loss/clutter loss simulation models. A random polarisation loss is generated by first generating a random polarisation mismatch angle,  $\theta$ , that is uniformly distributed from 0 to 360 degrees. The polarisation loss in dB is then given by:

$$\text{Polarisation Loss} = \min(-10 \log_{10}(\cos^2 \theta), 35) \times (0.2 - 0.1 \times \frac{B}{360} + 0.8 \times 10^{(-0.1 \times B)})$$

Where  $B$  is the boresight angle from WAS/RLAN to the FS link's receiver antenna. The exponential term accounts for the reduced polarisation mismatch in off-boresight regions of the typical FS antennas. In addition, the loss is capped at 35 dB at the boresight, i.e.  $B = 0$ , to account for imperfections in antenna design.

The FS Rx antenna angle off boresight in the direction of the WAS/RLAN is calculated considering the location of the FS Rx, FS TX and the WAS/RLAN Location. This angle and the table of antenna gains versus angle off boresight is then used to interpolate the FS Rx antenna gain in the direction of the WAS/RLAN.

In addition, a random body loss is generated using a discrete probability distribution provided in section 5.6.

The interference power at the FS Rx is computed by appropriately summing WAS/RLAN e.i.r.p., building entry loss, path loss, path clutter, polarisation loss, body loss, FS Rx gain in the direction of each



WAS/RLAN, FS Rx feeder loss and spectral overlap loss. This interference is aggregated over all WAS/RLANs for each FS Rx in the simulation.

The aggregate I/N is the ratio of the aggregate interference power and the receiver noise power. The receiver noise power is calculated, for each FS receiver, using the following equation:

$$N = 10 \log_{10}(kT_0B) + NF \text{ (dBW)}$$

where:

- $N$  = FS Rx noise power at receiver input (dBW);
- $k$  = Boltzmann's constant =  $1.3806488 \cdot 10^{-23}$  (J/K);
- $T_0$  = 290 K;
- $B$  = FS Rx Bandwidth (Hz);
- $NF$  = FS Rx Noise Figure = 5 dB.

A Noise Figure = 5 dB is selected in order to achieve close agreement with the Noise levels specified by Ofcom (UK) for planning purposes [60].

### 6.3.2 The Netherlands FS analysis results

#### 6.3.2.1 WAS/RLAN deployment model

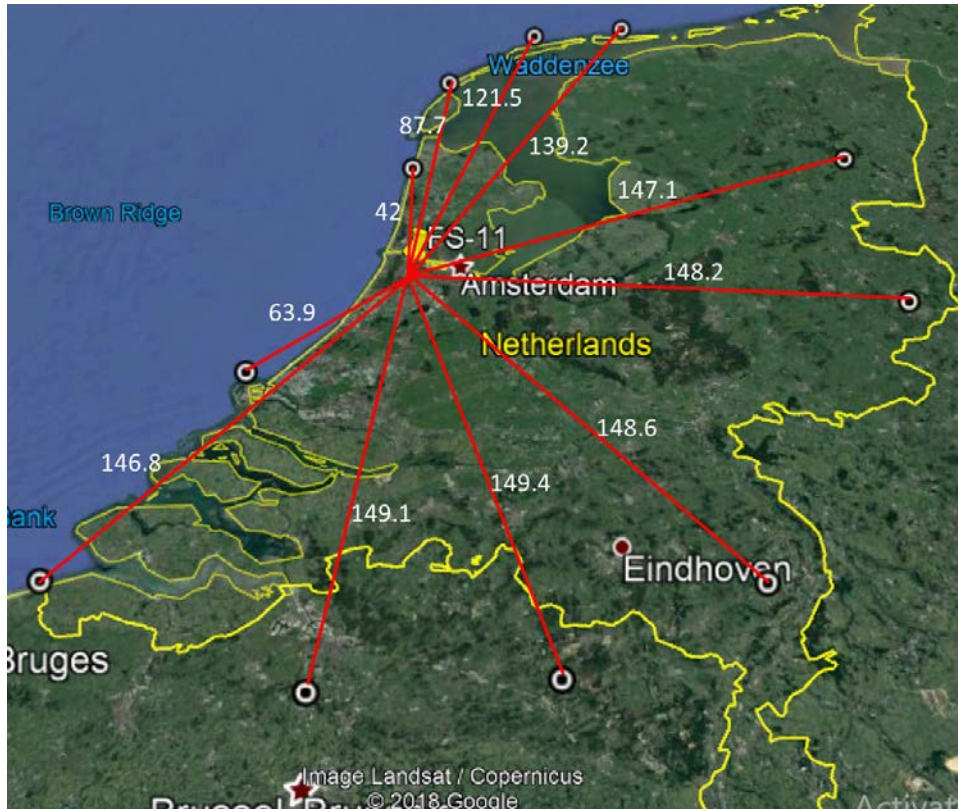
To visualise the Monte Carlo methodology in the placement of WAS/RLANs within 150 km of an FS receiver, as detailed in section 6.3.1, a single iteration of the Monte Carlo simulation was run for the Netherlands FS number 11. FS 11 corresponds to FS Name 7181438001 with Tx Freq1 = 5974.85 MHz in the Netherlands FS database per [61].

Table 31 shows how the Mid parameters outlined in Section 3.2 were implemented with respect to this simulation.

**Table 31: Number of active WAS/RLAN devices simulated in a single iteration of the Netherlands FS 11**

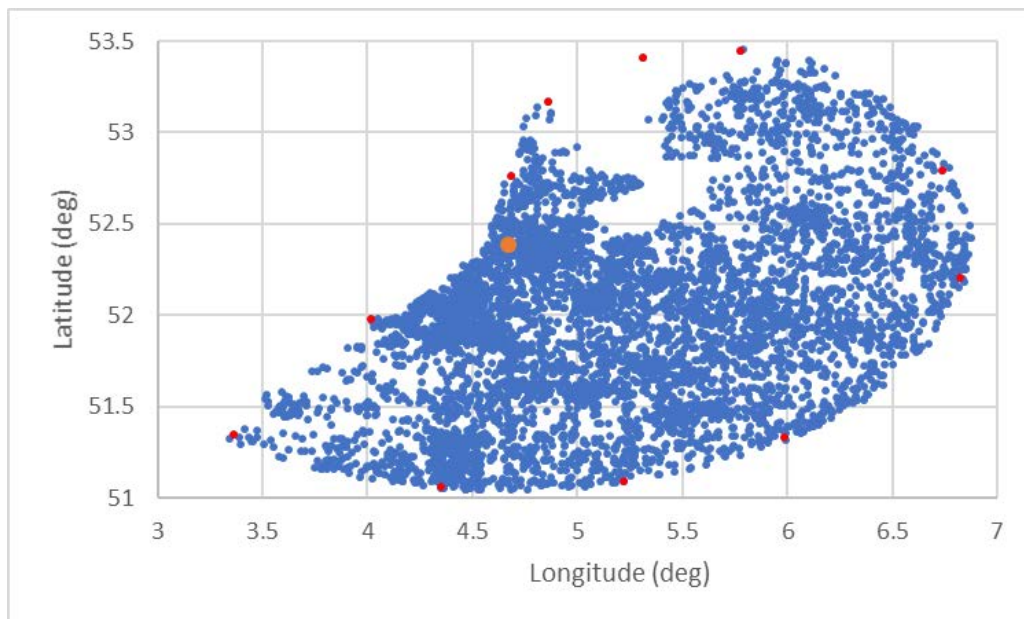
Study population	Instantaneously transmitting devices	Instantaneously transmitting devices in 150 km radius	Instantaneously transmitting devices overlapping FS frequency in 150 km radius
768 589 000	1 317 034	30 229	6 249

Figure 25 shows the location of FS 11 in the Netherlands on a map. It also shows the WAS/RLANs operating at the farthest distance from the FS receiver that contribute to the aggregate interference.



**Figure 25: Geographic location of WAS/RLANs that overlap frequencies with Netherlands FS 11 at the perimeter of 150 km radius (distance, in km, of each WAS/RLAN to the FS is indicated)**

Figure 26 shows the density of instantaneously transmitting devices that have non-zero spectral overlap with FS 11. Within a 150 km radius of FS 11, 30 229 WAS/RLAN devices are expected to be active every instant in time; 6 249 of them overlap with the FS's bandwidth of 29.65 MHz. Higher population areas are located at the higher density of blue dots. Each blue dot represents an active WAS/RLAN device overlapping with the FS bandwidth. The red dots represent the WAS/RLANs in Figure 25. The larger orange dot is FS 11.



**Figure 26: Density of 6249 instantaneously transmitting WAS/RLANs with frequency overlap in 150 km radius of Netherlands FS 11 receiver**

### 6.3.2.2 Long term interference

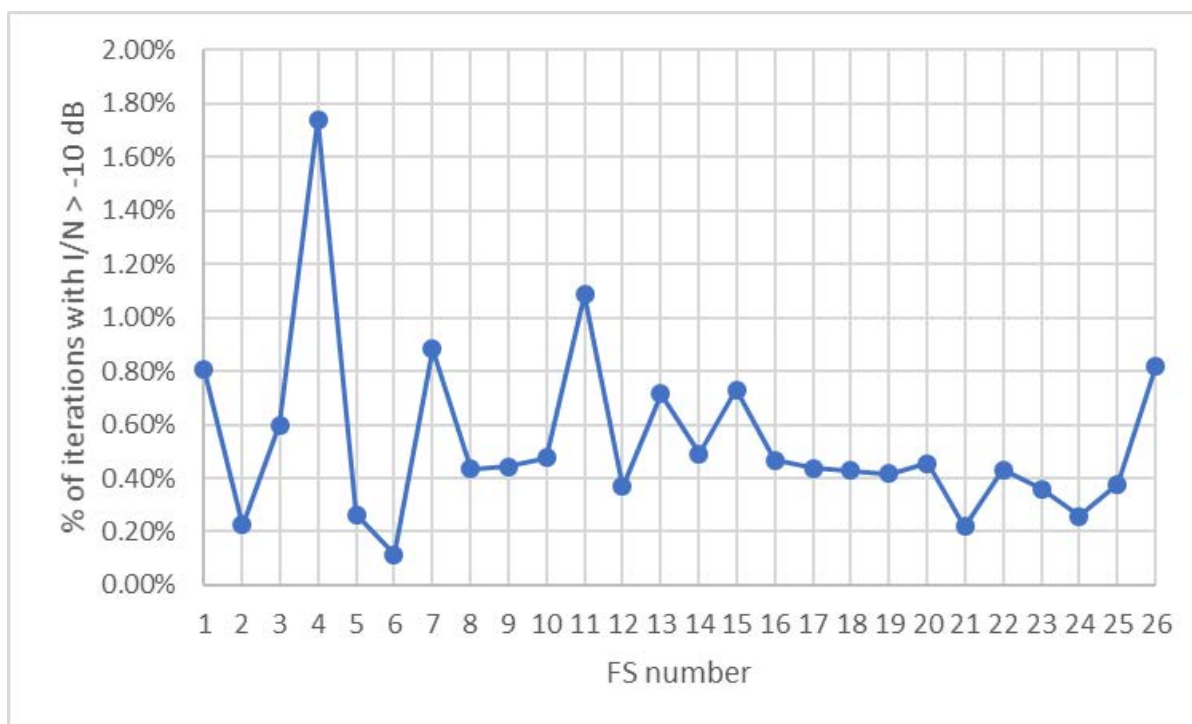
All 26 FS receivers in the Netherlands FS database per [61] were simulated. Ofcom UK antenna patterns (per [62]) were used for all FS stations with the exception of 2 FS stations (with antenna model CFWTC12-W59S) where Recommendation ITU-R F.1245 was used. In the absence of FS receiver feeder loss values in the Netherlands FS database, FS receiver feeder loss of 2.5 dB is applied to the 16 links with 64-QAM modulation and feeder loss of 1.1 dB is applied to the remaining 10 links with 256-QAM or 1024-QAM modulations (minimum values per Section 4.1.1).

Two-hundred-and-fifty-thousand (250 000) iterations of a Monte Carlo simulation were performed to determine the aggregate I/N at each of 26 FS receive locations. For each iteration, the active WAS/RLANs were deployed randomly throughout Europe according to population density in accordance with Section 3.2. The "Mid" parameters from Table 13 (Section 3.2) were employed, based on a European population of 768 589 000. Together, these iterations represent 6 500 000 different WAS/RLAN-to-FS interference morphologies in the Netherlands. Each iteration of the simulation models the set of instantaneously transmitting devices in the WAS/RLAN network.

Of the 250 000 simulation iterations for the 26 different FS receivers, only 0.540% of the iterations had aggregate I/N exceeding -10 dB. Further investigation into these threshold exceedance instances showed that 97.4% were dominated by a single WAS/RLAN. Of these single-entry threshold exceedance cases:

- 36.4% were dominated by a WAS/RLAN device at an angle less than or equal to 2° off boresight from the FS receiver;
- 46.9% were dominated by a WAS/RLAN device at an angle greater than 2° off boresight from the FS receiver and distance from the FS receiver less than 1 km;
- Other topologies that resulted in a single WAS/RLAN device causing an I/N value greater than -10 dB included WAS/RLAN devices:
  - Being outdoors;
  - Statistically having very small building entry loss;
  - Statistically having small path loss values and/or;
  - Having a height larger than buildings surrounding the FS receiver.

Figure 27 shows the percentage of the 250 000 iterations for each of the 26 FS Receivers where the I/N from all WAS/RLANs (indoor and outdoor) exceeded -10 dB.



### Figure 27: Statistics of aggregate I/N > -10 dB for each of the 26 FS receivers in the Netherlands

The simulation results clearly demonstrate that the long term aggregate interference protection criteria will not be exceeded in the Netherlands. In these results, the interference is above -10 dB I/N less than 2% of the time for all FS links, which is far less than the 20% requirement for meeting long term interference criteria. The Monte Carlo results also demonstrate that interference instances are dominated by a single WAS/RLAN causing high levels of interference. However, these events are short term and random. The impact of these events is analysed in the next section 6.3.2.3.

#### 6.3.2.3 Probability that a single WAS/RLAN in The Netherlands will exceed -10 I/N at FS receiver

This section is included for information only. The methodology used in this section is not in accordance with or based on any ITU-R or ECC interference protection studies, decisions or recommendations.

The 250 000 simulation iterations, which dropped 1 317 034 instantaneously transmitting WAS/RLAN devices over the CEPT countries in each iteration (Mid value per Section 3.2), provided a statistical analysis on the probability of I/N exceedance for any single 6 GHz WAS/RLAN operating in the Netherlands.

In the 250000 iterations of the Monte Carlo simulation, there were 71 884 588 217 instantaneously transmitting WAS/RLAN-FS pairs for which WAS/RLAN transmit power was aggregated at the FS receiver. This corresponds to the WAS/RLANs within 150 km of each FS and with nonzero spectral overlap of that FS. With RF activity factor of 1.97%, this corresponds to 3 648 963 868 883 total WAS/RLAN devices. Figure 28 shows the Complementary Cumulative Distribution Function (CCDF), or Interference Graph, for all the WAS/RLAN devices.

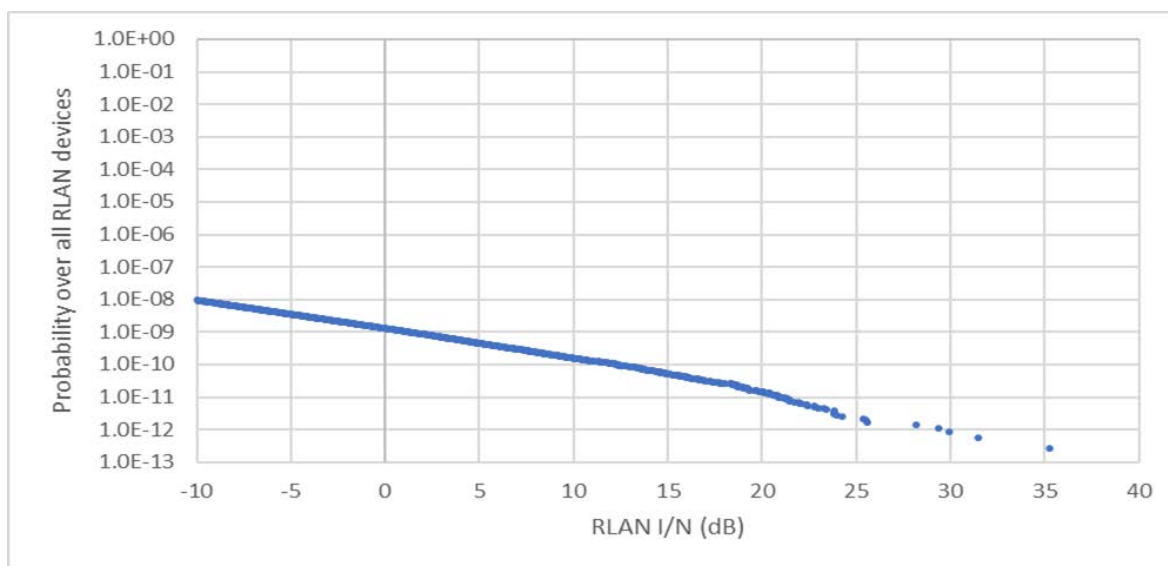
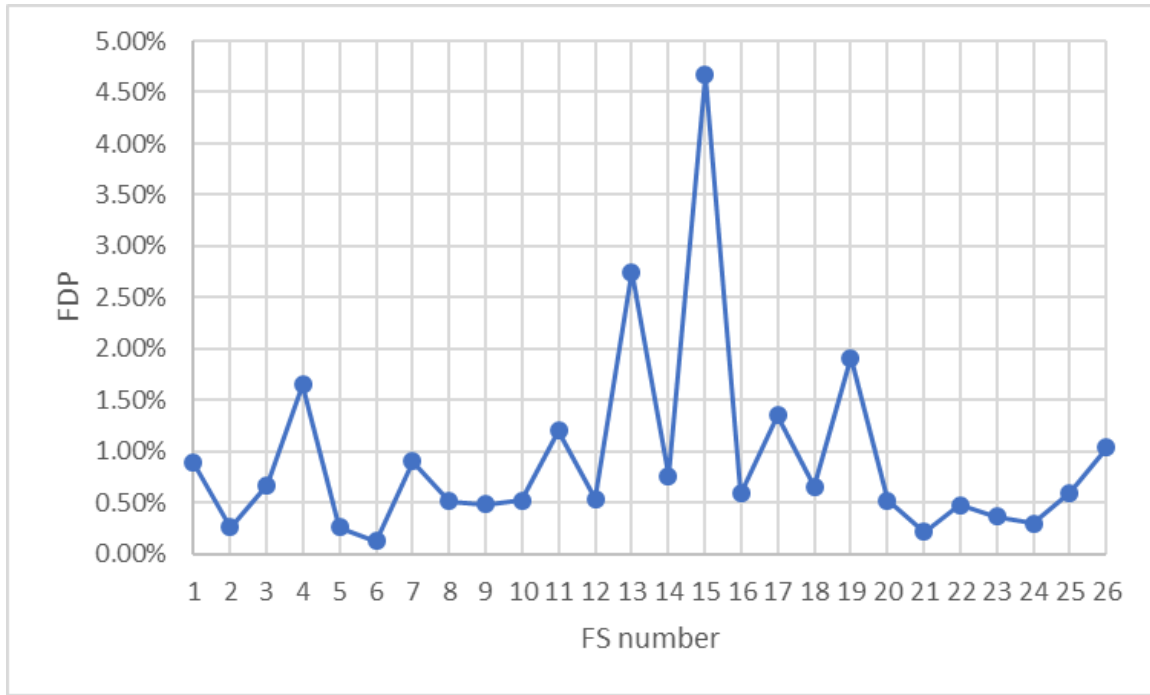


Figure 28: The Netherlands FS single-WAS/RLAN Interference graph for 26 FS receivers

Based on this analysis, there is a three in a billion probability that an unconstrained 6 GHz enabled WAS/RLAN would meet or exceed I/N = -10 dB at an FS receiver 2% of the time.

#### 6.3.2.4 FDP assessment

From the 250 000 iterations of the Monte Carlo simulation presented in the previous section for the long term interference analysis, the FDP was calculated for each FS, as shown in Figure 29 below.



**Figure 29: FDP for each of the 26 FS receivers in the Netherlands**

The Monte Carlo results indicate that the interference criterion of FDP < 10% is met for all of the Netherlands FS links since the FDP is below 5% for the worst case (FS 15).

### 6.3.3 UK Fixed Service analysis results

#### 6.3.3.1 WAS/RLAN deployment model

To visualise the Monte Carlo methodology in the placement of WAS/RLANs within 150 km of an FS receiver, as detailed in Section 6.3.1, a single iteration of the Monte Carlo simulation was run for the UK FS number 477. FS 477 corresponds to FS license no. 1126335/1 with centre frequency = 6093.45 MHz in the UK FS database per [63].

Table 32 shows how the parameters outlined in section 3.2 were implemented with respect to this simulation.

**Table 32: Number of active WAS/RLAN devices simulated in a single iteration of UK FS 477**

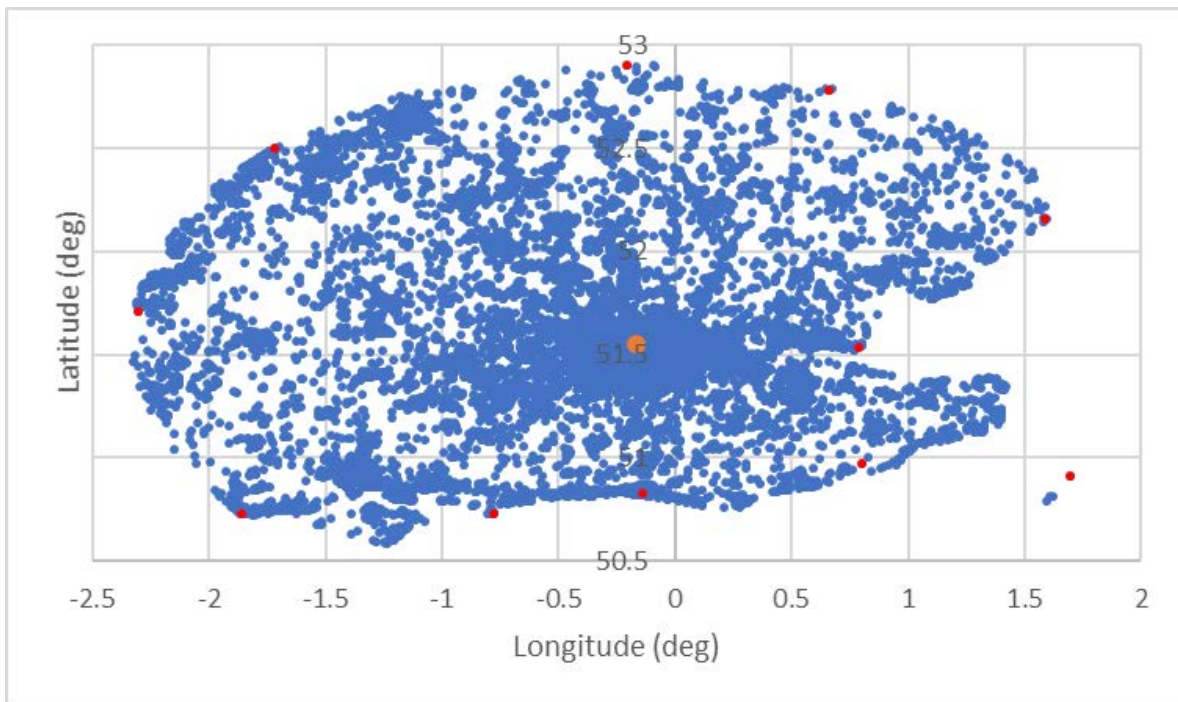
Study population	Instantaneously transmitting devices	Instantaneously transmitting devices in 150 km radius	Instantaneously transmitting devices overlapping FS frequency in 150 km radius
768 589 000	1 317 034	43 904	17 066

Figure 30 shows the location of FS 477 with respect to London. It also shows the WAS/RLANs operating at the furthest distance from the FS receiver that contribute to the total aggregate interference.



**Figure 30: Geographic location of WAS/RLANs that overlap frequencies with UK FS 477 at the perimeter of 150 km radius**

Figure 31 shows the density of instantaneously transmitting devices that have frequency overlap with FS 477. Within a 150 km radius of FS 477, 43 904 WAS/RLAN devices are expected to be active every instant in time; 17 066 of them overlap with FS's bandwidth of 29.65 MHz. The city centre is located at the highest density of blue dots. Each blue dot represents an active WAS/RLAN device falling into the FS band. The red dots represent the WAS/RLANs in Figure 30. The larger orange dot is FS 477.



**Figure 31: Density of 17066 instantaneously transmitting WAS/RLANs with frequency overlap in 150 km radius of UK FS 477 receiver**

### 6.3.3.2 Long term interference

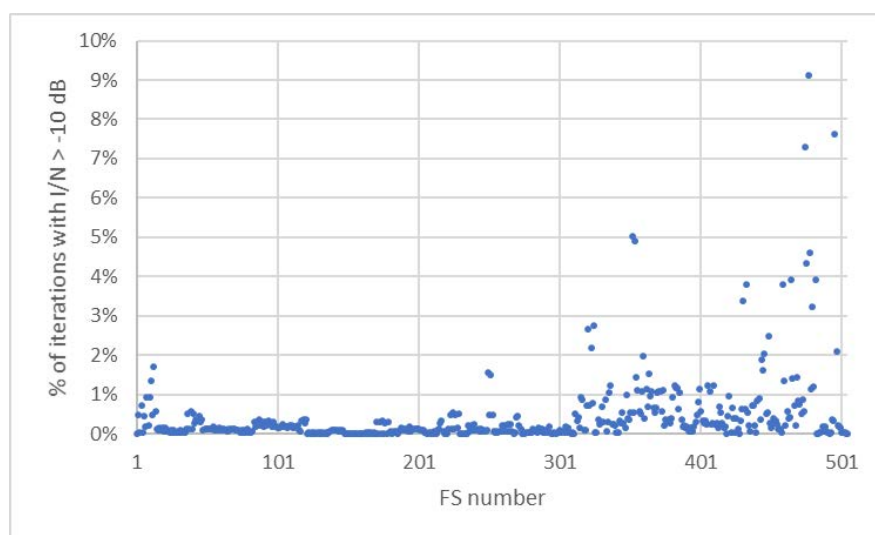
The United Kingdom FS database per [63] was used with the exception of 104 links which were oil rigs (in the North Sea), resulting in 505 simulated FS links. Ofcom UK antenna patterns [62] were used for all 505 FS stations. For some of the FS, the Rx feeder loss was 0 dB in the UK database [63], but this was assumed to be an error given the statement in Ofcom United Kingdom's OfW85 Point-to-Point Fixed Link licence Application Form<sup>2</sup>. For these instances, a feeder loss of 1.1 dB was added (minimum value per section 4.1.1).

Two-hundred-and-fifty-thousand (250 000) iterations of a Monte Carlo simulation were performed to determine the aggregate I/N at each of 505 FS receive locations. For each iteration, the active WAS/RLANs were deployed randomly in accordance with Section 3.2. The "Mid" parameters from Table 13 were employed, based on a European population of 768 589 000. Together, these iterations represent 126 250 000 different WAS/RLAN-to-FS interference morphologies in the United Kingdom. Each iteration of the simulation models the set of instantaneously transmitting devices in the WAS/RLAN network.

Of the 250 000 simulation iterations for the 505 different FS receivers, only 0.417% of the iterations had aggregate I/N (due to indoor and outdoor WAS/RLANs) for an FS receiver exceeding -10 dB. Further investigation into these threshold exceedance instances revealed that 94.42% were dominated by a single WAS/RLAN. Of these single-entry threshold exceedance cases:

- 51.5% were due to a WAS/RLAN device at an angle less than or equal to 2° off boresight from the FS receiver;
- 32.8% were due to a WAS/RLAN device at an angle greater than 2° off boresight from the FS receiver and distance from the FS receiver less than 1 km.
- Other topologies that resulted in a single WAS/RLAN device causing an I/N value greater than -10 dB included WAS/RLAN devices:
  - Being outdoors;
  - Statistically having very small building entry loss;
  - Statistically having small path loss values and/or;
  - Having a height larger than buildings surrounding the FS receiver.

Figure 32 shows the percentage of the 250 000 iterations for each of the 505 FS Receivers where the I/N from all WAS/RLANs (indoor + outdoor) exceeded -10 dB.



**Figure 32: Statistics of aggregate I/N > -10 dB for each of the 505 FS receivers in United Kingdom**

<sup>2</sup> "At lower frequencies, a value much greater than 0 dB is expected for feeder losses connecting the terminal indoor and outdoor units."

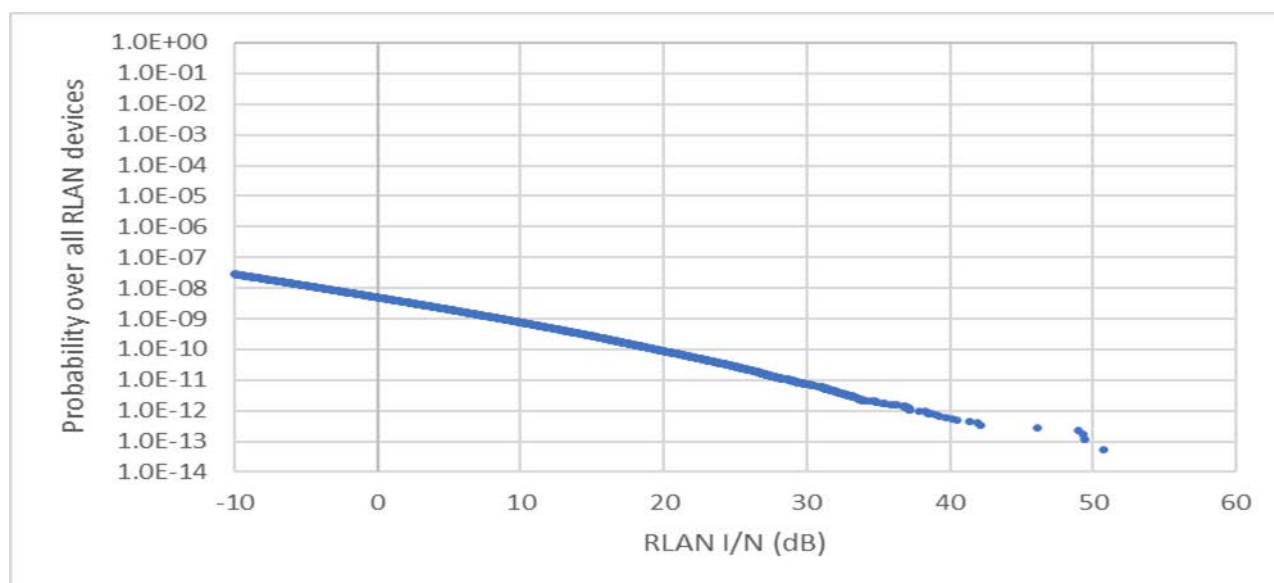
In the United Kingdom results, the interference is above -10 dB I/N less than 9.2% of the time for the worst-case link, which is less than the 20% requirement for long term interference. While the worst-case interference exceedance probability for an FS receiver is higher in the United Kingdom than in the Netherlands, the probability of interference exceeding the I/N threshold for all of the FS links is lower than that in the Netherlands, which demonstrates that factors beyond density of links, such as link design, play a role in determining the probability of harmful interference. As in the case of the Netherlands, the low probability and high interference, levels are primarily caused by individual WAS/RLANs that are close (in terms of propagation loss) to the FS station. FDP assessment will be analysed in section 6.3.3.4.

### 6.3.3.3 Probability that a single WAS/RLAN in the United Kingdom will exceed -10 I/N at FS receiver

This section is included for information only. The methodology used in this section is not in accordance with or based on any ITU-R or ECC interference protection studies, decisions or recommendations.

The 250 000 simulation iterations, which dropped 1 317 034 instantaneously transmitting WAS/RLAN devices over the CEPT countries in each iteration (Mid value per Section 4.3), provided a statistical analysis on the probability of I/N exceedance for any single 6 GHz WAS/RLAN operating in the United Kingdom.

In the 250 000 iterations of the Monte Carlo simulation, there were 353 687 421 941 instantaneously transmitting WAS/RLAN-FS pairs for which WAS/RLAN transmit power was aggregated at the FS receiver. This corresponds to the WAS/RLANs within 150 km of each FS and with non-zero spectral overlap of that FS. With RF activity factor of 1.97%, this corresponds to 17 953 676 240 660 total WAS/RLAN devices. Figure 33 shows the Complementary Cumulative Distribution Function (CCDF) or Interference Graph, for all the WAS/RLAN devices.



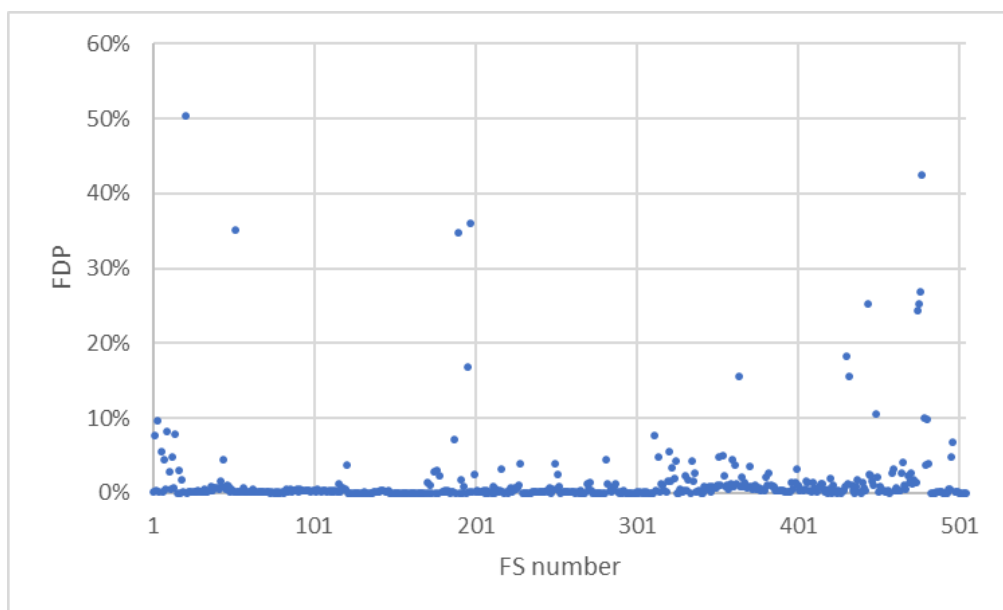
**Figure 33: United Kingdom FS single-WAS/RLAN Interference graph for 505 FS receivers**

Based on this analysis, there is a one in 100 million probability that an unconstrained 6 GHz enabled WAS/RLAN would meet or exceed I/N = -10 dB at an FS receiver 2% of the time.

### 6.3.3.4 FDP assessment

From the 250 000 iterations of the Monte Carlo simulation presented in the previous section for the long term interference analysis, the FDP was calculated for each FS, as shown in Figure 34 below.





**Figure 34: FDP for each of the 505 FS receivers in United Kingdom**

Remarkably, the FDP was well below the interference protection criteria threshold for the vast majority of the links without any mitigation. This indicates that the typical WAS/RLAN and FS topologies are such that proper link design will seldom lead to harmful interference.

There were 15 FS receivers for which FDP exceeded 10%. It has been noted that one third of these cases were located in the Isle of Lewis where population density is very low. In addition, some of the FS receivers were located at lower heights and the simulation methodology dropped WAS/RLANs at higher elevations than buildings in surrounding terrain leading to unrealistic geometries.

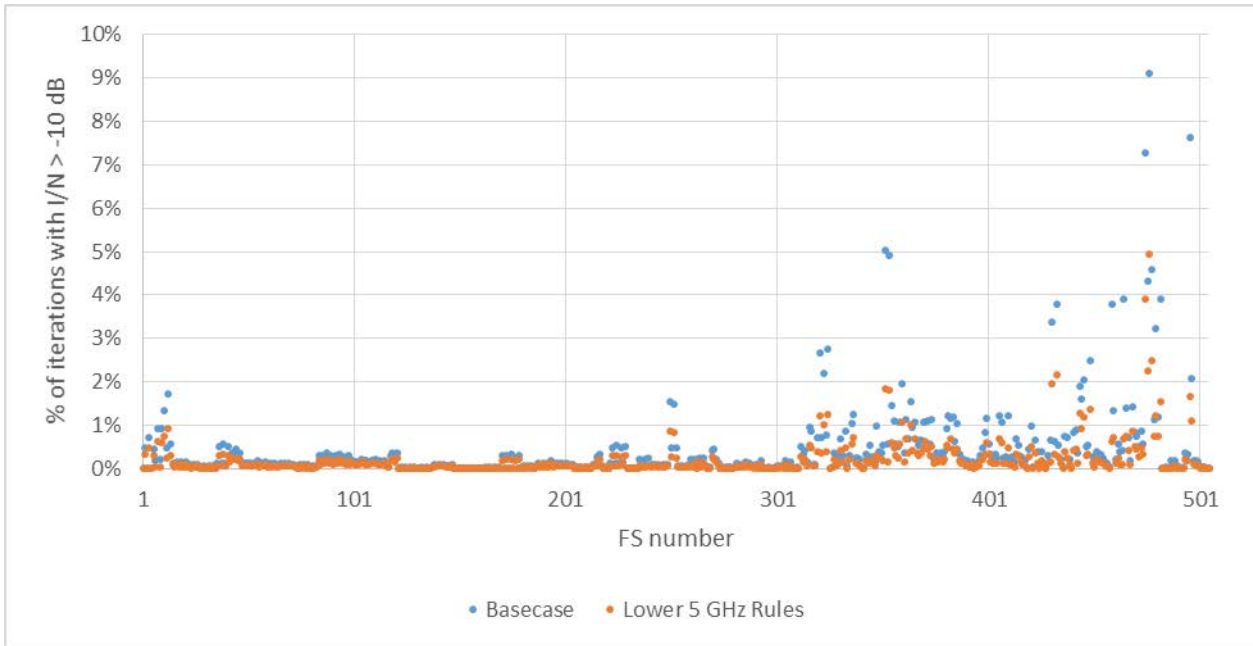
#### *6.3.3.5 Applying 5150-5250 MHz WAS/RLAN requirements*

In the following, the impact of applying 5150-5250 MHz band requirements (lower 5 GHz) is studied on long term interference and FDP by removing all outdoor and WAS/RLANs operating above 23 dBm e.i.r.p. The impact of accidental outdoor usage of portable devices without any coordination is not considered. This study is provided for analysis purposes only and the way to implement such a mitigation measure is out of scope of this Report.

##### Impact on long term interference:

Applying lower 5 GHz rules to all the WAS/RLANs in the 126 250 000 different WAS/RLAN-FS morphologies simulated, as presented in section 6.3.3.2, results in reducing the probability of interference exceeding -10 I/N by 50%, from 0.417% to 0.209%.

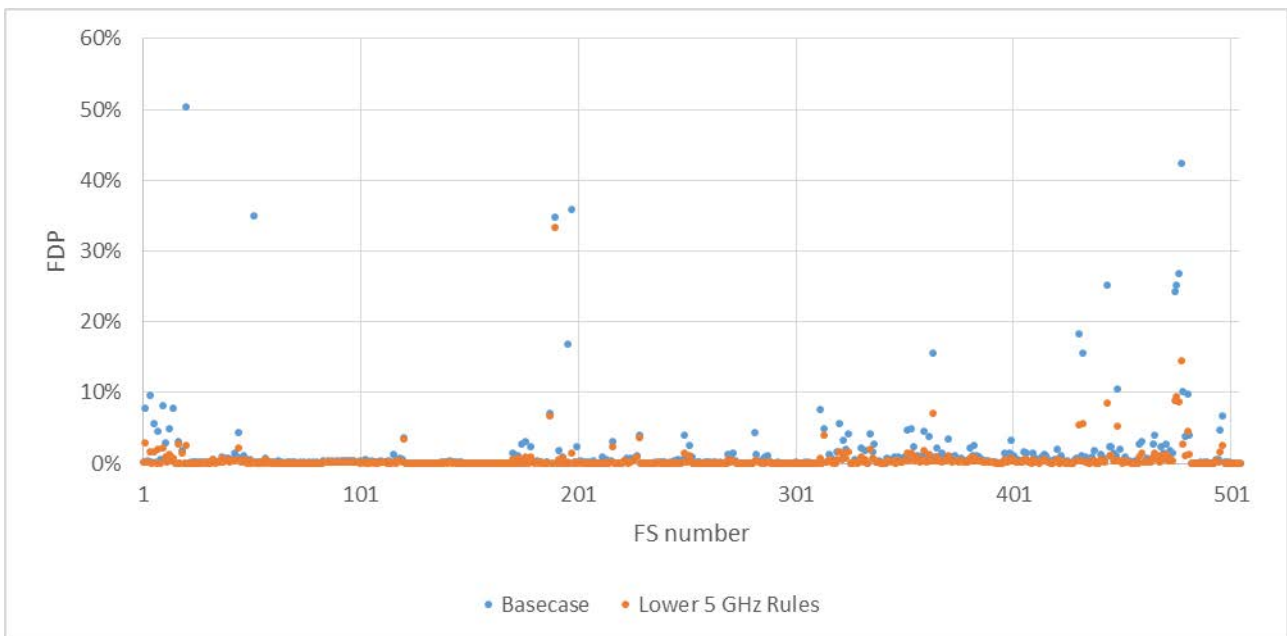
Figure 35 shows the reduction of I/N instances when applying the lower 5 GHz rules for each of the 505 FS Receivers.



**Figure 35: Statistics of aggregate I/N > -10 dB for each of the 505 FS receivers in the United Kingdom assuming lower 5 GHz rules**

Impact on FDP:

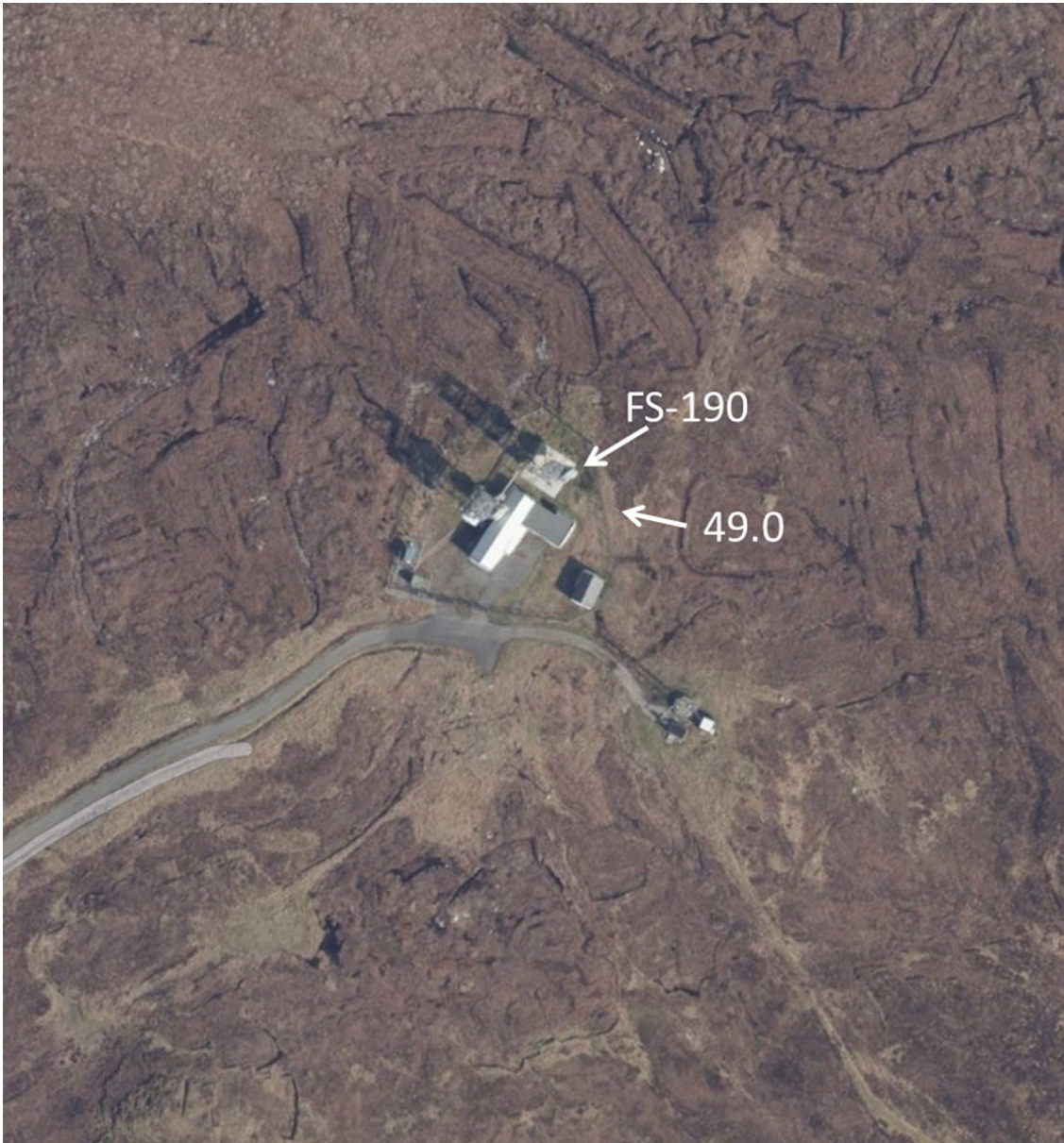
Figure 36 shows the reduction of FDP results when applying the lower 5 GHz rules for each of the 505 FS Receivers.



**Figure 36: FDP for each of the 505 FS receivers in the United Kingdom with lower 5 GHz rules**

After applying the lower 5 GHz rules, there are only two links out of 505 links that fail the FDP interference protection criteria. Based on the visual depiction of the very high I/N scenarios from a single interferer to these two FS links in Figure 37 and Figure 38 below, it is noted that further analysis is required to determine whether these geometries are possible in the real world.

For FS 190, the geometry that led to the FDP exceedance was a WAS/RLAN that was 16 m away and at 2.5 m higher than the FS (FS is 5 m and WAS/RLAN is 7.5 m) in an open field.



**Figure 37: Geographic location of top WAS/RLAN interferer to United Kingdom FS 190 (0.016 km away)**

FS 478 is at 15 m height and the WAS/RLAN is in an urban environment less than 8 m away from FS 478 and is at 12.5 m height. Figure 38 shows the location of this WAS/RLAN on a map. As shown, the height of this WAS/RLAN is not geometrically realistic for this location. If there were multi-story buildings surrounding this link, then the antenna would likely be on a higher tower.



**Figure 38: Geographic location of the top WAS/RLAN interferer to United Kingdom FS 478**

The Monte Carlo simulation results demonstrate that the interference criterion of FDP < 10% is met for 503 out of 505 FS in United Kingdom assuming that only low power indoor WAS/RLAN devices can transmit without coordination. Furthermore, the two FS links that did not meet the FDP interference protection criteria were based on unlikely WAS/RLAN interference scenarios and if these are removed, the FDP of 10% is satisfied for all FS receivers.

#### 6.3.4 Summary for Study B: Monte Carlo simulations

The results of the Monte Carlo simulations conducted with real FS data for the Netherlands and the United Kingdom show that long term interference criteria (I/N of -10 dB for 20% of the time) for FS will not be exceeded if WAS/RLAN is deployed in the 5925-6425 MHz band.

For an unconstrained deployment of WAS/RLAN, the interference limit (FDP < 10%) is met for all FS links in the Netherlands whereas in the United Kingdom there were a few instances for which the 10% limit was exceeded. When applying the regulatory conditions in force for the 5150-5250 MHz band, the FDP interference limit is met by 503 of the 505 United Kingdom links. Deeper analysis revealed that these exceedances were caused by combinations of WAS/RLAN parameters that resulted in unrealistic WAS/RLAN locations.

### 6.4 STUDY C: COVERAGE MAPPING AND MONTE CARLO ANALYSIS OF INTERFERENCE FROM WAS/RLAN INTO FS

#### 6.4.1 Introduction

The third study assesses sharing between the fixed service and WAS/RLANs in France. Two complementary approaches were adopted: first, calculation of geographical interference coverage is performed for each studied FS station and the impact of indoor WAS/RLAN (250 mW e.i.r.p.) is compared with the high power outdoor case (1 W); then a statistical approach is adopted with each FS station through a Monte Carlo simulation.

## 6.4.2 Fixed service usage in France

With 1688 registered fixed links, France is considered as a heavy user of the low 6 GHz band for the fixed service. To cope with the increase of data traffic, all the FS channels are used / or will be used in the near future.

## 6.4.3 Simulation methodology

### 6.4.3.1 Coverage mapping approach

In order to plot the potential interference created by a WAS/RLAN to an FS station, the following steps are followed:

- STEP 1: choose a fixed link station localised by its latitude, longitude, antenna height, azimuth and elevation angles;
- STEP 2: around this position, delimit an area of simulation;
- STEP 3: grid this area of simulation by creating simulation points each 0.01° of latitude and longitude;
- STEP 4: for each grid point compute the amount of interference that would a WAS/RLAN situated in this specific point create to the chosen FS;
- STEP 5: plot the resulted matrix on google earth;
- STEP 6: end.

Two cases are studied: outdoor and indoor. The outdoor case has an e.i.r.p. of 1 W and the indoor one has an e.i.r.p. of 250 mW. WAS/RLAN height is chosen as 1.5 m, as it is the most probable one according to the distributions provided by the ETSI TR 103 524 [3].

The used propagation model is according to Recommendation ITU-R P.452-16 ( $p = 20\%$ ) in addition to a clutter loss according to Recommendation ITU-R P.2108 (with the percentage of locations equal to 50%). For indoor case, an additional building entry loss according to Recommendation ITU-R P.2109 (with a probability = 50%, traditional building) is also considered. Terrain profile is according to SRTM data 3 arcsecond.

Note that this approach is a static approach that deals only with the interference created by a single active WAS/RLAN and that neither the population density nor the WAS/RLAN RF activity factor are taken into account.

### 6.4.3.2 Monte Carlo approach

The same methodology described in section 6.3.1 is adopted in this section, with the exception that only WAS/RLAN within the range of 70 km from the FS are taken into account. Also, a bandwidth factor of 5.38 dB and an overlapping factor of 21.25% are applied. Thus, instead of scattering WAS/RLANs with different random channels and then find which are the ones active within the FS channel and compute the bandwidth factor, case by case, these two factors are used to characterise this phenomenon.

**Table 33: Summary of WAS/RLAN deployment model**

Parameter	Mid
Total Population of Europe 2025	768 589 000
Wireless devices operating in licence exempt spectrum (remainder operating in licence spectrum)	90%
Busy hour population	62.70%
6 GHz Factor	48.17%
Market Factor	32%

Parameter	Mid
RF activity factor	1.97%
Overlap factor	21.25%
Instantaneously Transmitting Devices within a 29.65 MHz FS channel	279 869.776
Number of on-tune active WAS/RLAN within a 29.65 MHz FS channel	0.0003

The antenna pattern used in the simulation is according UX A 10-59 A (RFS) [81] as it is one of the most used in France, with a gain of 38.7 dBi.

#### 6.4.3.3 FS stations location

It was not possible to study all the 1688 FS links as the simulation time would last for a long time. The three links in Table 34 were studied. These links are believed to be worst cases as they are situated in urban environment.

**Table 34: Studied links**

Parameter	Station A					Station B					Length (km)
	Lat°	Long°	h(m)	Ele°	Az°	Lat°	Long°	h(m)	Ele°	Az°	
Link 1 (Clermont)	45.767	3.093	42.9	0	42.9	45.97	3.364	18	0	223	30.8
Link 2 (Dijon)	47.322	5.063	22	0.3	206.5	47.136	4.926	26.5	-0.3	26.5	23.2
Link 3 (Marseille)	43.29	5.596	31.5	1.2	261	43.278	5.489	49	-1.2	80	8.7

## 6.4.4 Simulation results

### 6.4.4.1 Coverage interference mapping

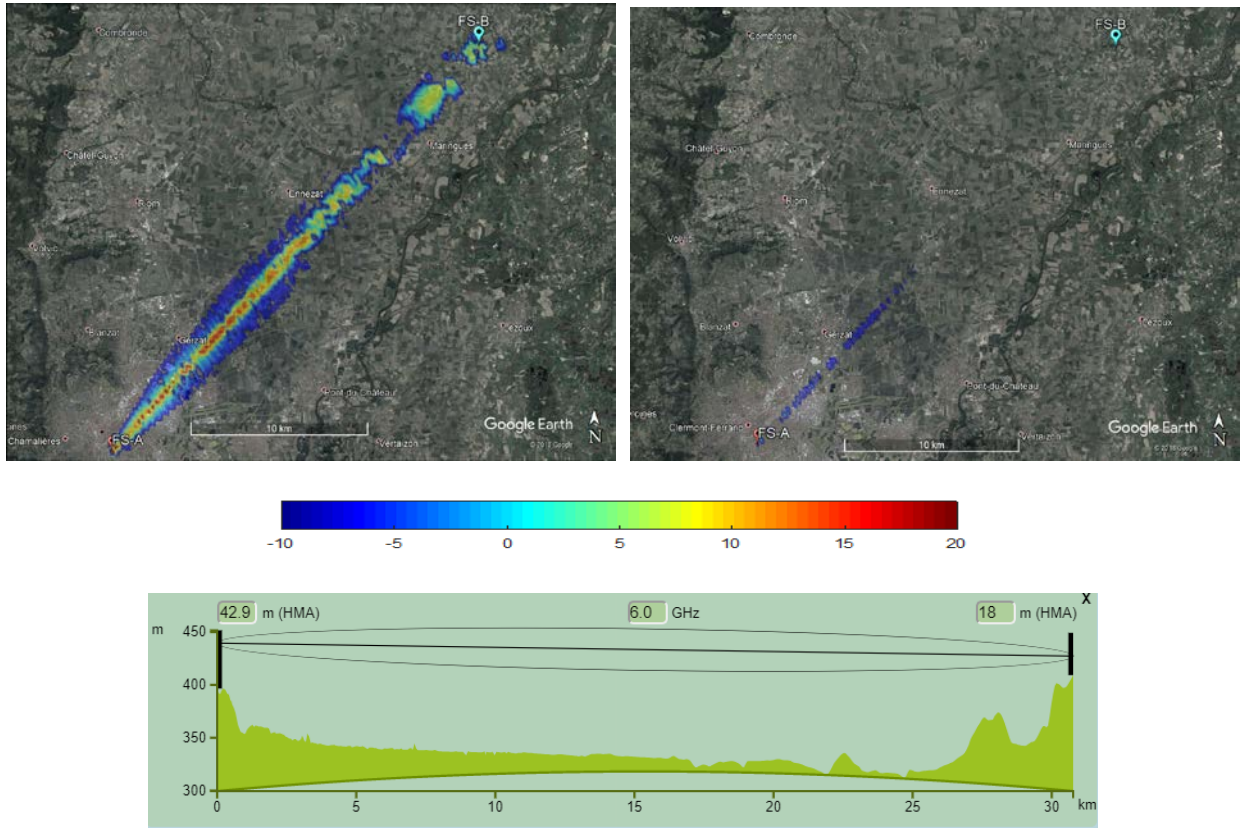
The obtained results are plotted in Figure 39, Figure 40 and Figure 41. In each figure, outdoor WAS/RLAN impact (left) is compared with indoor WAS/RLAN impact (right). The same I/N scale in dB is used for all depicted cases. All the coloured areas are the areas where the protection threshold (long term) I/N of -10 dB is exceeded at the FS receiver, because of a WAS/RLAN present at the coloured grid point. Areas where the WAS/RLANs will cause I/N values lower than -10 dB are not coloured deliberately. Areas coloured in dark red are areas where the I/N is higher than 20 dB.

Regarding the chosen FS stations, it is clear that for the links 1 and 2, outdoor WAS/RLAN will create interference (based on short or long term protection I/N threshold) to the FS within a large geographical area, while the indoor deployment seems to impact smaller areas.

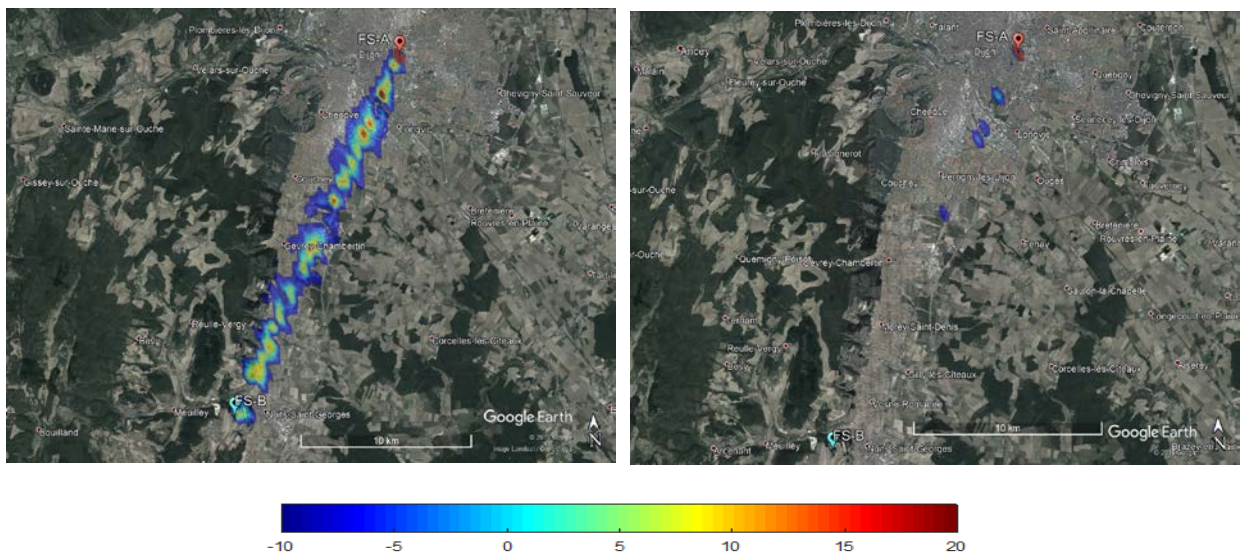
For the third link, given the terrain profile the outdoor WAS/RLAN deployment has less impact than for the two other links. However one should note that the interfered area visible on the map, near the FS station, is about 2.6 km<sup>2</sup> and that the farthest interfering grid point is at 2.4 km from the FS station.

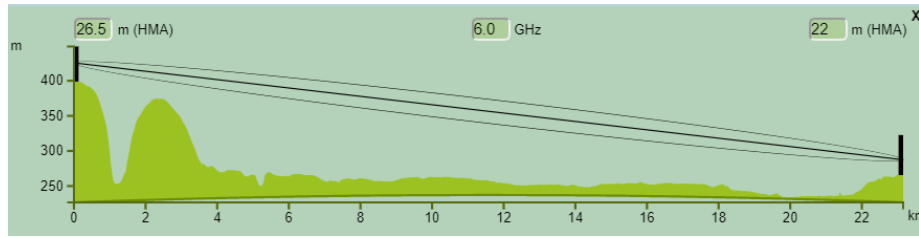
In the particular case of the second and third link (indoor and outdoor), the short term protection threshold is also exceeded within the close vicinity of the FS station (dark-red colours). This appears to be more critical than the long term protection criterion, which is always satisfied. Indeed, given the WAS/RLAN 2% RF

activity factor, the exceedance of the short term protection criterion for an access point situated within this area will be exceeded more than the  $4.5 \cdot 10^{-4}\%$  tolerated value, given that the conditions modelled in the static analysis persist over time.

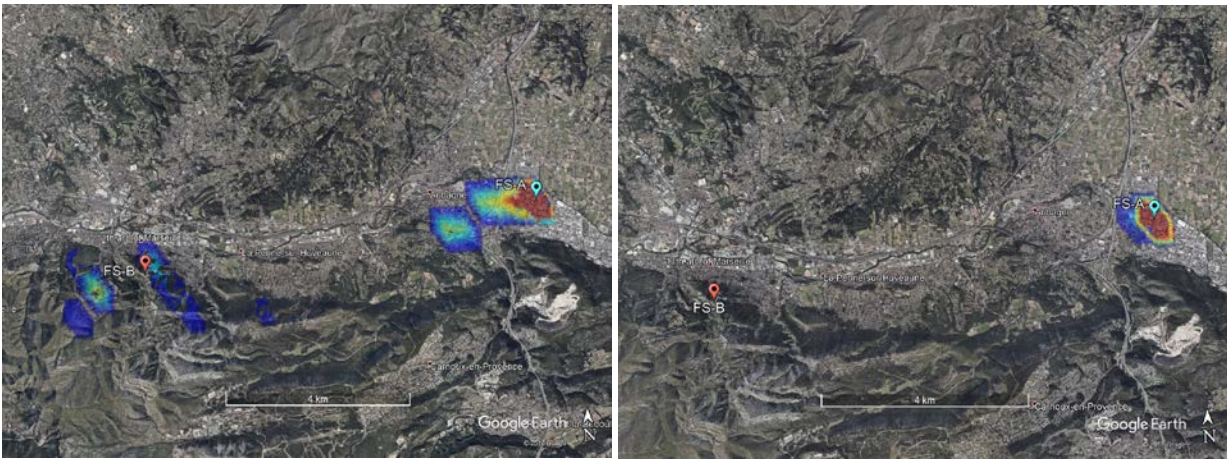


**Figure 39: Fixed link 1 at Clermont-Ferrand. Top left: Outdoor WAS/RLAN impact on the fixed link, Top right: Indoor WAS/RLAN impact on the fixed link. Bottom: Fresnel zone and path profile**





**Figure 40: Fixed link 2 at Dijon. Top left: Outdoor WAS/RLAN impact on the fixed link, Top right: Indoor WAS/RLAN impact on the fixed link. Bottom: Fresnel zone and path profile**



**Figure 41: Fixed link 3 at Marseille. Top left: Outdoor WAS/RLAN impact on the fixed link, Top right: Indoor WAS/RLAN impact on the fixed link. Bottom: Fresnel zone and path profile**

#### 6.4.4.2 Monte Carlo simulation results

Monte Carlo simulation results are depicted in Figure 42. Only the long term protection criterion is studied. Generally speaking for all the studied links, the long term protection criterion is respected.

For the FS link 1 (Clermont Ferrand) the protection criterion  $I/N = -10$  dB is exceeded for 1.89% of the time, which is below the long term 20% advised by Recommendation ITU-R F.758 [33]. However, the short term protection threshold of 19 dB is exceeded for 0.002% of time which is higher than the  $4.5 \cdot 10^{-4}$  % of time advised in Recommendation ITU-R SF.1650-1. Thus, the short term protection criterion is not respected in this case.

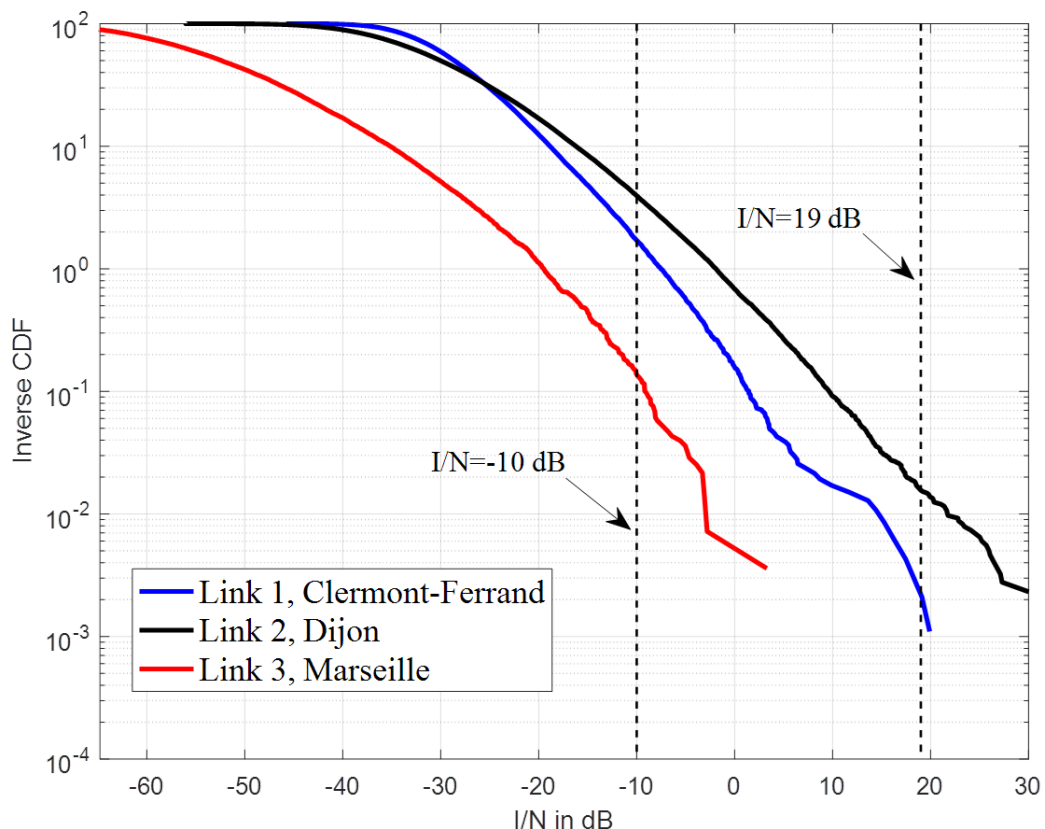
Regarding the FS link 2 (Dijon), the protection criterion is exceeded 4% of the time, which is still less than the 20% advised by Recommendation ITU-R F.758. However, the short term protection threshold of 19 dB is



exceeded for 0.0152% of time which is higher than the  $4.5 \cdot 10^{-4}$  % of time advised in Recommendation ITU-R SF.1650-1. Thus, the short term protection criterion is not respected in this case.

For the FS link 3 (Marseille), it is exceeded for 0.11% of the time. The difference between the two percentages can be explained using the interference mapping presented above. Links 1 and 2 are more subject to interference by WAS/RLANs given the terrain profile around them, while for the link 3, the area where the WAS/RLAN could create interference is smaller (see Figure 41). The number of Monte Carlo runs performed for this link did not allow the assessment of the short term protection criterion.

Looking at the critical area of the results from both the Monte Carlo analysis and the interference coverage map, it is believed that the cases where the I/N threshold is exceeded, are due to high power outdoor usage or in a rare event of indoor usage with small BEL situated within the main beam of the FS station.



**Figure 42: Monte Carlo simulations for the considered links**

#### 6.4.5 Summary for the sharing study C between WAS/RLAN and FS

Two set of complementary simulations have been run. The interference coverage mapping indicates that allowing outdoor WAS/RLAN operating with an e.i.r.p. of 1 W could create interference from a large area around the FS link, depending on the terrain profile. However, when restricting the usage to indoor only utilizing an e.i.r.p. up to 250 mW the possible interfering area is substantially reduced bringing the interference area within close proximity to the FS. However, these simulations also show that within close proximity of some FS stations, the short term protection threshold of 19 dB is exceeded (even in the indoor case). This appears to be more critical compared to the long term criterion. Indeed, given the WAS/RLAN 2% RF activity factor, the exceedance of the short term protection criterion for an access point situated within this area will be exceeded more than the  $4.5 \cdot 10^{-4}$ % tolerated value, and the FS station is interfered, given that the conditions modelled in the static analysis persist over time.

Complementary statistical study based on a Monte Carlo approach, indicated that the I/N threshold value of -10 dB was not exceeded for more than the 20% of the time, as advised by Recommendation ITU-R F.758 [33] for the long term protection criterion. The short term protection criterion (19 dB not exceeded for more than  $4.5 \cdot 10^{-4}$ % of the time) was exceeded for two of the three studied links. Unfortunately, the number of Monte Carlo runs performed for the third link did not allow the assessment of the short term protection criterion. It has to be noted, that as performed, the Monte Carlo runs lead to CDF expressing the space-time occurrence of events, while the fixed service protection is to be analysed in the time dimension only.

Taking into account the above elements, WAS/RLAN indoor-only usage brings a safe operation to the FS. Unfortunately, administrations have no way to control the client AP indoor/outdoor deployment, since they are unlicensed devices. Some additional techniques/restrictions may need to be applied in order to maintain the indoor usage or to mitigate the effect of accidental outdoor use, like a FS data base use for coordination, in particular, a geo-location methods that aims at detecting a spatial closeness between victim and interferer.

## 7 SHARING BETWEEN WAS/RLAN AND FSS

For the sharing analysis between WAS/RLAN and FSS, a satellite channel plan assuming 36 MHz channels in 40 MHz occupied bandwidth has been applied and this results in a bandwidth correction factor of 21.2 %. How this bandwidth factor was calculated can be seen in Table 75 from ANNEX 5. Taking account of the numbers from the WAS/RLAN deployment models shown in Section 3 of this Report in Table 13 (overall deployment) and Table 14 (outdoor only deployment) and applying the bandwidth correction factor of 21.2 % results in the number of WAS/RLAN devices overlapping in the 40 MHz FSS receiver bandwidths as shown in Table 76 from ANNEX 5.

### 7.1 SHARING BETWEEN WAS/RLAN AND FSS STUDY A: MONTE CARLO ANALYSIS OF WAS/RLAN INTERFERENCE INTO FSS (SPACE STATIONS)

This section reports the results of an aggregate I/N calculation into a number of satellite uplink beams using the agreed WAS/RLAN deployment and available satellite G/T contours, related to the satellites in Table 20. Peak G/T levels using satellite thermal noise temperature per Table 20 is used to derive the absolute G/T levels from the G/T contours (that indicate amount of dB down from peak G/T). The only exception is IS-33e, where the actual G/T levels over the beam's footprint were provided. In this case, factor of 1.675 dB was added to the G/T levels (based on system noise temperature) in the spreadsheet to convert to G/T levels based on thermal noise.

The analysis has been applied to a satellite channel plan assuming 36 MHz channels in 40 MHz occupied bandwidth on two polarisations. Each channel on each satellite has been subject to 10 independent WAS/RLAN deployments of a Monte Carlo simulation as detailed in the next Section.

Table 35 gives the worst I/N value found for each beam across all channels, under WAS/RLAN assumptions for the Mid scenario (see Table 13). The table shows that, in all cases, the I/N is more than 8.5 dB below the -10.5 dB threshold.

**Table 35: Summary worst case I/N into FSS under WAS/RLAN assumptions for the Mid scenario**

Satellite Reference (see Table 20)	Satellite Longitude	Satellite Name	Beam Reference	Populations included in calculation	Worst I/N under Mid Active WAS/RLAN assumptions (dB)
J	40.5° West	SES-6	40.5W Hemispheric	Europe, Africa and Middle East	-30.45
K	22° West	SES-4	22W Hemispheric	Europe, Africa, Middle East, North and South Americas and Caribbean	-24.19
L	20° West		20W Zone	Europe, Africa and Middle East	-21.98
M	50.5° East		50.5E Zone	Europe, Africa and Middle East	-24.28
N	57° East		57E Hemispheric	Europe, Africa and Middle East	-24.42
Q	37.5° West		37.5W	Europe, Africa and	-24.19

			Hemispheric	Middle East	
R	60° East	IS-33e	C4A	Europe, Africa and, Middle East	-19.64
T	34.5° West	IS-35e	C01	Europe, Africa and, Middle East	-19.07
Y	45° West	IS-14	CEUH	Europe, Africa and, Middle East	-27.96
Z	72° East	IS-22	WHLU	Europe, Africa and Middle East	-28.22

### 7.1.1 Simulation methodology

Interference from WAS/RLAN deployments into FSS satellite receiver is simulated using a Monte Carlo simulation of the WAS/RLAN deployment generated from the various probability distributions given in section 4.

The basic structure of the simulation is as follows:

- 1 Data setup:
  - a) Define the simulation region and create a database of population density at points within the simulation region;
  - b) Transform population data over the simulation region to active WAS/RLAN device population probability distribution over the simulation region;
  - c) Specify the orbital slot of the FSS satellite receiver and the G/T values over the simulation region;
  - d) Specify a list of FSS satellite channels to simulate.
- 2 Monte Carlo iterations:
  - a) Generate a random layout of WAS/RLANs using the device population probability distribution;
  - b) Generate the clutter loss and building entry loss values between each WAS/RLAN and FSS satellite receiver in accordance with the propagation modelling set out in Section 5.2;
  - c) Compute the aggregate interference from all co-channel WAS/RLANs into the FSS satellite receiver for each of the simulated FSS channels.
- 3 Iterate:
  - a) Repeat Step 2 for the total specified number of iterations;
  - b) Record I/N values for each FSS channel on each iteration and write results to a file.
- 4 Average the recorded aggregate I/N values (over the performed iterations) to create plot of average I/N versus FSS channel number.

Steps 1 and 2 above are further elaborated below.

#### Step 1: Data Setup

A population matrix file is created. Each row/line of the matrix contains a Longitude (LON)/Latitude (LAT) coordinate and the population density at that location. Furthermore, there is a region ID that specifies if the

point is in Europe, Africa or Middle East. The matrix resolution is 30 arcseconds for both LON and LAT coordinates.

Note that the collection of all points in the population density file defines the simulation region and the simulation region is, in general, not rectangular. Grid points that are in the ocean or other locations that are not part of the simulation are omitted from the population density file. Each grid point is classified as being URBAN, SUBURBAN or RURAL depending on the population density value for the grid point and threshold values that are inputs to the simulation.

The population density file is used to produce the active WAS/RLAN device population probability distribution over the simulation region. The first step is to convert population density values into population values for each grid point by multiplying the population density by the area of the 30 arcsec x 30 arcsec region centred at the grid point. These population values are then summed for each of the regions Europe, Africa and Middle East.

Let PE, PA and PM be the populations of Europe, Africa and the Middle East respectively. Let NE, NA, NM be the number of active WAS/RLAN devices in Europe, Africa and the Middle East respectively. These values are inputs to the simulation.

For each grid point, the population value is converted to the average active WAS/RLAN device count by multiplying by (NE/PE), (NA/PA) or (NM/PM) depending on whether the grid point is in Europe, Africa, of the Middle East. This is then converted into a large discrete probability distribution function where each grid point is assigned a probability equal to the average WAS/RLAN device count at that grid point divided by the total active WAS/RLAN device count (using ). A random WAS/RLAN position is generated by generating a random grid point using this discrete probability distribution, then selecting a location uniformly distributed over the 30 arcsec x 30 arcsec region centred at the grid point.

The values of G/T over the simulation region are specified in a matrix as well. Each row/line of the matrix specifies LON/LAT and the G/T value at the corresponding LON/LAT position. Bi-linear interpolation is used to compute G/T for LON/LAT points between the grid points specified in the matrix. For the GXT format, this standard file format specifies contours over which G/T values are constant. Given an arbitrary LON/LAT position, two contours are identified for which this position is between and the G/T value is taken to be the average of the corresponding G/T values. Furthermore, the region outside the outermost contour, when less than or equal to -20 dB, is set to that contour. When the outermost contour is greater than -20 dB (e.g. -10 dB), the region is set -20 dB in the absence of the beam roll-off pattern.

The list of FSS channels to be simulated is specified by a channel bandwidth, centre-to-centre channel spacing, start centre frequency and number of channels simulated. Figure 43 shows the nominal FSS transponder plan between 5925 to 6425 MHz that has been assumed. Each transponder has a bandwidth of 36 MHz and is spaced 40 MHz apart. Over this 500 MHz band there are 24 transponders, 12 in each polarisation. The channel centre frequencies for each polarisation are staggered by 20 MHz. The start frequency is 5927 MHz.

Channel	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Pol 1 (MHz)	5945		5985		6025		6065		6105		6145		6185		6225		6265		6305		6345		6385	
Pol 2 (MHz)		5965		6005		6045		6085		6125		6165		6205		6245		6285		6325		6365		6405

**Figure 43: Representative FSS Transponder Frequency Plan ( $f_c$  separation = 40 MHz)**

## Step 2: Monte Carlo Iterations

For each iteration, a random layout of active WAS/RLAN devices is generated one WAS/RLAN at a time. Each WAS/RLAN device is assigned a random longitude/latitude position generated using the device population probability distribution described above. Each WAS/RLAN device is assigned a random height, e.i.r.p. and building type using discrete probability distributions according to Table 10 and Table 8 respectively. Building types are outdoor (meaning no building attenuation) WAS/RLAN, indoor-traditional or thermally efficient (respecting a 30% thermally efficient/ 70% traditional balance). Each WAS/RLAN is assigned a random bandwidth using a discrete probability distribution as in Table 12 and a random centre frequency as in Table 11. The centre frequency is generated by considering all possible centre frequencies for the selected bandwidth and using a uniform distribution.

For each WAS/RLAN, a 4/3 earth model is used to determine whether the satellite is in view or over the horizon. WAS/RLANs for which the satellite is not in view are considered to contribute no interference to the satellite and are thus ignored in the interference calculation.

For each FSS channel in the simulation, interference from all WAS/RLANs for which the satellite is in view is computed and aggregated. The WAS/RLAN bandwidth and centre frequency along with the FSS channel bandwidth and centre frequency are used to compute the fraction of the WAS/RLAN bandwidth that overlaps with the FSS channel. If there is no overlap, the WAS/RLAN contributes no interference to the FSS channel. In addition, a random body loss is generated using a discrete probability distribution described in Section 5.6.

A random building entry loss is computed using Recommendation ITU-R P.2109-0 using the building type and elevation angle from the WAS/RLAN to the FSS satellite receiver orbital slot. Note that for outdoor WAS/RLANs the building entry loss is 0 dB. Random path clutter values are generated per Recommendation ITU-R P.2108 for urban and suburban WAS/RLANs and per Recommendation ITU-R P.452 for rural WAS/RLANs (as described in Section 5).

The path loss is computed using Free Space Path Loss (FSPL), per Recommendation ITU-R P.619-3, from the WAS/RLAN position to the FSS satellite orbital slot. Polarisation loss of 3 dB, per Section 5.5, is added. The FSS satellite Figure-of-Merit (G/T) is computed at the WAS/RLAN position as described above. The I/N contribution for a single WAS/RLAN into an FSS channel is computed by:

$$\frac{I}{N} = EIRP - L_{\text{bldg}} - L_{\text{body}} - PL - L_p - L_c - L_s + \frac{G}{T} - 10 \log_{10}(kB)$$

where:

- $EIRP$  = WAS/RLAN e.i.r.p. (dBW);
- $L_{\text{bldg}}$  = Building Entry Loss (dB);
- $L_{\text{body}}$  = Body Loss (dB);
- $PL$  = Free Space Path Loss (dB);
- $L_p$  = Polarisation Loss = 3 (dB);
- $L_c$  = Clutter Loss (dB);
- $L_s$  = Spectral overlap loss (dB);
- $\frac{G}{T}$  = Satellite receiver Figure-of-Merit (dB/K);
- $k$  = Boltzmann's constant =  $1.3806488 \times 10^{-23}$  (J/K);
- $B$  = FSS channel bandwidth (Hz).

This I/N is aggregated over all WAS/RLANs for each FSS channel in the simulation.

### 7.1.2 WAS/RLAN populations used in the simulations

The following total population projections for 2025, for each region, have been used in generating WAS/RLAN deployments in the simulations.

1 Europe (48 CEPT states), Total population: 768 589 000:

Excludes (time-zone outside UTC+[0:3]):

- Azerbaijan;
- Georgia;
- Regions in Russian Federation State with time zone > UTC+3.

2 Africa, Total Population: 1 407 870 000:

Excludes (time-zone outside UTC+[0:3]): 2 910 000:

- Cabo Verde, Mauritius, Reunion and Seychelles;

- Excludes Egypt (110 471 000) (counted in Middle East).
- 3 Middle East, Total Population: 396 751 000:
- Includes all of Middle East (even though majority lie outside UTC+[0:3]);
  - 15 countries; excluded Cyprus and Turkey (already counted in CEPT);
- 4 Americas and Caribbean Total Population: 1 075 892 659:
- Includes all 55 country codes;
  - Used GPW's 2020 population projection unscaled for Saint Martin and Saint Barthelemy due to absence of population prospects for 2025. Both have very small (< 50k populations).

Using the total populations per above and same assumptions as Table 13, Table 36 shows number of simultaneously transmitting WAS/RLAN devices that are simulated in each region within the satellite footprint. In addition, the number of active WAS/RLANs in Africa, Middle East, North America and South America and the Caribbean is divided by factor of 4 to reflect the delay in maturity of WAS/RLANs deployment at 6 GHz.

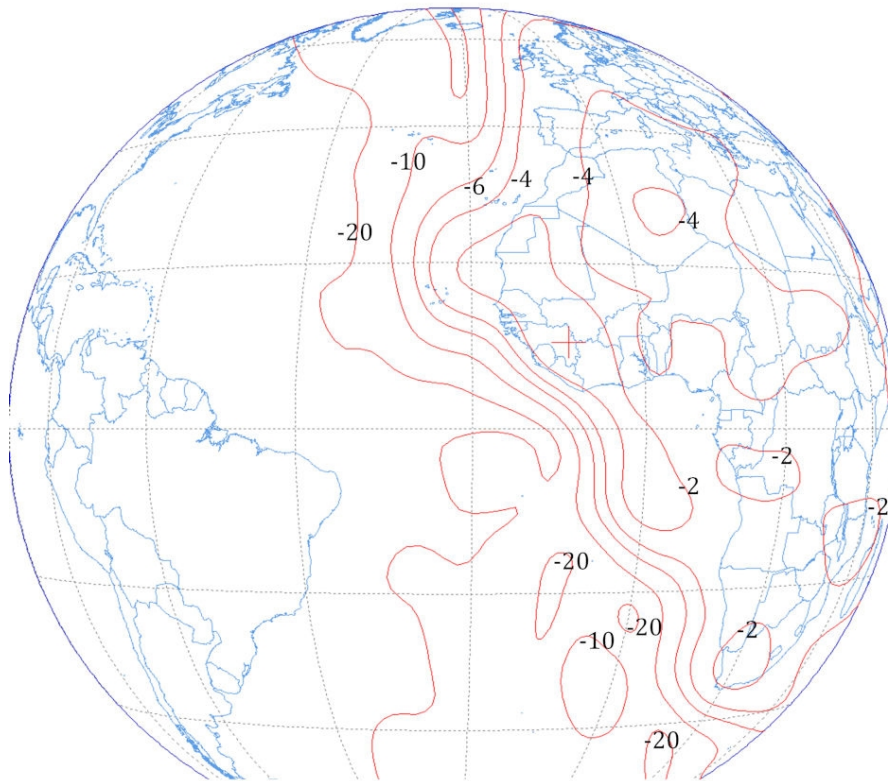
**Table 36: Number of active WAS/RLAN devices simulated**

Region	2025 Population	Number of instantaneously transmitting WAS/RLAN devices
		Mid
Europe	768 589 000	1 317 034
Africa	1 407 870 000	603 122
Middle East	396 751 000	169 966
North America, South America and the Caribbean	1 075 892 659	460 905

### 7.1.3 Results by FSS satellite beam

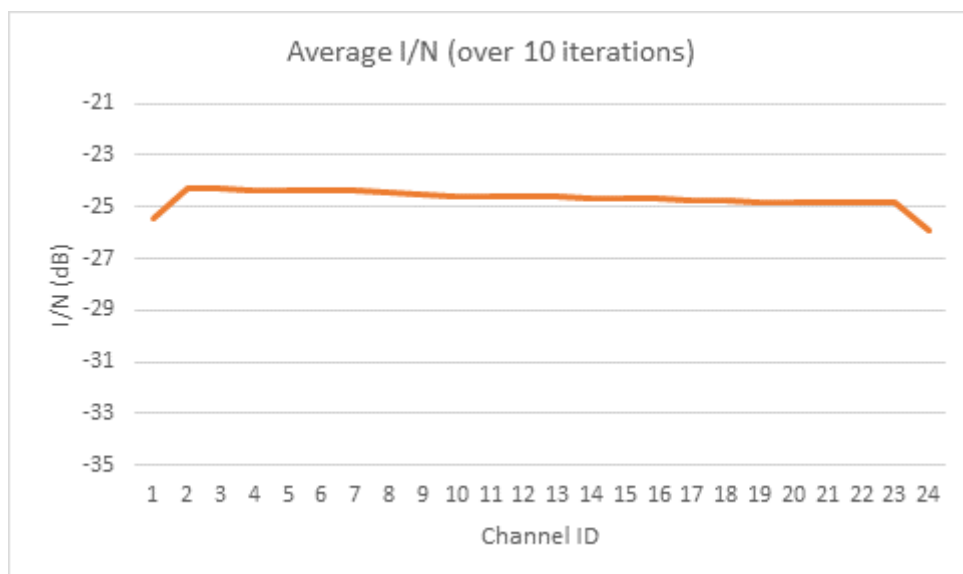
#### 7.1.3.1 SES 4 at 22° West

The SES-4 satellite at 22° west has a hemispheric beam with a peak G/T of 5.4 dB/K. The G/T contours are shown below.



**Figure 44: SES-4 G/T contours**

The aggregate I/N under Mid active WAS/RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown in the figure below. The calculation includes WAS/RLANs in Europe, Africa and the Middle East.



**Figure 45: SES-4 I/N per channel under Mid active WAS/RLAN assumptions**

The maximum I/N found in a single iteration is  $-24.19$  dB. The maximum averaged over 10 iterations is  $-24.31$  dB.



7.1.3.2 IS-33e at 60° East

The spot beam, C4A, over Europe has been simulated. The beam has peak G/T of 14.185 dB/K. The G/T contours are shown in Figure 46.

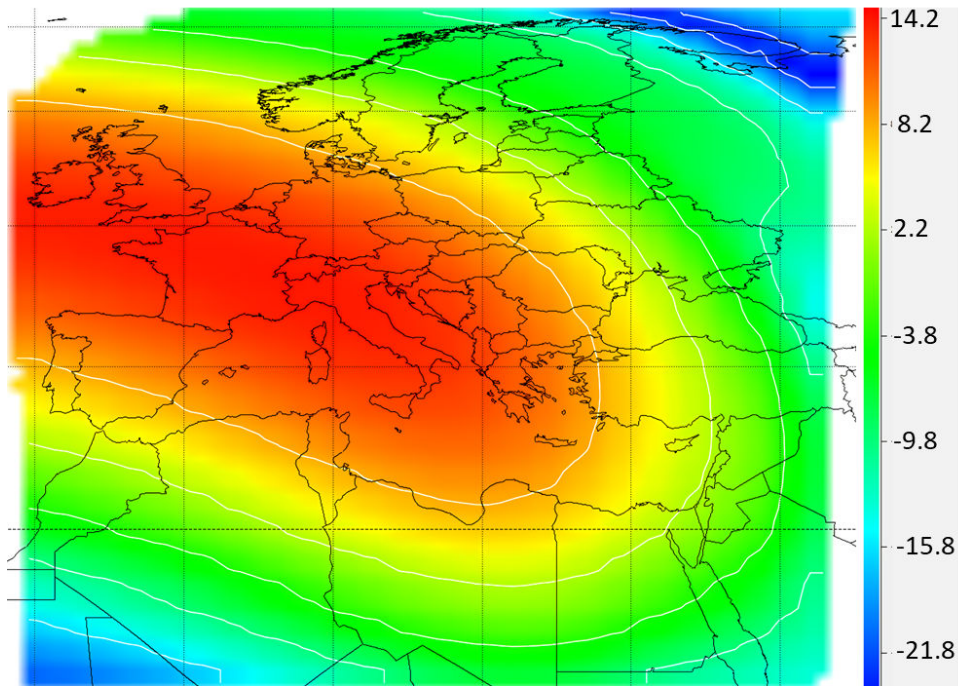


Figure 46: IS-33e G/T contours

The aggregate I/N under Mid active WAS/RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown in Figure 47. The calculation includes WAS/RLANs in Europe, Africa and the Middle East.

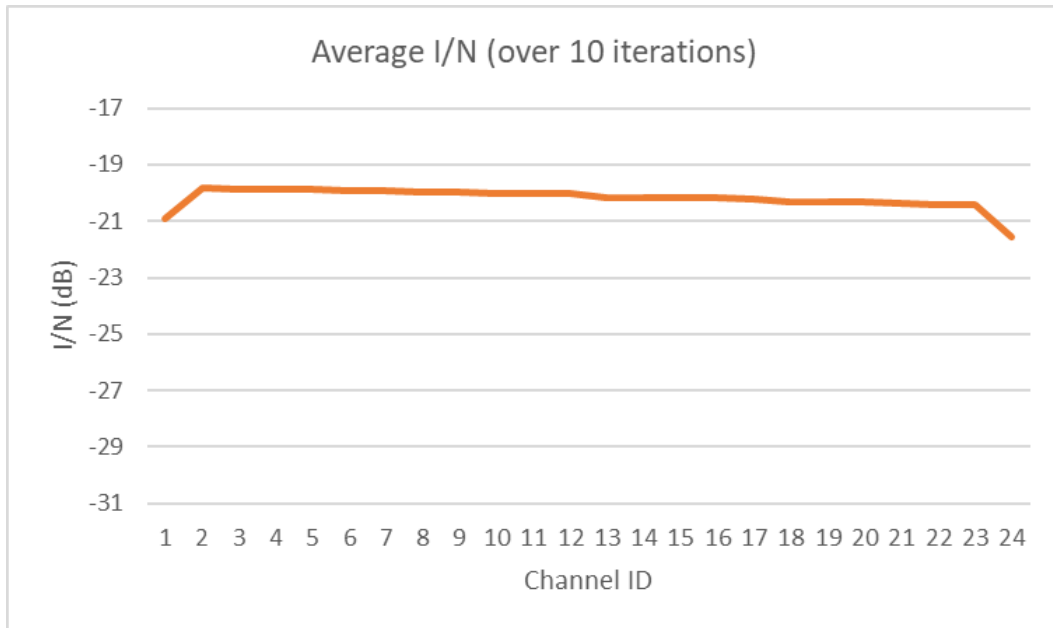
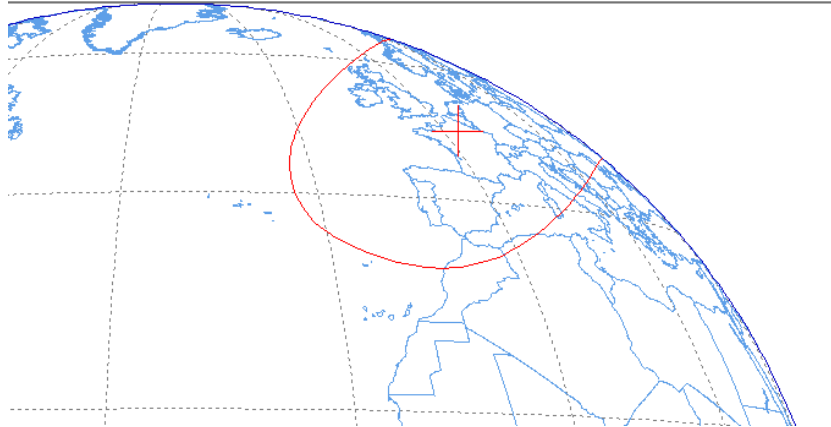


Figure 47: IS-33e I/N per channel under Mid active WAS/RLAN assumptions

The maximum I/N found in a single iteration is -19.64 dB. The maximum averaged over 10 iterations is -19.85 dB.

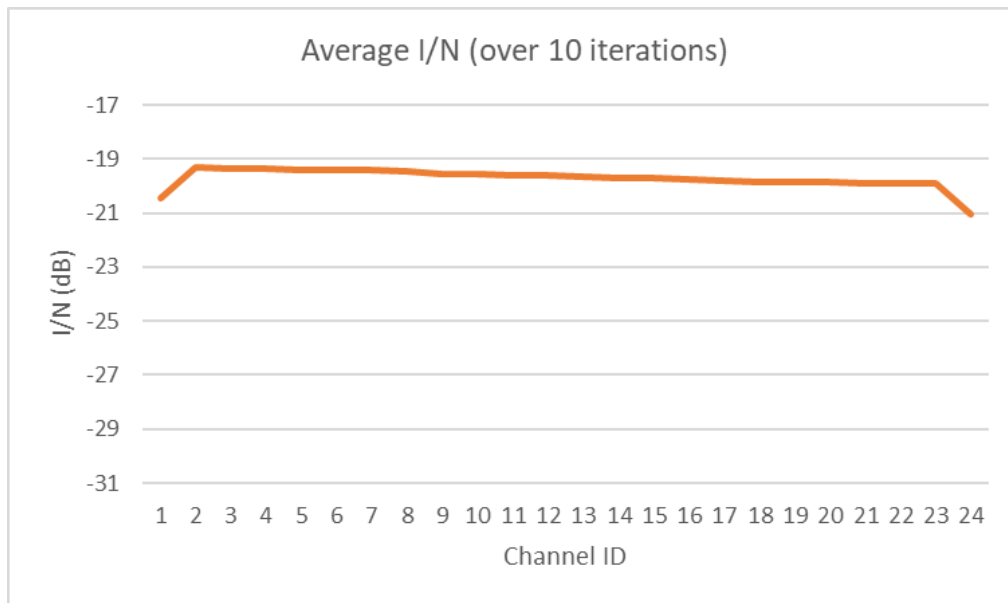
### 7.1.3.3 IS-35e at 34.5° West

The IS-35e satellite at 34.5° west has 17 provided contour files. The spot beam over Europe has been simulated. The beam has peak G/T of 16.39 dB/K. The -10-dB G/T contour is shown in Figure 48. The other 16 contours provided do not cover Europe.



**Figure 48: IS-35e G/T contours**

The aggregate I/N under Mid active WAS/RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown Figure 49. The calculation includes WAS/RLANs in Europe, Africa and the Middle East.

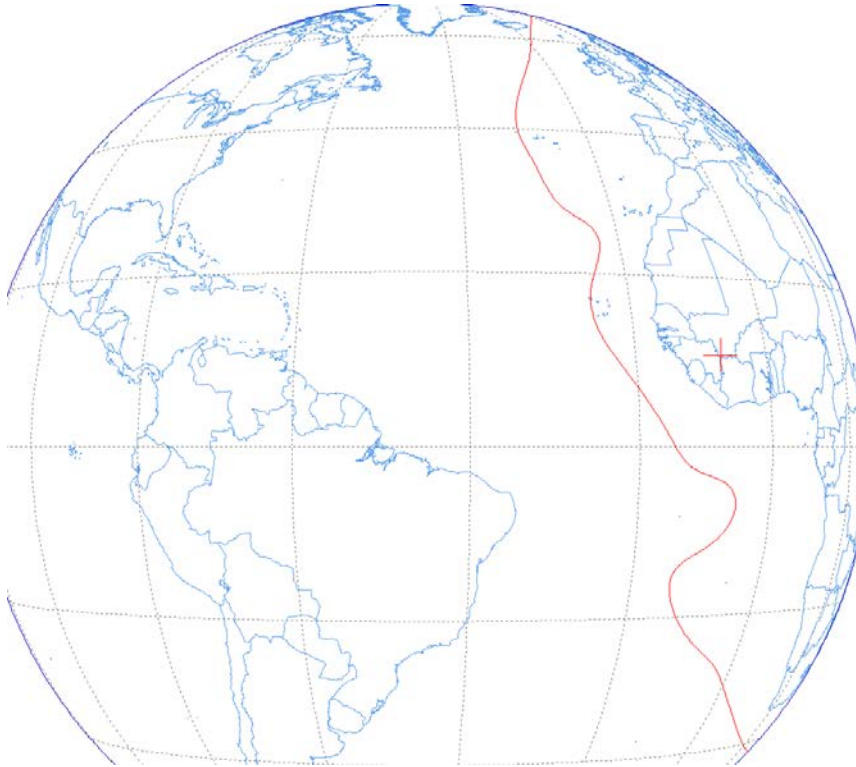


**Figure 49: IS-35e I/N per channel under Mid active WAS/RLAN assumptions**

The maximum I/N found in a single iteration is  $-19.07$  dB. The maximum averaged over 10 iterations is  $-19.32$  dB.

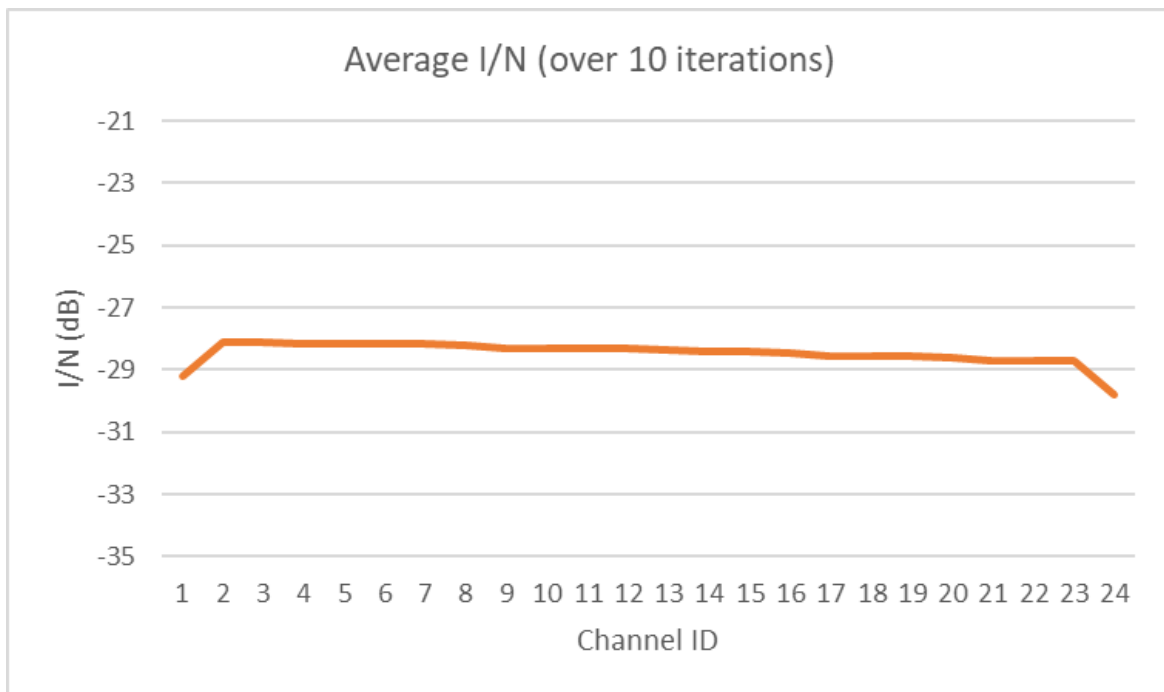
### 7.1.3.4 IS-14 at 45° West

The IS-14 satellite has a hemispheric beam covering the eastern hemisphere. The beam has peak G/T of 6.29 dB/K. The -10-dB G/T contour is shown in Figure 50.



**Figure 50: IS-14 G/T contours**

The aggregate I/N under Mid active WAS/RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown in Figure 51. The calculation includes WAS/RLANs in Europe, Africa and the Middle East.

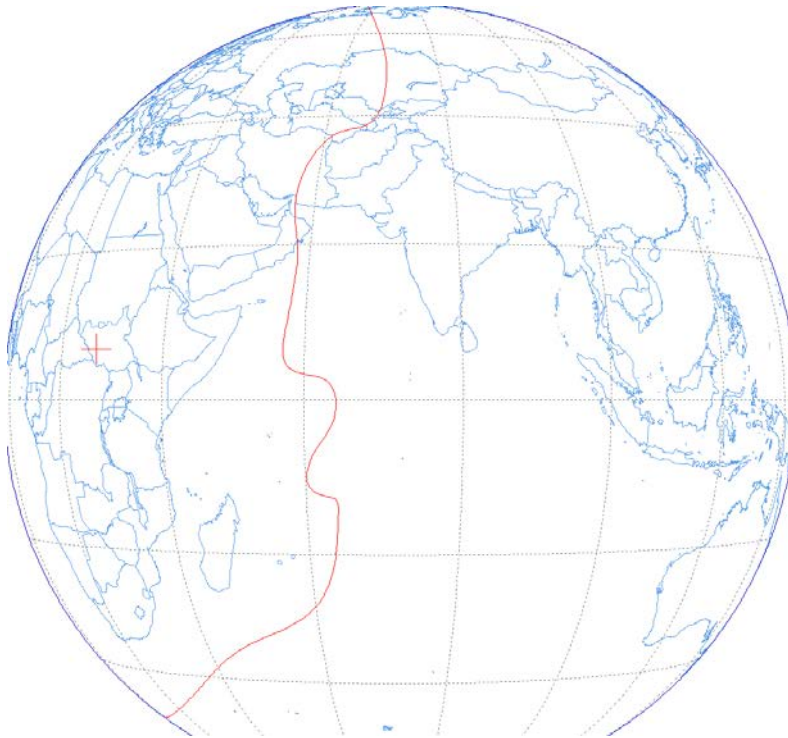


**Figure 51: IS-14 I/N per channel under Mid active WAS/RLAN assumptions**

The maximum I/N found in a single iteration is  $-27.96$  dB. The maximum averaged over 10 iterations is  $-28.11$  dB.

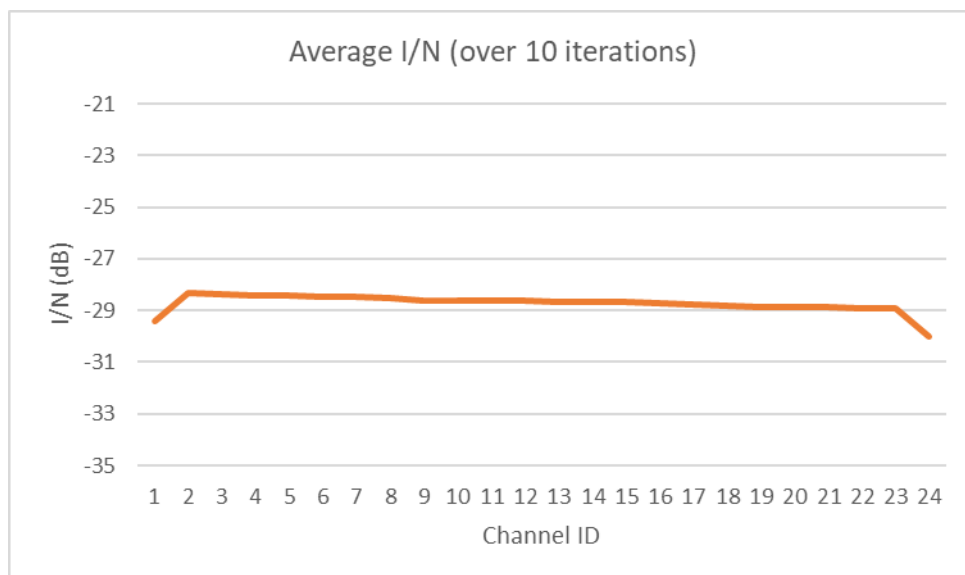
### 7.1.3.5 IS-22 at 72° East

The IS14 satellite has a hemispheric beam covering the eastern hemisphere. The beam has peak G/T of 4.3 dB/K. The -10-dB G/T contour is shown in Figure 52.



**Figure 52: IS-22 G/T contours**

The aggregate I/N under Mid active WAS/RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown in Figure 53. The calculation includes WAS/RLANs in Europe, Africa and the Middle East.

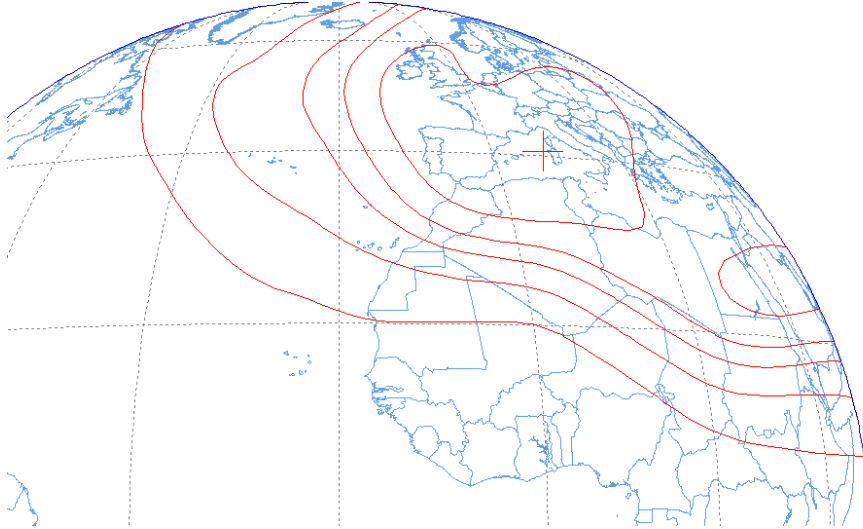


**Figure 53: IS-22 I/N per channel under Mid active WAS/RLAN assumptions**

The maximum I/N found in a single iteration is  $-28.22$  dB. The maximum averaged over 10 iterations is  $-28.33$  dB.

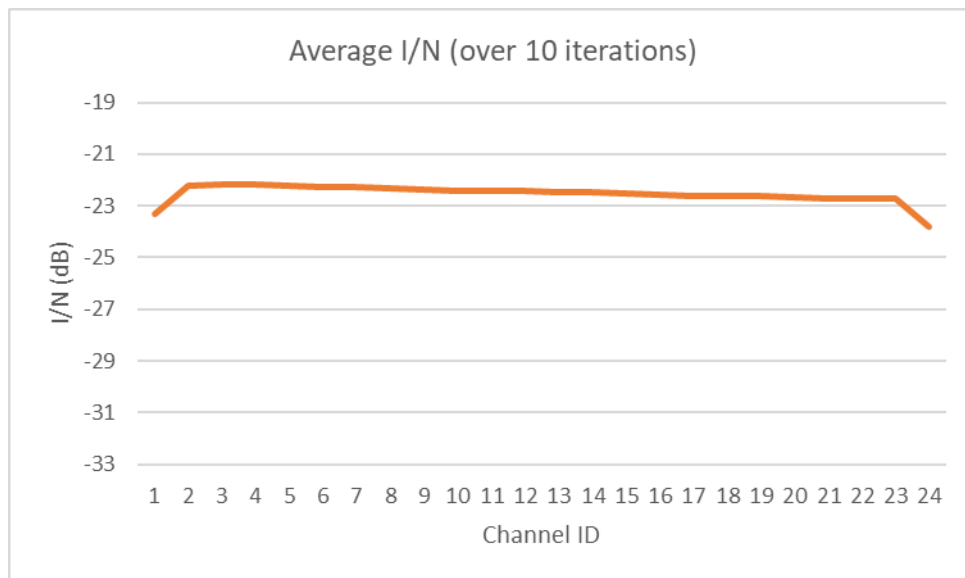
### 7.1.3.6 SES 20W Zone

The satellite SES 20W has a zonal beam covering Europe and Africa with a peak G/T of 7.8 dB/K. The G/T contours at -2, -4, -6, -10 and -20 dB are shown in Figure 54.



**Figure 54: SES 20W Zone G/T Contours**

The aggregate I/N under Mid active WAS/RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown in Figure 55. The calculation includes WAS/RLANs in Europe, Africa and the Middle East.

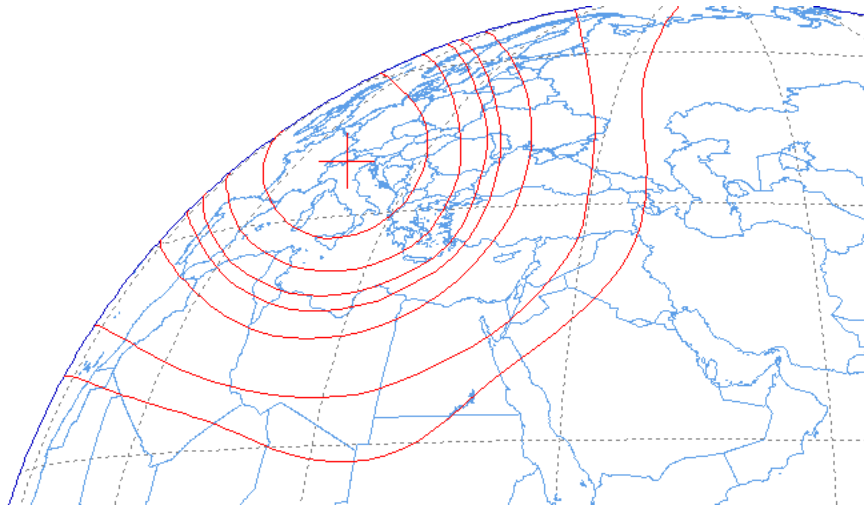


**Figure 55: SES 20W I/N per channel under Mid active WAS/RLAN assumptions**

The maximum I/N found in a single iteration is  $-21.98$  dB. The maximum averaged over 10 iterations is  $-22.18$  dB.

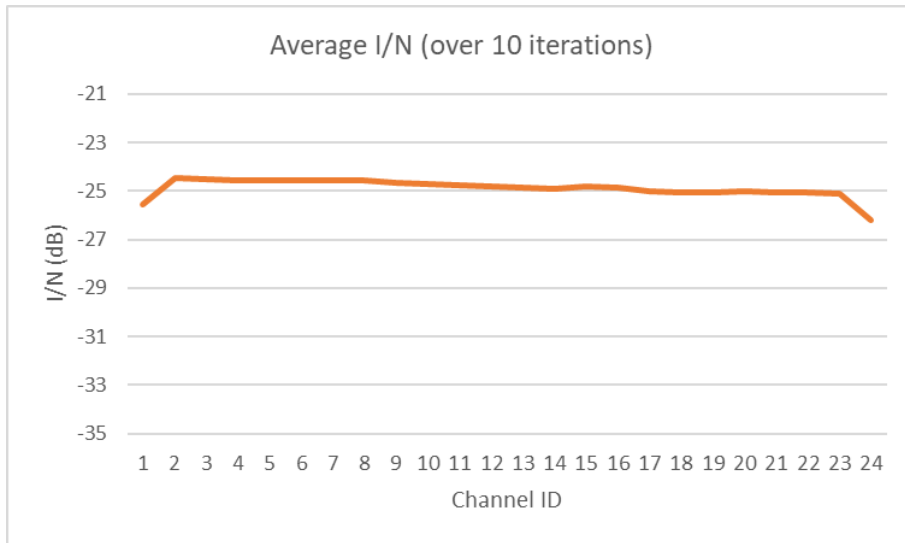
**7.1.3.7 SES 50.5E Zone**

The satellite SES 50.5E has a zonal beam covering Europe, Africa and the Middle East with a peak G/T of 8.4 dB/K. The G/T contours at -2, -4, -6, -7, -10, -20 and -30 dB are shown in Figure 56.



**Figure 56: SES 50.5E Zone G/T contours**

The aggregate I/N under Mid active WAS/RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown Figure 57. The calculation includes WAS/RLANs in Europe, Africa and the Middle East.

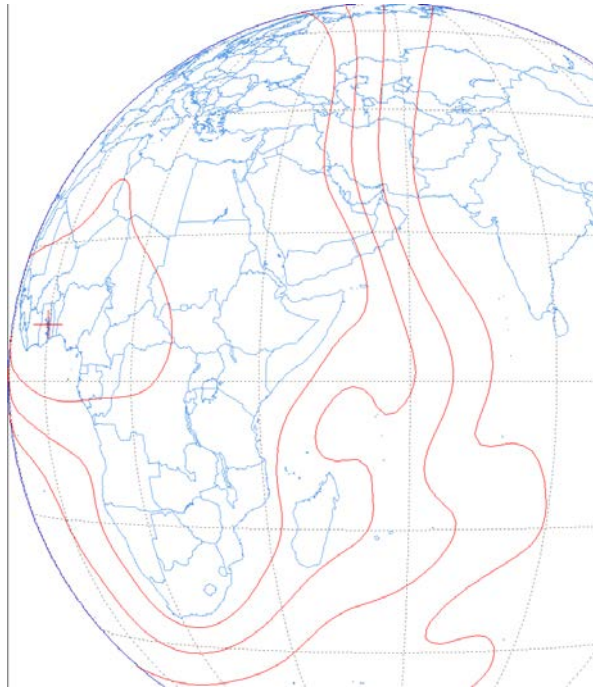


**Figure 57: SES 50.5E I/N per channel under Mid active WAS/RLAN assumptions.**

The maximum I/N found in a single iteration is -24.28 dB. The maximum averaged over 10 iterations is -24.47 dB.

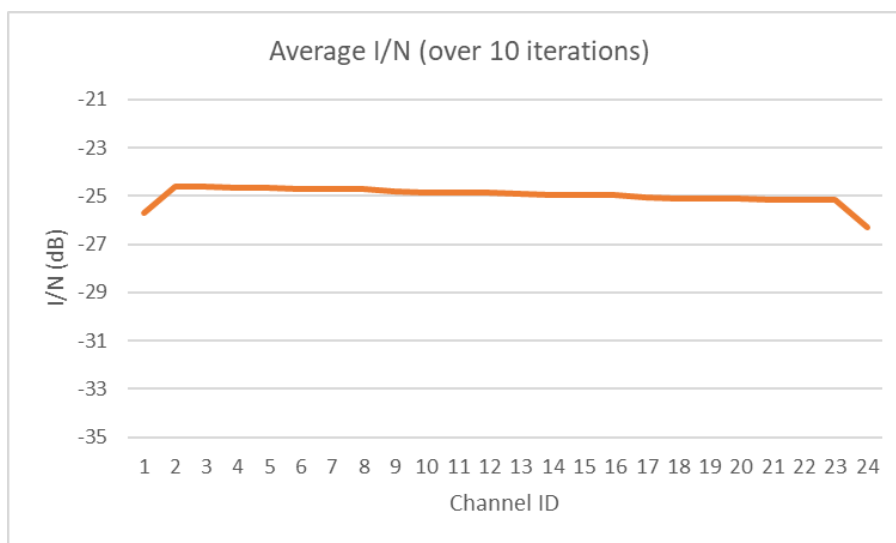
**7.1.3.8 SES 57E Hemispheric**

The satellite SES 57E has a hemispheric beam covering Europe, Africa and the Middle East with a peak G/T of 5.1 dB/K. The G/T contours at -2, -4, -6, -10 and -20 dB are shown in Figure 58.



**Figure 58: SES 57E Hemispheric G/T contours**

The aggregate I/N under Mid active WAS/RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown in Figure 59. The calculation includes WAS/RLANs in Europe, Africa and the Middle East.

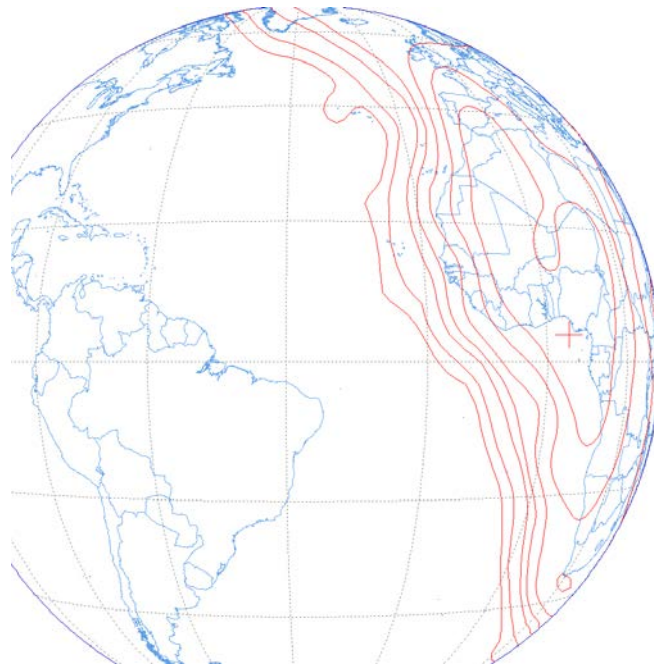


**Figure 59: SES 57E I/N per channel under Mid active WAS/RLAN assumptions**

The maximum I/N found in a single iteration is  $-24.42$  dB. The maximum averaged over 10 iterations is  $-24.63$  dB.

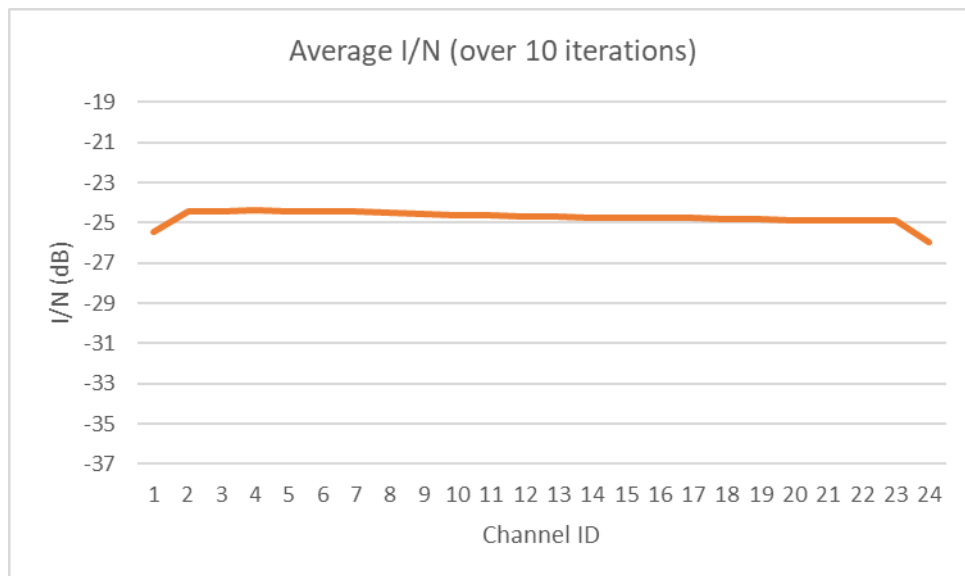
#### 7.1.3.9 SES 37.5W Hemispheric

The satellite SES 37.5W has a hemispheric beam covering Europe, Africa and the Middle East with a peak G/T of 7.7 dB/K. The G/T contours (37.5W Hemispheric) at -2, -4, -6, -8, -10, -15 and -20 dB are shown in Figure 60.



**Figure 60: SES 37.5W Hemispheric G/T contours**

The aggregate I/N under Mid active WAS/RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown in Figure 61. The calculation includes WAS/RLANs in Europe, Africa and the Middle East.



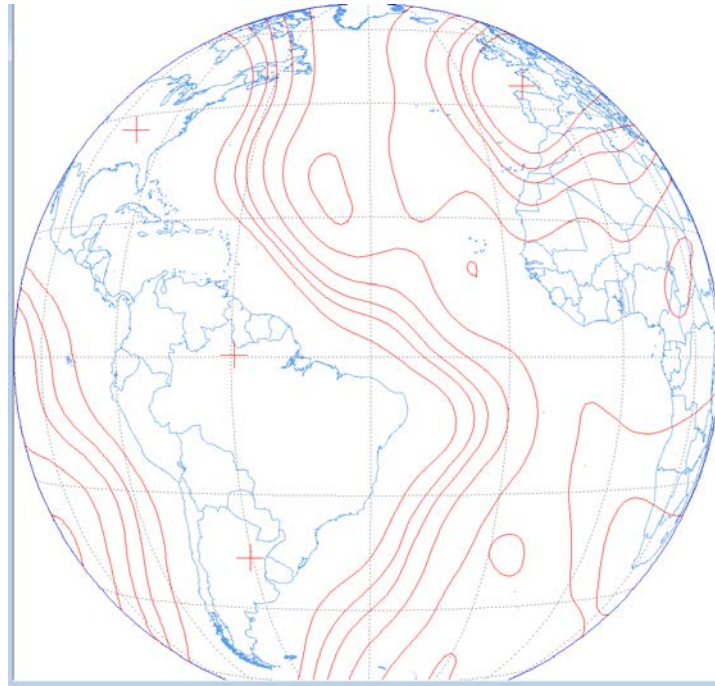
**Figure 61: SES 37.5W I/N per channel under Mid active WAS/RLAN assumptions**

The maximum I/N found in a single iteration is  $-24.19$  dB. The maximum averaged over 10 iterations is  $-24.39$  dB.

**7.1.3.10 SES-6 40.5W**

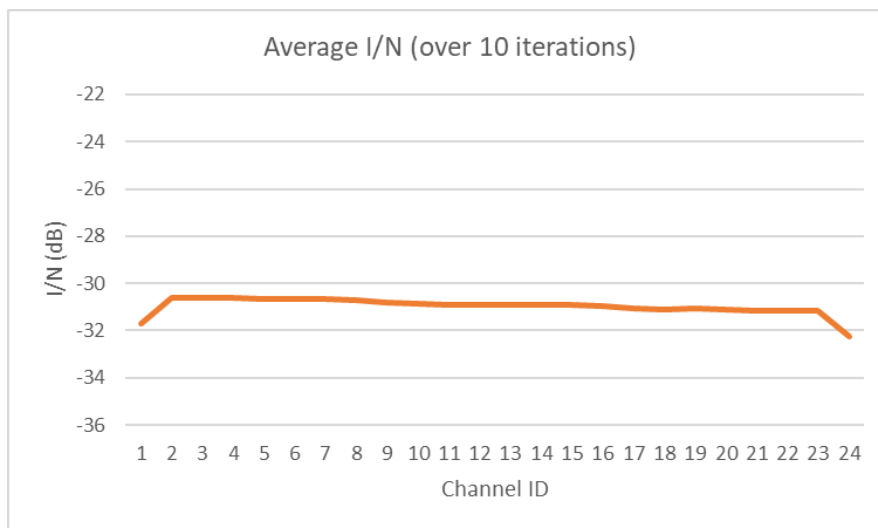
The satellite SES-6 at 40.5W has the global G/T contour per Figure 62. The peak G/T is  $-0.8$  dB/K.





**Figure 62: SES-6 40.5 W Global G/T contours**

The aggregate I/N under Mid active WAS/RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown in Figure 63. The calculation includes WAS/RLANs in Europe, Africa, the Middle East, North and South America and the Caribbean.



**Figure 63: SES-6 40.5W I/N per channel under Mid active WAS/RLAN assumptions**

The maximum I/N found in a single iteration is  $-30.45$  dB. The maximum averaged over 10 iterations is  $-30.60$  dB.

#### 7.1.4 FSS link budgets

Table 37, Table 38, Table 39 and Table 40 show aggregate link budgets for 4 of the satellites (IS-33e, SES 50.5E Zone, SES 57E Hemispheric and SES 37.5W Hemispheric).

As indicated in the tables, the average Building Entry Loss, Clutter Loss, Free Space Path Loss and G/Ts are the averages over the values used by the Monte Carlo simulation amongst all the WAS/RLANs within the

corresponding region. Averaging for the transmit powers and simulation parameters (building entry losses, clutter losses and GT values) are done in linear domain. Note that this results in much lower building entry and clutter losses than their mean values, i.e. 50<sup>th</sup> percentile.

The link budgets match the Monte Carlo simulation results within about 1 dB for IS-33e, SES 50.5E and SES 57E and within about 2 dB for SES 37.5W. The differences are due to the coarse approximation of the link budget versus the very detailed precise calculations in the Monte Carlo simulation.

**Table 37: IS-33e (at 60° East), Beam C4A, link budget for the Mid scenario**

Parameter	Unit	Europe	Africa	Source
Number of Mid Active WAS/RLANs		1 317 034	603 122	Table 36
Number of Active WAS/RLANs contributing to I/N		1 314 896	604 121	WAS/RLANs within the coverage area
Total Average e.i.r.p. per WAS/RLAN	mW	50.42		Includes Body Loss per Table 21 (Section 5.6)
Average Building Entry Loss (Indoor WAS/RLAN)				
Traditional Building	dB	-12.93	-14.92	Simulation; Average in linear domain
Thermally Efficient Building	dB	-20.81	-21.89	
Total Aggregate Average e.i.r.p. (all WAS/RLANs)	dBW	36	32	Includes Building Loss
Bandwidth Correction		0.075 (=36/480)		= Satellite Noise Bandwidth / Total WAS/RLAN Band (5935 to 6415 MHz)
Total Aggregate Average e.i.r.p. (Bandwidth correction)	dBW	25	20	
Average Free Space Path Loss (FSPL)	dB	-200.20	-199.84	Simulation
Polarisation Loss	dB	-3		
Average Clutter Loss	dB	-3.77	-1.87	Simulation; Average in linear domain
Total Aggregate Interference Power at Satellite	dBW	-182.22	-184.43	
Satellite Receiver Antenna Peak G/T	dB/K	14.185		Not used;
Satellite Receiver Antenna Avg. G/T	dB/K	10.55	-4.24	Simulation; Average in linear domain over the area
Boltzmann's Constant	dBW/K/Hz	-228.60		
Satellite Noise Bandwidth	MHz	36		
Calculated Average I/N	dB	-18.64	-35.64	
Simulated Max I/N	dB	-19.76	-36.26	Simulation
"Calculated Avg. I/N" - "Simulated Max I/N"	dB	1.12	0.62	

**Table 38: SES Satellite at 50.5° East, Zone Beam, link budget for the Mid scenario**

Parameter	Unit	Europe	Africa	Source
Number of Mid Active WAS/RLANs		1 317 034	603 122	Table 36
Number of Active WAS/RLANs contributing to I/N		1 315 290	604 081	WAS/RLANs within Satellite View
Total Average e.i.r.p. per WAS/RLAN	mW	50.42		Includes Body Loss per Table 21 (Section 5.6)
Average Building Loss (Indoor WAS/RLAN)				
Traditional Building	dB	-13.45	-16.09	Simulation; Average in linear domain
Thermally Efficient Building	dB	-21.03	-22.49	
Total Aggregate Average e.i.r.p. (all WAS/RLANs)	dBW	36	31	Includes Building Loss
Bandwidth Correction		0.075 (=36/480)		= Satellite Noise Bandwidth / Total WAS/RLAN Band (5935-6415 MHz)
Total Aggregate Average e.i.r.p. (Bandwidth correction)	dBW	24	20	
Average Free Space Path Loss (FSPL)	dB	-200.10	-199.69	Simulation
Polarisation Loss	dB	-3		
Average Clutter Loss	dB	-3.23	-1.29	Simulation; Average in linear domain
Total Aggregate Interference Power at Satellite	dBW	-181.89	-184.24	
Satellite Receiver Antenna Peak G/T	dB/K	8.4		Not used
Satellite Receiver Antenna Avg. G/T	dB/K	5.15	-9.57	Simulation; Average in linear domain
Boltzmann's Constant	dBW/K/Hz	-228.60		
Satellite Noise Bandwidth	MHz	36		
Calculated Average I/N	dB	-23.70	-40.78	
Simulated Max I/N	dB	-24.36	-40.61	Simulation
"Calculated Avg. I/N" - "Simulated Max I/N"	dB	0.66	-0.17	

**Table 39: SES Satellite at 57° East, Hemispheric Beam, link budget for the Mid scenario**

Parameter	Unit	Europe	Africa	Middle East	Source
Number of Mid Active WAS/RLANs		1 317 034	603 122	169 966	Table 36
Number of Active WAS/RLANs contributing to I/N			604 449	170 188	WAS/RLANs within Satellite View
Total Average e.i.r.p. per WAS/RLAN	mW			50.42	Includes Body Loss per Table 21 (Section 5.6)
Average Building Loss (Indoor WAS/RLAN)					
Traditional Building	dB	-13.11	-15.29	-16.68	Simulation; Average in linear domain
Thermally Efficient Building	dB	-20.88	-22.08	-22.59	
Total Aggregate Average e.i.r.p. (all WAS/RLANs)	dBW	36	31	25	Includes Building Loss
Bandwidth Correction				0.075 (=36/480)	= Satellite Noise Bandwidth / Total WAS/RLAN Band (5935 to 6415 MHz)
Total Aggregate Average e.i.r.p. (Bandwidth correction)	dBW	25	20	14	
Average Free Space Path Loss (FSPL)	dB	-200.16	-199.79	-199.63	Simulation
Polarisation Loss	dB		-3		
Average Clutter Loss	dB	-3.59	-1.67	-1.11	Simulation; Average in linear domain
Total Aggregate Interference Power at Satellite	dBW	-182.11	-184.36	-189.74	
Satellite Receiver Antenna Peak G/T	dB/K		5.1		Not used
Satellite Receiver Antenna Avg. G/T	dB/K	2.05	2.94	1.23	Simulation; Average in linear domain
Boltzmann's Constant	dBW/K/Hz		-228.60		
Satellite Noise Bandwidth	MHz			36	
Calculated Average I/N	dB	-27.02	-28.38	-35.47	
Simulated Max I/N	dB	-26.93	-28.52	-35.14	Simulation
"Calculated Avg. I/N" - "Simulated Max I/N"	dB	-0.10	0.14	-0.33	

**Table 40: SES Satellite at 37.5° West, Hemispheric Beam, link budget for the Mid scenario**

Parameter	Unit	Europe	Africa	Middle East	Source
Number of Mid Active WAS/RLANs		1 317 034	603 122	169 966	Table 36
Number of Active WAS/RLANs contributing to I/N		1 314 430		170 188	WAS/RLANs within Satellite View
Total Average e.i.r.p. per WAS/RLAN	mW	50.42			Includes Body Loss per Table 21 (Section 5.6)
Total Aggregate Average e.i.r.p. (all WAS/RLANs)	dBW	36	32	25	Includes Building Loss
Bandwidth Correction		0.075 (=36/480)			= Satellite Noise Bandwidth / Total WAS/RLAN Band (5935 to 6415 MHz)
Total Aggregate Average e.i.r.p. (Bandwidth correction)	dBW	25	21	14	
Average Free Space Path Loss (FSPL)	dB	-200.31	-200.12	-200.51	Simulation
Polarisation Loss	dB	-3			
Average Clutter Loss	dB	-4.71	-3.19	-9.05	Simulation; Average in linear domain
Total Aggregate Interference Power at Satellite	dBW	-183.22	-185.27	-198.92	
Satellite Receiver Antenna Peak G/T	dB/K	7.7			Not used
Satellite Receiver Antenna Avg. G/T	dB/K	2.91	4.45	1.08	Simulation; Average in linear domain
Boltzmann's Constant	dBW/K/Hz	-228.60			
Satellite Noise Bandwidth	MHz	36			
Calculated Average I/N	dB	-27.27	-27.79	-44.80	
Simulated Max I/N	dB	-28.89	-27.27	-43.91	Simulation
"Calculated Avg. I/N" - "Simulated Max I/N"	dB	1.62	-0.52	-0.89	

### 7.1.5 Summary for the sharing study A between WAS/RLAN and FSS

Simulations show that in all cases studied under WAS/RLAN assumptions for the Mid scenario the I/N for all satellites in all channels is more than 8.5 dB below the -10.5 dB threshold. It can be concluded that a worldwide deployment of WAS/RLANs limited to the assumptions taken in the simulations will not impact the operation of the European FSS uplinks in the band 5925-6425 MHz.

## 7.2 STUDY B: AGGREGATE INTERFERENCE FROM WAS/RLAN INTO FSS SPACE STATIONS

### 7.2.1 Introduction

A deterministic study between WAS/RLAN and FSS in the band 5925-6425 MHz is provided for satellites at 20W, 50.5E, 60E and 5E.

### 7.2.2 WAS/RLAN parameters

The WAS/RLAN e.i.r.p distribution including body loss of 4 dB (as described in Table 21) has been used in this study. Outdoor and indoor deployment are weighted by 2% and 98% factors respectively. WAS/RLAN bandwidth distribution introduced in Table 12 is used for simulations.

A sensitivity analysis scenario for 95% indoor and 5% outdoor is provided in A6.1.

Only omnidirectional antennas are considered in the studies and no WAS/RLAN antenna discrimination is assumed. The WAS/RLAN deployment model used in the simulations corresponds to the one presented for Europe for the year 2025 in Table 13. The resulting number of instantaneously transmitting WAS/RLAN devices per satellite receiver bandwidth is given in Table 76 in ANNEX 5:

**Table 41: WAS/RLAN deployment models for Europe for the year 2025**

	Low	Mid	High
Total number of devices in Europe 2025	7 685 890 000	7 685 890 000	7 685 890 000
Wireless devices operating in licence exempt spectrum (remainder operating in licence spectrum): 90%	90.00%	90.00%	90.00%
Effective Number of Active WAS/RLAN Devices in Licence Exempt Spectrum: (remainder operating in licence spectrum): 90%	6 917 301 000	6 917 301 000	6 917 301 000
Busy Hour Factor	50.00%	62.70%	62.70%
Licence Exempt WAS/RLANS Transmitting During Busy Hours	3 458 650 500	4 337 147 727	4 337 147 727
6 GHz Factor (6GHz / (6 GHz + 5 GHz + 2.4GHz))	48.17%	48.17%	48.17%
Licence exempt WAS/RLANS transmitting during busy hours in 6 GHz band	1 666 031 946	2 089 204 060	2 089 204 060
Market Adoption Factor (6 GHz capable devices)	25.00%	32.00%	50.00%
Effective 6 GHz devices	416 507 986	668 545 299	1 044 602 030
RF Activity Factor for devices	1.97%	1.97%	1.97%
Instantaneously transmitting devices	820 521	1 317 034	2 057 866
Percentage of outdoor WAS/RLANS:	2.00%	2.00%	2.00%

	Low	Mid	High
Instantaneous number of outdoor transmitting 6 GHz devices	16 410	26 341	41 157
Percentage of indoor WAS/RLANs:	98.00%	98.00%	98.00%
Instantaneous number of indoor transmitting 6 GHz devices	804 110	1 290 694	2 016 709

### 7.2.3 FSS Parameters

#### 7.2.3.1 FSS protection criteria

For the long term criteria for interference from all co-primary services, the FSS protection criterion is an I/N value of  $-10.5$  dB, where N is the space station noise (Section 4.2.2).

Apportionment of the interference allowance between co-primary services (e.g. FS, WAS/RLAN) is on a case-by-case basis.

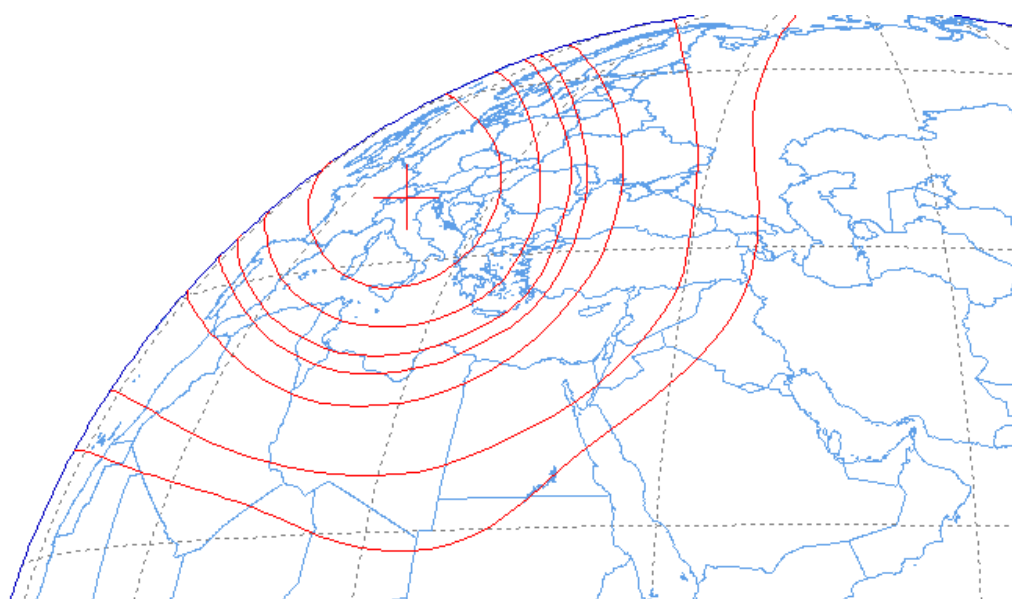
The study is based on an apportionment of 3 dB of the interference allowance to take account of the Fixed Service (FS) in the band.

#### 7.2.3.2 FSS space station parameters

The following satellites, for which the study is representative because of their technical characteristics and respective orbital positions, have been considered:

- SES satellite L at 20W with a zone beam centred over Europe;
- SES satellite M at 50.5E with a zone beam centred over Europe;
- Intelsat satellite R at 60E with a spot beam centred over Europe;
- Future satellite R' at 5E with a spot beam centred over Europe.

Parameters of these satellites are available in Table 20.



**Figure 64: SES 50.5E (NSS-5) zone beam coverage over Europe in 5925-6425 MHz**

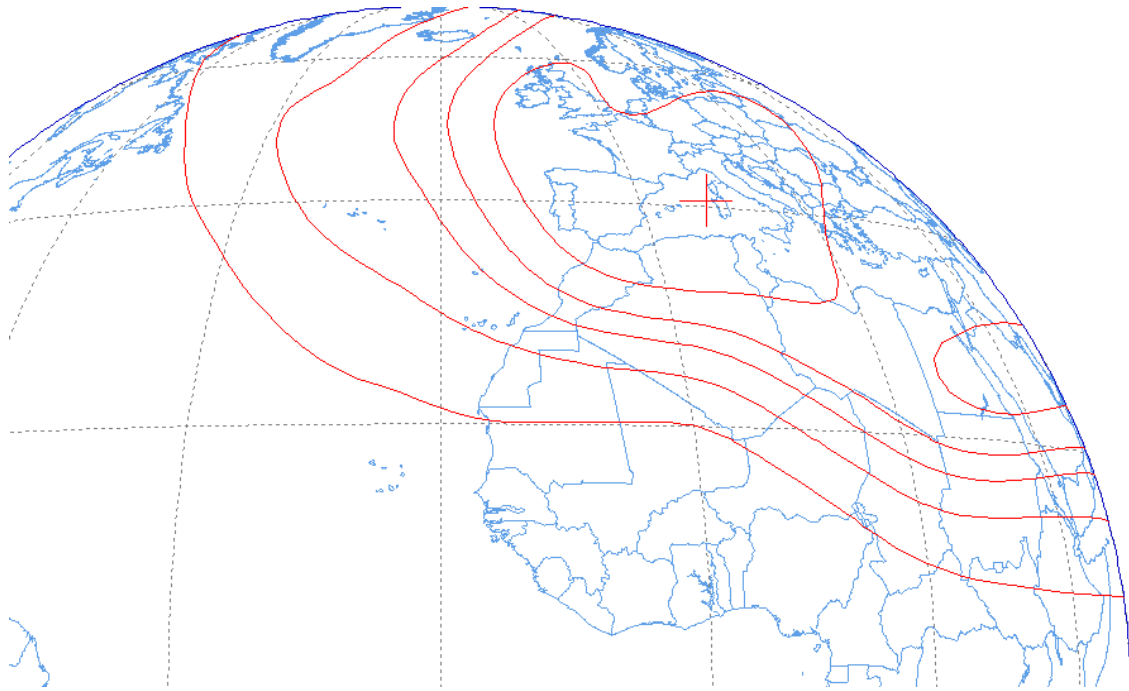


Figure 65: SES 20W (NSS) zone beam coverage over Europe in 5925-6425 MHz

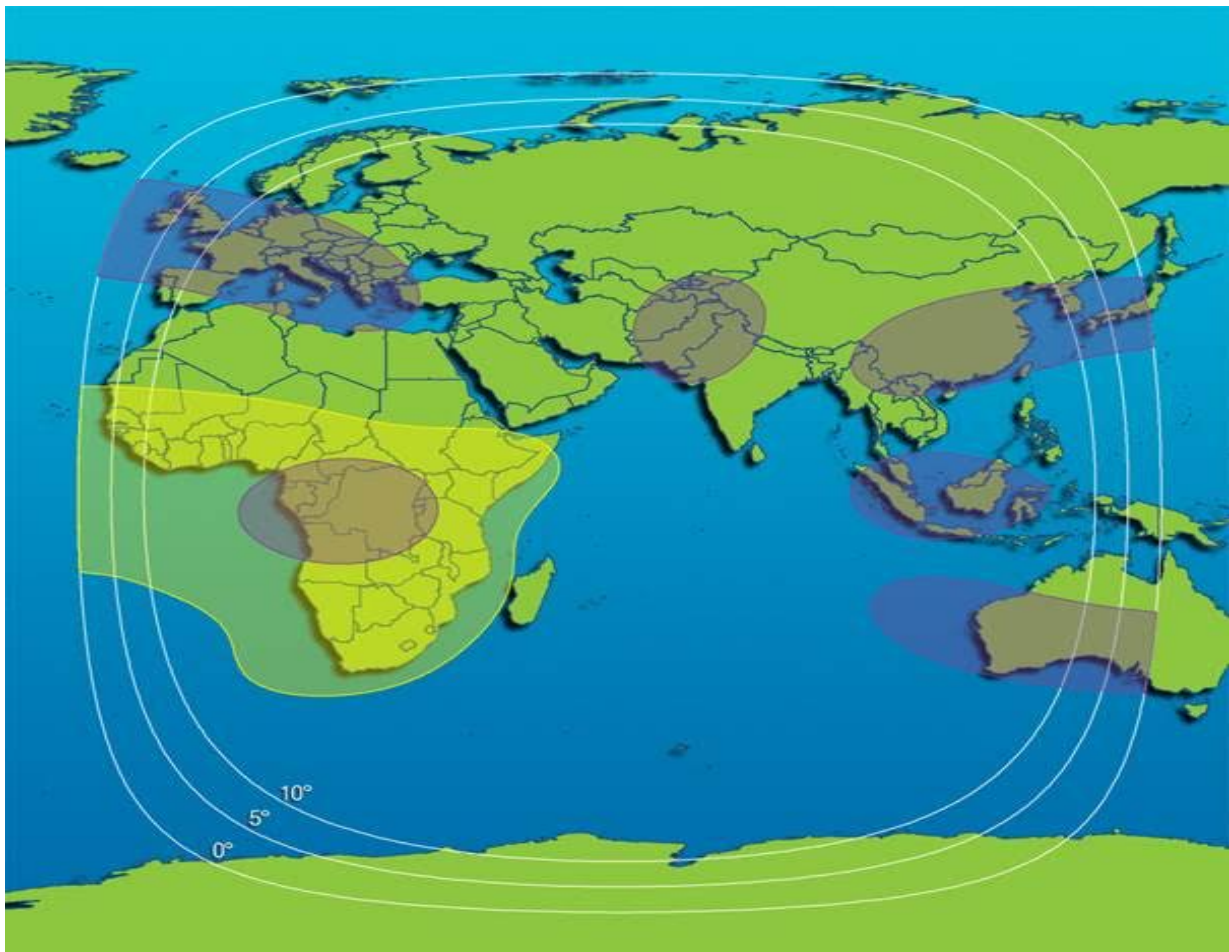


Figure 66: Intelsat 60E spot beam coverage over Europe in 5925-6425 MHz



### 7.2.3.3 Propagation models

- Recommendation ITU-R P.525 for free-space loss ;
- Recommendation ITU-R P.2108 for clutter losses (model for Earth-space paths in Section 3.3): average values of 1.5 dB, 1.7 dB and 3 dB, depending on the orbital position, are considered;
- Recommendation ITU-R P.2109 for building entry losses: average values of 14 dB and 17 dB are considered;
- Gas and atmospheric absorption: less than 1 dB;
- Polarisation mismatch: 3 dB (aggregate interference from a large number of WAS/RLAN devices).

### 7.2.4 Results of interference calculations

WAS/RLAN characteristics as reported in section 7.2.2 are considered in the simulations. Calculations of the bandwidth correction factor are provided in ANNEX 5.

Detailed results of I/N interference calculations are provided in ANNEX 6.

**Table 42: Summary of I/N results for 98% indoor and 2% outdoor (BEL 17 dB)**

	WAS/RLAN deployment model	Low	Mid	High
	No. of simultaneously transmitting WAS/RLAN devices within the FSS receive bandwidth (Note 1)	173 950	27 911	43 668
SES 50.5E (clutter 3 dB) Zone beam Europe Gain 32.4 dB	I/N (dB)	-26.1	-24.0	-22.1
SES 20W (clutter 1.7 dB) Zone beam Europe Gain 31.8 dB	I/N (dB)	-23.6	-21.5	-19.6
INT 60E (clutter 3 dB) Spot beam Europe Gain 37.3 dB	I/N (dB)	-21.0	-19.0	-17.0
SAT 5E (clutter 1.5 dB) Spot beam Europe Gain 37.3 dB	I/N (dB)	-19.5	-17.5	-15.5
Note 1: The number of high power devices within the FSS receive bandwidth is given in Table 76				

**Table 43: Summary of I/N results for 98% indoor and 2% outdoor (BEL 14 dB)**

	WAS/RLAN deployment model	Low	Mid	High
	No. of simultaneously transmitting WAS/RLAN devices within the receiver bandwidth (Note 1)	173 950	279 211	436 268
SES 50.5E (clutter 3 dB) Zone beam Europe Gain 32.4 dB	I/N (dB)	-24.5	-22.4	-20.5
SES 20W (clutter 1.7 dB) Zone beam Europe Gain 31.8 dB	I/N (dB)	-22.0	-20.0	-18.0
INT 60E (clutter 3 dB) Spot beam Europe Gain 37.3 dB	I/N (dB)	-19.5	-17.4	-15.5
SAT 5E (clutter 1.5 dB) Spot beam Europe Gain 37.3 dB	I/N (dB)	-18.0	-15.9	-14.0

Note 1: The number of high power devices within the FSS receive bandwidth is given in Table 76

Results above are conducted using an outdoor usage percentage of 2%.

However, it should be noted that several sharing studies in the past conducted on WAS/RLAN both internationally and in CEPT have considered 5.3% outdoor usage instead. These include for example sharing studies in the 5 GHz band in ECC Report 244 [32] as well as most of the sharing studies conducted in ITU-R for WRC-19 Agenda Item 1.16. The percentage of the outdoor usage is a critical parameter for the interference to the FSS space receiver, therefore, sensitivity analysis using 5% is provided in A6.1.

As can be seen from the results given in A6.1, using the outdoor percentage from the previous WAS/RLAN sharing studies, the protection criteria for the FSS is exceeded for two of the four considered FSS space receivers.

### 7.2.5 Summary of the sharing study B between WAS/RLAN and FSS

This study has been performed in order to assess compatibility and coexistence scenarios for WAS/RLANs and the FSS in the 5925-6425 MHz band and identify relevant parameters and coexistence conditions in order to enable coexistence between existing usages and WAS/RLAN systems without constraining incumbent uses in CEPT countries in the band 5925-6425 MHz and adjacent to that band.

Results of the study show that the calculated levels of interference are highly sensitive to some WAS/RLAN parameters and assumptions in the study, for example but not limited to the RF activity factor of WAS/RLAN devices (1.97% in this study). Since FSS receiver sees interference from WAS/RLANs within the entire footprint, limiting the high-power outdoor devices to the amount used in the simulations is critical when developing the harmonized European framework.

It should also be noted that satellites can be moved from one orbital position to the other, in particular when companies have a large number of satellites and orbital positions. C-band is a frequency band with important fleet movements. High throughput satellites (HTS) with zone/spot beams represent the state of the art

technology for the FSS, providing even up to 20 times the capacity of a traditional satellite with global or hemispheric beams. Therefore, the use of HTS is increasing at fast pace as satellites reaching end of life are being replaced at these orbital positions by HTS satellites. On this basis, an alternative orbital location is considered for one satellite.

The purpose of the coexistence studies performed in this Report is to determine whether coexistence between WAS/RLANs and existing services is possible without undue constraints to the existing services. Limiting the operation of HTS satellites to some orbital positions would be a major constraint to the future deployment of the FSS. Therefore, in order to assess the long term potential for sharing between WAS/RLAN and FSS, the satellite with highest G/T (state-of-the-art satellite) should be considered at the orbital position over Europe that has the lowest clutter loss, e.g. 5E (same longitude as major urban areas in Europe). This study takes such an approach in order to ensure long term protection of the FSS receivers from aggregate interference from WAS/RLAN devices.

In order to demonstrate the impact of the orbital position to the interference experienced by the satellite receiver, a satellite with similar G/T as that at 60E was also considered at 5E.

Also, a sensitivity analysis on the distribution of Indoor and Outdoor WAS/RLAN devices, from "98% Indoor and 2% Outdoor" to "95% Indoor and 5% Outdoor" is provided in A6.1. Sensitivity analysis confirms the need to control the distribution of the devices by demonstrating how increased outdoor devices will lead to exceedance of the FSS protection criteria.

For several scenarios considered for the WAS/RLAN deployment model in Europe for 2025, the calculated levels of interference are close to the FSS protection criteria and may exceed it in the case of the sensitivity analysis and application of apportionment. Considering coexistence conditions for WAS/RLAN, such as limiting the use to indoor deployment and/or introducing an e.i.r.p. limit would help further ensuring long term protection of FSS space stations from aggregate interference from WAS/RLAN devices in the band 5925-6425 MHz.

## **8 ADJACENT-BAND COMPATIBILITY BETWEEN WAS/RLAN AND ROAD-INTELLIGENT TRANSPORT SYSTEMS (ITS)**

### **8.1 INTERFERENCE FROM WAS/RLAN INTO ROAD-ITS**

### **8.2 DESCRIPTION OF SCENARIOS**

The following scenarios established in ECC Report 244 [32] describe realistic, worst-case conditions applicable to both directions of interference between Road-ITS and WAS/RLAN.

#### **Scenario A1: Indoor WAS/RLAN**

The 6 GHz WAS/RLAN device is placed inside a building at street level. Under this scenario, the minimum distance between the 6 GHz WAS/RLAN antenna and the ITS antenna, placed on the roof of a vehicle, can be approximately a few meters. In this assessment, the distance between the AP (inside the building) and the Road-ITS device is about 6 m. The building attenuation considered is of 17 dB.

#### **Scenario A2: Outdoor WAS/RLAN**

This is the same scenario as A1 but where the 6 GHz WAS/RLAN device is situated outside. Under this scenario, the minimum distance between the 6 GHz WAS/RLAN antenna and the ITS antenna placed on the roof of a vehicle can be approximately a few meters. In this assessment, the distance between the AP and the Road-ITS device is about 5 m.

#### **Scenario B1: In-vehicle WAS/RLAN with external ITS antenna**

One or more 6 GHz WAS/RLAN devices are situated inside the vehicle. The ITS antenna is installed on the roof of the vehicle. There can be a distance of around 1 m between the interferer and the victim. The attenuation between the ITS antenna and the 6 GHz WAS/RLAN antenna is highly variable, depending on antenna positions, antenna performance, glass or metal on the vehicle roof etc. In this study, it was assumed 20 dB extra attenuation in addition to the ordinary path loss, due to the vehicle roof attenuation.

#### **Scenario B2: In-vehicle WAS/RLAN with in-vehicle ITS antenna**

This is the same scenario as B1 but with the ITS antenna integrated inside the vehicle passenger compartment. There can be a distance of 1 m between the interferer and the victim. This scenario is very unlikely to occur since the ITS antennas are most of the time outside the vehicle.

#### **Scenario C: Portable outdoor WAS/RLAN devices**

The ITS radio is mounted on the road side such as on a traffic light. One or several 6 GHz WAS/RLAN devices are in close proximity. In this example, pedestrians carrying smart phones are waiting under a traffic light to cross the street or waiting for the bus. There can be a distance of 2 m between the interferer and the victim. A 4 dB body loss is considered as the pedestrian is carrying the WAS/RLAN.

### **8.3 PROPAGATION MODEL**

Given the considered distances the free space model [51] is valid for this study. Additional 3 dB attenuation is considered to characterise the polarisation mismatch for all the scenarios.

## 8.4 SIMULATION METHODOLOGY

In the extension band for Road-ITS, the last available channel is the one centred at 5920 MHz. Given the 10 MHz bandwidth, this channel extends from 5915 to 5925 MHz.

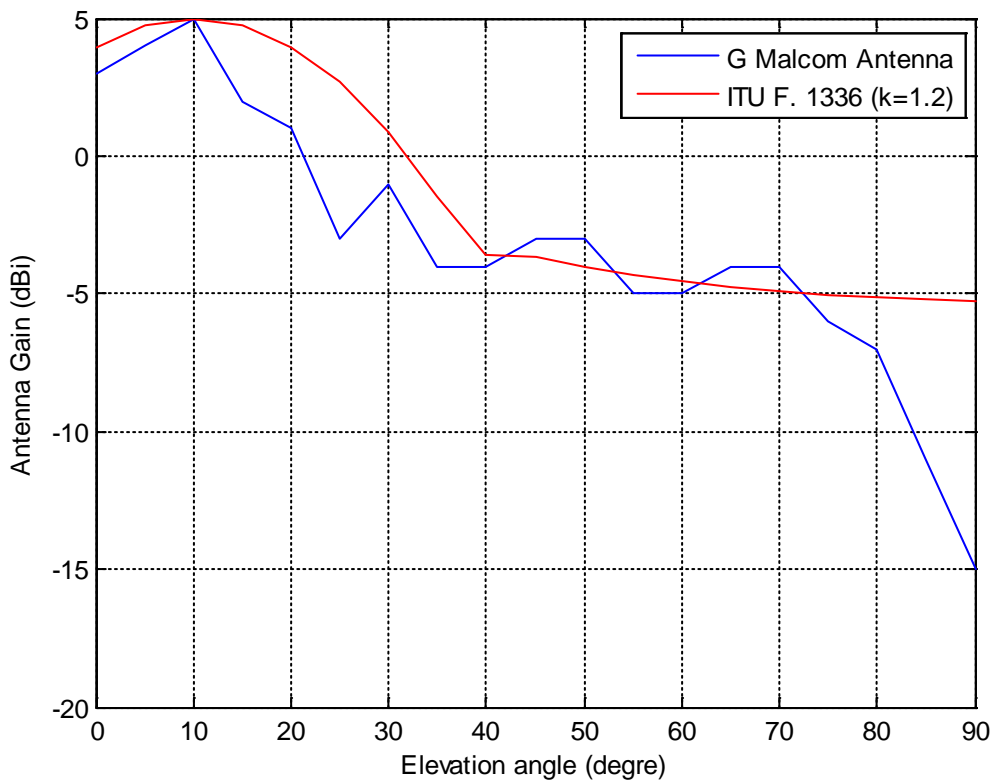
The simulation methodology consists in determining the maximum WAS/RLAN out-of-band (OoB) emissions below 5925 MHz. Considering a protection criterion of -6 dB (as in ECC Report 244 [32] and ECC Report 277 [76]), the I/N criterion in dB is expressed as:

$$\frac{I}{N} = P_{\text{OoB,WAS/RLAN}} - \sum \text{Loss} + G_{\text{ITS}} - N$$

where  $P_{\text{OoB,WAS/RLAN}}$  is the WAS/RLAN out-of-band emission gathered by the 10 MHz Road-ITS channel,  $\sum \text{Loss}$  is the sum of all possible losses and  $N$  is the ITS noise power. Given these elements, the maximum WAS/RLAN out-of-band emissions gathered by the 10 MHz Road-ITS channel is deduced as

$$P_{\text{OoB,WAS/RLAN}} = -6 + N + \sum \text{Loss} - G_{\text{ITS}} + N = -6 - 100 - 4 + \sum \text{Loss} = -110 + \sum \text{Loss} \quad \text{in dBm}$$

The radiation pattern of the ITS antenna is depicted in Figure 67 with a maximum gain of 4 dBi and 10 dB side-lobe attenuation (as in ECC Report 244 [32]).



**Figure 67: ITS OBU and RSU antenna pattern**

## 8.5 RESULTS OF MCL CALCULATIONS FOR INTERFERENCE FROM WAS/RLAN INTO ROAD-ITS

For the scenarios described above, MCL calculations are performed to derive maximum WAS/RLAN out-of-band emissions below 5925 MHz. The results are summarised in Table 44 for the case where the WAS/RLAN signal is falling within the ITS main-lobe but also for the case where the WAS/RLAN signal is falling within the ITS side-lobe. It should be noted that for the scenarios B1, B2 and C, the side-lobe case is more likely to occur than the main-lobe one. Indeed, given the ITS antenna position and the WAS/RLAN AP location elevation angles are within the side-lobe range.

**Table 44: MCL calculations for interference from WAS/RLAN into Road-ITS - separation distances, main lobe and side-lobe**

Parameter	Unit	Sc A1	Sc A2	Sc B1	Sc B2	Sc C
<b>Transmitter part: WAS/RLAN</b>						
Distance between WAS/RLAN and Road-ITS	m	6.0	5.0	1.0	1.0	2.0
Free Space Loss	dB	63.4	61.8	47.8	47.8	53.9
Building Entry Loss	dB	17.0	0.0	0.0	0.0	0.0
Vehicle roof loss	dB	0.0	0.0	20.0	0.0	0.0
Polarisation mismatch	dB	3.0	3.0	3.0	3.0	3.0
Body Loss	dB	0.0	0.0	0.0	0.0	4.0
Sum of losses	dB	83.4	64.8	70.8	50.8	60.9
<b>Reception part: Road-ITS</b>						
Receiver bandwidth	MHz	10.0	10.0	10.0	10.0	10.0
Noise power	dBm	-100.0	-100.0	-100.0	-100.0	-100.0
Antenna gain	dBi	4.0	4.0	4.0	4.0	4.0
Protection Criterion I/N	dB	-6.0	-6.0	-6.0	-6.0	-6.0
Allowable interfering power level 'I' at the receiver antenna input	dBm	-110.0	-110.0	-110.0	-110.0	-110.0
<b>Results main lobe</b>						
Maximum tolerable OoB WAS/RLAN incident in the 10 MHz ITS channel	dBm	-26.6	-45.2	-39.2	-59.2	-49.1
Maximum tolerable OoB WAS/RLAN density per MHz	dBm/MHz	-36.6	-55.2	-49.2	-69.2	-59.1
<b>Results side-lobe</b>						
Maximum tolerable OoB WAS/RLAN incident in the 10 MHz ITS channel	dBm	-16.6	-35.2	-29.2	-49.2	-39.1
Maximum tolerable OoB WAS/RLAN density per MHz	dBm/MHz	-26.6	-45.2	-39.2	-59.2	-49.1

## 8.6 SUMMARY OF ADJACENT-BAND COMPATIBILITY BETWEEN WAS/RLAN AND ROAD-ITS

Studies conducted between WAS/RLAN and Road-ITS below 5925 MHz show that the WAS/RLAN OoB emissions below 5925 MHz should vary between -69 dBm/MHz and -36 dBm/MHz for the main-lobe case and between -59 dBm/MHz and -26 dBm/MHz for the side-lobe case. Indoor usage appears to require less stringent WAS/RLAN OoB emissions below 5925 MHz.

## 9 SHARING AND COMPATIBILITY BETWEEN WAS/RLAN AND COMMUNICATION BASED TRAIN CONTROL (CBTC) SYSTEMS

### 9.1 ADJACENT BAND INTERFERENCE FROM WAS/RLAN INTO CBTC

CBTC systems usage and needs in terms of quality of transmissions (throughput, packet loss rate and maximum delay) are defined in ETSI TR 103 442 [78]. Only an MCL-based study is performed in this case to define the compatibility conditions between WAS/RLAN and CBTC.

#### 9.1.1 CBTC characteristics

The Communication Based Train Control (CBTC) characteristics considered in this study are summarised in Table 45.

**Table 45: CBTC characteristics taken into account in the study**

	unit	IEEE 802.11 derived		TDMA/DSSS		TD-LTE	
		BS	TU	BS	TU	BS <sup>1</sup>	TU <sup>2</sup>
Antenna gain	dBi	18	14	18	14	18	14
Boxing loss	dBi	-	3	-	3	-	3
HW Losses	dBi	9	3	9	3	9	3
Noise floor (N)	dBm	-94	-94	-102	-102	-102.4	-98.4
Required C/(N+I)	dB	9	9	-3	-3	0.9	0.6
Sensitivity	dBm	-85	-85	-105	-105	-101.5	-99
Adjacent Channel Selectivity (ACS)	dB	-	-	50	50	48.7 <sup>6</sup>	33 <sup>7</sup>
		-	-			57.7 <sup>6</sup>	43.7 <sup>7</sup>
Adjacent Channel Rejection (ACR)	dB	16 <sup>4</sup>	16 <sup>4</sup>	-	-	-	-
		32 <sup>5</sup>	32 <sup>5</sup>				
Desensitization (D) <sup>3</sup>	dB	2	3	2	3	2	3

<sup>1</sup> cf. 3GPP TS 37.104 [88] and TR 36.942 [89]  
<sup>2</sup> cf. 3GPP TS 36.101 [90] and TR 36.942 [89]  
<sup>3</sup> Constructor information  
<sup>4</sup> Valid in the first adjacent 5 MHz  
<sup>5</sup> Beyond the first adjacent 5 MHz  
<sup>6</sup> See ANNEX 8 (First value for the first 3 MHz and the second value is beyond)  
<sup>7</sup> First value for the first 3 MHz and the second value is beyond

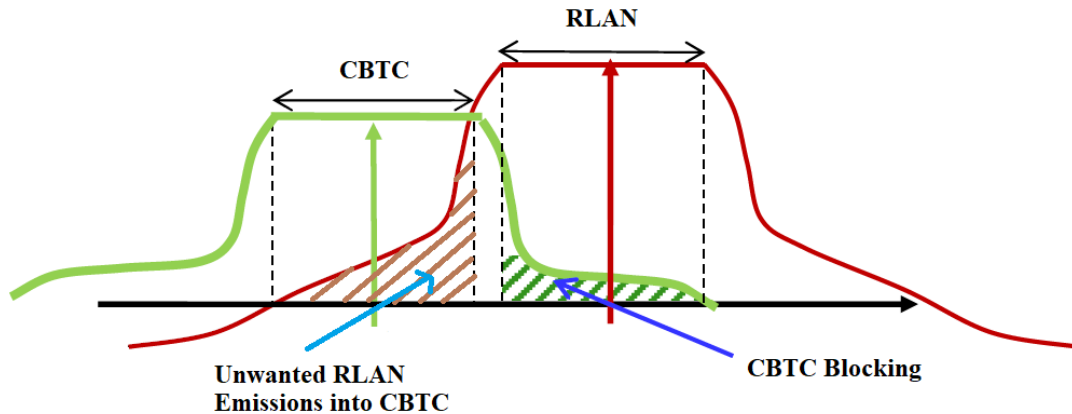
The boxing loss is the loss due to the fact that the train unit is put inside a box made of plexiglas in most of the cases. HW losses denote hardware losses including all the losses between the antenna and the connector (feeder loss, connecting loss, etc.).

Regarding the LTE CBTC BS, no Adjacent Channel Selectivity (ACS) is available; one has to deduce it starting from the blocking levels given for a receiver desensitization of 6 dB and adapt it to 2 dB and 3 dB for BS and TU respectively (see ANNEX 8 for details).

### 9.1.2 Simulation methodology

WAS/RLAN and CBTC are to coexist in adjacent bands. The worst case coexistence is the one where a WAS/RLAN operating in the first channel dedicated to WAS/RLAN is emitting close to a CBTC station operating in the last CBTC channel allowed in Europe from 5930 to 5935 MHz.

Considering only the adjacent bands coexistence, the most significant interference mechanisms are unwanted emissions from interfering transmitters (WAS/RLAN in our case) as well as blocking in the victim link receiver (CBTC). Figure 68 depicts these two interference mechanisms. The CBTC blocking is caused in our case by the WAS/RLAN in-band emissions. The interference inside the CBTC channel is, on the other hand, created by the WAS/RLAN unwanted emission.



**Figure 68: Unwanted emission from WAS/RLAN into the CBTC channel as well as the CBTC blocking**

A two-step methodology is adopted here: first, the maximum level of OoB WAS/RLAN emission tolerable by CBTC, as well as CBTC blocking are deduced, given the characteristics depicted in Table 45; secondly, a reverse engineering is performed in order to compute what the WAS/RLAN e.i.r.p. densities and OoB emissions are, that will allow respecting such levels at the CBTC antenna, given a set of different scenarios.

Each value has been computed as detailed in the following section.

### 9.1.3 Maximum out-of-band emission from WAS/RLAN into the CBTC channel

This value represents the maximum tolerable amount of interference energy falling from the WAS/RLAN OoB emission into the effective 5 MHz CBTC channel.

To ensure proper CBTC operation, the receiver is designed to include a margin equal or lower than the desensitization, which allows tolerating a certain level of interference in the listened channel. The relationship between the desensitization and the interference over noise ratio is defined as:

$$\frac{I}{N} = 10 \log_{10} \left( 10^{\frac{D}{10}} - 1 \right) \quad \text{in dB.}$$

When considering a margin equal to  $D$ , the receiver is operating at the the maximum tolerable interference coming from the OoB WAS/RLAN into the in-band CBTC and this value is derived from the above equation as:

$$I_{\max\_In\_CBTC} = 10 \log_{10} \left( 10^{\frac{D}{10}} - 1 \right) + N \quad \text{in dBm}$$



### 9.1.4 Blocking levels

Blocking refers to the unwanted input signal on a frequency other than the frequency of the wanted signal. In our case, this represents the WAS/RLAN signal received by CBTC within the WAS/RLAN band (higher than 5935 MHz, since CBTC stops at 5935 MHz). Given that the CBTC applies the ACS to any observed signal above 5935 MHz, the maximum blocking level is

$$B_{CBTC} = I_{\max\_In\_CBTC} + ACS \quad \text{in dBm}$$

The latter equation applies when the ACS is flat, however in few cases the ACS is not flat and has different levels, in those cases the blocking needs to be aggregated taking into account each ACS level, portion per portion.

When dealing with ACR values, the following formula applies:

$$B_{CBTC} = \text{Sensitivity} + D + ACR \quad \text{in dBm}$$

### 9.1.5 Results

#### 9.1.5.1 STEP 1: Maximum level of OoB WAS/RLAN emission and CBTC blocking

Table 46 depicts the achieved results for the first step of the computation.

**Table 46: Results obtained for IEEE 802.11 derived CBTC and TDMA/DSS CBTC**

	unit	IEEE 802.11 derived		TDMA/DSSS		TD-LTE	
		BS	TU	BS	TU	BS	TU
Antenna gain	dBi	18	14	18	14	18	14
Boxing loss	dBi	–	3	–	3	–	3
HW Losses	dBi	9	3	9	3	9	3
Noise floor	dBm	–94	–94	–102	–102	–102.4	–98.4
Required C/(N+I)	dB	9	9	–3	–3	0.9	0.6
Sensitivity	dBm	–85	–85	–105	–105	–101.5	–99
ACS	dB	–	–	50	50	48.7	33
		–	–			57.7	43.7
ACR	dB	16 <sup>2</sup>	16 <sup>2</sup>	-	-	-	-
		32 <sup>3</sup>	32 <sup>3</sup>				
Target desensitization	dB	2	3	2	3	2	3
Maximum allowable unwanted emission from WAS/RLAN into the CBTC channel in the air <sup>1</sup>	dBm	–105.3	–102	–113.3	–110	–113.8	–106.5
Aggregated blocking level in the air, WAS/RLAN in 5935-5955 MHz	dBm	–70.3	–68.3	–63.3	–60	–60.4	–68.4
Aggregated blocking level in the air, WAS/RLAN in 5940-5960 MHz	dBm	–60	–58			–56.1	–62.8

	IEEE 802.11 derived	TDMA/DSSS	TD-LTE
<sup>1</sup> use eq.(1) - antenna gain + HW losses + boxing loss			
<sup>2</sup> First floor of the ACS in the first adjacent 5 MHz			
<sup>3</sup> Second floor of the ACS valid after 5940 MHz			

Table 46 includes CBTC receiver selectivity for adjacent channels. The impact from blocking beyond the adjacent channels is believed to be mitigated by increased ACS and lower antenna gains.

#### 9.1.5.2 STEP 2: Required in-band and out-of-band emission for WAS/RLANS

The following scenarios are studied

- **Scenario A: A fixed WAS/RLAN Access Point interfering into a CBTC BS.** Both indoor and outdoor cases are considered. The distance between the AP and the victim is considered to be around 5 m (the AP is near the track). A BEL attenuation of 17 dB is considered for the indoor case.
- **Scenario B: A fixed WAS/RLAN Access Point interfering into a CBTC TU.** Both indoor and outdoor cases are considered. The distance between the AP and the victim is considered to be around 6 m. A BEL attenuation of 17 dB is considered for the indoor case.
- **Scenario C: A mobile WAS/RLAN AP (tethering) is on the platform and interfering into a CBTC BS, while the user is waiting for the train.** The distance between the AP and the victim is considered to be around 10 m. Only outdoor case is considered, since there is no way to control tethering.
- **Scenario D: A mobile WAS/RLAN AP (tethering) is on the platform and interfering into a CBTC TU, while the user is waiting for the train.** The distance between the AP and the victim is considered to be around 6 m. Only outdoor case is considered, since there is no way to control tethering.

Table 47 describes the elements taken into account in the simulations. Given the small distances, the free space loss is considered as a propagation model.

**Table 47: Considered propagation parameters**

Parameter	Value in different scenarios			
	A	B	C	D
Distance between interferer and victim (m)	5	6	10	6
Path loss (dB)	61.8	63.5	67.9	63.5
Victim vertical antenna discrimination (dB)	0	1 <sup>1</sup>	5 <sup>2</sup>	1 <sup>3</sup>
Victim horizontal antenna discrimination (dB)	6 <sup>4</sup>	3 <sup>5</sup>	5 <sup>6</sup>	3 <sup>7</sup>
<sup>1</sup> At 10°, <sup>2</sup> at 11°, <sup>3</sup> at 10°, <sup>4</sup> at 11°, <sup>5</sup> at 17°, <sup>6</sup> at 10°, <sup>7</sup> at 17° cf. CBTC antenna diagrams				

#### 9.1.5.3 Maximum WAS/RLAN out-of-band emissions below 5935 MHz

The maximum WAS/RLAN out-of-band emission is computed thanks to the following equation:

$$I_{WAS/RLAN\_max\_OoB} = I_{In\_CBTC} + \sum Losses + \sum Antenna\_discriminations$$

The losses include the path loss as well as the building entry loss when required. The polarisation mismatches are both vertical and horizontal. Using the above equation, the results are summarised in Table 48.

**Table 48: Maximum WAS/RLAN out-of-band emission below 5935 MHz**

Technology	unit	Value in different scenarios					
		A		B		C	D
		indoor	outdoor	indoor	outdoor		
IEEE 802.11 like	dBm/5MHz	-20.5	-37.5	-17.5	-34.5	-27.4	-34.5
TDMA/DSSS	dBm/5MHz	-28.5	-45.5	-25.5	-42.5	-35.4	-42.5
TD-LTE	dBm/4.5MHz	-29	-46	-22	-39	-35.9	-39

From the results depicted above, it can be concluded that the most stringent level of out-of-band emissions tolerable for WAS/RLAN below 5935 MHz are as follows:

- Outdoor fixed WAS/RLAN AP: -46 dBm/5MHz e.i.r.p.;
- Indoor fixed WAS/RLAN AP: -29 dBm/5MHz e.i.r.p. (less stringent value that may be easier to fulfil);
- Mobile AP (Tethering): -42 dBm/5MHz.

#### 9.1.5.4 Maximum WAS/RLAN in-band emission

In order to respect the CBTC blocking, appropriate levels of in-band emission for WAS/RLANs need to be derived. Using the same approach as in Section 9.1.5.3, it is found:

$$P_{\text{WAS/RLAN\_Inband}} = B_{\text{CBTC}} + \sum \text{Losses} + \sum \text{Antenna\_discriminations}$$

Applying this equation, the results shown in Table 49 for WAS/RLAN first channel in 5935-5955 MHz are obtained.

**Table 49: Maximum WAS/RLAN e.i.r.p. if operating in 5935-5955 MHz**

Technology	unit	Value in different scenarios					
		A		B		C	D
		indoor	outdoor	indoor	outdoor		
IEEE 802.11 like	dBm/20 MHz	14.5	-2.5	14.2	-2.8	7.6	-2.8
TDMA/DSSS	dBm/20 MHz	21.5	4.5	24.5	7.5	14.6	7.5
TD-LTE	dBm/20 MHz	24.4	7.4	16.1	-0.9	17.5	-0.9

If the first WAS/RLAN channel is to be configured above 5940 MHz, the results are shown in Table 50.

**Table 50: Maximum WAS/RLAN e.i.r.p., in first adjacent channels, if operating above 5940 MHz**

Technology	unit	Value in different scenarios					
		A		B		C	D
		indoor	outdoor	indoor	outdoor		
IEEE 802.11 like	dBm/20 MHz	24.8	7.8	26.5	9.5	17.9	9.5
TDMA/DSSS	dBm/20 MHz	21.5	4.5	24.5	7.5	14.6	7.5

Technology		Value in different scenarios					
TD-LTE	dBm/20 MHz	28.7	11.7	21.7	4.7	21.8	4.7

### 9.1.6 Summary for the CBTC Adjacent-Band Study

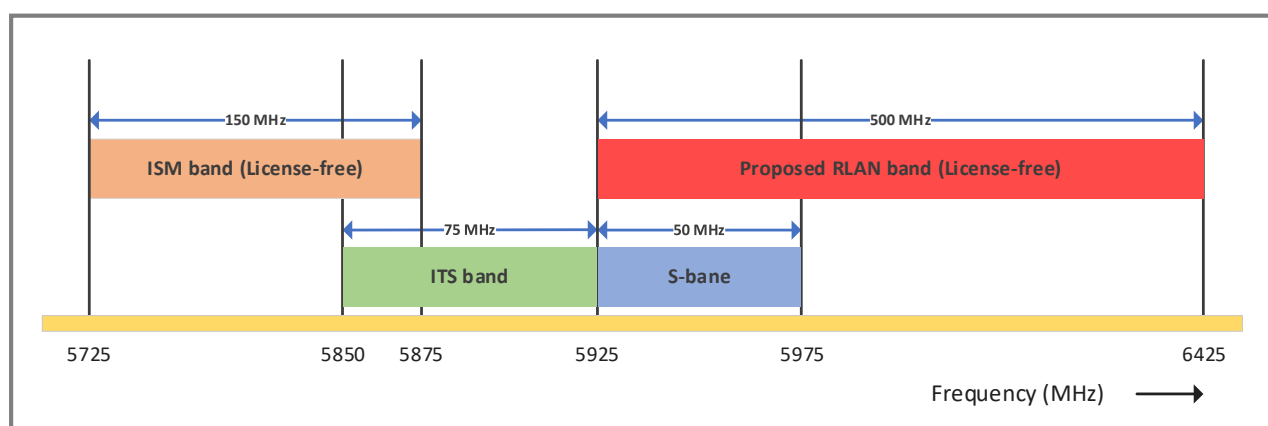
Indoor usage allows less stringent requirement to WAS/RLAN emissions (In-band and OoB).

The simulations show that a density of OoB WAS/RLAN emission of -29 dBm/5MHz is sufficient to ensure the CBTC operation, if considering a WAS/RLAN indoor only operation.

When comparing the results achieved assuming WAS/RLAN operation starting at 5940 MHz and 5935 MHz, it appeared that WAS/RLAN operation above 5940 MHz is the one that less restricts the WAS/RLAN emissions. In that case, an in-band e.i.r.p. value of 21.5 dBm/ 20 MHz for indoor WAS/RLAN usage would fulfil the CBTC blocking requirements for the three systems. It is believed that applying this value for the first 20 MHz WAS/RLAN range is sufficient.

## 9.2 INTERFERENCE FROM WAS/RLAN INTO CBTC OPERATING IN THE SAME BAND

In Denmark, the Copenhagen S-train CBTC system operates in the licensed band 5925-5975 MHz, which constitutes the first 50 MHz of the proposed WAS/RLAN band 5925-6425 MHz, as shown in Figure 69. The time-critical and safety-related nature of a CBTC railway signalling system imposes stringent reliability and availability requirements, particularly on radio communication. The co-existence with public WAS/RLAN networks might thus severely impact the performance of the CBTC system.



**Figure 69: Overview of frequency bands**

In this context, this section evaluates the impact of the interference produced by a WAS/RLAN device on the operation of the Copenhagen S-train CBTC system.

### 9.2.1 Overview of the Copenhagen S-train rail system

S-train is the mass-transit rail system of the Copenhagen urban area that serves more than 350 000 passengers a day. Table 51 lists the key figures of the Copenhagen S-train system.

**Table 51: Key figures of Copenhagen S-train rail system**

Parameter	Value
Length of double track	170 km
Length of double track in tunnel	2 km
Length of double track in trench	1.5 km
Number of train stations	92
Number of rail lines	7
Number of trains (with passengers)	135 vehicles
Number of yellow fleets	18 vehicles
Number of depots	3
Number of traffic control centres (TCC)	1

The Copenhagen S-train system is currently being equipped with CBTC, to enable the exchange of high resolution and real-time train control information between the train and the wayside infrastructure. The Copenhagen S-train system use a radio technology based on IEEE 802.11 technology.

The train and the wayside communicate each other by sending special CBTC messages. The train continuously sends its location to the wayside. Based on this information, the traffic control centre (TCC) at the wayside calculates the maximum speed and distance the train is permitted to travel and sends it to the train. This information is called "Movement Authority". Based on this information, the train on-board equipment continuously adjusts the train speed and maintains the safety distance to the preceding train. In the S-train CBTC system; these CBTC messages are exchanged every 400 milliseconds. This real-time communication increases the line capacity by safely reducing the distance (headway) between the trains travelling on the same line [77].

To ensure continuous radio connectivity, a large number of Access Points (APs) are installed at the wayside. Train is likewise equipped with at least two client devices, called a Train Unit (TU). As the train moves, it establishes a radio connection with the nearest AP.

The system availability in CBTC depends highly on the radio communication. Since railway operations involve safety of passengers, there exist particularly high requirements about the system availability. For this reason, CBTC systems generally support exceptionally high availability. For S-train, the supported system availability is 99.999% (6.05 seconds of downtime per week).

In the S-train CBTC system, the number of APs installed is approximately 650. The average distance between two consecutive APs is 600 m. This number is based on the link budget calculations and ensures that there is adequate radio coverage at any given location on the track.

As CBTC is highly dependent on radio communication, stringent requirements are imposed to maintain a certain quality of communication. These requirements can be found in [78] and [79].

- **Packet errors:** A packet must be received with a minimum signal-to-noise ratio before it could be demodulated correctly. The number of errors introduced is directly proportional to the amount of interference received above this threshold. In the given scenario, the amount of interference will additionally depend on the number of WAS/RLAN interferers present in the proximity. Furthermore, it will depend highly on the type of application used and its data traffic characteristics. In other words, someone browsing websites on their WAS/RLAN device is less harmful compared to someone streaming videos or downloading large files on their WAS/RLAN device. The requirements listed in [78] specify maximum 1 erroneous packet out of 100 packets received, i.e. a Packet Error Rate (PER) of 1%.
- **Bandwidth:** The IEEE 802.11 radio technology is based on shared medium access. It uses the Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) mechanism to prevent a user from transmitting

when another user is already transmitting (using the so-called back-off mechanism). This implies that the greater the number of users trying to transmit simultaneously at a given time, the lower the per user available bandwidth. As the S-train CBTC system is also based on IEEE 802.11, it will recognise WAS/RLAN transmissions and will back-off (and vice-versa). In the S-train CBTC system, the supported bandwidth is 18 Mbit/s. The required minimum bandwidth per train is 160 kbit/s, which is analogous to voice over Wi-Fi traffic flows from a bitrate and priority perspective. As an example, note that streaming High Definition (HD) video requires a bandwidth of approximately 5 Mbit/s. This implies, for example, that with large numbers of WAS/RLAN users streaming HD videos, the probability of simultaneous transmissions that could prevent a train from transmitting its location (i.e. due to the back-off mechanism) is increased.

Note that the above example assumes that these WAS/RLAN users are also using a channel of 20 MHz width and the same modulation and coding rate as S-train. For WAS/RLAN users using a wider channel (i.e. 40, 80 or 160 MHz) and/or a higher modulation and coding rate, the number of WAS/RLAN users that would prevent the train from transmitting would be greater, particularly given the short RF activity factor of 1.97% (see section 3.2) achievable due to the resulting high data rates.

Note also that the above-mentioned bandwidth of 160 kbit/s per train is for CBTC-related traffic only. In addition, 2 Mbit/s is allocated for non-CBTC-related traffic e.g. for software updates.

- **Latency:** Both low bandwidth and high interference can result in high latency. CBTC systems impose stringent requirements on latency as the location received from a train with an unacceptable delay does not accurately represent the train's current location. The requirements listed in [78] specify a maximum allowed delay of 100 milliseconds.

A radio communication failure in CBTC can be defined as an event when the above requirements on packet errors, bandwidth and latency are not met. In such an event, a train may not be able to receive the "Movement Authority" from the wayside in time. As the headways in CBTC are very short, it means in this situation, the train immediately stops automatically (i.e. it applies emergency brakes). Likewise, the train may not be able to send its location to the wayside, in which case the wayside might not be able to calculate the "Movement Authority" for other nearby trains, and thus those trains must also stop. For this reason, in CBTC systems, a radio communication loss of more than 1 second is not acceptable, as listed in [78]. Once the train is stopped, it is considered "de-localised" and drops out of the CBTC control. TCC must subsequently issue a written order to the train driver, allowing him to drive the train manually at a low speed until the train has passed over two "balises" to acquire its location again—a balise is a transponder device placed on the rails transmitting the train its exact location. Table 52 lists the key figures of the S-train CBTC system.

**Table 52: Key figures of Copenhagen S-train CBTC system**

Parameter	Value
Number of Access Points (AP)	650
Number of Train Units (TU)	270
Inter-AP distance (average)	600 m
CBTC message interval	400 ms
Headway interval (minimum)	70 s

Currently, the S-train CBTC system is operating as a Semi-Automated Train Operation (STO) system. It will subsequently be upgraded to a Driverless Train Operation (DTO) system that enables minimum or no driver involvement. Upgrading to a fully automated operation without any on-board staff — called Unattended Train Operation (UTO) — is under consideration after 2020.

The S-train CBTC system is operating in the licensed band 5925-5975 MHz. It uses 2 channels of 20 MHz bandwidth each, centred at 5935 and 5965 MHz. Table 53 lists the key radio-related figures of the S-train CBTC system.

In the S-train system, both AP and TU operate at 30 dBm transmission power which translates to an e.i.r.p. of 38 dBm and 35 dBm, respectively, after the losses and gains are included.

**Table 53: Radio related parameters for Copenhagen S-train CBTC system**

Parameter	Value
Radio frequency band	5925-5975 MHz
Radio technology	Based on IEEE 802.11
Frequency channels	5935 MHz, 5965 MHz
Channel width	20 MHz
Transmission power	30 dBm
e.i.r.p. AP	38 dBm
e.i.r.p. TU	35 dBm
Maximum allowed e.i.r.p.	46 dBm (33 dBm/MHz)

## 9.2.2 Experimental setup and methodology

The study in this section has to be regarded more as an analytical study than as an empirical study. Furthermore, it is in part based on the MCL methodology [80]. The analytical MCL methodology serves as a simplified approach as it relies mainly on calculations. For example, it supposes a single interferer transmitting at a fixed — usually the maximum — transmission power and using a fixed channel.

The following types of devices/units are involved in this study.

- **CBTC receiver:** there are two types of CBTC receivers involved:
  - A wayside CBTC receiver, i.e. a wayside Access Point (AP) radio device, referred to as a CBTC AP;
  - A train on-board CBTC receiver, i.e. a Train Unit (TU) radio device, referred to as a CBTC TU.
- **WAS/RLAN interferer:** a WAS/RLAN interferer could either be an AP or a mobile device. While a WAS/RLAN AP could generally only be located at the wayside, a WAS/RLAN mobile device, typically carried by a passenger, could be located either at the wayside or inside the train.

### 9.2.2.1 Propagation model

The following propagation model originally presented in [32] has been used for this study.

$$Path\ loss = \begin{cases} 20 \log_{10} \left( \frac{4\pi}{c} \right) + 20 \log_{10}(d) + 20 \log_{10}(f) & d \leq d_0 \\ 20 \log_{10} \left( \frac{4\pi}{c} \right) + 20 \log_{10}(d_0) + 20 \log_{10}(f) - 10n_0 \log \left( \frac{d}{d_0} \right) & d_0 < d \leq d_1 \\ 20 \log_{10} \left( \frac{4\pi}{c} \right) + 20 \log_{10}(d_0) + 20 \log_{10}(f) - 10n_0 \log \left( \frac{d_1}{d_0} \right) - 10n_1 \log \left( \frac{d}{d_1} \right) & d > d_1 \end{cases}$$

Here  $c$  is the speed of light,  $d$  is the distance between the transmitter and receiver and  $f$  is the frequency. The values of the breakpoint distance ( $d_0$  and  $d_1$ ) and path loss exponent ( $n_0$  and  $n_1$ ) in the formula depend on the environment and are listed in Table 54. Note that since the S-train CBTC system operates primarily in an urban (or semi-urban) environment, this study uses the values for the urban case.

**Table 54: Parameter values used for propagation model**

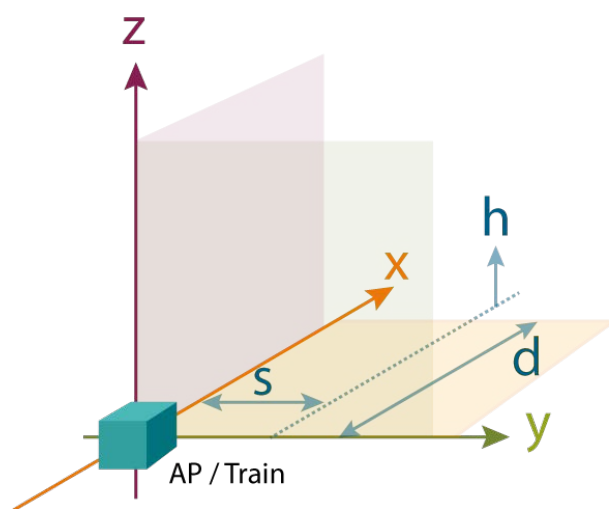
Parameter	Urban	Suburban	Rural
Breakpoint distance $d_0$ (m)	64	128	256
Path loss exponent $n_0$ beyond $d_0$	3.8	3.3	2.8
Breakpoint distance $d_1$ (m)	128	256	1024
Path loss exponent $n_1$ beyond $d_1$	4.3	3.8	3.3

Breakpoint distance is defined as the distance after which the signal power starts to degrade more sharply. The values of the breakpoint distance are normally based on real-life data. With the use of the path loss exponent, the loss that incurs due to the existence of obstructions along the path is incorporated in the path loss calculation. Note that while the resulting path loss may not accurately represent a real-life scenario, it serves as a reliable indicator. In addition to the path loss, this study includes antenna gains in the calculation as well, as described subsequently.

For this study, the following coordinate system is used to describe the location of the WAS/RLAN interferer relatively to the location of the CBTC receiver.

- The x-axis represents the axis parallel to the train track, therefore, also parallel to the boresight of the CBTC AP antennas;
- The y-axis represents the axis perpendicular to the train track;
- The z-axis represents the axis vertical to the train track.

For a given scenario, the CBTC receiver, either an AP or a TU, is located at the origin of the coordinate system. For each scenario, the coordinates  $h$  (height) and  $s$  (separation) of the WAS/RLAN interferer are defined and the impact of the WAS/RLAN interferer at a given distance  $d$  from the CBTC receiver is studied. The coordinate system is shown in Figure 70.

**Figure 70: Coordinate system**

The S-train CBTC system uses uni-directional antennas on both the AP and the TU. On the contrary, for simplicity, this study assumes that the WAS/RLAN device uses an omnidirectional antenna. For a given location of the interferer ( $d, s, h$ ), the antenna gain value is calculated according the azimuth and elevation angles using the radiation pattern of the antenna. Depending on the values of  $h$  and  $s$ , the “main lobe/main lobe” situation is achieved for a certain distance  $d$ . For shorter distances, the gain value is taken from the radiation pattern table for the antenna.



Note that the situation where the antennas of the CBTC unit (i.e. AP or TU) and the WAS/RLAN device are not aligned (i.e. the “main lobe/main lobe” situation is not met) might lead to the so called “hidden node problem”, where the WAS/RLAN device is not able to hear the transmissions from the CBTC unit, i.e. CBTC unit is hidden from the WAS/RLAN device. The hidden node problem renders the “carrier sensing” protocol of IEEE 802.11 (i.e. CSMA/CA) ineffective as the two nodes are not able to hear each other. As a result, the WAS/RLAN device might not refrain from transmitting and thus produce interference for a CBTC unit that is already transmitting.

### 9.2.2.2 Experiment parameters

Table 55 lists the S-train specific parameter values used in this section, including the values from the S-train link budget calculations.

The antenna used in the S-train CBTC system for both APs and TUs is HUBER+SUHNER Sencity SPOT-S antenna which has a gain of 14 dBi.

The value of the train windscreen loss is based on measurements carried out in the S-train system. The value ranges between 3 and 6 dB. For this study, the maximum value (6 dB) has been used. For simplicity, the same loss value has been assumed for the train body as well.

**Table 55: S-train specific parameter values used in the study**

Parameter	Value
Antenna gain	14 dBi
Cable loss	3 dB
AP splitter loss	0.5 dB
Train windscreen loss	6 dB
Modulation type	OFDM with QPSK
Coding rate	3/4
Supported bandwidth	18 Mbit/s

Table 56 lists the generic parameter values used in this study, i.e. parameter values that are applicable for both CBTC and WAS/RLAN.

The e.i.r.p. values of 29.9 dBm and 18.5 dBm for WAS/RLAN AP and WAS/RLAN mobile device, respectively, have been used. These values have been adopted from in line with Section 3.1.1.1.

It is assumed that S-train is using the frequency channel centered at 5965 MHz. For simplicity, it is assumed that the WAS/RLAN interferer is also using the same channel as S-train, which is also of 20 MHz width.

**Table 56: Generic parameter values used in the study**

Parameter	Value
e.i.r.p. WAS/RLAN AP	29.9 dBm
e.i.r.p. WAS/RLAN mobile device	18.5 dBm
Frequency	5965 MHz
Channel width	20 MHz
Protection ratio (PR)	9 dB

### 9.2.3 Scenarios

The following six, worst-case scenarios are considered. It is worth noting that there will be a large number of additional scenarios affecting CBTC transmissions. For example, interference from WAS/RLAN mobile devices inside the buildings alongside the tracks is a common scenario. Nonetheless, it is not the worst-case scenario and, therefore, is not considered here.

For these scenarios, it is assumed that the distance between the track and the CBTC APs installed alongside the track is 2 m. Likewise, it is assumed that the distance between the track and the station platform is 4 m.

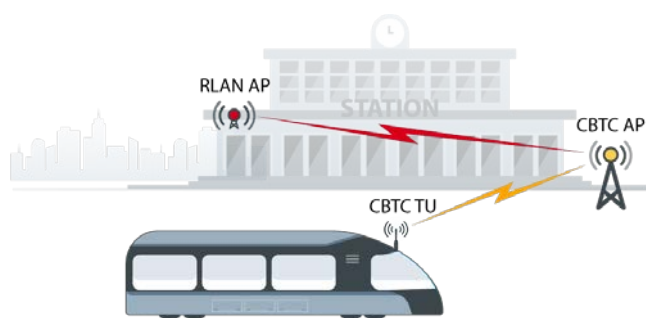
For each scenario, the distance between the CBTC receiver and the WAS/RLAN interferer (i.e.,  $d$  in Figure 70) is increased incrementally by moving the WAS/RLAN interferer.

#### 9.2.3.1 Scenario A - CBTC AP vs WAS/RLAN AP close to track

This scenario studies the impact on a CBTC AP from the transmissions of a WAS/RLAN AP located close to the track, such that:

- Height of the WAS/RLAN AP antenna is equal to the height of the CBTC AP antenna:  $h = 0$ ;
- Separation is at least  $s = 5$  m, i.e. the WAS/RLAN AP is outside of the CBTC protected area.

The scenario is applicable only in the elevated/outside systems. The scenario is illustrated in Figure 71.



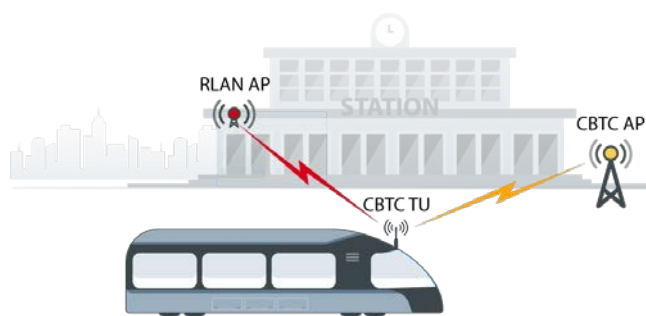
**Figure 71: Scenario A**

#### 9.2.3.2 Scenario B - CBTC TU vs WAS/RLAN AP close to track

This scenario studies the impact on a CBTC TU from the transmissions of a WAS/RLAN AP located close to the track, such that:

- Height of the WAS/RLAN AP antenna is equal to the height of the CBTC TU antenna:  $h = 0$ ;
- Separation is at least  $s = 7$  m, i.e. the WAS/RLAN AP is outside of the CBTC protected area.

The scenario is applicable only in the elevated/outside systems. The scenario is illustrated in Figure 72.



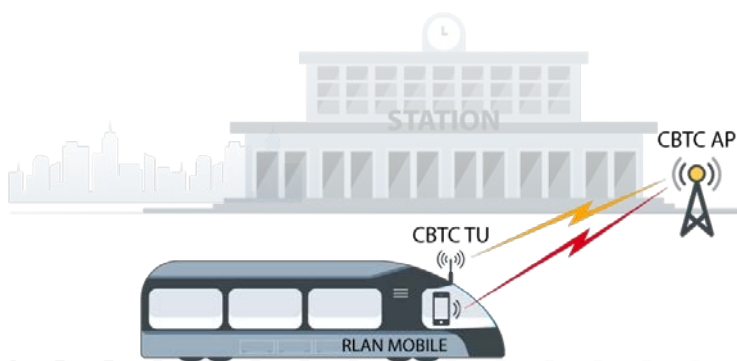
**Figure 72: Scenario B**

### 9.2.3.3 Scenario C - CBTC AP vs. WAS/RLAN mobile inside train

This scenario studies the impact on a CBTC AP from the transmissions of a WAS/RLAN mobile device inside a train, just behind the windscreen of the train. Due to the following scenario, a passenger is using his/her mobile phone as a hotspot to provide Internet connectivity to his computer.

- The height of the WAS/RLAN mobile device antenna is 3 m less than the height of the CBTC AP antenna:  $h = 3$  m;
- Separation is  $s = 2$  m.

The scenario is applicable for elevated/outside stations as well as underground stations such as the Nørreport Station in Copenhagen. The scenario is illustrated in Figure 73.



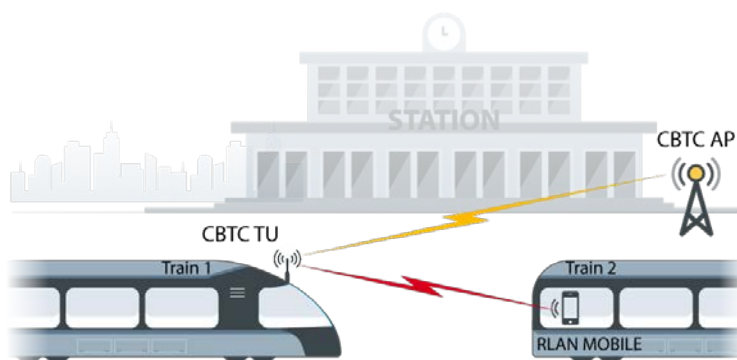
**Figure 73: Scenario C**

### 9.2.3.4 Scenario D - CBTC TU vs. WAS/RLAN mobile inside train

This scenario studies the impact on a CBTC TU from the transmissions of a WAS/RLAN mobile device inside another train on the same track, just behind the windscreen of that train. Due to the following scenario: a passenger is using his mobile phone as a hotspot to provide Internet connectivity to his/her computer.

- The height of the WAS/RLAN mobile device antenna is 1 metre less than the height of the CBTC TU antenna:  $h = 1$  m;
- Separation is  $s = 0$  m.

The scenario is applicable for elevated/outside stations as well as underground stations such as the Nørreport Station in Copenhagen. The scenario is illustrated in Figure 74.



**Figure 74: Scenario D**

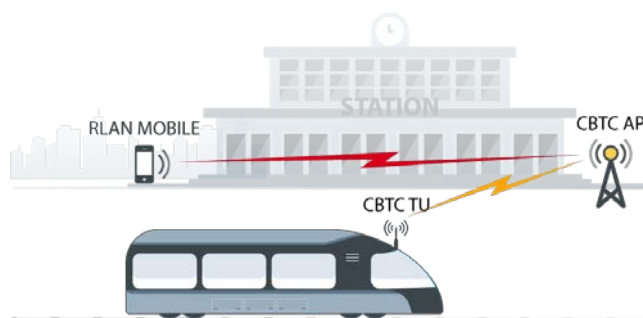
### 9.2.3.5 Scenario E - CBTC AP vs. WAS/RLAN mobile on platform

This scenario studies the impact on a CBTC AP from the transmissions of a WAS/RLAN mobile device on the platform. Due to the following scenario, a passenger or a staff member on the platform is either using

his/her mobile phone to connect to a public AP at (or close to) the station or using it as a hotspot to provide Internet connectivity to his/her computer:

- The height of the WAS/RLAN mobile device antenna is 2 m less than the height of the CBTC AP antenna:  $h = 2$  m;
- Separation is  $s = 2$  m.

The scenario is applicable for elevated/outside stations as well as underground stations such as the Nørreport Station in Copenhagen, Denmark. The scenario is illustrated in Figure 75.



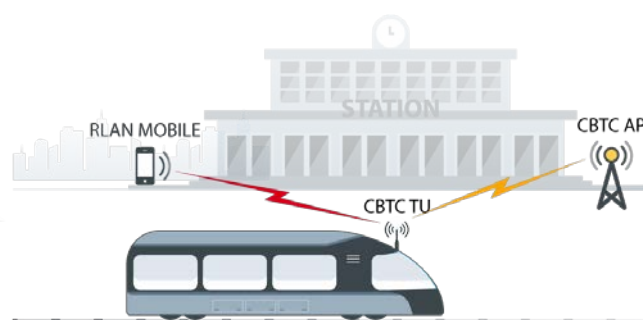
**Figure 75: Scenario E**

#### 9.2.3.6 Scenario F - CBTC TU vs. WAS/RLAN mobile on platform

This scenario studies the impact on a CBTC TU from the transmissions of a WAS/RLAN mobile device on the platform. Due to the following scenario, a passenger or a staff member on the platform is either using his/her mobile phone to connect to a public AP at (or close to) the station or using it as a hotspot to provide Internet connectivity to his computer:

- The height of the WAS/RLAN mobile device antenna is 1 metre less than the height of the CBTC TU antenna:  $h = 1$  m;
- Separation is  $s = 4$  m.

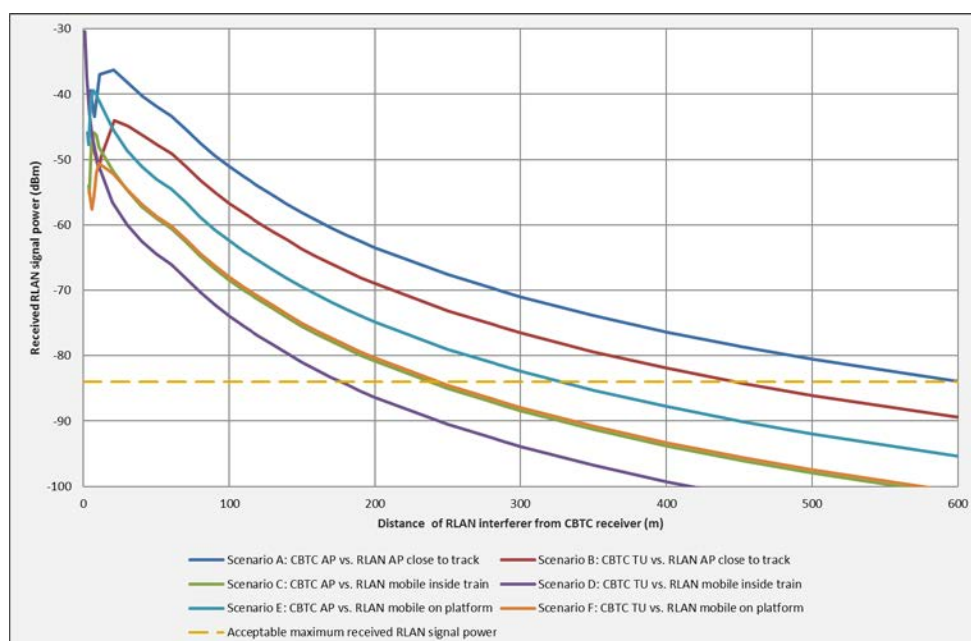
The scenario is applicable for both elevated/outside and underground systems. The scenario is illustrated in Figure 76.



**Figure 76: Scenario F**

## 9.2.4 Results and Discussion

Figure 77 presents the results for the above described six scenarios. The x-axis shows the distance of the WAS/RLAN interferer from the CBTC receiver, i.e.  $d$  in Figure 70. The y-axis shows the received interfering signal power from a WAS/RLAN device.



**Figure 77: Interference from WAS/RLAN**

According to the radio coverage data collected from a train in the S-train CBTC system, the average signal power received is -75 dBm. The train in this case ran on the Early Deployment Phase (ED) line, from Jægersborg station to Hillerød Station, Denmark, over a distance of 24 km, and connected to 36 APs.

To receive a packet without errors, the wanted signal (i.e. CBTC signal) must be received with a power significantly higher than the interfering signal (i.e. WAS/RLAN signal). In other words, a certain signal-to-noise ratio must be guaranteed (note that a more accurate term in this case is “carrier to interference plus noise ratio  $C/(N+I)$ ”). This is referred to as Protection Ratio (PR) and its value has been defined to be 9 dB for CBTC systems (Section 9.1.1). This implies that the power of the CBTC signal must be 9 dB above the power of the WAS/RLAN signal. Since the power of the CBTC signal is known in this case (i.e. -75 dBm), it means the power of the WAS/RLAN signal must be at least 9 dB less than -75 dBm. In other words, the power of the WAS/RLAN signal must be equal or less than  $-75 \text{ dBm} - 9 \text{ dB} = -84 \text{ dBm}$ . The horizontal yellow line in Figure 77 represents this value. Specifically, the received power from a WAS/RLAN interferer must be below this line to enable the CBTC receiver to correctly demodulate the signal. In short, anything in Figure 77 shown above this line is bad.

Figure 77 shows that for Scenario B, the WAS/RLAN AP must be at least 450 m away from the CBTC receiver in order not to interfere with it. It has to be recalled that in this scenario, the interferer is a WAS/RLAN AP close to the track and the receiver is a CBTC train (TU). In other words, the results show that if the WAS/RLAN AP is located within the 450 m proximity of the CBTC TU, the CBTC TU will not be successfully able to receive the signal from a CBTC AP, i.e. the signal will not meet the signal-to-noise ratio requirement.

The results show further that the highest interference is received in the case of Scenario A. It has to be recalled that in Scenario A, the interferer is a WAS/RLAN AP close to the track and the receiver is a CBTC AP. The results show that the WAS/RLAN AP in this case must be 600 m away from the CBTC AP for the CBTC AP to successfully receive the signal from the CBTC TU.

For Scenario C and Scenario F, the WAS/RLAN interferer must be 250 m away from the CBTC receiver to achieve the required signal-to-noise ratio. It has to be recalled that in Scenario C, the interferer is a WAS/RLAN mobile device inside the train and the receiver is a CBTC AP. In Scenario F, the interferer is a WAS/RLAN mobile device on the platform and the receiver is a CBTC TU.

The results show that Scenario D is the most favourable scenario as it causes the least interference. It has to be recalled that in this scenario, the receiver is a CBTC TU and the interferer is a WAS/RLAN mobile device inside another train. The main reason why the WAS/RLAN mobile device could not have a critical impact on

the CBTC TU is that its signal must penetrate through the body of two trains, causing certain loss to the signal power. Nonetheless, the results show that the WAS/RLAN mobile device must still be approximately 180 m away from the CBTC TU in the first train for the CBTC TU to successfully receive a signal from a CBTC AP.

The required distances seen in Figure 77 have been summarised in Table 57. In the event that CBTC and WAS/RLAN have to share the same frequency band, it will not be possible to guarantee that no WAS/RLAN device will be present inside these distances from the S-train system. Thus, it can be concluded that WAS/RLAN will have a critically negative impact on the CBTC operation.

**Table 57: Required minimum distance between CBTC receiver and WAS/RLAN interferer**

Scenario	Distance (m)
A	600
B	450
C	250
D	180
E	190
F	250

Note that if the signal-to-noise ratio requirement is not met, the CBTC receiver will receive a packet with errors and thus will discard it. As discussed above, a lack of communication between the train and the wayside for more than 1 second is considered unacceptable and, consequently, the train stops automatically. In other words, it means that it will only take a WAS/RLAN device interfere - with a certain impact - with a given CBTC receiver continuously for 1 second for the train to stop automatically.

As discussed above, the amount of interference will depend on the number of WAS/RLAN devices in the proximity and the data traffic characteristics of the applications used by them. Nonetheless, the case of a malicious “jammer” WAS/RLAN device will be of a particular concern. Jamming is a deliberate attempt of sabotaging a radio communication system by e.g. producing excessive interference. Today, such activities are deemed illegal due to the use of the licensed band by S-train. However, once this band becomes license-free, it will become increasingly hard to identify and control such activities. As an example, in Siemens’ CBTC systems deployed in China where the 2.4 GHz license-free band is used, a large number of incidents involving trains stopping due to radio interference has been recorded.

#### **9.2.5 Summary on the study on interference from WAS/RLAN to CBTC operating in the same band**

This section presents the results from a study investigating the impact of WAS/RLAN devices coexisting in the same frequency band as the Copenhagen S-train CBTC system. Six worst-case scenarios are considered where the WAS/RLAN device is either functioning as a WAS/RLAN AP or a WAS/RLAN mobile device, located in the close proximity of the train, e.g. a train station or inside the train. The study investigates whether a CBTC receiver, (e.g. on-board a train) will be able to receive signals from a CBTC sender (e.g. a CBTC AP) with an acceptable signal-to-noise ratio in the presence of interference from a WAS/RLAN device. The distance of the WAS/RLAN device from the CBTC receiver is then increased incrementally. The objective is to identify the minimum distance between the two devices required for the CBTC system to function normally.

The results show that the interference produced by the WAS/RLAN device is above the maximum acceptable threshold, which results in a significantly low signal-to-noise ratio at the CBTC receiver. In real life, this will lead to a large number of errors in the data (i.e. packets) received by the CBTC receiver and, as a result, the packets will have to be discarded.

The results present the required minimum distance between the WAS/RLAN device and CBTC receiver to avoid the interference from the WAS/RLAN device. This distance ranges from the 180 m for Scenario D (minimum) to 600 m for Scenario A (maximum). If S-train and WAS/RLAN share the same frequency band eventually, it will not be feasible to reasonably assume that no WAS/RLAN devices will be present within these distances.

In the S-train CBTC system, the train and the wayside must communicate with each other continuously using radio communication to share train control information. An interruption of more than 1 second in this communication between the train and the wayside is not acceptable and, eventually, the train stops automatically—by applying emergency brakes—for safety reasons. Specifically, this means if a WAS/RLAN device continuously interferes with a given CBTC receiver for 1 second, the train will stop.

It is, therefore, concluded that WAS/RLAN will have a critical impact on the operation of the S-train CBTC system.

## 10 COMPATIBILITY BETWEEN WAS/RLAN AND RADIO ASTRONOMY

### 10.1 SYSTEM CHARACTERISTICS AND PROTECTION CRITERIA FOR THE RADIO ASTRONOMY SERVICE

The frequency band 6650-6675.2 MHz is important for the radio astronomy service for observations of methanol ( $\text{CH}_3\text{OH}$ ). This transition of methanol is a very powerful cosmic maser found exclusively in regions where massive stars form. It is widely observed in Europe using single dishes and very long baseline interferometry (VLBI). This band is mentioned in RR No. **5.149**, which urges administrations to take all practicable steps to protect the radio astronomy service from harmful interference.

Recommendation ITU-R RA.769-2 [13] provides general characteristics of radio astronomy stations and the protection criteria for radio astronomy stations. The threshold interference levels for radio astronomy observations with an integration time of 2000 s and an antenna gain of 0 dBi in neighbouring bands are given in Table 1 of Recommendation ITU-R RA.769-2.

The thresholds of Recommendation ITU-R RA.769 and the methodology of Recommendation ITU-R RA.1031-2 [65] are applicable to this case. Recommendation ITU-R RA.1031-2 is a practical guideline for assessing the potential for interference at specific radio astronomy sites; it further references Recommendation ITU-R RA.1513 [66].

Recommendation ITU-R RA.769 gives a threshold power flux density (pfd) value.

Recommendation ITU-R RA.1031 gives a method to calculate the separation required to ensure this value is met during a single period of observation.

Recommendation ITU-R RA.1513 specifies the data loss criterion - which is 2% of all observations.

For example, the plot in Figure 78 for the Radio Astronomy site at Westerbork in the Netherlands shows a coordination zone contour based on a single 2000-second observation [13]. Here the larger contour represents the coordination zone under worst case assumptions. The smaller contour represents a 5 dB improvement on the worst case, an improvement that could come from many factors. For reference the outer circle is 10 km from the centre of the Westerbork site.



**Figure 78: Contours based on a single 2000 second observation for the Radio Astronomy site at Westerbork, The Netherlands**



Note that in Figure 78, under the worst case assumptions, the coordination zone would be about 10 km in radius. Within that radius there are a few small settlements. However, with a 5 dB improvement the coordination zone would cover no populated areas. This improvement could come, among other factors, from the AP antenna being pointed away from the Radio Astronomy Service (RAS), the local clutter loss being higher than the values derived from a general model or the WAS/RLAN operating below the maximum power density.

The calculation of a coordination zone is dependent on so many assumptions which are site specific and specific to the observational schedule. To get an accurate idea, if 2% of observations are lost, one would need to calculate the contour based on many 2000-second periods that reflect the specific observational schedule. Noting this specific nature of each case, the relevance of a general sharing study is questionable.

However such studies are easy to do and the number of RAS sites in Europe is small. The three relevant ITU-R Recommendations provide a framework for administrations to assess the potential impact of WAS/RLAN deployment on the operation of the RAS on a site-by-site basis.

## 11 COEXISTENCE BETWEEN WAS/RLAN AND ULTRA WIDE BAND (UWB) SYSTEMS

### 11.1 INTRODUCTION

Ultra-wideband (UWB) is a unique technology that can provide safe and secure wireless access services. Services include secure mobile transactions, vehicle access and consumer ranging using devices such as smart phones, IoT connected devices, smart home devices and industrial tags.

It is unique in that it provides the most precise locating capability using the least energy of any wireless technology. For example; a single coin cell can provide constant visibility for years.

UWB is unlicensed and coexists with incumbent radio services without causing or suffering interference. The installed base is greater than 2 million and some of the installed base is already at 6.5 GHz centre frequency and cannot change. Market projections are 3.1 billion devices per year in 2025.

### 11.2 TECHNICAL PARAMETERS

Ultra-wideband systems are short-range devices operating in the 6-8.5 GHz range with a minimum bandwidth of 50 MHz following ECC Decision (06)04 [58].

The characteristics of UWB systems and use cases considered in this study are based on:

- ETSI TR 103 181-1 [67];
- ETSI TR 103 181-2 [68].

The frequency range above 6 GHz is the most important frequency range for communications and location tracking applications and is the only band with international acceptance for UWB services. These frequencies are also important for sensor applications which are heavily dependent on the material properties for their use cases. The improved resolution and availability without mitigation techniques make the 6 GHz band attractive for these applications among others.

In this frequency range, UWB devices operate with a mean e.i.r.p. limited to -41.3 dBm/MHz. While the minimum bandwidth is 50 MHz, typical devices use bandwidths of 500 MHz or higher. Communication and location tracking devices typically use omnidirectional antennas. Sensing devices employ directional antennas, with typical antenna gains from 6 dBi.

Measurements performed by the UWB industry for the compatibility studies here have shown that interfering signals with a level above -78 dBm, whether in a bandwidth of 40 or 160 MHz, at the receiver cause at least 3 dB degradation in the receiver sensitivity for communications and location tracking devices. For sensing applications, signal levels above -65 dBm cause more than 3 dB Signal to noise ratio (SNR) degradation at the receiver.

The measurements demonstrate that the total interfering power in the UWB bandwidth determines the degradation of the UWB system performance.

Note that a degradation higher than 3 dB in link budget implies that the useful coverage area for the UWB link is at least halved, i.e. significantly impacting the performance of the UWB system.

### 11.3 MCL STUDIES FOR A SINGLE INTERFERER

#### 11.3.1 Communication systems

A lot of the interest in UWB technology stems from the fact that the high bandwidth can be used for transmitting very high-data rate digital signals over relatively short ranges. High data rate communication of

up to 500 Mbps over short distances up to 10 m can be achieved. Particularly in highly reflective, often industrial, environments, the wide bandwidth is attractive as it mitigates power variations due to multipath fading. UWB communications technology can, therefore, be found in a wide variety of environments, ranging from industrial and professional to office and consumer applications. In many regulatory environments, fixed outdoor transmitters are not allowed, so many UWB communications take place indoors. The high bandwidth and multipath resistance also make UWB technology very successful for Program making and special events (PMSE) applications for professional wireless audio, providing an attractive solution to the loss of low-band spectrum for the operation of wireless microphone and other audio devices.

An overview of the technical characteristics of UWB systems is provided in ETSI TR 103 181-1. Most UWB communication applications are covered by ETSI EN 302 065-1 [69] and described in System Reference Document ETSI TR 101 994-1 [70]. Specific regulations exist for vehicular and railroad applications, covered by ETSI EN 302 065-3, and for applications on-board aircraft, subject of ETSI EN 302 065-5.

Previously, ECC Report 64 [71] considered the compatibility of WAS/RLAN and UWB systems. A reference distance of 36 cm between the UWB device and the WAS/RLAN terminal was considered, in combination with free space propagation and omnidirectional antennas.

Table 58 lists the separation distances for the various proposed WAS/RLAN transmit powers that limit the degradation to UWB sensitivity to 3 dB. Based on the results of the measurement campaign, it targets a total power level of -78 dBm coming from a single WAS/RLAN transmitter at the UWB victim receiver and assumes that the highest 160 MHz channel, centred at 6335 MHz is used.

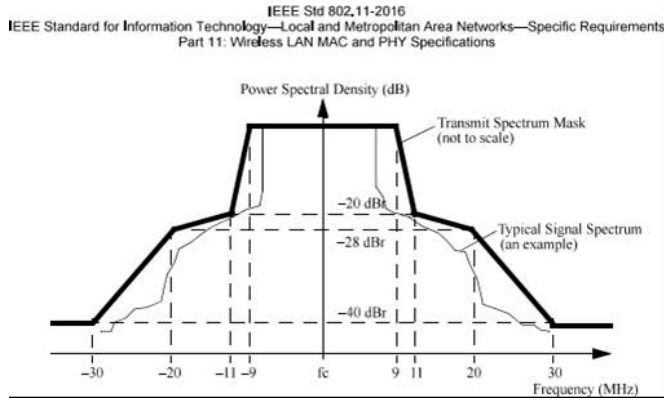
**Table 58: Separation distances resulting in 3 dB loss to UWB communications systems from WAS/RLAN transmitter**

WAS/RLAN e.i.r.p. transmit power	Separation distance
1000 mW	946 m
250 mW	473 m
100 mW	299 m
50 mW	212 m
13 mW	108 m
1 mW	30 m
<b>Assumptions</b>	
WAS/RLAN device	1 transmitter, centred at 6335 MHz -78 dBm total power at UWB receiver
UWB device	3 dB sensitivity reduction
Propagation	Free space loss

It is clear that these separation distances are orders of magnitude larger than the 36 cm assumed in ECC Report 64. Reducing these separation distances result in further degradation of the UWB devices performance. To meet the separation distance of 36 cm results in a WAS/RLAN transmit power level of -38.4 dBm.

### 11.3.2 Example study regarding Wi-Fi out-of-band emissions impact on 6.5 GHz UWB signal

Figure 80 shows a spectrum analyser capture of a double-wide over-the-air (OTA) Wi-Fi transmission at 5 GHz. Observed OoB emission is (barely) meeting IEEE 802.11 requirements, shown in Figure 79, and bottoms out at -55 dBr at  $f_c \pm 120$  MHz and beyond. The floor is most likely the spectrum analyser's noise floor.



Param/Mode	Single-Wide	Double-Wide
RF Channel Spacing	20 MHz	40 MHz
A	11 MHz	21 MHz
B	20 MHz	40 MHz
C	30 MHz	60 MHz

Figure 79: IEEE 802.11 Out-of-band (OoB) emission requirement for OFDM transmissions

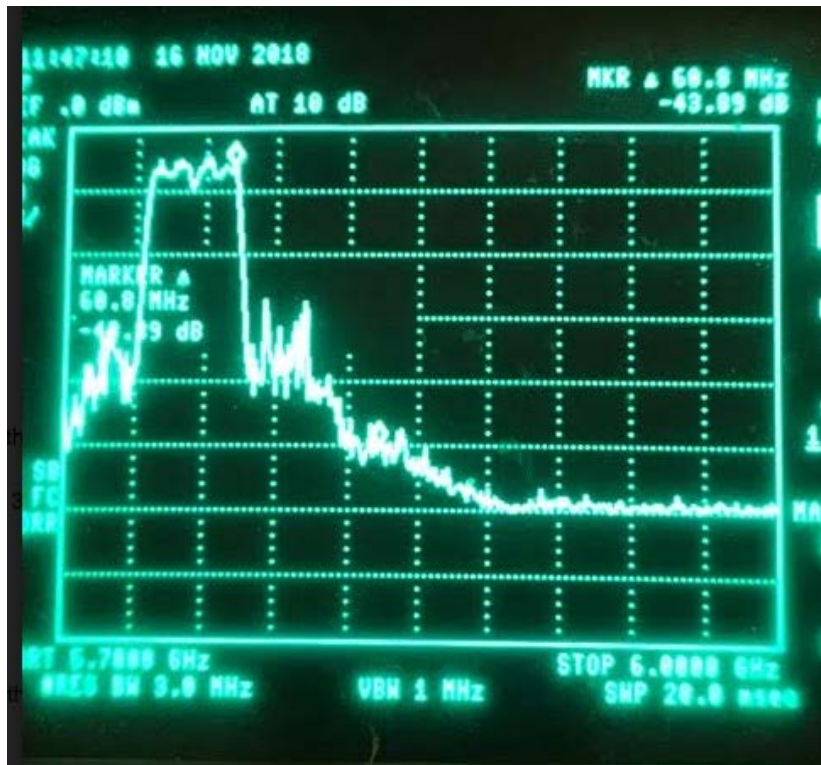
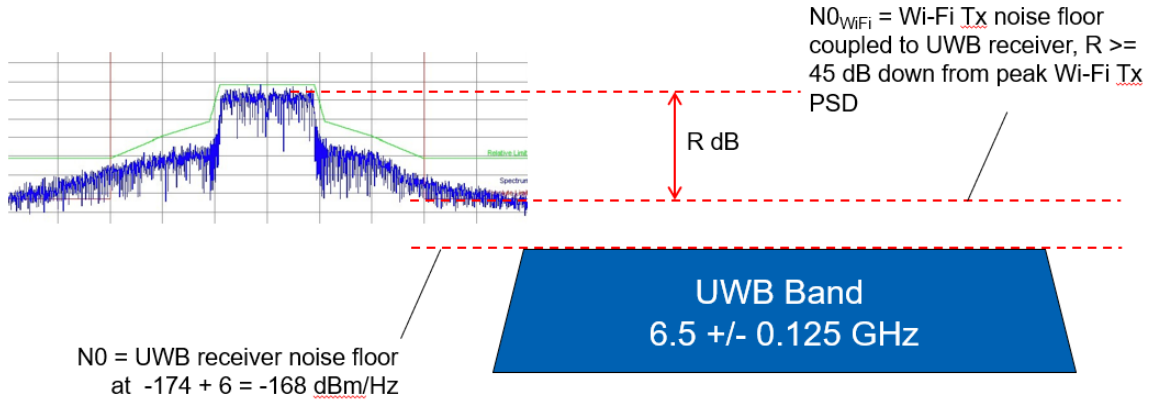


Figure 80: WAS/RLAN spectrum mask measurement

For the analysis, it is assumed that the Wi-Fi transmissions with 20 MHz (40 MHz) channel spacing occur at Wi-Fi centre frequencies that are at least 30 MHz (60 MHz) outside of the UWB band, so that any OoB emission that hit the UWB band are at least 45 dB down from the peak PSD (see Figure 81)

It is also assumed (conservatively) that the shape of the noise power spectrum density (PSD) is flat so that the Wi-Fi OoB emission can be modelled as AWGN that adds to the UWB receiver’s thermal noise floor (again see Figure 81)

A 6 dB UWB receiver noise figure and Tx + Rx antenna gains of 0 dB are also assumed.



**Figure 81: Noise floor analysis**

The noise floor seen by UWB receiver due to an out-of-band Wi-Fi transmission is illustrated in Figure 81 and can be calculated as

$$N_{0\text{WiFi}} = P_{\text{Tx}} - 10 \log_{10}(BW) - R - P(d)$$

where

- $P_{\text{Tx}}$  = Wi-Fi device's total transmit power in dBm.
- $BW$  = Wi-Fi device's Tx bandwidth, typically either 16.7 MHz or 33.3 MHz in the United State. The first two terms are the Tx PSD in dBm/Hz.
- $R$  = level of attenuation (down from peak Tx PSD) of Wi-Fi OoB emission. Per IEEE 802.11 spectrum mask requirement,  $R$  is at least 40 dB. Spectrum analyser captures of an actual Wi-Fi transmission shows that 45 dB can be considered to be conservative.  $R = 55$  dB is closer to reality for at least some Wi-Fi devices.
- $P(d)$  = path loss in dB between Wi-Fi transmitter and UWB receiver. In this Report path loss is computed in free space conditions using the Friis formula, using a path loss exponent of 2.0:

$$P(d) = 20 \log_{10}(4\pi/\lambda) + 20 \log_{10}(d),$$

And where  $d$  = distance in meters between UWB Rx and Wi-Fi transmitter and  $\lambda$  = Tx wavelength in meters =  $c / 6.5$  GHz.

To assess how a UWB receiver is affected by an out-of-band double-wide Wi-Fi transmission of 14 dBm e.i.r.p. (typical for a Wi-Fi device) at 10 m away, the path loss  $P(10)$  between Wi-Fi transmitter and UWB receiver at distance 10 m can be computed as:

$$P(10) = 20 \log_{10}(4\pi/(c/6.5 \cdot 10^9)) + 20 \log_{10}(10) = 48.7 + 20 = 68.7 \text{ dB}$$

Substituting  $P(10)$  into the above equation for  $N_{0\text{WiFi}}$  yields the following expression for the broadband noise level due to the Wi-Fi transmitter as seen by the UWB receiver:

$$N_{0\text{WiFi}} = 14 - 10 \log_{10}(33.3 \text{ MHz}) - R - P(10) = -130 - R, \text{ (dBm/Hz)}$$

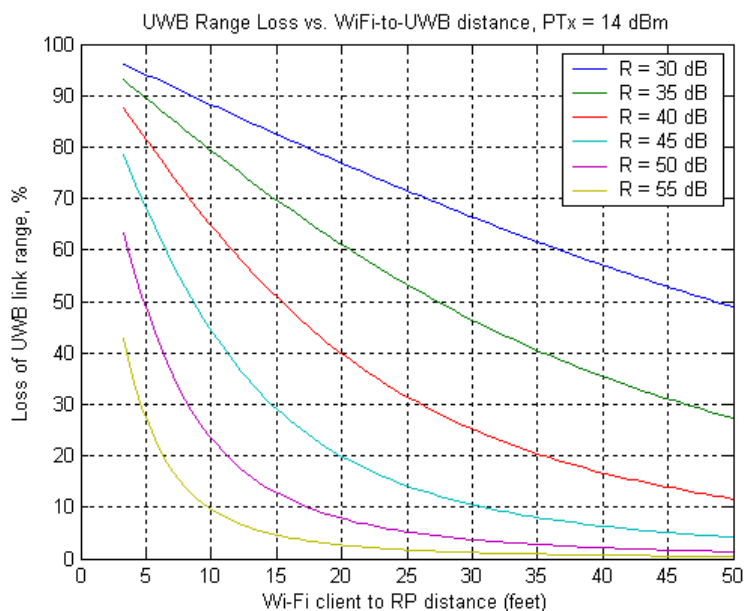
If the Wi-Fi Tx OoB emission barely meets the IEEE 802.11 specifications, then  $R = 40$  dB and  $N_{0\text{WiFi}} = -175$  dBm/Hz.

The UWB receiver has a thermal noise floor of  $N_0 = -168$  dBm/Hz. The Wi-Fi OoB emission will add in a root mean square (RMS) fashion to the thermal noise floor. Thus, the total noise floor is:

$$N_{0\text{Tot}} = 10 \log_{10} \left[ 10^{-\frac{170}{10}} + 10^{-\frac{168}{10}} \right] = -165.9 \text{ dBm} = -168 + 2.1 \text{ dBm}$$

As a result, the Wi-Fi OoB emission coming from a 14 dBm Wi-Fi mobile device 10 m away will desensitise the UWB receiver by 2.1 dB. The impact on the range of the UWB link is  $10 - 2.1/20 = 0.785 =$  about 21% less range than the interference-free case. A 3 dB loss of sensitivity would cause a  $10 - 3/20 = 0.7071 = 30\%$  UWB range impact; a 6 dB desense would cause a 50% range impact.

Using an approach very much like what was used in the previous example, a Matlab simulation was used to characterise UWB receiver range impact as a function of Wi-Fi transmit power  $P_{Tx}$ , distance  $d$  and OoB emission attenuation  $R$ . Results are summarised in Figure 82 below.



**Figure 82: UWB range loss versus separation distance**

Let's assume that Wi-Fi transmissions can be limited:

- in power to +14 dBm,
- in frequency to sufficiently outside of the UWB band so that their OoB emission is attenuated by at least 45 dB relative to the peak Tx PSD per the IEEE 802.11 specification and
- in distance to at most 9 m from a UWB receiver

Then the impact on UWB link range is less than 10%, which is not particularly severe. Note that owners of co-deployed UWB and WAS/RLAN systems in professional settings control all three of these parameters for WAS/RLANs (e.g. e.i.r.p., channel selection and physical placement).

Looking back at how the analysis was performed, one can trade off  $P_{Tx}$  and  $R$  "dB for dB" to explore different scenarios, taking into account possible constraints (e.g. limitations in Wi-Fi Tx output power). For example:

- If OoB emission can be limited to at most 55 dB from peak Tx PSD, the Wi-Fi Tx power can be increased to +24 dBm without causing more than a 10% UWB range impact at 9 m.
- If Wi-Fi OoB emission is exactly 45 dB and Wi-Fi Tx power is increased to +24 dBm at 9 m distance, the impact on UWB range is significant, almost 50%.

It becomes clear that if any Wi-Fi transmissions occur inside the UWB band, the impact on UWB would be severe. This is because UWB link wouldn't benefit from the  $R \geq 45$  dB attenuation it gets when Wi-Fi transmissions are kept out-of-band.

### 11.3.3 Location tracking systems

UWB devices employ bandwidths of up to several GHz, thus allowing centimetre-level localisation and positioning even in the presence of severe multipath effects caused by walls, furniture etc. In UWB location tracking sensors, small mobile or portable tags, operating as either transmitters or receivers or both, are attached to the objects to be located or are carried by personnel within an area under surveillance. A network of fixed equipment around the area to be covered communicates with the tags. The 2D/3D position of the tag can be found by analysing the time-of-arrival and/or angle-of-arrival of the radio signal relative to the known set of reference stations. Typically, the range between a tag and a reference station might be up to 200 m, depending on the area to be observed.

UWB is used within vehicles to prevent relay attacks in passive keyless entry systems. UWB services are also employed in a wide range of environments ranging from IoT connectivity to smart phones, to smart home connectivity, to industrial automation.

Location tracking type 1, LT1, is intended for applications in the frequency band from 6 GHz to 8.5 GHz for indoor, portable and mobile outdoor applications. These regulations were based on the System Reference Document ETSI TR 102 495-3 [72]. Passive keyless entry systems are described in System Reference Document ETSI TR 103 416 [73]. These systems typically offer localisation down to centimetre level accuracy.

ETSI TR 102 495-3 mentions typical ranges from tag to anchor between 10 m and 100 m over which the UWB system can achieve location accuracy below 10 cm.

Location tracking is achieved by an exchange of messages between UWB devices. The measurement campaign in section 11.2 showed the same -78 dBm total power coming from a single WAS/RLAN transmitter at the UWB receiver resulting in 3 dB sensitivity loss. Hence, the results from Table 58 are equally valid for location tracking systems.

### 11.3.4 Sensing applications

The UWB-band frequency range and large available bandwidth make UWB technology very well suited for sensing applications. These parameters enable fine range-resolution combined with good penetration capabilities at an affordable energy and bill of materials cost budget. Most sensing applications are based on radiodetermination detecting various static or dynamic objects and their distance, position, speed etc. either measured from a remote distance or directly coupled to the object. These parameters are calculated based on a very precise and coherent time-of-flight measurement of a transmitted and reflected UWB pulse, enabling range and Doppler information with very high resolution and accuracy (mm-range).

Commercially available products based on such technology are found within industrial, digital health/medical and consumer markets including professional power tools for detecting obstacles in walls, presence sensors, vital-signs monitoring devices and user interface sensors for portable/mobile consumer devices. In the past, most applications were found within professional segments, but recently the focus and market growth are mainly within high-volume markets like digital health, intelligent homes/buildings and consumer devices where the ability to securely and safely detecting human presence, position and vital signs is the main driver.

UWB sensing applications are operated in frequency bands from 3.1 GHz to 4.8 GHz and 6.0 GHz to 9.0 GHz for fixed (indoor only), mobile or portable use. As for communication devices, the technical characteristics of UWB sensing devices are described in ETSI TR 103 181-1 while their use are covered by the harmonised standards ETSI EN 302 065-1, ETSI EN 302 065-3, ETSI EN 302 065-4. More detailed descriptions of certain applications and use-cases may be found in System Reference Documents ETSI TR 103 313 [74] and ETSI TR 103 314 [75].

Table 59 lists the separation distances for the various proposed WAS/RLAN transmit powers that limit the degradation to UWB sensitivity to 3 dB. Based on the results of the measurements, it targets a total power level of -65 dBm coming from a single WAS/RLAN transmitter at the UWB victim receiver.

**Table 59: Separation distances resulting in 3 dB loss to UWB sensor systems from WAS/RLAN transmitter**

WAS/RLAN e.i.r.p. transmit power	Separation distance
1000 mW	212 m
250 mW	106 m
100 mW	67 m
50 mW	47 m
13 mW	24 m
1 mW	7 m
<b>Assumptions</b>	
WAS/RLAN device	1 transmitter, centred at 6335 MHz -78 dBm total power at UWB receiver
UWB device	3 dB sensitivity reduction
Propagation	Free space loss

As many sensor systems have omnidirectional antennas, antenna gain compensation has not been included in the above table. Like in Table 58, a centre frequency of 6335 MHz for the WAS/RLAN system is used.

## 11.4 MONTE CARLO STUDIES FOR AGGREGATE INTERFERENCE

### 11.4.1 UWB apartment block scenario

In a first aggregate interference scenario, the interference to an UWB receiver in an apartment block is considered.

The UWB victim receiver is located in an apartment block that is assumed to be 100 m long, 16 m wide and 10 floors high. Each individual apartment is 10 m by 8 m. Floors are assumed to be 3.5 m high. On average, there are 3 people living in an apartment.

The UWB victim and the WAS/RLAN interferers are spread randomly throughout the building. Each person's WAS/RLAN is active on average 1.97% of the time. This is combined with a license factor, busy hour factor, 6 GHz factor and market adoption factor as shown in Table 13 of Section 3.2 to give three resulting curves, corresponding to Low, Mid and High deployment.

WAS/RLAN power is randomly distributed according to weighted average WAS/RLAN e.i.r.p. from Section 3.1.1.4. The WAS/RLAN bandwidth is chosen according to the distribution in Section 4.2.4. A channel index is then randomly chosen. Only channels that overlap with the UWB bandwidth are taken into account.

The indoor path loss model from IEEE 802.11ax channel model B (IEEE 802.11-14/0882r4) is used. Following the model, a building entry loss of 5 dB is used.

The results of the Monte Carlo simulations are shown in Figure 83 and Figure 84. Half a million iterations were run for every simulation.



Figure 83 considers UWB systems with 500 MHz centred at 6.5 GHz. The red line is the value of -78 dBm, which causes 3 dB degradation to the UWB communication and location tracking systems. There is 0.2% probability that this value is exceeded.

Figure 84 considers UWB systems with 1 GHz bandwidth centred on 6.5 GHz. As this wider bandwidth is mainly used for sensing applications, the red line corresponds is at -65 dBm, the value at which these suffer 3 dB sensitivity degradation. There is a 0.1% probability that this value is exceeded.

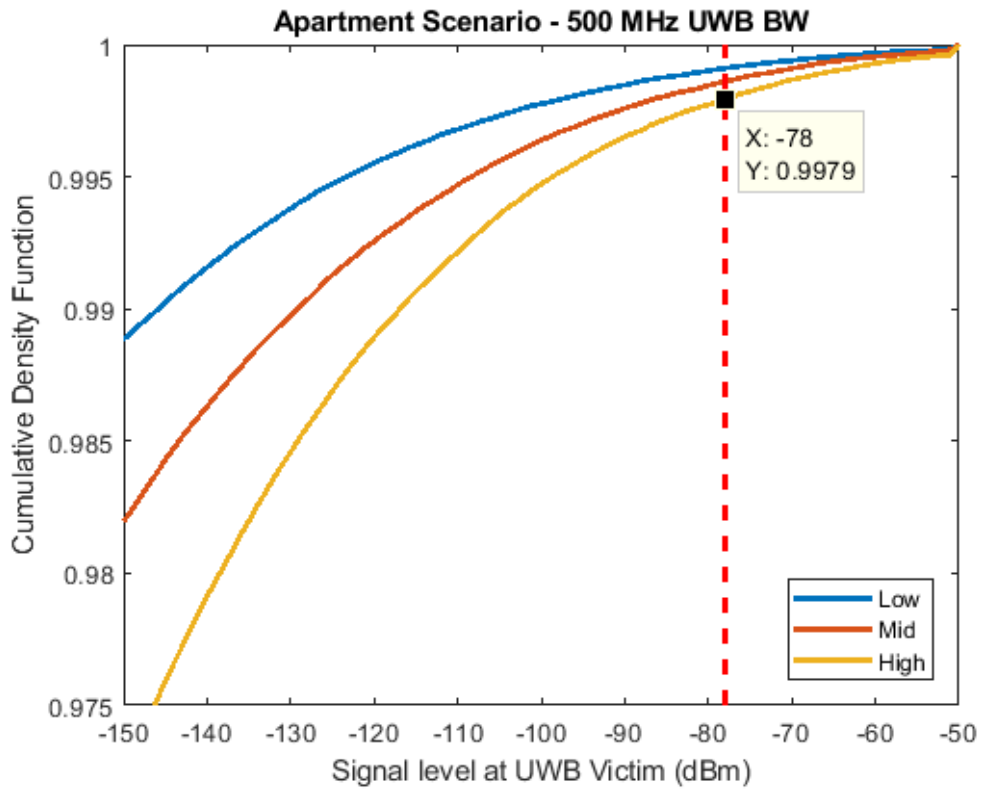
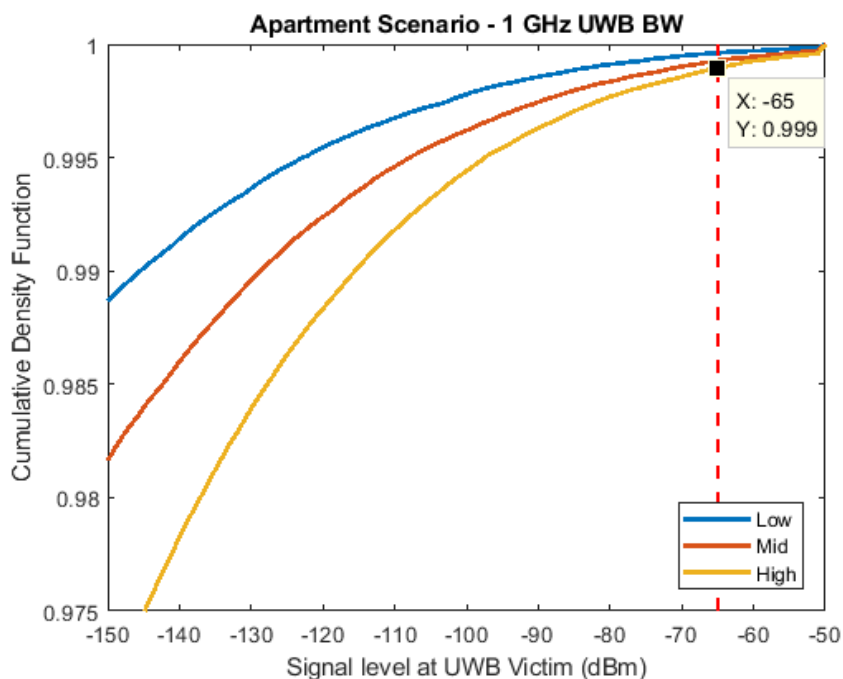


Figure 83: Monte Carlo results UWB apartment block scenario - 500 MHz UWB bandwidth

Table 60: Monte Carlo results UWB apartment block scenario - 500 MHz UWB bandwidth

Deployment Scenario	Probability of WAS/RLAN power > -65 dBm
Low	0.079%
Mid	0.13%
High	0.21%



**Figure 84: Monte Carlo results UWB apartment block scenario - 1 GHz UWB bandwidth**

**Table 61: Monte Carlo results UWB apartment block scenario - 1 GHz UWB bandwidth**

Deployment Scenario	Probability of WAS/RLAN power > -65 dBm
Low	0.042%
Mid	0.067%
High	0.10%

#### 11.4.2 UWB London scenario

In this aggregate interference scenario, it is assumed that a random person in the city of London is trying to use an UWB receiver at their home.

Statistics of the total population and population density per borough are available from <https://data.london.gov.uk/dataset/london-borough-profiles>. Projections of the population in 2025 from <https://data.london.gov.uk/dataset/projections/> ('Central trend') are used. A random borough is chosen with a probability proportional to its number of inhabitants.

Based on the results of the MCL studies, the UWB receiver is assumed to be at the centre of a 1 by 1 kilometre square. The square is randomly populated with people according to the population density of the chosen borough. At any moment in time, 1.97% of the population is assumed to have an active WAS/RLAN transmission. This is combined with a license factor, busy hour factor, 6 GHz factor and market adoption factor as shown in Table 13 of Section 3.2 to give three resulting curves, corresponding to Low, Mid and High deployment.

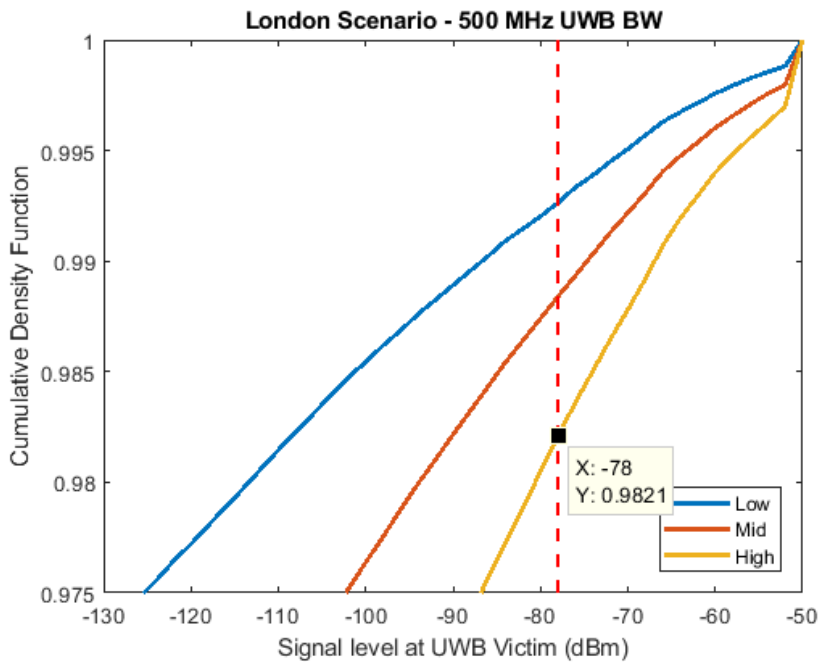
WAS/RLAN power is randomly distributed according to weighted average WAS/RLAN e.i.r.p. from Section 3.1.1.4. The WAS/RLAN height distribution for sub-urban indoor homes from Section 4.2.2 is used to distribute the WAS/RLAN randomly in height. The WAS/RLAN bandwidth is chosen according to the

distribution in Section 3.1.4. A channel index is then randomly chosen. Only channels that overlap with the UWB bandwidth are taken into account.

The site general path-loss model for propagation between terminals located from below roof-top height to near street level from Recommendation ITU-R P.1411-9 is used in combination with building entry loss on both sites of the link, i.e. both the WAS/RLAN transmitter and UWB receiver are assumed to be indoors. Buildings have 30% probability of being thermally efficient, with a building entry loss of 32.2 dB. Otherwise, the building entry loss is assumed to be 16.7 dB.

Monte Carlo simulation has been run for half a million iterations per curve.

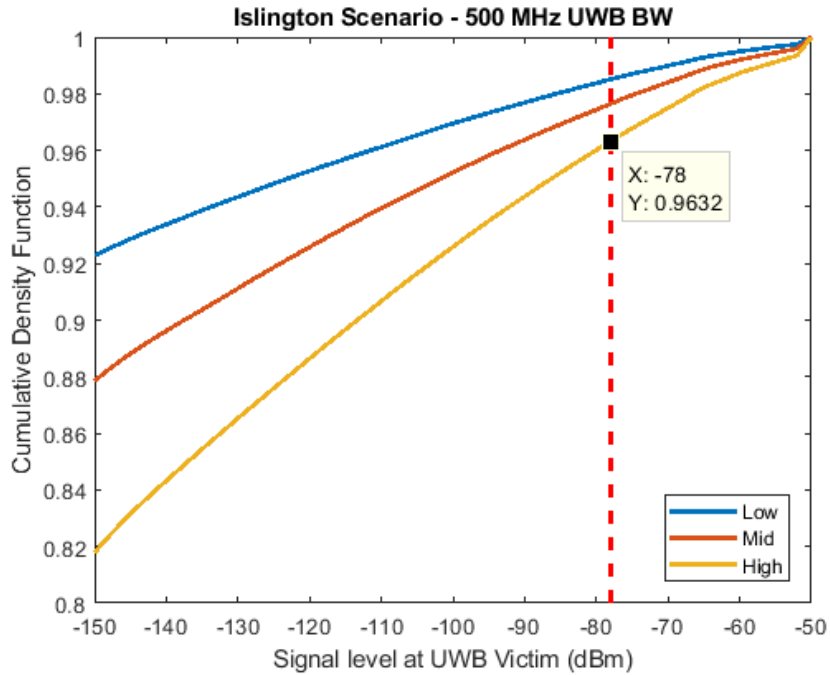
Figure 85 considers UWB systems with 500 MHz centred at 6.5 GHz. The red line is the value of -78 dBm, which causes 3 dB degradation to the UWB communication and location tracking systems. There is 1.8% probability that this value is exceeded. This result is very depended on the probability of having nearby WAS/RLAN transmitters. That can be seen from Figure 86, which has the results of the same simulation restricted to the most densely populated borough Islington. In that borough, the probability having more than 3 dB sensitivity degradation is increased to 3.7%.



**Figure 85: Monte Carlo results UWB London scenario - 500 MHz UWB bandwidth**

**Table 62: Monte Carlo results UWB London scenario - 500 MHz UWB bandwidth**

Deployment Scenario	Probability of WAS/RLAN power > -78 dBm
Low	0.74%
Mid	1.2%
High	1.8%



**Figure 86: Monte Carlo results UWB Islington scenario - 500 MHz UWB bandwidth**

**Table 63: Monte Carlo results UWB Islington scenario - 500 MHz UWB bandwidth**

Deployment Scenario	Probability of WAS/RLAN power > -78 dBm
Low	1.5%
Mid	2.4%
High	3.7%

The equivalent results for UWB system using 1 GHz bandwidth are shown in Figure 87 and Figure 88 respectively. As this wider bandwidth is mainly used by sensing applications, the red dashed line is at -68 dBm, the value at which those applications experience more than 3 dB sensitivity degradation. Averaged over all of London, the probability that that happens is 0.9%. In the most densely populated borough of Islington, this probability doubles to 1.9% due to the increased chance of being closer to a WAS/RLAN transmitter.

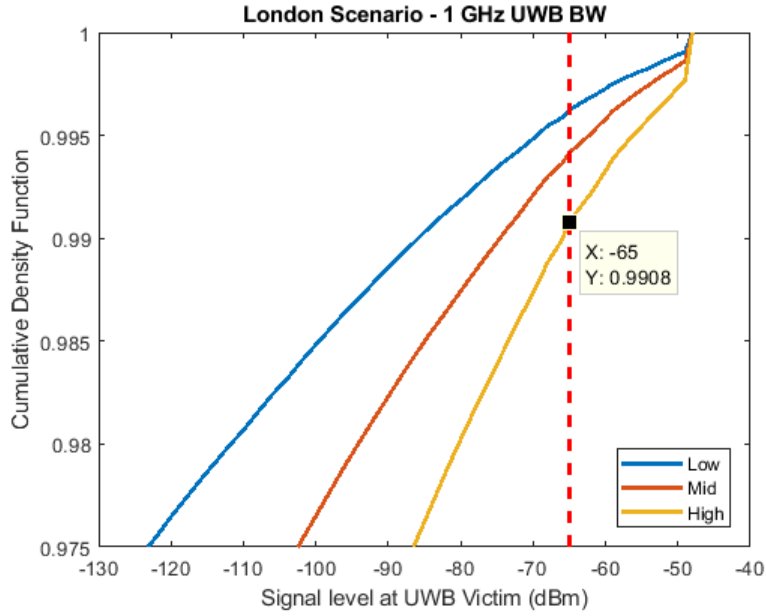


Figure 87: Monte Carlo results UWB London scenario - 1 GHz UWB bandwidth

Table 64: Monte Carlo results UWB London scenario - 1 GHz UWB bandwidth

Deployment Scenario	Probability of WAS/RLAN power > -65 dBm
Low	0.37%
Mid	0.58%
High	0.92%

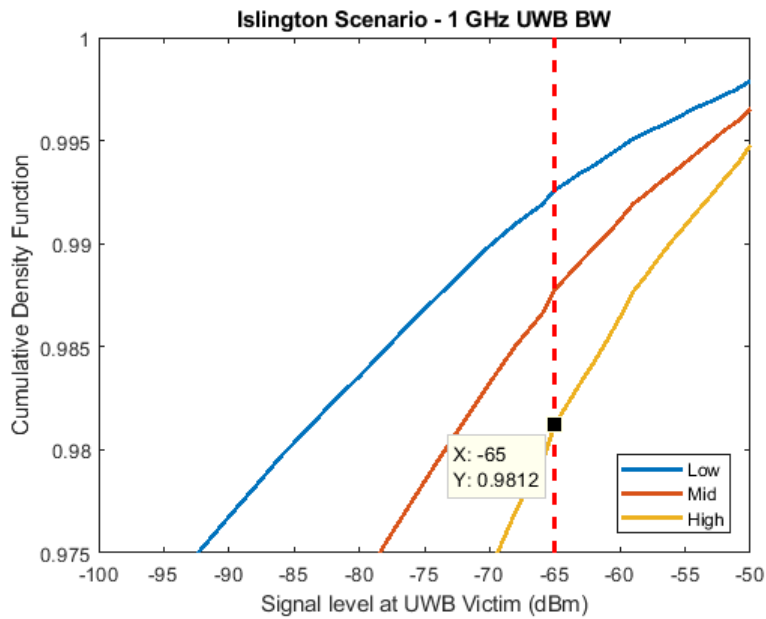


Figure 88: Monte Carlo results UWB Islington scenario - 1 GHz UWB bandwidth

**Table 65: Monte Carlo results UWB Islington scenario - 1 GHz UWB bandwidth**

Deployment Scenario	Probability of WAS/RLAN power > -65 dBm
Low	0.74%
Mid	1.2%
High	1.9%

### 11.4.3 UWB vehicular access scenario

In this Section, UWB based vehicular access to a car parked outside an apartment block is considered.

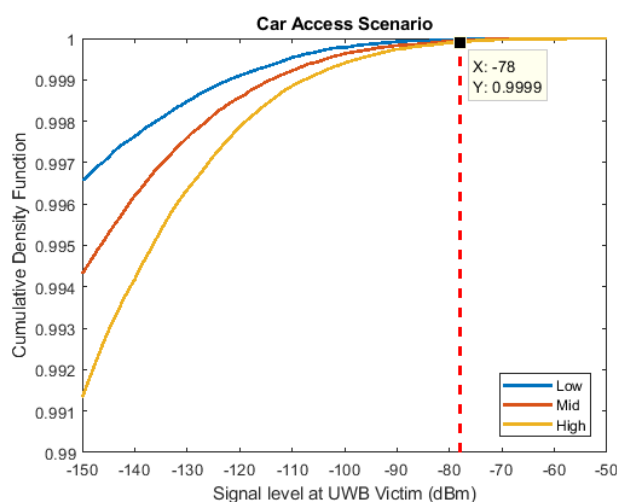
The UWB victim is an UWB passive keyless entry unit, located on a car parked in the middle of the apartment block considered in Section 11.4.1. The apartment block is assumed to be 100 m long, 16 m wide and 10 floors high. Each individual apartment is 10 m by 8 m. Floors are assumed to be 3.5 m high. On average, there are 3 people living in an apartment. The car is parked in the middle of the building, 5 m in front of it.

The UWB victim and the WAS/RLAN interferers are spread randomly throughout the building. Each person's WAS/RLAN is active on average 1.97% of the time. Like before, a centre frequency of 6335 MHz for the WAS/RLAN system is used. WAS/RLAN power is randomly distributed according to weighted average WAS/RLAN e.i.r.p. from Section 3.1.1.4. This is combined with a license factor, busy hour factor, 6 GHz factor and market adoption factor as shown in Table 13 of Section 3.2 to give three resulting curves, corresponding to Low, Mid and High deployment.

The indoor path loss model from IEEE 802.11ax channel model B (IEEE 802.11-14/0882r4) is combined with an extra building entry loss. Following the model, a building entry loss of 5 dB is used. The apartment block has 30% probability of being thermally efficient, with a building entry loss of 32.2 dB. Otherwise, the building entry loss is assumed to be 16.7 dB.

For every curve in Figure 89, half a million iterations of the Monte Carlo simulation were run.

UWB car access units are a form of UWB communications and location tracking devices usually operating in 500 MHz bandwidth. Therefore, the limit at -78 dBm is evaluated. Figure 89 shows that the probability that the sensitivity degradation is more than 3 dB is exceeded equals 0.01%.

**Figure 89: Monte Carlo results UWB vehicular access scenario**

**Table 66: Monte Carlo results UWB vehicular access scenario**

Deployment Scenario	Probability of WAS/RLAN power > -65 dBm
Low	0.0024%
Mid	0.003%
High	0.0048%

## 11.5 SUMMARY ON THE COEXISTENCE BETWEEN UWB AND WAS/RLAN

Single interference scenario, minimum coupling loss study has shown that WAS/RLAN interferers up to 946 m away cause more than 3 dB sensitivity reduction in UWB communications and location tracking systems. For sensing applications, the equivalent distance is 212 m.

Aggregate interference evaluation with Monte Carlo simulations show that even when taking the WAS/RLAN RF activity factor into account, the probability that the sensitivity reduction to UWB communications and location tracking devices exceeds 3 dB can be up to 3.3%. For sensing device, the probability that the sensitivity reduction is more than 3 dB is up to 1.7%<sup>3</sup>.

The introduction of WAS/RLAN as specified in this report could have an impact on the applications and users of studied UWB systems that can only operate over the frequency range under study in this Report.

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<sup>3</sup> For simplicity, the Monte Carlo study assumes a constant RF activity factor WAS/RLAN transmitter interfering with a constant RF activity factor UWB receiver. It does not consider the probability of coincidence of real-world WAS/RLAN and UWB transmissions.

## 12 CONCLUSIONS

This Report contains sharing and compatibility studies between WAS/RLAN systems and existing incumbent systems in the 5925-6425 MHz band and adjacent bands, in line with the EC Mandate on 6 GHz [1].

Studies have been performed in order to assess sharing and compatibility scenarios for WAS/RLANs in the 5925-6425 MHz band and identify technical conditions that would enable coexistence between existing usages and WAS/RLAN systems without constraining incumbent uses in CEPT countries, in the band 5925-6425 MHz and adjacent to that band.

The studies rest on an agreed set of inputs including parametric inputs and distributions which are detailed in Sections 3 and 4 of the Report. The Report covers sharing and compatibility scenarios based on models of 2025 deployments.

Section 5 of the Report addresses modelling issues, methodologies and approaches that are common to all studies. This includes agreed propagation and loss models on terrestrial paths and earth-to-space paths.

Sections 6-11 of the Report set out the study results for each sharing and compatibility system. Each of these Sections is summarised below. Note that the detailed descriptions of specific elements of each study are provided in a separate annex.

### 12.1 SHARING BETWEEN WAS/RLAN AND FS

In order to investigate sharing potential between WAS/RLAN and FS, both Minimum Coupling Loss (MCL) and Monte Carlo analyses were performed.

In the first study (A), based on an MCL approach, two different types of areas have been identified where a single WAS/RLAN could possibly exceed the protection criterion: a circular area which has a relatively small radius and a peak area which has a relatively large extent down the boresight. This keyhole shaped area is due to the FS antenna pattern (see ITU-R Recommendation F.699 [37]).

Sensitivity analyses have taken into account different WAS/RLAN e.i.r.p. density levels, indoor and outdoor deployments, population density types, FS and WAS/RLAN antenna heights, FS antenna gains and building types. The short term interference was not assessed in this study.

For the long term protection threshold  $I/N = -10$  dB, which relates to co-primary status for mobile service as given in the ECA table [2], the range of required separation distances has been calculated:

- Circle distances are found to be varying from 43 m to 4017 m, peak distances are found to be varying from 48 m to 40400 m.

For the long term protection threshold  $I/N = -20$  dB, which relates to the systems that do not have a co-primary status, the range of required separation distances has been calculated:

- Circle distances are found to be varying from 72 m to 4017 m, peak distances are found to be varying from 103 m to 47100 m.

Sensitivity analyses showed that reduction of the power density level or indoor use are examples of measures that can be taken to reduce the calculated separation distances.

MCL calculations have revealed critical scenarios, but did not allow final conclusions to be made about the statistical likelihood of occurrence of these scenarios. Therefore, a statistical approach based on Monte Carlo studies was carried out.

A second study (B) looking at providing results for a statistical approach, analysed the publicly available population of fixed links in United Kingdom (UK) and the Netherlands. The results of this Monte Carlo study show that the long term interference criterion is met ( $I/N = -10$  dB not exceeded for more than 20% of time). Furthermore, Fractional Degradation in Performance (FDP) was assessed in study B, the results show



that although the FDP < 10%, which is a complementary protection criterion, was exceeded for some of the links studied in the UK, some of the scenarios seemed to lead to interference events that were highly improbable, but may occur as a result of the parameters of the Monte Carlo simulations that were carried out. It is assumed that these situations would be unlikely to occur. However, if only indoor deployment with a maximum e.i.r.p. of 200 mW is considered, the studies showed that all but 2 cases of FDP exceedances were resolved. Under those conditions, the study considered sharing to be feasible.

A third study (C) assessed two sets of complementary simulations based on three existing FS receivers in France. First, an interference coverage mapping approach studied the geographical area from where a WAS/RLAN (indoor 250 mW and outdoor 1 W) would exceed the interference threshold of  $I/N = -10$  dB. It indicated that allowing outdoor WAS/RLAN operating with an e.i.r.p. of 1 W would create interference from a large area around the FS link, depending on the terrain profile. However, when restricting the usage to indoor only utilizing an e.i.r.p. up to 250 mW the possible interfering area is substantially reduced, bringing the interference area within close proximity to the FS receiver. These simulations also showed that when WAS/RLANs are within close proximity of some FS receivers, the short term protection threshold of 19 dB is exceeded (even in the indoor case). In terms of time percentage, this appears to be more critical compared with the long term protection criterion. Indeed, considering the WAS/RLAN 2% RF activity factor, the short term protection threshold for an access point situated within this area will be exceeded more than the  $4.5 \cdot 10^{-4}\%$  tolerated value, given that the conditions modelled in the static analysis persist over time. A complementary statistical study based on a Monte Carlo approach, using the WAS/RLAN parameters distributions described in this Report, indicated that the I/N value of -10 dB was not exceeded for more than 20% of the time as advised by Recommendation ITU-R F.758 [33] for the long term protection criterion. The short term protection criterion was exceeded for two of the three studied links, the number of iterations performed in the study did not allow the assessment of the short term protection criterion for the third studied link.

## 12.2 SHARING BETWEEN WAS/RLAN AND FSS

Studies have been performed in order to assess compatibility and coexistence scenarios for WAS/RLANs and the FSS in the 5925-6425 MHz band and identify technical conditions allowing to enable coexistence between existing usages and WAS/RLAN systems without constraints to the incumbents in CEPT countries.

Studies assumed a representative set of FSS satellites with coverage over Europe.

Two studies were conducted to assess aggregate interference from WAS/RLAN into FSS receivers in space, assuming WAS/RLAN deployment models in Europe by 2025. Study A employs a Monte Carlo methodology involving stochastic inputs to the WAS/RLAN deployment model for the Mid scenario, while study B delivers a static analysis based on average values for the Low, Mid and High scenarios detailed in the Report in Table 13. The number of instantaneously transmitting WAS/RLANs within the FSS receive bandwidth used in the simulations are given in Table 76. The statistical study A has shown that the obtained level is consistent over the Monte Carlo runs.

Studies show that the calculated levels of interference are highly sensitive to some WAS/RLAN parameters and assumptions in the study, including but not limited to the RF activity factor of WAS/RLAN devices.

Study A considers the Mid scenario for a representative set of FSS satellites. The results show that the protection criterion of  $I/N = -10$  dB is satisfied with more than 8.5 dB of margin available in all cases. Service apportionment was not taken into account. The margins found in study A show that sharing is feasible on the basis of the technical parameters agreed for FSS and WAS/RLAN systems for the Mid scenario, with no constraints on WAS/RLAN deployment or operations.

Study B also considers a representative set of existing FSS satellites (as well as a potential future satellite) and the WAS/RLAN deployment model in Europe by 2025 in accordance with Low, Mid and High scenarios. For the studies that were carried out using agreed Low, Mid and High WAS/RLAN deployment numbers with other agreed baseline parameters, the results showed that no instances of excess of interference were found to the FSS receivers studied. However, for the most sensitive satellite case in the High scenario the calculated levels of interference were close to the FSS protection criteria used in this study (i.e. -13.5 dB, including 3 dB service apportionment), with the smallest margin equal to 0.5 dB when assuming a BEL (14 dB) for normal building types only.

As part of Study B additional analysis looked at the sensitivity of the results by increasing the proportion of outdoor WAS/RLAN usage above the agreed baseline parameter (up to 5%). The results showed that for the high scenario that aggregate interference was sometimes close to or exceeded the interference threshold slightly for the most sensitive satellites studied. These results highlight the risk of excess interference should higher power outdoor usage increase beyond that specified in the agreed baseline parameters. This concern and potential risk could be addressed by controlling the usage of higher power WAS/RLAN devices operating outdoors.

Considering coexistence conditions for uncontrolled WAS/RLAN use, taking steps such as limiting the use to indoor only deployment and/or introducing an e.i.r.p. limit, would help further ensuring long term protection of FSS space stations from aggregate interference from WAS/RLAN devices in the band 5925-6425 MHz.

### **12.3 COMPATIBILITY BETWEEN WAS/RLAN AND ROAD-ITS**

One adjacent-band compatibility study, using the MCL methodology, was conducted to assess the impact of WAS/RLAN out-of-band (OoB) emission on Road-ITS below 5925 MHz, considering a protection criterion of  $I/N = -6$  dB. WAS/RLAN deployment scenarios of indoor, outdoor (fixed AP and portable device) and in-vehicle were studied. The results of this compatibility study show that, depending on the scenario, the WAS/RLAN OoB emissions below 5925 MHz should meet a limit between -69 dBm/MHz and -36 dBm/MHz for the main-lobe case and between -59 dBm/MHz and -26 dBm/MHz for the side-lobe case. The scenario where the ITS antenna is integrated inside the vehicle resulted in the most stringent requirement. However, it is noted that this scenario is unlikely to occur since the ITS antennas are usually installed outside the vehicle. The indoor usage scenario results in the least stringent requirement for WAS/RLAN OoB emissions below 5925 MHz.

### **12.4 SHARING AND COMPATIBILITY BETWEEN WAS/RLAN AND CBTC**

A first study, using the MCL methodology, assesses the adjacent band coexistence between WAS/RLAN and Communication based train control (CBTC) below 5935 MHz, both WAS/RLAN OoB and in-band emissions were studied. Different scenarios taking into account both indoor only (inside a building) and outdoor (fixed AP and portable device) were studied. The indoor usage scenario results in the least stringent requirement for WAS/RLAN OoB and in-band emissions.

The study shows that, if considering an indoor only WAS/RLAN operation, a density of OoB WAS/RLAN emission of -29 dBm/5 MHz is sufficient to ensure the CBTC operation.

When comparing the results achieved assuming WAS/RLAN operation starting at 5940 MHz and 5935 MHz, it is found that the WAS/RLAN operation above 5940 MHz is less restrictive for the WAS/RLAN emissions. In that case, an in-band e.i.r.p. of 21.5 dBm/20 MHz for indoor WAS/RLAN usage in adjacent channels (restricted to the first 20 MHz WAS/RLAN) would fulfil the CBTC blocking requirement for the three studied CBTC technologies.

Concerning the portable device in adjacent channels, studies show that a density of OoB WAS/RLAN emission of -42 dBm/5 MHz and an e.i.r.p. density of 4.7 dBm/20 MHz (WAS/RLAN first channel starting at 5940 MHz) are sufficient to ensure the CBTC operation.

Another study, also using the MCL methodology, investigated the impact of WAS/RLAN devices coexisting in the same frequency band as the Copenhagen S-train CBTC system. The results present the required minimum distance between the WAS/RLAN device and CBTC receiver to avoid the interference from the WAS/RLAN device. This distance ranges from 180 to 600 m. If S-train and WAS/RLAN share the same frequency band, it is very probable that WAS/RLAN devices will be present within these distances. Dedicated mitigations techniques, to be locally applied, may need to be defined.

## 12.5 COMPATIBILITY BETWEEN WAS/RLAN AND RADIO ASTRONOMY SERVICE

The number of Radio Astronomy Service (RAS) sites in Europe observing in this frequency range is small, possibly around 19. The local environment of each site is very well understood. Compatibility between WAS/RLAN and those sites could be addressed on a case-by-case basis at national level.

An I/N threshold can be used to derive a contour around the RAS site following applicable ITU-R Recommendations and taking into account the details of the site and possibly the typical observation schedule. The contours, which can be considered as a coordination zone or exclusion zone, represent a zone which needs to be managed by the regulator.

## 12.6 COEXISTENCE BETWEEN WAS/RLAN AND ULTRA WIDE BAND (UWB) SYSTEMS

A minimum coupling loss study of a range of e.i.r.p. levels (from 0 dBm to 30 dBm) has shown that an individual WAS/RLAN interferer between 30 m and 946 m away, respectively, causes more than 3 dB sensitivity reduction in UWB communications and location tracking systems. For UWB sensing applications, the equivalent distances range from 7 m to 212 m.

Aggregate interference evaluations with Monte Carlo simulations show that when taking the WAS/RLAN RF activity factor into account, the probability that the sensitivity reduction to UWB communications and location tracking devices exceeds 3 dB ranges from 0.0024% to 3.3% depending on the scenario considered. For UWB sensing devices, the probability that the sensitivity reduction is more than 3 dB varies from 0.042% to 1.7%.

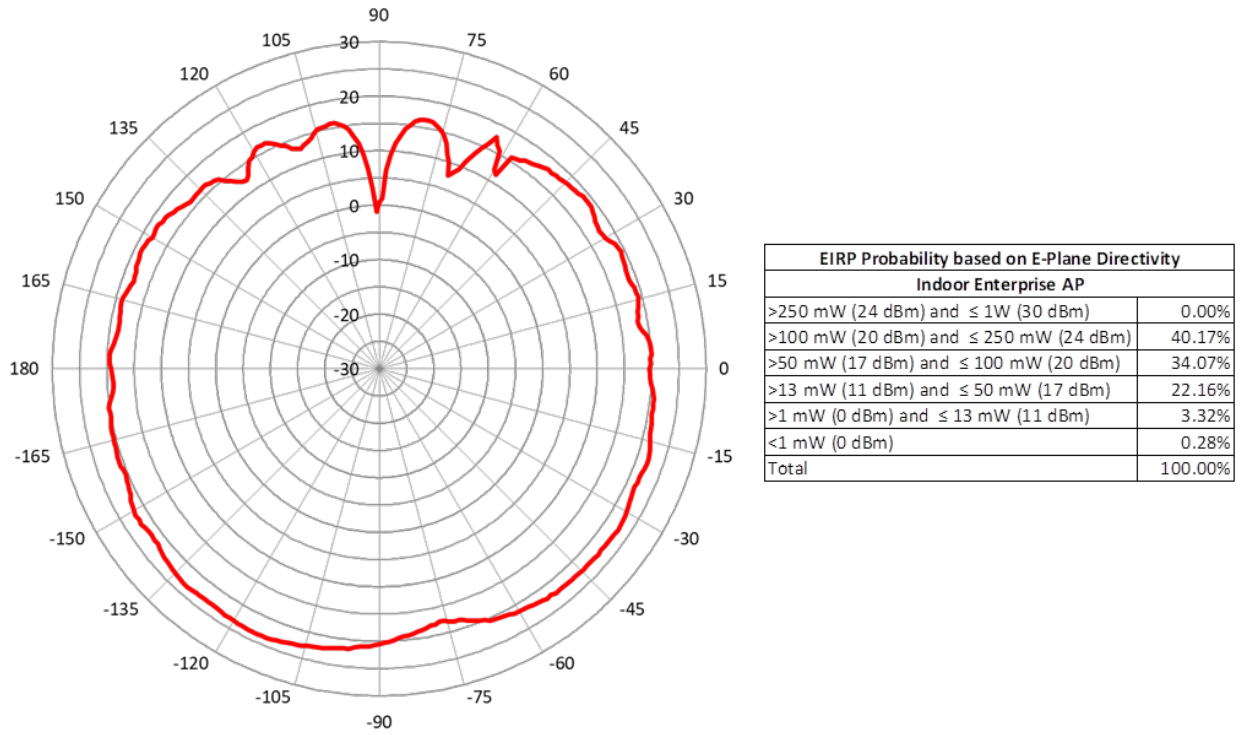
The introduction of WAS/RLANs as specified in this Report could have an impact on the applications and users of studied UWB systems that can only operate over the frequency range under study in this Report.

### 13 AREAS FOR FURTHER COMPLEMENTARY WORK

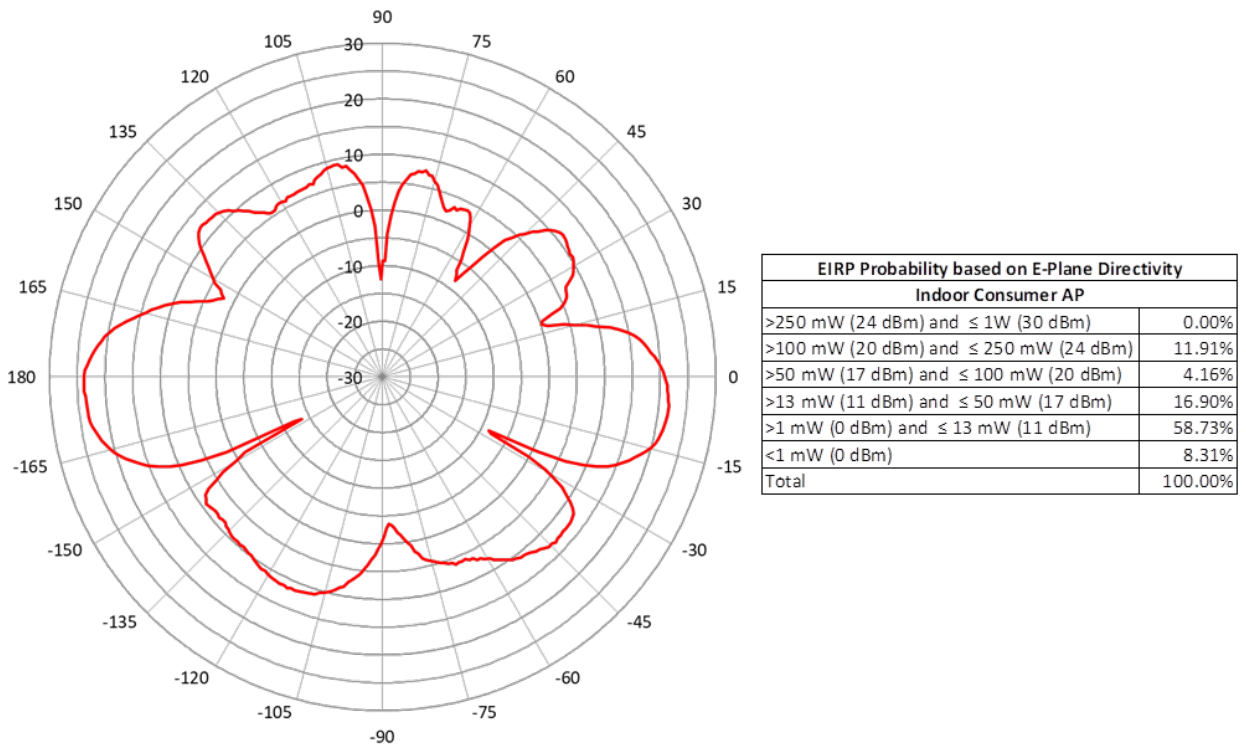
The results in this Report show that sharing is feasible under certain conditions. There are some areas that are highlighted below, where additional complementary technical studies could be carried out, such as:

- Complementary studies on sharing with fixed service, covering the robustness of fixed link equipment to the intermittent nature of WAS/RLAN interference at different receiver input levels and different I/N, C/I and C/(I+N) values/thresholds, could possibly give more margin for sharing. Additionally, the effect of the increase to minimum fade margins may have on the sharing results could also be studied. Some further analysis of very low power portable WAS/RLAN devices that may operate outdoor could be performed.
- Mitigation techniques not studied in this Report may need to be investigated in order to maintain the protection of the FS where studies have shown there could be marginal or severe cases of interference (e.g. data base use for coordination).
- Explore further the type of limitations and technical conditions that would be needed to allow a regime for higher power outdoor usage.

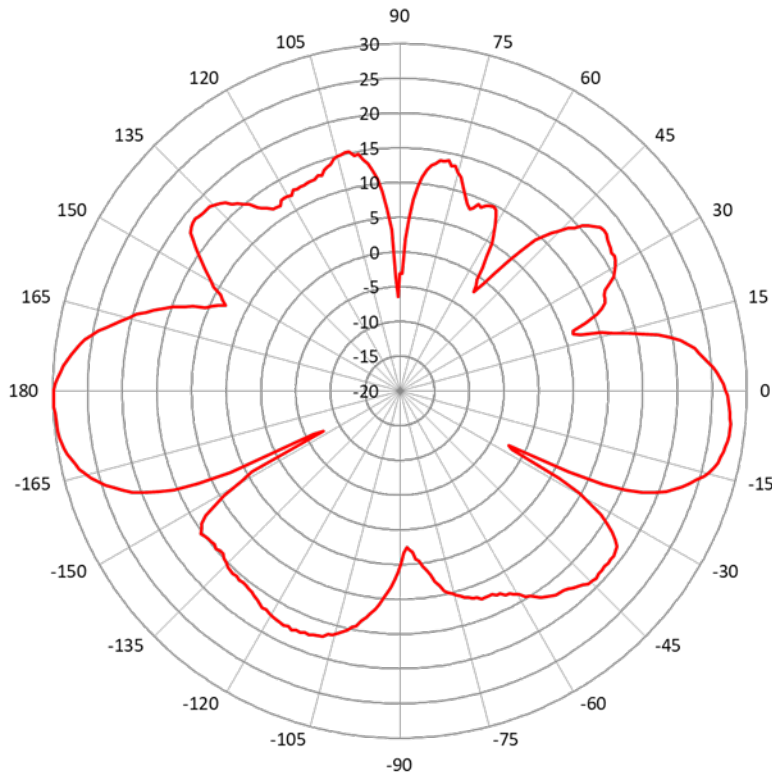
**ANNEX 1: E-PLANE ANTENNA PATTERNS FOR WAS/RLAN ACESS POINTS**



**Figure 90: e.i.r.p. probability based on E-plane directivity for indoor enterprise AP**

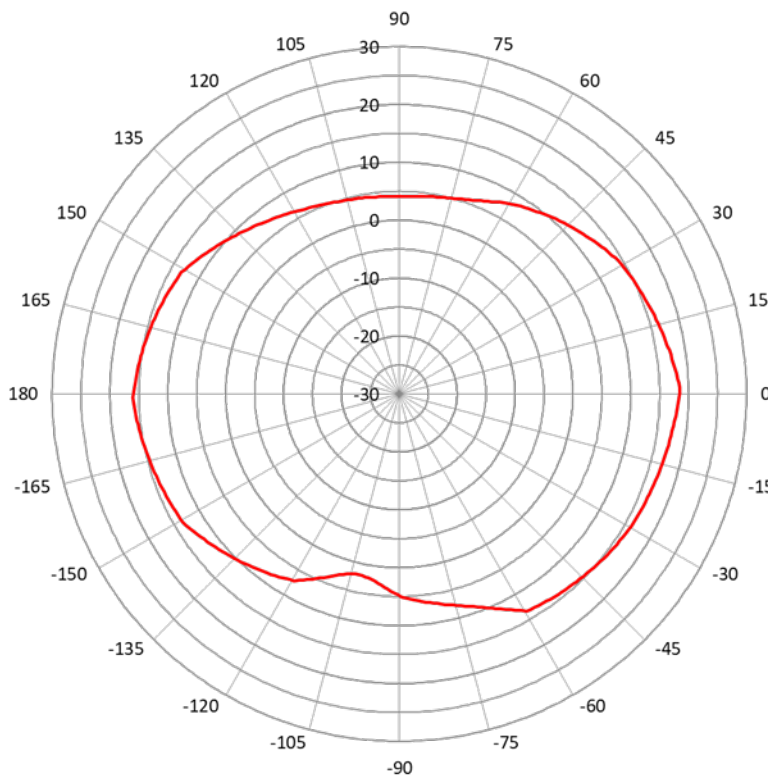


**Figure 91: e.i.r.p. probability based on E-plane directivity for indoor consumer AP**



EIRP Probability based on E-Plane Directivity	
Indoor High Performance Gaming Router	
>250 mW (24 dBm) and ≤ 1W (30 dBm)	14.96%
>100 mW (20 dBm) and ≤ 250 mW (24 dBm)	4.16%
>50 mW (17 dBm) and ≤ 100 mW (20 dBm)	15.51%
>13 mW (11 dBm) and ≤ 50 mW (17 dBm)	41.55%
>1 mW (0 dBm) and ≤ 13 mW (11 dBm)	20.50%
<1 mW (0 dBm)	3.32%
Total	100.00%

Figure 92: e.i.r.p. probability based on E-plane directivity for indoor high performance gaming router



EIRP Probability based on E-Plane Directivity	
Indoor/Outdoor Client	
>1W (30 dBm) and ≤ 4W (36 dBm)	0.00%
>250 mW (24 dBm) and ≤ 1W (30 dBm)	0.00%
>100 mW (20 dBm) and ≤ 250 mW (24 dBm)	0.00%
>50 mW (17 dBm) and ≤ 100 mW (20 dBm)	6.93%
>13 mW (11 dBm) and ≤ 50 mW (17 dBm)	45.71%
>1 mW (0 dBm) and ≤ 13 mW (11 dBm)	47.37%
<1 mW (0 dBm)	0.00%
Total	100.00%

Figure 93: e.i.r.p. probability based on E-plane directivity for indoor/outdoor client

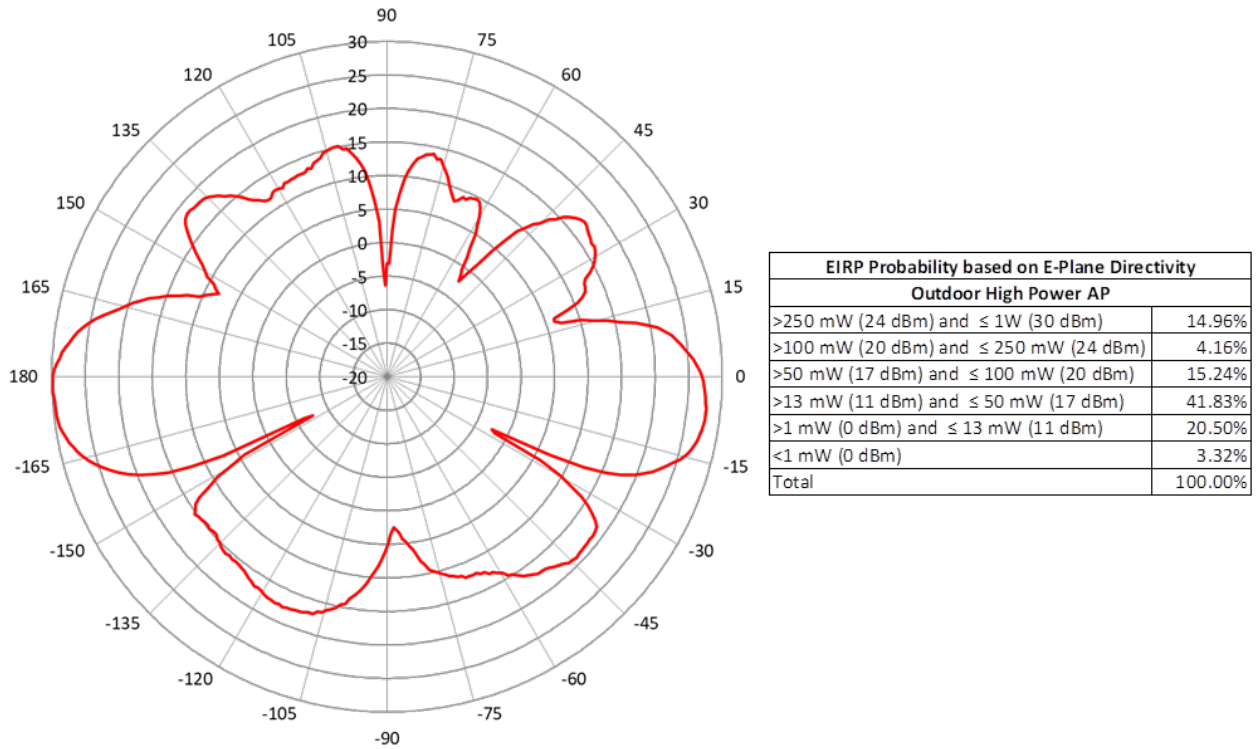


Figure 94: e.i.r.p. probability based on E-plane directivity for outdoor high power AP

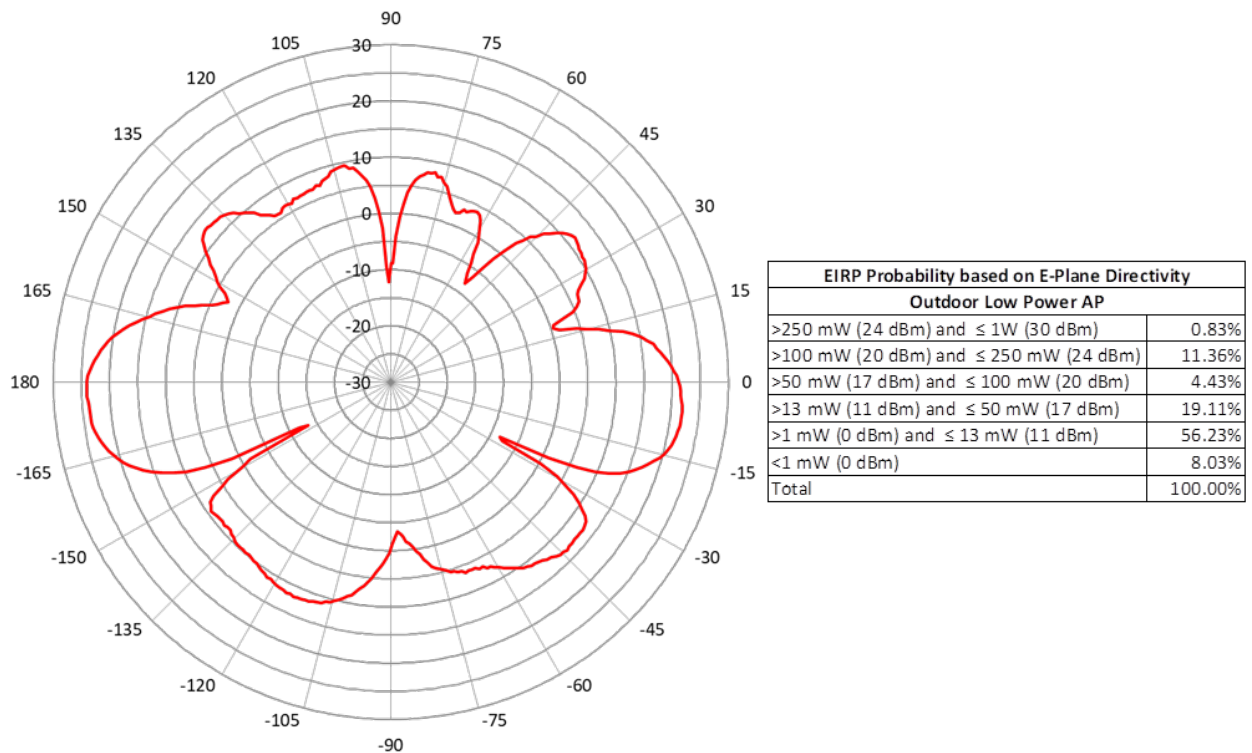
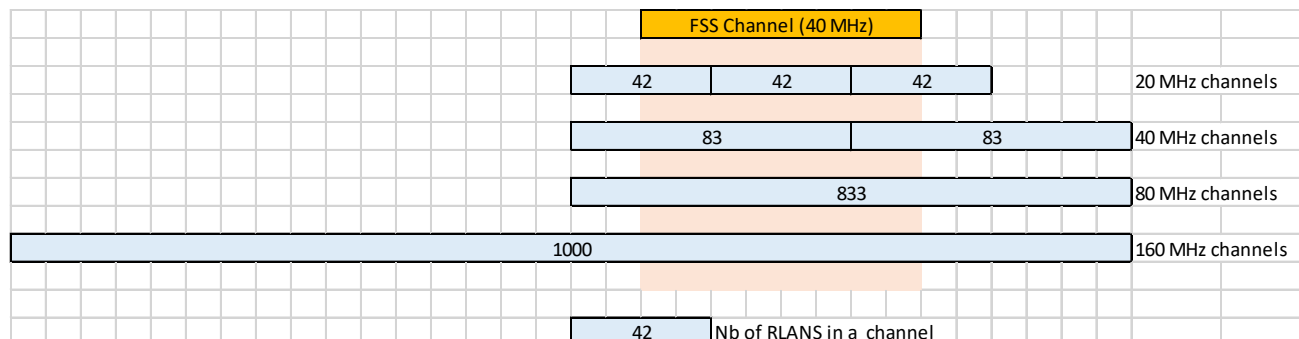


Figure 95: e.i.r.p. probability based on E-plane directivity for outdoor low power AP

## ANNEX 2: NUMBER OF ACTIVE, ON-TUNE, APS OPERATING AT 6 GHZ DURING BUSY HOUR, INCIDENT TO A 40 MHZ VICTIM RECEIVER BANDWIDTH

The FSS vs WAS/RLAN case can be depicted as in Figure 96 (assuming an example of 10000 WAS/RLAN in the 6 GHz band considered in this Report, i.e. 5925 MHz to 6425 MHz).



**Figure 96: WAS/RLAN channels incident to a 40 MHz FSS receiver bandwidth**

This corresponds to an FSS band overlapping:

- 3 channels of 20 MHz;
- 2 channels of 40 MHz;
- 1 channel of 80 MHz; and
- 1 channel of 160 MHz.

It should be read in conjunction with the following Table 67.

**Table 67 : Number of WAS/RLAN APs for different WAS/RLAN channels**

WAS/RLAN Channels	# of channels	Percentage of WAS/RLAN	# of WAS/RLAN per bandwidth	# of WAS/RLAN per channel
20 MHz	24	10%	1000	42
40 MHz	12	10%	1000	83
80 MHz	6	50%	5000	833
160 MHz	3	30%	3000	1000
Number of WAS/RLAN in the 6 GHz range				10000

The situation, therefore, represents a total of  $(3 \times 42 + 2 \times 83 + 1 \times 833 + 1 \times 1000) = 2125$  WAS/RLAN overlapping the FSS channel.

There are 2 options to handle such situation and consider the effective aggregate e.i.r.p. produced by WAS/RLAN within the 40 MHz FSS channel:

**Option 1:** to consider the different bandwidth factors pertaining to the different channels and that will apply to the corresponding WAS/RLAN within each channel

**Option 2:** to normalise the number of WAS/RLAN in each channel as an equivalent number of WAS/RLAN fully within the FSS channel

### A2.1 OPTION 1

Step by step each of the WAS/RLAN channels bandwidth can be considered.



### A2.1.1 For 20 MHz channels

The first 20 MHz channel overlaps 1/2 the FSS channel. This is, therefore, equivalent to having 42 WAS/RLAN with a bandwidth factor of 0.5 (linear).

The second 20 MHz channel overlaps fully the FSS channel. This is, therefore, equivalent to having 42 WAS/RLAN without bandwidth factor or a bandwidth factor of 1 (linear).

The third 20 MHz channel overlaps 1/2 the FSS channel. This is, therefore, equivalent to having 42 WAS/RLAN with a bandwidth factor of 0.5 (linear).

In summary, this is, therefore, equivalent to having 126 WAS/RLAN using 20 MHz channels with an average bandwidth factor of  $((0.5 \times 42 + 1 \times 42 + 0.5 \times 42)/126) = 0.667$  (rounded to 0.7 in step1).

### A2.1.2 For 40 MHz channels:

The first 40 MHz channel overlaps 3/4 the FSS channel. This is, therefore, equivalent to having 83 WAS/RLAN with a bandwidth factor of 0.75 (linear).

The second 40 MHz channel overlaps 1/4 the FSS channel. This is, therefore, equivalent to having 83 WAS/RLAN with a bandwidth factor of 0.25 (linear).

In summary, this is, therefore, equivalent to having 166 WAS/RLAN that use 40 MHz channels with an average bandwidth factor of  $((0.75 \times 83 + 0.25 \times 83)/166) = 0.5$ .

### A2.1.3 For 80 MHz channel:

The 80 MHz channel overlaps 1/2 the FSS channel. Therefore, 833 WAS/RLAN with a bandwidth factor of 0.5 (linear) exist.

### A2.1.4 For 160 MHz channel

The 160 MHz channel overlaps 1/4 the FSS channel. This is, therefore, equivalent to having 1000 WAS/RLAN with a bandwidth factor of 0.25 (linear).

Assuming the 80 mW (19 dBm) average e.i.r.p. per WAS/RLAN (based on the e.i.r.p. distribution), one can then calculate the aggregate e.i.r.p. based on the above assumptions.

**Table 68: Option 1. Calculation of the aggregated e.i.r.p.**

WAS/RLAN Channels	Average e.i.r.p. (mW)	Number of WAS/RLAN	Bandwidth factor	Aggregate e.i.r.p. (mW)
20 MHz	80	126	0.66666	6720
40 MHz	80	166	0.5	6640
80 MHz	80	833	0.5	33320
160 MHz	80	1000	0.25	20000
TOTAL		2125		66680 48.24 dBm
Note: this represent an average of $(48.24 - 10\log(2125))=14.97$ dBm per WAS/RLAN in the FSS band, thus an average $(19 - 14.97)=4.03$ dB bandwidth factor.				

As a summary, option 1 leads to 21.3% of the total number of WAS/RLAN in the FSS band with an average e.i.r.p. of 14.97 dBm (or an average 4.03 dB bandwidth factor).

## A2.2 OPTION 2

Step by step, each of the WAS/RLAN channels bandwidth can be considered.

### A2.2.1 For 20 MHz channels

The first 20 MHz channel overlaps 1/2 the FSS channel. This is, therefore, equivalent to having  $42/2 = 21$  equivalent WAS/RLAN fully in the FSS channel.

The second 20 MHz channel overlaps fully the FSS channel. This is, therefore, equivalent to having 42 WAS/RLAN fully in the FSS channel.

The third 20 MHz channel overlaps 1/2 the FSS channel. This is, therefore, equivalent to having  $42/2 = 21$  equivalent WAS/RLAN fully in the FSS channel.

In summary, this is equivalent to  $(21 + 42 + 21) = 84$  WAS/RLAN transmitting fully in the FSS channel.

### A2.2.2 For 40 MHz channels

The first 40 MHz channel overlaps 3/4 the FSS channel. This is, therefore, equivalent to having  $83 \times 3/4 = 62.25$  WAS/RLAN fully in the FSS channel.

The second 40 MHz channel overlaps 1/4 the FSS channel. This is, therefore, equivalent to having  $83 \times 1/4 = 20.75$  WAS/RLAN fully in the FSS channel.

In summary, this is equivalent to  $(62.25 + 20.75) = 83$  WAS/RLAN transmitting fully in the FSS channel.

### A2.2.3 For 80 MHz channel:

The 80 MHz channel overlaps 1/2 the FSS channel. This is, therefore, equivalent to having  $833/2 = 416.5$  WAS/RLAN transmitting fully in the FSS channel.

### A2.2.4 For 160 MHz channel:

The 160 MHz channel overlaps 1/4 the FSS channel. This is, therefore, equivalent to having  $1000/4 = 250$  WAS/RLAN transmitting fully in the FSS channel.

Assuming the 80 mW (19 dBm) average e.i.r.p. per WAS/RLAN (based on the e.i.r.p. distribution), one can then calculate the aggregate e.i.r.p. based on the above assumptions.

**Table 69: Option 2. Calculation of the aggregated e.i.r.p.**

WAS/RLAN Channels	Average e.i.r.p. (mW)	Number of RLAN	Bandwidth factor	Aggregate e.i.r.p. (mW)
20 MHz	80	84	1 (0 dB)	6720
40 MHz	80	83	1 (0 dB)	6640
80 MHz	80	416.5	1 (0 dB)	33320
160 MHz	80	250	1 (0 dB)	20000
TOTAL		833.5		66680 48.24 dBm

As a summary option 2 leads to 8.33% of the total number of WAS/RLAN in the FSS band with an average e.i.r.p. of 19 dBm.

### **A2.3 CONCLUSION**

Both options handle the WAS/RLAN vs FSS from different angles but lead to a similar end result, i.e. an aggregate e.i.r.p. of 48.24 dBm in the FSS channel for the example of 10000 WAS/RLAN over the whole 6 GHz band.

**ANNEX 3: WAS/RLAN DEPLOYMENT MODEL**

This Annex provides further detail, rationale and evidence in support of inputs to the WAS/RLAN deployment model set out in Section 3.2 of this Report.

**A3.1 TOTAL POPULATION OF EUROPE 2025**

Table 70 gives the human populations of the current CEPT Member countries in 2025. The population of the 48 CEPT Member Countries is expected to be 768 589 000 in 2025 [10]. This list excludes populations in Azerbaijan, Georgia and regions of the Russian Federation beyond the Moscow Time Zone shown in Figure 97.



UTC Time Zone Offsets are Standard Time. Colors represent time observance which may vary from legislated time.

**Figure 97: Time zone map**

**Table 70: The human populations (thousands) of CEPT Member countries in 2025**

<b>Geo/Time</b>	<b>2025</b>
Total CEPT Population	768 589
Albania	2 947
Andorra	78
Austria	8 879
Belarus	9 311
Belgium	11 819
Bosnia and Herzegovina	3 456
Bulgaria	6 694
Croatia	4 003
Cyprus	1 247
Czech Republic	10 613
Denmark	5 913
Estonia	1 280
Finland	5 669
France	66 842
Germany	82 455
Greece	10 945
Hungary	9 439
Iceland	355
Ireland	5 064
Italy	58 623
Latvia	1 813
Liechtenstein	40
Lithuania	2 788
Luxembourg	642
Malta	439
Moldova	3 943
Monaco	40
Montenegro	628
Norway	5 707
Poland	37 373
Portugal	10 048
Romania	18 927
Russian Federation	81 628

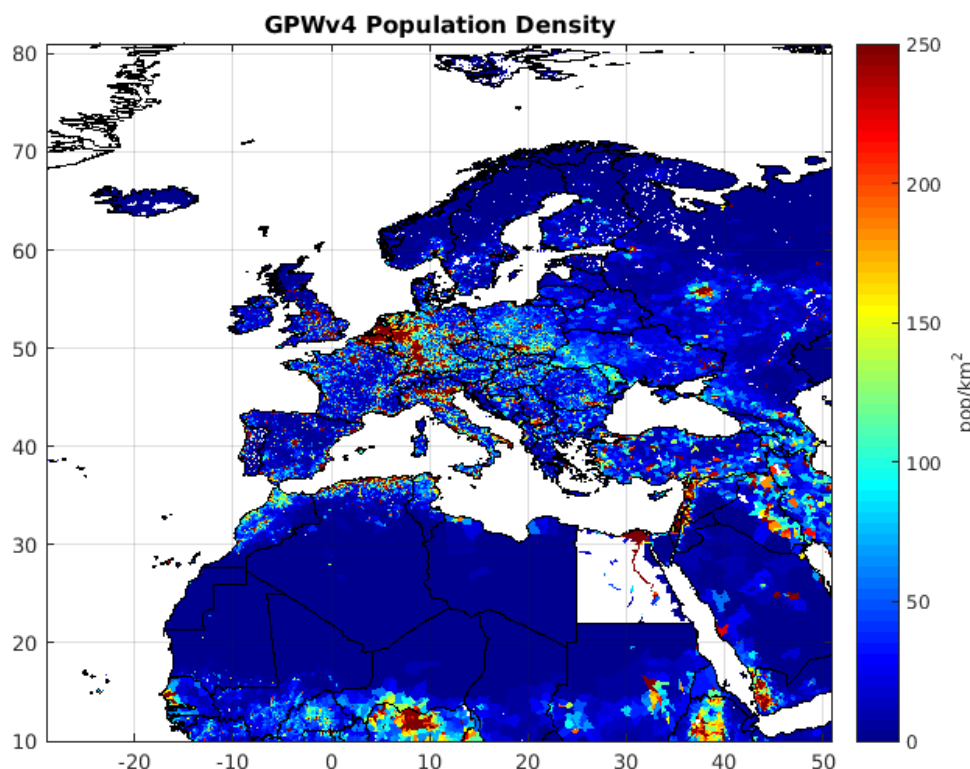
Geo/Time	2025
San Marino (Republic of)	34
Serbia (Republic of)	8 541
Slovak Republic	5 438
Slovenia	2 076
Spain	46 307
Sweden	10 435
Switzerland	8 955
North Macedonia	2 088
The Netherlands	17 414
Turkey	86 125
Ukraine	42 453
United Kingdom	69 074
Vatican	1

### A3.2 SPATIAL DISTRIBUTION OF WAS/RLANS

To characterise the spatial characteristics of WAS/RLAN interference into other services such as FS, it is necessary to estimate the spatial distribution of WAS/RLANs throughout the impacted areas. In sharing scenarios involving terrestrial services in particular, the resolution of such a spatial estimate is often of key importance. For example, the high directivity of point-to-point microwave antennas exhibit a similarly high degree of spatial selectivity, which effectively isolates specific regions where such a system can be more sensitive to WAS/RLAN interference under some circumstances.

A common method to determine a large number of terminal positions in a wide-area aggregate interference scenario is to generate a weighting function or joint probability distribution to probabilistically synthesise positions for terminals. Such weighting functions may be generated from and/or highly correlated to common geographic characteristics such as population density.

One dataset that is readily available for use in weighting function generation is the Gridded Population of the World V4 (GPWv4) from NASA's Socioeconomic Data and Applications Center (SEDAC). GPWv4 provides a global composite raster grid of population density at 30 arcsecond resolution (approximately 1 km at the equator) using population estimates for the years 2000, 2005, 2010, 2015 and 2020. This dataset can also be supplemented with national population projections from other sources for intermediate or extrapolated years through linear scaling approximations over administration boundaries. Refer to Figure 98 for a plot of population density in 2020 generated using the GPWv4 population density dataset. The horizontal and vertical coordinates are in longitude and latitude, respectively.



**Figure 98: European population map projected for 2020 (GPWv4 dataset)**

### A3.3 MARKET ADOPTION FACTOR

The Mid value Market Adoption factor of 32% is based on the following analysis. From a population of 1.9 billion WAS/RLAN devices currently in use throughout Europe, 600 million new devices come into play each year and 20% of existing devices are replaced. The percentage of new devices equipped to operate at 6 GHz is assumed to be 10% in 2020, 20% in 2021, 30% in 2022, 40% in 2023 and 50% in 2024 and thereafter. This approach delivers a Market Penetration Factor of 30.86% in 2025.

### A3.4 RF ACTIVITY FACTOR

This input is the RF activity factor per person during busy hour. An RF factor of 1.97% per person was used in this study based on projected European data demand in 2025 and the RF activity factor measurements for streaming video provided in ANNEX 7. An RF activity factor per person can be converted to an RF activity factor per household by multiplying 1.97% by the average household size.

### A3.5 BUSY HOUR DATA RATE

An analysis of the typical wireless demand for the corporate, public hotspot and residential use cases [11] found that the demand for high activity mode devices operating in a residence is going to be much higher than other use cases. It is assumed that this is because one of the largest drivers for wireless data consumption is to transmit video within the residence. Streaming HD video requires a throughput of 4-5

Mbps.<sup>4</sup> Assuming nearly everyone is consuming HD video with no down-time, this leads to an average throughput of 4.44 Mbps (16 Gbytes/hour).

While HD video is also consumed in the corporate and public hotspot environments, it was determined to be significantly less for these use-cases. For the corporate user, a significant amount of traffic goes over wired as well as wireless infrastructure. In addition, there are many other activities consumed in the enterprise environment other than streaming video (e.g. word processing, meetings). Based on this, 1 Gbyte/hour is conservatively assumed as an average wireless consumption requirement in the corporate use case (2.22 Mbps)<sup>5</sup>.

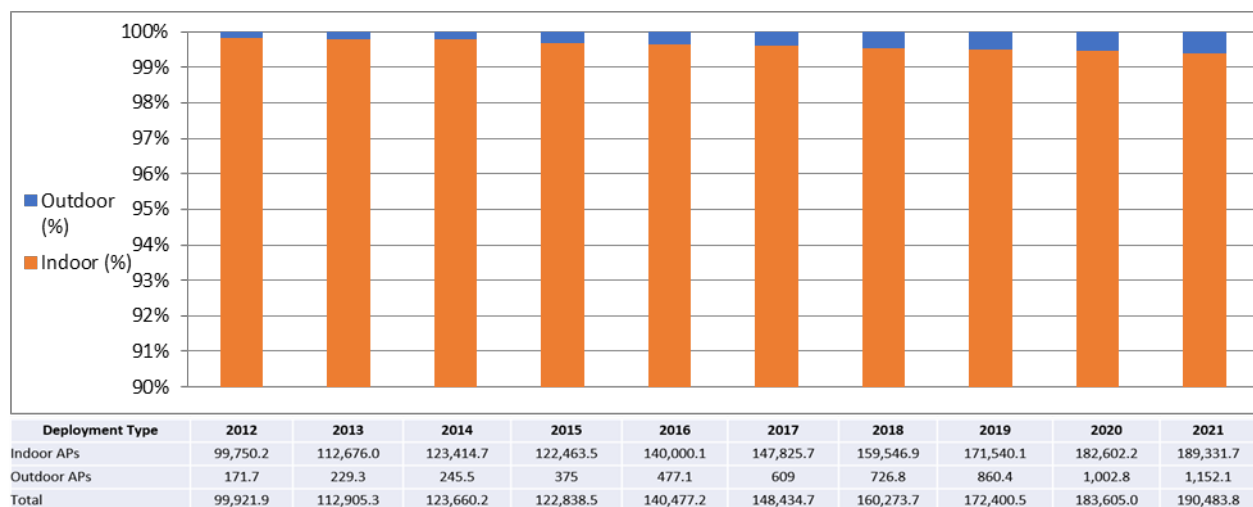
For public hotspot use, streaming video is an expected use case but it is more intermittent with average session length being shorter than the corporate and residential use-cases. Web browsing and other lower data rate activities are expected to consume activity time. It was assumed that 500 Mbytes/hour (1.11 Mbps) on average for each public (hotspot connected) user was well beyond the typical demand.

On the basis of this analysis, the residential use-case was considered to be the most conservative modelling available for the sharing studies.

### A3.6 INDOOR/OUTDOOR DEPLOYMENTS

Indoor/outdoor ratios for WAS/RLAN are based on an analysis of shipping and forecast data for Wi-Fi and small cell technologies.

Figure 99 depicts the ratio of indoor vs outdoor Wi-Fi AP shipments from 2011 to 2021, including actual shipment figures for Wi-Fi APs through 2016 as well as a forecast for future years. Outdoor unit shipments in 2021 are estimated at 0.6% of all Wi-Fi APs.



**Figure 99: Worldwide indoor vs outdoor Wi-Fi shipments (thousands) [86].**

Table 71 depicts a small cell forecast of 3GPP based technologies, such as License Assisted Access (LAA), of 1.5 million outdoor units in 2021<sup>6</sup>.

<sup>4</sup> Netflix recommends a bit rate for HD Video of 5 Mbps, see: <https://help.netflix.com/en/node/306>; Hulu recommends 3 Mbps for 720p

<sup>5</sup> Per Cisco VNI published June 16, 2017, "[a]n average business user might generate 4 GB per month of Internet and WAN traffic. A large-enterprise user would generate significantly more traffic, 8–10 GB per month (Table 14)". This is orders of magnitude less than the 1 GB per hour than is forecasted for residential.

<sup>6</sup> 5G Americas and Small Cell Forum, Multi-operator and Neutral Host Small Cells: Drivers, Architectures, Planning and Regulation,



**Table 71: Small Cell Forum forecast for outdoor small cell shipments (thousands)**

	2014	2015	2016	2017	2018	2019	2020	2021	CAGR
Indoor	176	310	794	1080	1901	2946	3420	3239	52%
Outdoor	47	78	251	441	937	1387	1466	1596	66%
Total	223	388	1045	1521	2838	4333	4886	4835	55%

Combining the forecast for small cell and Wi-Fi devices for the outdoor market is 1% of total units worldwide in 2021, and then doubling this for 2025 leads to a ratio for indoor/outdoor WAS/RLANs of 98% indoor and 2% outdoor.

## ANNEX 4: SELECTION OF PROPAGATION MODELS FOR MCL WAS/RLAN-FS ANALYSIS

In this analysis, the most appropriate propagation model will be chosen for MCL compatibility studies between WAS/RLANs and FS. The following propagation models are analysed:

- WINNER II model as described in "WINNER II Part I Channel Models" deliverable (WINNER II);
- WINNER II model as described in Report ITU-R M.2135-1 (WINNER II M.2135);
- Propagation model as described in Recommendation ITU-R P.452-16 (P.452);
- Propagation model as described in Recommendation ITU-R P.525-3 (P.525);
- Propagation model as described in Recommendation ITU-R P.1411-9 Section 4.2.1 (P.1411).

In addition, the following models are considered to be added to propagation models (e.g. when there is no description for non line of sight (NLOS) conditions):

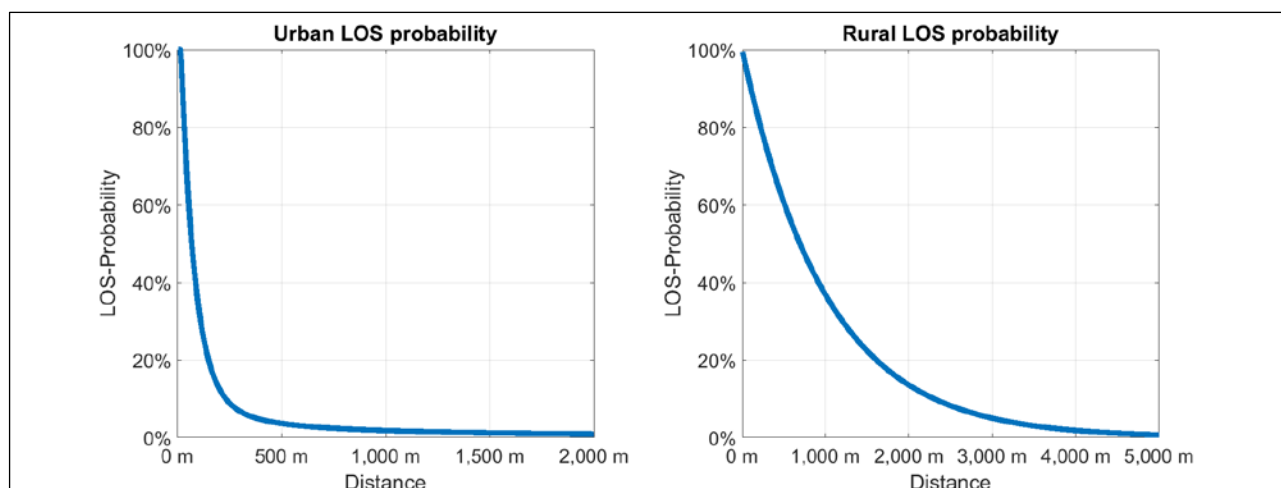
- Clutter loss as described in Recommendation ITU-R P.2108-0 (P.2108);
- Clutter loss as described in Recommendation ITU-R P.452-16 (P.452) for rural environments;
- Building entry loss as described in Recommendation ITU-R P.2109-0 (P.2109);
- It has to be noted that no examination of the time percentage of P.452 and of the percentage of P.2109 have been conducted. These values have to be determined in the main study.

### A4.1 DEFINING LINE OF SIGHT (LOS) AND NLOS AREAS

The "WINNER II Part I Channel Models" deliverable [52] in Table 4-7 describes the probability for line of sight (LOS) situations. These formulas are given in Table 72 and the probabilities have been plotted below in Figure 100 in order to calculate applicability ranges for LOS conditions. The scenarios of interest are C2 (urban outdoor) and D1 (rural outdoor). According to the equations nonline of sight (NLOS) conditions begin at 1000 m for the urban scenario and at 4017 m for the rural scenario. For this analysis it was assumed that LOS probability has to be less than 1.8% to start with NLOS conditions. This should for urban environments reflect the description of break point distances in the WINNER II deliverables.

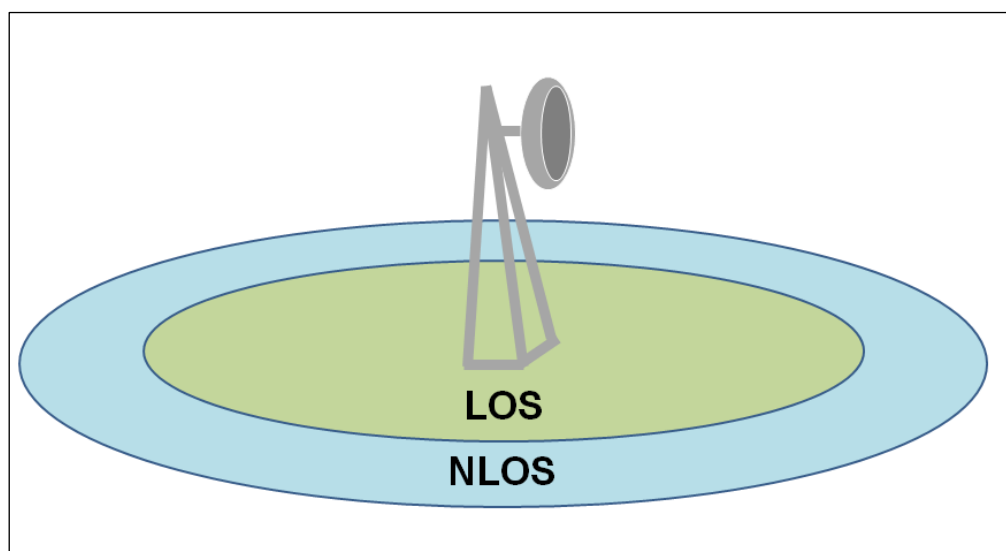
**Table 72: Formulas for LOS probabilities**

Scenario	LOS probability as function of distance d [m]	Note
A1	$P_{\text{LOS}} = \begin{cases} 1, & d \leq 2.5 \\ 1 - 0.9(1 - (1.24 - 0.61 \log_{10}(d))^3)^{1/3}, & d > 2.5 \end{cases}$	
B1	$P_{\text{LOS}} = \min(18/d, 1) \cdot (1 - \exp(-d/36)) + \exp(-d/36)$	
B3	$P_{\text{LOS}} = \begin{cases} 1, & d \leq 10 \\ \exp\left(-\frac{d-10}{45}\right), & d > 10 \end{cases}$	For big factory halls, airport and train station
C1	$P_{\text{LOS}} = \exp\left(-\frac{d}{200}\right)$	
C2	$P_{\text{LOS}} = \min(18/d, 1) \cdot (1 - \exp(-d/63)) + \exp(-d/63)$	
D1	$P_{\text{LOS}} = \exp\left(-\frac{d}{1000}\right)$	



**Figure 100: LOS probabilities for urban and rural scenarios**

It can be concluded that the area around a FS receiver is characterised by LOS conditions followed by non line of sight (NLOS) conditions. An illustration of that behaviour is shown in Figure 101.

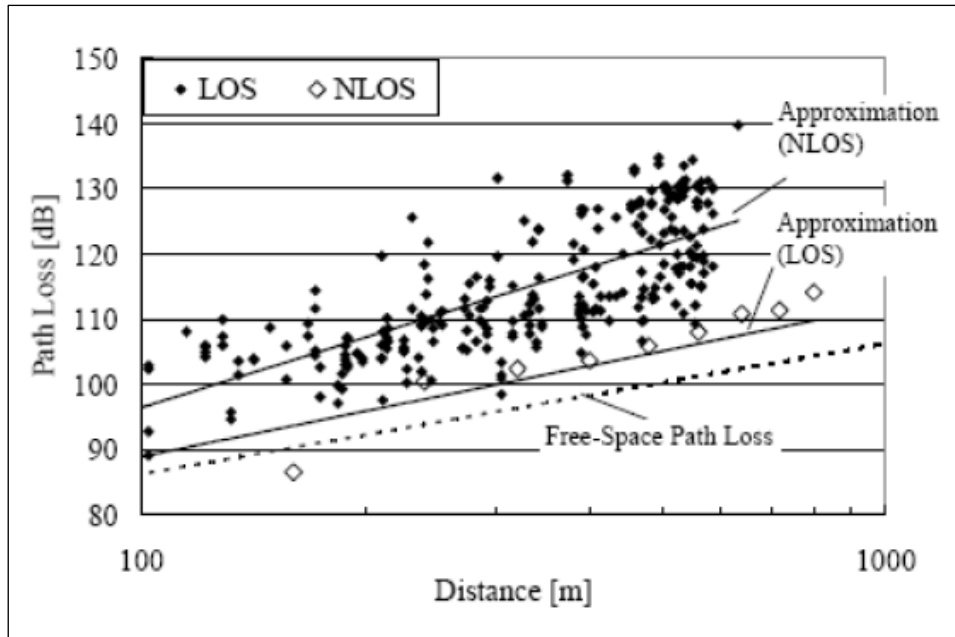


**Figure 101: Illustration of LOS and NLOS areas**

For indoor scenarios, building entry loss is added to all models following Recommendation ITU-R P.2109. This does not change the comparison of propagation models. Additionally, measurements (Figure 102) used to validate the proposed models had been made outdoors. Therefore, building entry loss has not been regarded for the choice of propagation models.

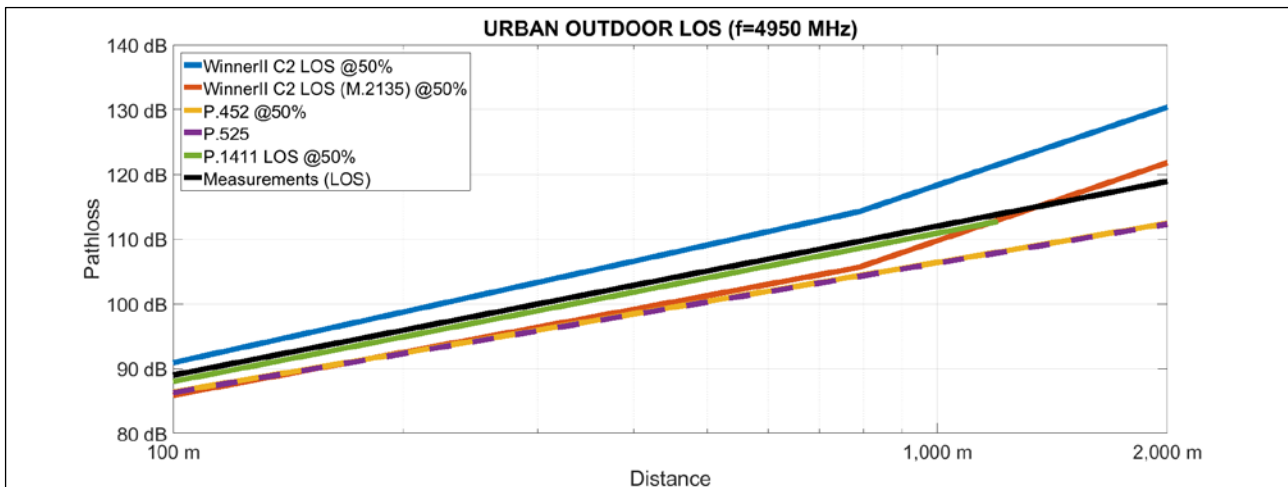
#### **A4.2 PROPAGATION MODEL: URBAN LOS (0 - 1000 M)**

For urban LOS scenarios, a propagation model has to be chosen which does not deviate strongly compared to the Free Space Loss Model Recommendation ITU-R P.525. The frequency of 4.95 GHz will be used to get comparable results to measurements which were made at a frequency of 4.95 GHz. These measurements which had been shown in "WINNER II Part II Radio Channel Measurement and Analysis Results" deliverable Figure 3-129 are depicted in Figure 102.



**Figure 102: Measurements from WINNER II deliverable @4.95 GHz**

It should be noted that in the legend of Figure 102 the markers for LOS and NLOS are swapped. In the plot itself the description is correct.



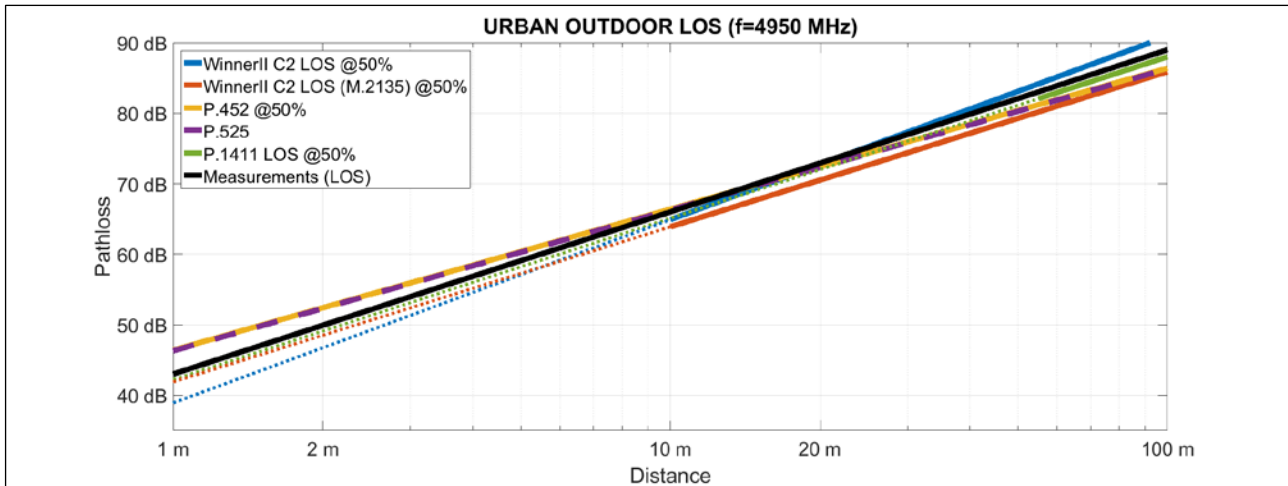
**Figure 103: Comparison of propagation models**

It should be noted that the WINNER II models (blue and red lines) are defined for the frequencies up to 6 GHz.

Model WINNER II C2 (blue line) seems to overestimate losses against free space loss up to 12 dB. On the other hand, the model WINNER II C2 M.2135-1 (red line) seems to be more appropriate. Also Recommendation ITU-R P.1411 [53] (green line) seems to be a good estimation.

Additionally the model should align with measurements (black line). It can be seen again that model WINNER II C2 M.2135-1 (red line) and model Recommendation ITU-R P.1411 (green line) estimate the measured values very good.

The same comparison for shorter distances is shown in Figure 104.



**Figure 104: Comparison of propagation models**

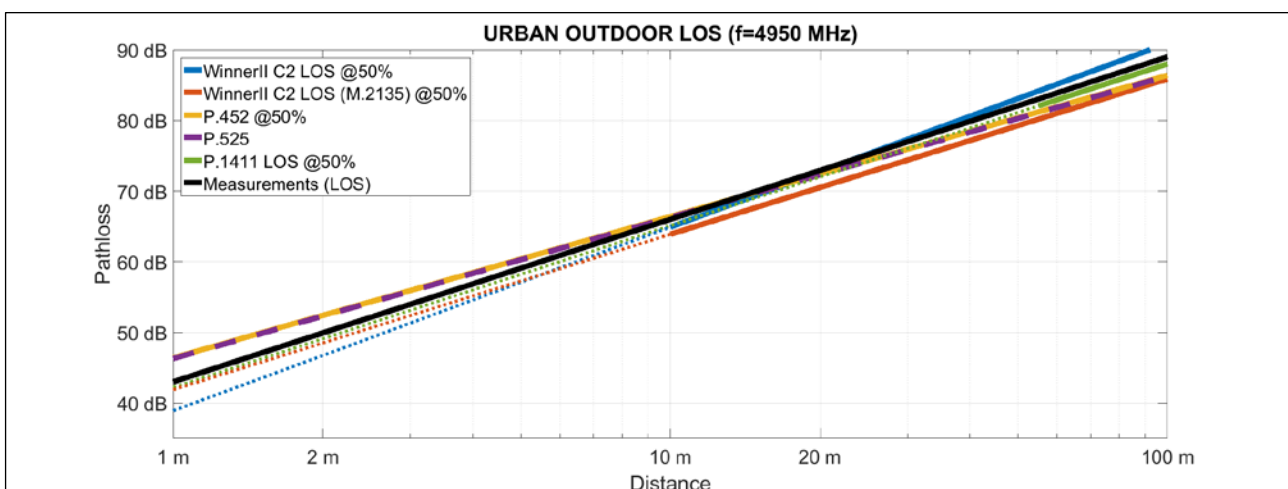
It should be noted that only for the free space loss model Recommendation ITU-R P.525 the distance is described as a 3 dimensional distance (consideration of antenna height difference). This implies that for short distances and great differences of height an error will appear in the illustration, because the other models define a 2 dimensional distance. However, this error is negligible for the considered scenarios. The free space model should generate slightly higher losses than Recommendation ITU-R P.452.

It can be seen that for short distances model Recommendation ITU-R P.1411 is closer to free space loss model and the regression line from the measurements. The WINNER II models generate even lower values.

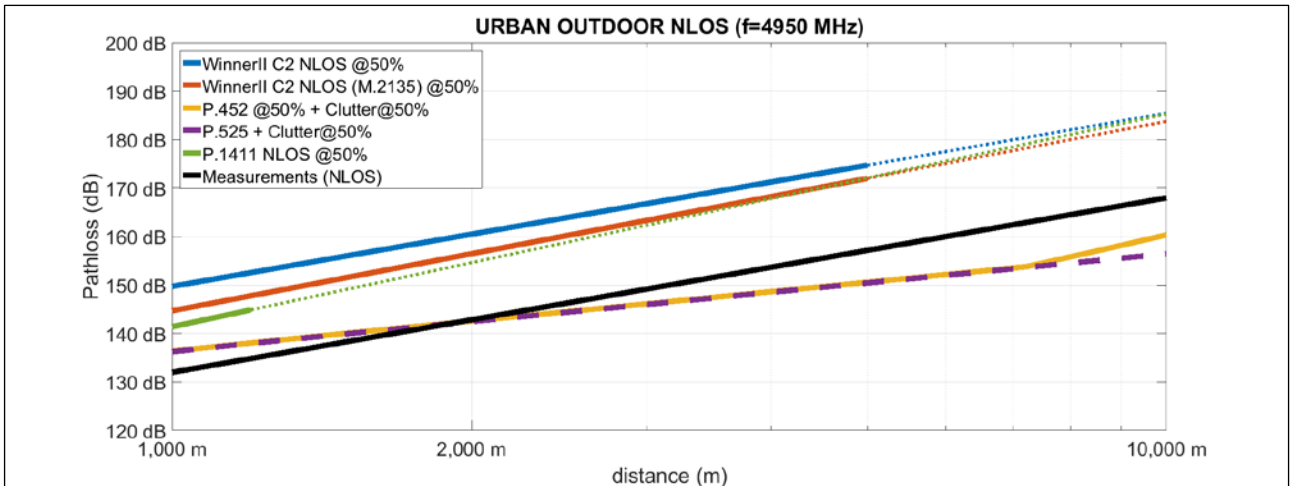
Therefore, model Recommendation ITU-R P.1411 will be used for urban LOS scenarios for distances from 0 m to 1000 m. It should be noted that this model is defined for distances greater than 55 m but as it has been shown it will generate appropriate values in this range.

#### A4.3 PROPAGATION MODEL: URBAN NLOS (>1000 M)

The measurements shown in Figure 102 should be confirmed when evaluating propagation models for NLOS conditions. For greater distances (measurements have been done for up to 1 km in distance) the chosen propagation model should not have a strong deviation compared to the model Recommendation ITU-R P.452 combined with Recommendation ITU-R P.2108 for clutter losses. If there is no description for NLOS conditions in a propagation model (e.g. Recommendation ITU-R P.525 [51]) Recommendation ITU-R P.2108 will also be used to generate additional clutter losses.



**Figure 105: Comparison of propagation models @1% Clutter Loss percentage**



**Figure 106: Comparison of propagation models @50% Clutter Loss percentage.**

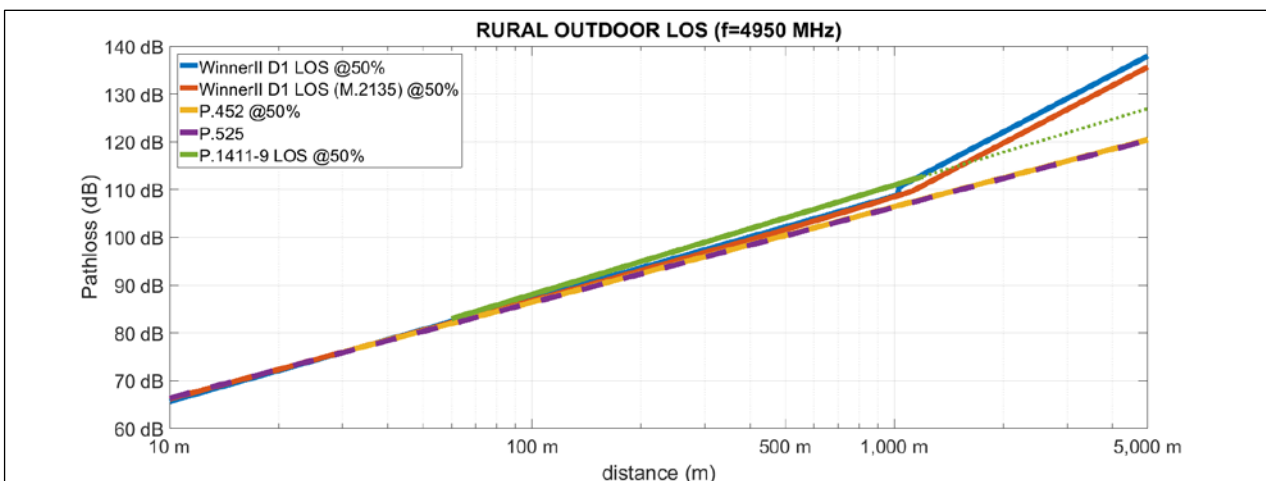
It should be noted that model Recommendation ITU-R P.1411 [53] is just defined up to 1200 m and the WINNER II models up to 5000 m. The dotted lines represent the models if they were used outside of their bounds.

It can be seen that only model Recommendation ITU-R P.452 in combination with clutter loss model Recommendation ITU-R P.2108 [49] at a percentage of 50% describes values comparable to the measurements shown in Figure 102. The WINNER II models will overestimate the losses up to 20 dB. Model Recommendation ITU-R P.1411 for urban scenarios has also been plotted to generate a maximum limit of losses. Losses generated by another propagation model should be lower than from model Recommendation ITU-R P.1411. The WINNER II models do not show this behaviour.

Therefore, model Recommendation ITU-R P.452 combined with Recommendation ITU-R P.2108 at a percentage of 50% for clutter loss will be used for urban NLOS scenarios.

**A4.4 PROPAGATION MODEL: RURAL LOS (0-4017 M)**

For rural scenarios, Recommendation ITU-R P.1411 is not valid anymore. Again, it can be assumed that models generating higher losses would not be appropriate because there will be not more clutter than in urban scenarios.



**Figure 107: Comparison of propagation models**

According to Figure 107, the WINNER II models generate higher losses at about 1200 m than Recommendation ITU-R P.1411 [53]. The results will very much depend on the antenna heights. WINNER II models are just valid for antenna heights of 32 m. Therefore, model Recommendation ITU-R P.452 [48], will be used for rural LOS scenarios.

#### A4.5 PROPAGATION MODEL: RURAL NLOS (>4017M)

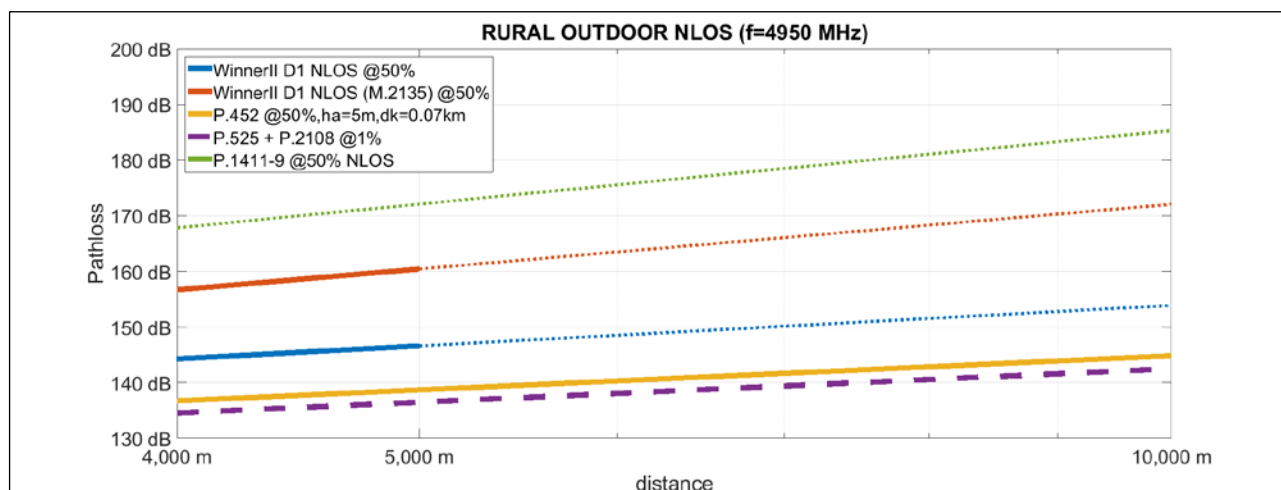


Figure 108: Comparison of propagation models

For distances greater than 5 km, neither Recommendation ITU-R P.1411 nor the WINNER II models are valid. Again the dotted lines represent the models if they were used outside of their bounds.

Therefore, model Recommendation ITU-R P.452 combined with its clutter implementation (e.g.  $h_a = 5$  m,  $d_k = 0.07$  km for rural village centre) will be used for rural NLOS scenarios, although the WINNER II models would generate smaller losses than model Recommendation ITU-R P.1411.

#### A4.6 CONCLUSION ON PROPAGATION MODELS

Table 73: Urban propagation model

Distance	Propagation Model	Clutter	Building entry (applied in main study)
$0 \text{ m} \leq d < 1000 \text{ m}$ (LOS)	Recommendation ITU-R P.1411-9 ( $p=50\%$ )		Recommendation ITU-R P.2109-0 [47]
$d \geq 1000 \text{ m}$ (NLOS)	Recommendation ITU-R P.452-16 ( $p=50\%$ )	Recommendation ITU-R P.2108-0 ( $p=50\%$ )	Recommendation ITU-R P.2109-0

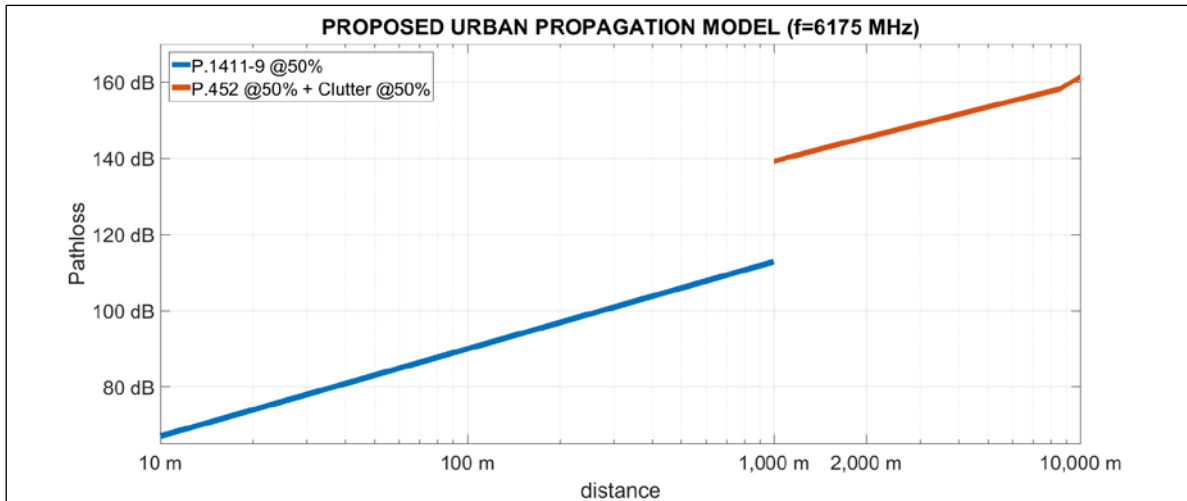


Figure 109: Proposed urban propagation model (outdoor)

For the proposed model under urban conditions as depicted in Figure 109, the assumed heights used by Recommendation ITU-R P.452 are 1.5 m and 25 m. For other heights the model will look slightly different in the red part of the curve. At the distance of 1 km, the loss will jump about 27 dB.

Table 74: Rural propagation model

Parameter	Propagation model	Clutter	Building entry (applied in main study)
$0 \text{ m} \leq d < 4017 \text{ m}$ (LOS)	Recommendation ITU-R P.452-16		Recommendation ITU-R P.2109-0
$d \geq 4017 \text{ m}$ (NLOS)	Recommendation ITU-R P.452-16	Recommendation ITU-R P.452-16 (e.g. $h_a = 5 \text{ m}$ , $d_k = 0.07 \text{ km}$ for rural village center)	Recommendation ITU-R P.2109-0

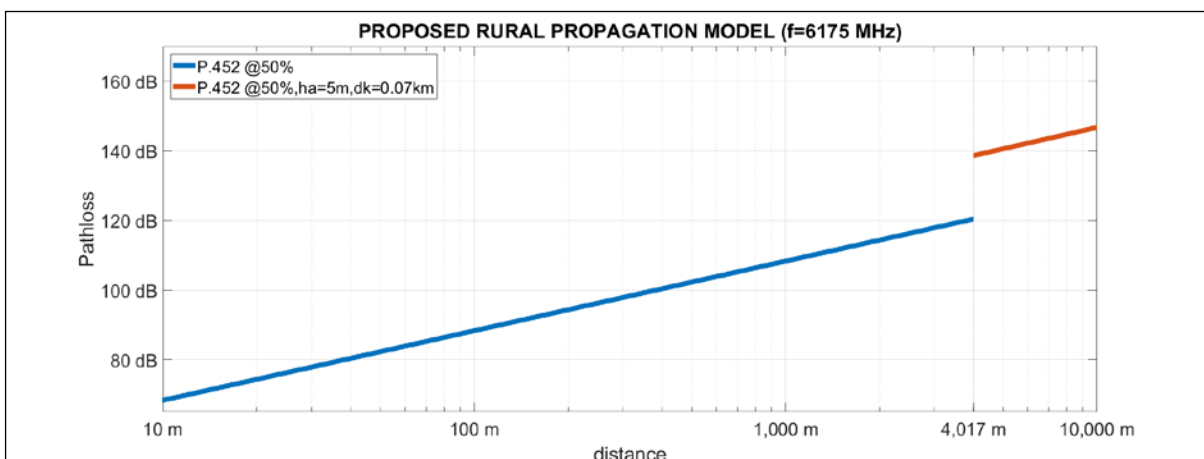


Figure 110: Proposed rural propagation model (outdoor)

It is obvious that the behaviour of the proposed rural propagation model as depicted in Figure 110 is not continuous. This sudden increase occurs because of the discrete change from LOS to NLOS conditions as described in section 6.2.2. For the single interferer analysis this behaviour is not relevant since the targeted separation distances are less than 4017 m.



### ANNEX 5: BANDWIDTH CORRECTION FACTOR AND NUMBER OF WAS/RLAN DEVICES IN INTERFERENCE CALCULATIONS FOR SHARING STUDIES BETWEEN WAS/RLAN AND FSS

Application of the bandwidth correction factor leads to 21.2 % of WAS/RLAN devices overlapping in the 40 MHz FSS receiver, with an average e.i.r.p. level reduced by 3.55 dB.

**Table 75: Number of WAS/RLAN devices overlapping in the 40 MHz receiver - derivation**

No. of channels overlapping with 40 MHz FSS	WAS/RLAN channels	No. of channels	% of WAS/RLAN	No. of WAS/RLAN per bandwidth	No. of WAS/RLAN per channel
3	20 MHz	25	10	1000	40
2	40 MHz	12	10	1000	83
1	80 MHz	6	50	5000	833
1	160 MHz	3	30	3000	1000
				10000	10000
				21.2	% of WAS/RLAN overlapping in the 40 MHz FSS receiver bandwidth

**Table 76: Number of instantaneously transmitting WAS/RLAN devices used in FSS studies**

Instantaneously transmitting WAS/RLAN devices within the 40 MHz FSS receive bandwidth	Low	Mid	High
Total number of WAS/RLAN devices	173 950	279 211	436 268
Outdoor high power ( $\geq 250$ mW) WAS/RLAN installations	260	418	654

## ANNEX 6: RESULTS OF INTERFERENCE CALCULATIONS FOR THE SHARING STUDY B BETWEEN WAS/RLAN AND FSS

**Table 77: SES 50.5E - Results for scenario for indoor and outdoor (98% indoor and 2% outdoor) (BEL 17 dB)**

Building loss (dB)	17.00		
Instantaneous Number of Transmitting 6 GHz Devices (Total)	820 521	1 317 034	2 057 866
Number of WAS/RLAN in 40 MHz receiver (bandwidth factor 21.2%)	173 950	279 211	436 268
Aggregate e.i.r.p. (main beam) (mW) with Body Loss	394 722	633 576	989 963
Transponder bandwidth (MHz)	40	40	40
Aggregate e.i.r.p. (bandwidth correction) (mW)	175 651	281 941	440 533
Aggregate e.i.r.p. (bandwidth correction) dBW	22.45	24.50	26.44
WAS/RLAN antenna discrimination (dB)	0	0	0
Free Space Path Loss (dB)	199.8	199.8	199.8
Polarisation discrimination (dB)	3	3	3
Clutter loss (dB)	3	3	3
Weighted satellite antenna gain (dBi)	28.7	28.7	28.7
Aggregate interference incident to satellite (dBW)	-154.66	-152.60	-150.66
Satellite receiver Noise Temp. (K)	250	250	250
Boltzmann's Constant (dBW/K/Hz)	-228.6	-228.6	-228.6
Equiv. interfering Temp. (K)	0.62	0.99	1.55
$\Delta T/T$ (%)	0.2	0.4	0.6
I/N (dB)	-26.1	-24.0	-22.1
<b>Assumptions</b>			
I/N criteria for interference from all co-primary services	-10.5 dB		
Apportionment between FS and WAS/RLAN	3		
I/N criteria for interference from WAS/RLAN	-13.5 dB		

**Table 78: SES 50.5E - Results for scenario for indoor and outdoor (98% indoor and 2% outdoor)  
(BEL 14 dB)**

Building loss (dB)	14.00		
Instantaneous Number of Transmitting 6 GHz Devices (Total)	820 521	1 317 034	2 057 866
Number of WAS/RLAN in 40 MHz receiver (bandwidth factor 21.2%)	173 950	279 211	436 268
Aggregate e.i.r.p. (main beam) (mW) with Body Loss	564 892	906 720	1 416 750
Transponder bandwidth (MHz)	40	40	40
Aggregate e.i.r.p. (bandwidth correction) (mW)	251 377	403 490	630 454
Aggregate e.i.r.p. (bandwidth correction) dBW	24.00	26.06	28.00
WAS/RLAN antenna discrimination (dB)	0	0	0
Free Space Path Loss (dB)	199.8	199.8	199.8
Polarisation discrimination (dB)	3	3	3
Clutter loss (dB)	3	3	3
Weighted satellite antenna gain (dBi)	28.7	28.7	28.7
Aggregate interference incident to satellite (dBW)	-153.10	-151.05	-149.11
Satellite receiver Noise Temp. (K)	250	250	250
Boltzmann's Constant (dBW/K/Hz)	-228.6	-228.6	-228.6
Equiv. interfering Temp. (K)	0.89	1.42	2.22
$\Delta T/T$ (%)	0.4	0.6	0.9
I/N (dB)	-24.5	-22.4	-20.5
<b>Assumptions</b>			
I/N criteria for interference from all co-primary services	-10.5 dB		
Apportionment between FS and WAS/RLAN	3		
I/N criteria for interference from WAS/RLAN	-13.5 dB		

**Table 79: SES 20W - Results for scenario for indoor and outdoor (98% indoor and 2% outdoor)  
(BEL 17 dB)**

Building loss (dB)	17.00		
Instantaneous Number of Transmitting 6 GHz Devices (Total)	820 521	1 317 034	2 057 866
Number of WAS/RLAN in 40 MHz receiver (bandwidth factor 21.2%)	173 950	279 211	436 268
Aggregate e.i.r.p. (main beam) (mW) with Body Loss	394 722	633 576	989 963
Transponder bandwidth (MHz)	40	40	40
Aggregate e.i.r.p. (bandwidth correction) (mW)	175 651	281 941	440 533
Aggregate e.i.r.p. (bandwidth correction) dBW	22.45	24.50	26.44
WAS/RLAN antenna discrimination (dB)	0	0	0
Free Space Path Loss (dB)	199.8	199.8	199.8
Polarisation discrimination (dB)	3	3	3
Clutter loss (dB)	1.7	1.7	1.7
Weighted satellite antenna gain (dBi)	29.9	29.9	29.9
Aggregate interference incident to satellite (dBW)	-152.17	-150.11	-148.17
Satellite receiver Noise Temp. (K)	250	250	250
Boltzmann's Constant (dBW/K/Hz)	-228.6	-228.6	-228.6
Equiv. interfering Temp. (K)	1.10	1.77	2.76
$\Delta T/T$ (%)	0.4	0.7	1.1
I/N (dB)	-23.6	-21.5	-19.6
<b>Assumptions</b>			
I/N criteria for interference from all co-primary services	-10.5 dB		
Apportionment between FS and WAS/RLAN	3		
I/N criteria for interference from WAS/RLAN	-13.5 dB		

**Table 80: SES 20W - Results for scenario for indoor and outdoor (98% indoor and 2% Outdoor)  
(BEL 14 dB)**

Building loss (dB)	14.00		
Instantaneous Number of Transmitting 6 GHz Devices (Total)	820 521	1 317 034	2 057 866
Number of WAS/RLAN in 40 MHz receiver (bandwidth factor 21.2%)	173 950	279 211	436 268
Aggregate e.i.r.p. (main beam) (mW) with Body Loss	564 892	906 720	1 416 750
Transponder bandwidth (MHz)	40	40	40
Aggregate e.i.r.p. (bandwidth correction) (mW)	251 377	403 490	630 454
Aggregate e.i.r.p. (bandwidth correction) dBW	24.00	26.06	28.00
WAS/RLAN antenna discrimination (dB)	0	0	0
Free Space Path Loss (dB)	199.8	199.8	199.8
Polarisation discrimination (dB)	3	3	3
Clutter loss (dB)	1.7	1.7	1.7
Weighted satellite antenna gain (dBi)	29.9	29.9	29.9
Aggregate interference incident to satellite (dBW)	-150.61	-148.56	-146.62
Satellite receiver Noise Temp. (K)	250	250	250
Boltzmann's Constant (dBW/K/Hz)	-228.6	-228.6	-228.6
Equiv. interfering Temp. (K)	1.57	2.53	3.95
$\Delta T/T$ (%)	0.6	1.0	1.6
I/N (dB)	-22.0	-20.0	-18.0
<b>Assumptions</b>			
I/N criteria for interference from all co-primary services	-10.5 dB		
Apportionment between FS and WAS/RLAN	3		
I/N criteria for interference from WAS/RLAN	-13.5 dB		

**Table 81: INT 60E - Results for scenario for indoor and outdoor (98% indoor and 2% outdoor)  
(BEL 17 dB)**

Building loss (dB)	17.00		
Instantaneous Number of Transmitting 6 GHz Devices (Total)	820 521	1 317 034	2 057 866
Number of WAS/RLAN in 40 MHz receiver (bandwidth factor 21.2%)	173 950	279 211	436 268
Aggregate e.i.r.p. (main beam) (mW) with Body Loss	394 722	633 576	989 963
Transponder bandwidth (MHz)	40	40	40
Aggregate e.i.r.p. (bandwidth correction) (mW)	175 651	281 941	440 533
Aggregate e.i.r.p. (bandwidth correction) dBW	22.45	24.50	26.44
WAS/RLAN antenna discrimination (dB)	0	0	0
Free Space Path Loss (dB)	199.8	199.8	199.8
Polarisation discrimination (dB)	3	3	3
Clutter loss (dB)	3	3	3
Weighted satellite antenna gain (dBi)	32.8	32.8	32.8
Aggregate interference incident to satellite (dBW)	-150.56	-148.51	-146.57
Satellite receiver Noise Temp. (K)	201	201	201
Boltzmann's Constant (dBW/K/Hz)	-228.6	-228.6	-228.6
Equiv. interfering Temp. (K)	1.59	2.55	3.99
$\Delta T/T$ (%)	0.8	1.3	2.0
I/N (dB)	-21.0	-19.0	-17.0
<b>Assumptions</b>			
I/N criteria for interference from all co-primary services	-10.5 dB		
Apportionment between FS and WAS/RLAN	3		
I/N criteria for interference from WAS/RLAN	-13.5 dB		

**Table 82: INT 60E - Results for scenario for indoor and outdoor (98% indoor and 2% outdoor)  
(BEL 14 dB)**

Building loss (dB)	14.00		
Instantaneous Number of Transmitting 6 GHz Devices (Total)	820 521	1 317 034	2 057 866
Number of WAS/RLAN in 40 MHz receiver (bandwidth factor 21.2%)	173 950	279 211	436 268
Aggregate e.i.r.p. (main beam) (mW) with Body Loss	564 892	906 720	1 416 750
Transponder bandwidth (MHz)	40	40	40
Aggregate e.i.r.p. (bandwidth correction) (mW)	251 377	403 490	630 454
Aggregate e.i.r.p. (bandwidth correction) dBW	24.00	26.06	28.00
WAS/RLAN antenna discrimination (dB)	0	0	0
Free Space Path Loss (dB)	199.8	199.8	199.8
Polarisation discrimination (dB)	3	3	3
Clutter loss (dB)	3	3	3
Weighted satellite antenna gain (dBi)	32.8	32.8	32.8
Aggregate interference incident to satellite (dBW)	-149.00	-146.95	-145.01
Satellite receiver Noise Temp. (K)	201	201	201
Boltzmann's Constant (dBW/K/Hz)	-228.6	-228.6	-228.6
Equiv. interfering Temp. (K)	2.28	3.66	5.71
$\Delta T/T$ (%)	1.1	1.8	2.8
I/N (dB)	-19.5	-17.4	-15.5
<b>Assumptions</b>			
I/N criteria for interference from all co-primary services	-10.5 dB		
Apportionment between FS and WAS/RLAN	3		
I/N criteria for interference from WAS/RLAN	-13.5 dB		

**Table 83: Satellite similar to INT 60E positioned at 5E - Results for scenario for indoor and outdoor (98% indoor and 2% outdoor) (BEL 17 dB)**

Building loss (dB)	17.00		
Instantaneous Number of Transmitting 6 GHz Devices (Total)	820 521	1 317 034	2 057 866
Number of WAS/RLAN in 40 MHz receiver (bandwidth factor 21.2%)	173 950	279 211	436 268
Aggregate e.i.r.p. (main beam) (mW) with Body Loss	394 722	633 576	989 963
Transponder bandwidth (MHz)	40	40	40
Aggregate e.i.r.p. (bandwidth correction) (mW)	175 651	281 941	440 533
Aggregate e.i.r.p. (bandwidth correction) dBW	22.45	24.50	26.44
WAS/RLAN antenna discrimination (dB)	0	0	0
Free Space Path Loss (dB)	199.8	199.8	199.8
Polarisation discrimination (dB)	3	3	3
Clutter loss (dB)	1.5	1.5	1.5
Weighted satellite antenna gain (dBi)	32.8	32.8	32.8
Aggregate interference incident to satellite (dBW)	-149.06	-147.01	-145.07
Satellite receiver Noise Temp. (K)	201	201	201
Boltzmann's Constant (dBW/K/Hz)	-228.6	-228.6	-228.6
Equiv. interfering Temp. (K)	2.25	3.61	5.64
$\Delta T/T$ (%)	1.1	1.8	2.8
I/N (dB)	-19.5	-17.5	-15.5
<b>Assumptions</b>			
I/N criteria for interference from all co-primary services	-10.5 dB		
Apportionment between FS and WAS/RLAN	3		
I/N criteria for interference from WAS/RLAN	-13.5 dB		

**Table 84: Satellite similar to INT 60E positioned at 5E - Results for scenario for indoor and outdoor (98% indoor and 2% outdoor) (BEL 14 dB)**

Building loss (dB)	14.00		
Instantaneous Number of Transmitting 6 GHz Devices (Total)	820 521	1 317 034	2 057 866
Number of WAS/RLAN in 40 MHz receiver (bandwidth factor 21.2%)	173 950	279 211	436 268
Aggregate e.i.r.p. (main beam) (mW) with Body Loss	564 892	906 720	1 416 750
Transponder bandwidth (MHz)	40	40	40



Building loss (dB)	14.00		
Aggregate e.i.r.p. (bandwidth correction) (mW)	251 377	403 490	630 454
Aggregate e.i.r.p. (bandwidth correction) dBW	24.00	26.06	28.00
WAS/RLAN antenna discrimination (dB)	0	0	0
Free Space Path Loss (dB)	199.8	199.8	199.8
Polarisation discrimination (dB)	3	3	3
Clutter loss (dB)	1.5	1.5	1.5
Weighted satellite antenna gain (dBi)	32.8	32.8	32.8
Aggregate interference incident to satellite (dBW)	-147.50	-145.45	-143.51
Satellite receiver Noise Temp. (K)	201	201	201
Boltzmann's Constant (dBW/K/Hz)	-228.6	-228.6	-228.6
Equiv. interfering Temp. (K)	3.22	5.16	8.07
$\Delta T/T$ (%)	1.6	2.6	4.0
I/N (dB)	-18.0	-15.9	-14.0
<b>Assumptions</b>			
I/N criteria for interference from all co-primary services	-10.5 dB		
Apportionment between FS and WAS/RLAN	3		
I/N criteria for interference from WAS/RLAN	-13.5 dB		

## A6.1 SENSITIVITY ANALYSIS FOR 95% INDOOR AND 5% OUTDOOR

**Table 85: Sensitivity scenario for indoor and outdoor (95% indoor and 5% outdoor)**

e.i.r.p. and indoor-outdoor distributions							
e.i.r.p. (mW)	1000	250	100	50	13	1	Total
indoor (%)	0.67	8.69	5.90	24.50	49.85	5.57	95.18
outdoor (%)	0.16	0.21	0.39	1.85	2.23	0.15	5.00

**Table 86: Summary of the sensitivity analysis (BEL 17 dB)**

	WAS/RLAN deployment model	Low	Mid	High
	Number of simultaneously transmitting WAS/RLAN devices within the receive bandwidth	173 950	279 211	436 268
SES 50.5E (clutter 3 dB) Zone beam Europe Gain 32.4 dB	I/N (dB)	-23.4	-21.4	-19.4
SES 20W (clutter 1.7 dB) Zone beam Europe Gain 31.8 dB	I/N (dB)	-20.9	-18.9	-16.9
INT 60E (clutter 3 dB) Spot beam Europe Gain 37.3 dB	I/N (dB)	-18.4	-16.3	-14.4
SAT 5E (clutter 1.5 dB) Spot beam Europe Gain 37.3 dB	I/N (dB)	-16.9	-14.8	-12.9

**Table 87: Summary of the sensitivity analysis (BEL 14 dB)**

	WAS/RLAN deployment model	Low	Mid	High
	Number of simultaneously transmitting WAS/RLAN devices within the receive bandwidth	173 950	279 211	436 268
SES 50.5E (clutter 3 dB) Zone beam Europe Gain 32.4 dB	I/N (dB)	-22.5	-20.5	-18.5
SES 20W (clutter 1.7 dB) Zone beam Europe Gain 31.8 dB	I/N (dB)	-20.0	-18.0	-16.0
INT 60E (clutter 3 dB) Spot beam Europe Gain 37.3 dB	I/N (dB)	-17.5	-15.4	-13.5
SAT 5E (clutter 1.5 dB) Spot beam Europe Gain 37.3 dB	I/N (dB)	-16.0	-13.9	-12.0

## ANNEX 7: WAS/RLAN AT 6 GHZ - RF ACTIVITY FACTOR GENESIS

### A7.1 THE RELEVANCE OF RF ACTIVITY FACTOR

To utilise the radio spectrum as efficiently as possible, digital WAS/RLAN systems do not transmit data continuously, but in bursts. In spectrum sharing studies, the “burstiness” of a signal, expressed through its RF activity factor, is generally accepted to provide a realistic estimate of its interference potential.

RF activity factor is generally defined as the ratio:

$$\frac{\sum T_{\text{ON}}}{T_{\text{OBS}}}$$

where:

- $T_{\text{ON}}$  is the duration of time the level of a transmit signal exceeds a certain defined threshold;
- $T_{\text{OBS}}$  is the time period during which the signal is observed.

In the sharing model developed in this Report, DC is used to determine the number of concurrently transmitting WAS/RLAN devices, following the rationale that a number of  $x$  devices transmitting with a DC of  $y\%$  equals a number of  $x \cdot y/100$  devices transmitting with a DC of 100%.

By combining high-order modulations, large channel bandwidths, highly efficient channel access mechanisms and various other techniques, next generation WAS/RLAN systems such as those based on emerging IEEE 802.11ax technology are expected to achieve very high data rates whilst maintaining a low RF activity factor.

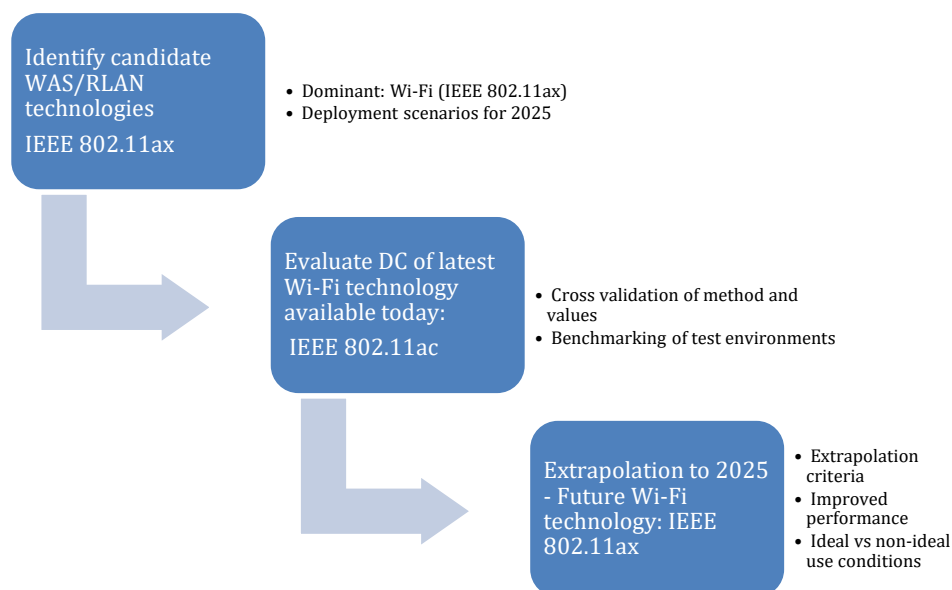
The next Section describes the evolution of a technical approach adopted to make a reliable estimation of RF activity factor for future WAS/RLAN systems based on IEEE 802.11ax. This technology is still in the phase of development but early versions of products are expected to reach market in 2019.

### A7.2 ESTIMATING THE RF ACTIVITY FACTOR OF FUTURE 6 GHZ WAS/RLAN SYSTEMS

To evaluate the coexistence scenarios studied in the current Report, a RF activity factor representative of the WAS/RLAN deployment situation in the year 2025 had to be determined.

It is noted that WAS/RLAN equipment deployed in the 6 GHz band will exclusively support next generation technologies such as IEEE 802.11ax. As the IEEE 802.11ax standard is still under development (and, consequently, compliant equipment does not exist yet), all subsequent measurements referred to in this Annex were conducted with IEEE 802.11ac-compliant equipment and a channel bandwidth of 80 MHz.

Figure 111 shows the general process applied to estimate the RF activity factor for WAS/RLAN devices deployed in CEPT countries in 2025.



**Figure 111: Process applied to estimate the 6 GHz WAS/RLAN RF activity factor**

Initially, this RF activity factor had been calculated on the basis of the projected WAS/RLAN traffic per device and deployment scenario (residential, corporate and public/hotspot) and measurements of HD video traffic. For these measurements, various high definition videos with different average bit rates were streamed from an access point (AP) to a client device (STA). An HD video with an average bit rate of 4.5 Mbits per second, which corresponds to the projected busy hour traffic of 2 GB per hour, was chosen as reference. The result from these studies was a compound DC value of 0.42%. The maximum value was 0.44%.

The WAS/RLAN effective bit rate of 1 Gbit per second on which the above DC calculation was based was confirmed by the results of measurements conducted by HPE. Taking into account potential protocol overhead, a preliminary agreement on a RF activity factor of 1% for high-activity devices was made, with the proviso to confirm this value through further measurements.

Such measurements were then conducted individually by HPE and the Joint Research Centre (JRC). HPE measurements showed per-client RF activity factors of 1.17% (one client) and 0.93% (three clients) based on an experiment featuring a combination of an enterprise-grade AP and a laptop PC. These values were then extrapolated to IEEE 802.11ax, taking into account various improvements with respect to channel access, protocol efficiency and physical layer performance. The resulting per-client RF activity factors for IEEE 802.11ax equipment were 0.97% (one client) and 0.72% (three clients).

The JRC presented a proposal to measure the RF activity factor using a combination of RF measurements (direct observation) and MAC frame captures (indirect observation) and subsequently conducted measurements with different combinations of commercial IEEE 802.11ac APs and STAs. MAC RF activity factors varied between 1.85% and 3.8%, while PHY values varied from 1.88% to 4.5%, revealing that the choice of AP and STA had considerable impact on the RF activity factor value due to performance variations across the different models of IEEE 802.11ac equipment that were tested.

Subsequently, the JRC and HPE conducted a joint measurement campaign at the JRC Radio Spectrum Laboratory with the objective of building a joint dataset of RF activity factor measurements based on agreed test conditions, measurement procedures and combinations of APs and STAs. Test conditions included maximum throughput, the use of high-end consumer- and enterprise-grade APs, an RF shielded room and short line of sight distance between AP and STA, amongst other. The measured RF activity factors ranged from 1.21% to 2.32%. These results were subject to stringent quality criteria applied to the MAC packet capture losses, the number of MIMO spatial streams and the percentage of downlink data bytes transmitted at the maximum MCS index.

HPE presented an additional set of measurements conducted with various IEEE 802.11ac devices that produced RF activity factors between 1.16% and 1.78%, which correspond, after conversion to IEEE 802.11ax, to RF activity factors of 0.66% to 0.68%. This conversion method introduced some modifications

to the previously agreed analysis procedure, such as excluding RTS (Request-to-Send) and CTS (Clear-to-Send) control frames from RF activity factor calculations.

After reviewing above results the group eventually reached a consensus on a single representative RF activity factor value of 1.97%. This value was derived from the maximum RF activity factor value of 2.32% for the IEEE 802.11ac devices that had been measured by the JRC. A conversion factor from IEEE 802.11ac to IEEE 802.11ax was applied based on the average WAS/RLAN channel bandwidth of 94 MHz for IEEE 802.11ax used in the sharing studies, compared to the 80 MHz used in the IEEE 802.11ac tests. Technological improvements in IEEE 802.11ax over IEEE 802.11ac were not taken into account to offset the effect of less-than-optimal deployment conditions of WAS/RLAN systems in practice.

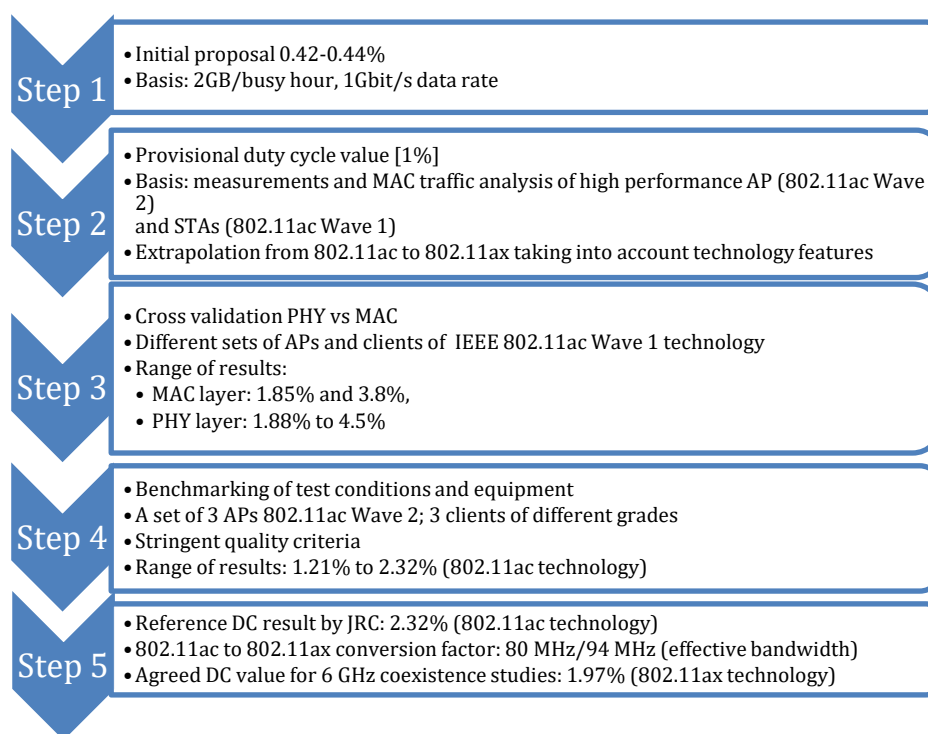
The conversion factor is summarised in the formula below:

$$DC_{802.11ax} = DC_{802.11ac} \cdot \left( \frac{BW_{802.11ac}}{BW_{802.11ax}} \right) = 2.32\% \cdot \left( \frac{80 \text{ MHz}}{94 \text{ MHz}} \right) = 1.97\%$$

where:

- $DC_{802.11ax}$  is the IEEE 802.11ax RF activity factor,
- $DC_{802.11ac}$  is the IEEE 802.11ac RF activity factor,
- $BW_{802.11ac}$  is the IEEE 802.11ac channel bandwidth and
- $BW_{802.11ax}$  is the IEEE 802.11ax channel bandwidth.

Figure 112 summarises the steps followed in the evolution of an agreed DC value for 6 GHz WAS/RLAN for 2025.



**Figure 112: Steps followed in the evolution of an agreed DC value**

## ANNEX 8: COMPUTING THE 2 DB DESENSITISATION EQUIVALENT ACS FOR LTE CBTC BS

Documents 3GPP TS 37.104 [88] and TR 36.942 [89] do not specify the ACS values for LTE base stations (BSs). Only blocking levels associated with a 6 dB desensitization are specified. Therefore, the ACS has been computed first and then the blocking levels associated with a 2 dB desensitisation have been deduced, since the relationship is not linear.

The input parameters for LTE CBTC BS are given in Table 88.

**Table 88: Parameters of LTE CBTC BS**

Parameter	Value
Channel	5930-5935 MHz
Occupied bandwidth	4.5 MHz
Noise figure	5 dB
Noise floor	-102.4 dBm
Required C/(N+I)	0.9 dB
Sensitivity	-101.5 dBm
3GPP desensitization	6 dB
Associated blocking level	-49 dBm (first 3 MHz)
	-40 dBm (beyond 3 MHz)

In order to compute the blocking level for a desensitization of 2 dB (CBTC BS desensitization), the ACS has been computed (Table 89) using the equations for the maximum tolerable interference and the maximum blocking level from Sections 9.1.3-9.1.4:

$$ACS = B_{CBTC} - I_{\max\_In\_CBTC}$$

$$ACS = B_{CBTC} - 10 \log_{10} \left( 10^{\frac{D}{10}} - 1 \right) - N$$

**Table 89: ACS**

Parameter	Value
ACS	48.7 dB (first 3 MHz)
	57.7 dB (beyond 3 MHz)

The associated blocking levels are then as listed in Table 45 in section 9.1.1.

**ANNEX 9: LIST OF REFERENCES**

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