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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1 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 4 and 5 of the Report. The Report covers sharing and compatibility scenarios based on models of 2025 deployments.

Section 6 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 7-12 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. Further, note that for some of these inter-service sharing and compatibility problems, there have been no studies done and for others only very basic investigations have been performed, which do not identify the risk of interference as required in the EC Mandate on 6 GHz. However, the studies addressing the WAS/RLAN vs FS and WAS/RLAN vs FSS sharing problems, are fully developed allowing for conclusions to be drawn with regard to the feasibility of spectrum sharing.

1.1 SHARING BETWEEN RLAN AND FS

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

In the first study (A), two different types of areas have been shown in the MCL analysis where a single 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 based on the FS antenna pattern (here: ITU-R Recommendation F.699).

Sensitivity analyses have taken into account different RLAN e.i.r.p. density levels, indoor and outdoor deployments, population density types, FS and RLAN antenna heights, FS antenna gains and building types.

For the long term protection criterion $I/N = -10$ dB the range of required separation distances has been calculated:

- Circle distances are found to be varying from 400 m to 4017 m, peak distances are found to be varying from 48 m to 40400 m.

For the long term protection criterion $I/N = -20$ dB the range of required separation distances has been calculated:

- Circle distances are found to be varying from 1000 m to 4017 m, peak distances are found to be varying from 103 m to 47100 m.

Sensitivity analyses showed that reduction of power density level or indoor use are examples of measures reducing separation distances.

MCL calculations have revealed critical scenarios, but do not allow concluding about the likelihood of these scenarios. Therefore, a statistical approach based on Monte Carlo studies is required.

A second study (B) analysed population of fixed links in 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 FDP < 10%, which is a complementary short term protection criterion, was exceeded in the UK due to highly improbable, even non-realisable, interference events that can occur in the Monte Carlo simulations. If only indoor deployment with a maximum e.i.r.p. of 200 mW is considered, it was shown that all but 2 cases of FDP exceedances were resolved. Under those conditions sharing is considered 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 an RLAN (indoor 250 mW and outdoor 1 W) would exceed the interference threshold of $I/N=-10$ dB. It indicated that allowing outdoor 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. Then a complementary statistical study based on a Monte Carlo approach, using the 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 for the long term protection criterion.

1.2 SHARING BETWEEN 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 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.

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

Two studies were conducted to assess aggregate interference from RLAN into FSS receivers in space, assuming RLAN deployment models in Europe by 2025. Study A employs a Monte Carlo methodology involving stochastic inputs to the 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.

Studies show that the calculated levels of interference are highly sensitive to some RLAN parameters and assumptions in the study, for example but not limited to the duty cycle of high activity RLAN devices.

Study A considers the Mid scenario for a representative set of FSS satellites. The results show that the protection criterion of $I/N=-10.5$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 RLAN systems, with no constraints on RLAN deployment or operations.

Study B considers a representative set of existing FSS satellites (as well as a potential future satellite) and the RLAN deployment model in Europe by 2025 in accordance with the Low, Mid and High scenarios. FSS protection criterion was satisfied in all cases for the baseline scenarios noting that the calculated levels of interference are close to the FSS protection criteria (i.e. -13.5 dB, including 3 dB service apportionment), with the smallest margin equal to 0.5 dB for the High scenario.

If the aggregate interference levels from RLAN deployments increase beyond those modelled for 2025, then the levels of interference from RLANs may result in an exceedance of the FSS protection criteria.

A sensitivity analysis on the distribution of Indoor and Outdoor RLAN devices with “95% Indoor & 5% Outdoor” is provided, in which case the protection criteria was exceeded in two cases for the High scenario.

Considering the need to address protection of FSS space receivers in long term (beyond 2025) from aggregate interference from RLANs, coexistence conditions, such as limiting RLAN use to indoor, introducing e.i.r.p. limits, etc. could be applied.

1.3 COMPATIBILITY BETWEEN RLAN AND ROAD-ITS

One adjacent-band coexistence study was conducted to assess the impact of RLAN OoB emission on Road-ITS below 5925 MHz, considering a protection criterion of -6 dB I/N. RLAN deployment scenarios of indoor, outdoor (fixed AP and portable device) and in-car were studied. The results of this co-existence study show that, depending on the scenario, the RLAN OoB emissions below 5925 MHz should meet a limit between -69dBm/MHz and -36dBm/MHz for the main-lobe case and between -59dBm/MHz and -26dBm/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 installed outside the car most of the time. The indoor usage scenario results in the least stringent requirement for RLAN OoB emissions below 5925 MHz.

1.4 SHARING AND COMPATIBILITY BETWEEN RLAN AND CBTC

A first study assesses the adjacent band coexistence between RLAN and CBTC below 5935 MHz, both 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 RLAN OoB and In-band emissions.

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

When comparing the results achieved assuming RLAN operation starting at 5940 MHz and 5935 MHz, it is found that the RLAN operation above 5940 MHz is less restrictive for the RLAN emissions. In that case, an in-band e.i.r.p. of $21.5\, dBm/20\, MHz$ for indoor RLAN usage in adjacent channels 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 RLAN emission of $-42\, dBm/5\, MHz$ and an e.i.r.p. density of $4.7\, dBm/20\, MHz$ (RLAN first channel starting at 5940 MHz) are sufficient to ensure the CBTC operation.

Another study investigated the impact of RLAN devices coexisting in the same frequency band as the Copenhagen S-train CBTC system. The results present the required minimum distance between the RLAN device and CBTC receiver to avoid the interference from the RLAN device. This distance ranges from the 180 to 600 m. If S-train and RLAN share the same frequency band eventually, it will not be feasible to reasonably assume that no RLAN devices will be present within these distances. Dedicated mitigations techniques, to be locally applied, may need to be defined.

1.5 COMPATIBILITY BETWEEN RLAN AND RADIO ASTRONOMY

The number of RAS sites in Europe observing in this frequency range is small, possibly around 16. The local environment of each site is very well understood. Compatibility between 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.

1.6 COEXISTENCE BETWEEN RLAN AND ULTRA WIDE BAND (UWB) SYSTEMS

UWB is designated as an underlay technology which cannot claim protection from interference nor cause interference to other services. 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 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, respectively.

Aggregate interference evaluations with Monte Carlo simulations show that when taking the RLAN duty cycle 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%.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
3GPP	Third generation partnership project
5G	Fifth generation
AP	Access point
BEL	Building entry loss
BS	Base station
BLER	Block error rate
CBTC	Communication based train control
CDF	Cumulative distribution function
CEPT	European Conference of Postal and Telecommunications Administrations
CET	Central European time
C/I	Carrier to interferer ratio
C/(I+N)	Carrier to interference plus noise ratio
CS	Channel spacing
CSV	Comma separated values
e.i.r.p.	Effective isotropically radiated power
ECA	European common allocation
ECC	Electronic Communications Committee
EET	Eastern European time
ERC	Electronic Radiocommunications Committee
ETSI	European Telecommunications Standards Institute
EST	Eastern standard time
EU	European Union
FDP	Fractional Degradation Performance
FSS	Fixed-Satellite Service
FS	Fixed Service
FSPL	Free Space Path Loss
Gbps	Gigabits per second
GPWv4	Gridded Population of the World V4
HTS	High throughput satellites
JRC	Joint Research Centre of the European Commission
IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Telecommunications
I/N	Interferer to noise ratio
IoT	Internet of things
ITS	Intelligent transport systems

ITU	International Telecommunication Union
Mbps	Megabits per second
MCL	Minimum coupling loss
MFCN	Mobile/Fixed Communications Networks
MIMO	Multiple input and multiple output
MSK	Moscow standard time
NASA	National Aeronautics and Space Administration
NL	The Netherlands
NLOS	Non line of sight
NR	New radio
LAA	Licensed assisted access
LAT	Latitude
LON	Longitude
LOS	Line of sight
LTE	Long term evolution
MERLIN	Multi-Element Radio-Linked Interferometer Network
Ofcom	Office of communications (G)
OFCOM	Federal Office of Communications (SUI)
OFDM	Orthogonal Frequency-Division Multiplexing
OoB	Out of band
PER	Packet error rate
pfd	Power flux density
PP	Point-to-point
PR	Protection ratio
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase-shift keying
RAS	Radio astronomy
RLAN	Radio local area networks
RX	Receiver
RF	Radiofrequency
SEDAC	Socioeconomic Data and Applications Center
SNR	Signal to noise ratio
SNIR	Signal to noise plus interferer ratio
TDMA	Time division multiple access
TX	Transmitter
TU	Train unit
TZ	Time zone
UK	United Kingdom
UN	United Nations

UTC	Coordinated universal time
UWB	Ultra-wide band
VLBI	Very Long Baseline Interferometry
WAS	Wireless access systems
WET	Western European time
Wi-Fi	Wireless fidelity

2 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. It is to be noted e that the terms WAS/RLAN and RLAN are used interchangeably throughout the Report.

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 Transportation 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.

3 ALLOCATIONS AND APPLICATIONS IN THE BAND 5925-6425 MHZ AND ADJACENT BANDS

3.1 FREQUENCY BAND ALLOCATION AND USE

Table 1 below 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) 5.1495.440 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 EFIS, fifteen CEPT administrations have a primary mobile allocation and one CEPT administration has a secondary mobile allocation in this band.

Note 2: Passive sensors (satellite) and radio astronomy are located above the 5925-6425 MHz frequency band.

Note 3: The text of the footnotes of the ITU Radio Regulations can be found at https://www.bakom.admin.ch/bakom/en/homepage/frequencies-and-antennas/national-frequency-allocation-plan/fussnoten-rr.html

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

3.2 DEPLOYMENT OF OTHER SERVICES/APPLICATIONS BY CEPT ADMINISTRATIONS

3.2.1 Urban Rail Systems (CBTC)

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

France reported of several metro lines equipped in Paris and about many new projects ongoing.

3.2.2 Radio astronomy

The frequency band 6650.0-6675.2 MHz is important for observations of methanol (CH_3OH). 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, MERLIN interferometry and VLBI.

4 WAS/RLAN IN THE 6 GHZ FREQUENCY RANGE

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

4.1.1 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 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. 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 methodology outlined in the study entitled "Frequency Sharing for Radio Local Area Networks in the 6 GHz Band" [4].

4.1.1.1 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.

Given expected market factors and regulatory limitations, 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

	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	4.1	5.3	5.3	3.5	5.3	5.3

Gain (dBi)						
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.						

4.1.1.2 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.

Table 4 provides busy hour weights for indoor use cases 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%

4.1.1.3 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 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.

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 101 through Figure 106 in ANNEX 1:. The tables next to the elevation patterns are for illustrative purposes only.

4.1.1.4 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 4.2.4).

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

		Weighted e.i.r.p. distribution (mW)						
Indoor Use Case	Weight	1000	250	100	50	13	1	Total
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%
Sub-Total	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%)

		Weighted e.i.r.p. distribution (mW)						
Outdoor Use Case	Weight	1000	250	100	50	13	1	Total
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%
Sub-Total	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 for indoor RLANs, 18.76 dBm for outdoor RLANs and 17.51 dBm for combined indoor/outdoor 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

4.1.2 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 [5])

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

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

		Urban Indoor			Suburban Indoor			Rural Indoor			Out-door
Build-ing Story	Height (m)	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%
7	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].

4.1.3 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:

$$f_{cn(g)} = 5\,940 + (g \times 5)\, MHz\, , where\ 0 \leq g \leq 93$$

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.

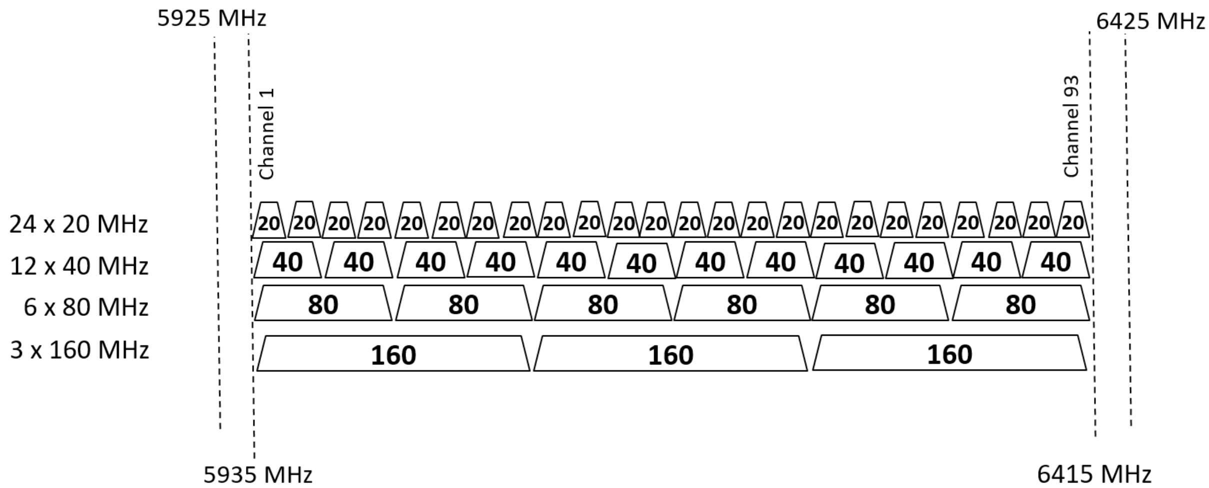


Figure 1: Example band plan with 5 MHz channel number increment

The 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 NR standard, too.

4.1.4 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 RLAN channel bandwidths used in 6 GHz band.

Table 12: Bandwidth distribution

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

4.1.5 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 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.

4.1.6 Unwanted emissions

4.1.6.1 Transmitter unwanted emissions in the 6 GHz bands

It is expected that WAS/RLANs that operate in the 6 GHz band will use modulations similar to the ones currently used in 5 GHz band i.e. OFDM. Hence, spectral emissions would follow a similar pattern. For sharing/compatibility studies, the spectral mask given in Figure 2 can be used.

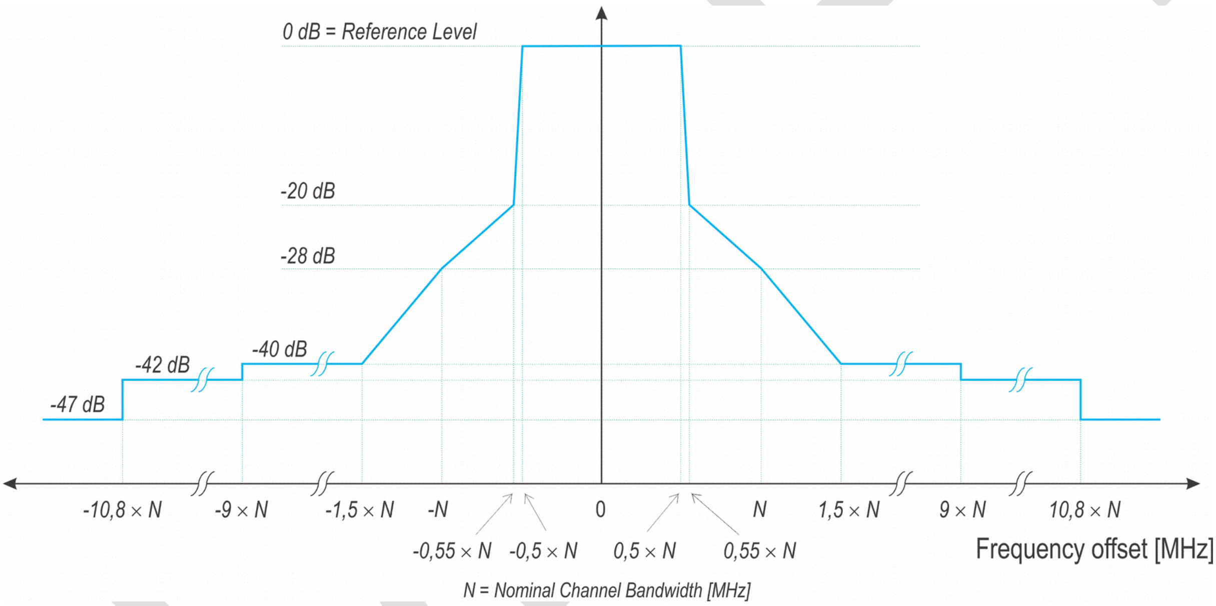


Figure 2: Transmit spectral power mask

Smart antenna system (devices with multiple transmit chains) parameters will be similar to those already defined for the 5 GHz band in ETSI EN 301 893 [9].

For transmitter unwanted emissions within the 6 GHz bands, simultaneous transmissions in adjacent channels may be considered as one signal with an actual Nominal Channel Bandwidth of "n" times the individual Nominal Channel Bandwidth where "n" is the number of adjacent channels used simultaneously.

For simultaneous transmissions in multiple non-adjacent channels, the overall transmit spectral power mask is constructed in the following manner. First, a mask as provided in Figure 2 is applied to each of the channels. Then, for each frequency point, the highest value from the spectral masks of all the channels assessed should be taken as the overall spectral mask requirement at that frequency.

4.1.6.2 Transmitter unwanted emissions outside the 6 GHz bands

The level of transmitter unwanted emissions outside the 6 GHz WAS/RLAN bands will comply with the ERC Recommendation 74-01 [10].

4.1.7 **Receiver parameters**

Receiver parameters will be similar to those already defined for the 5 GHz band in ETSI EN 301 893 [9].

4.2 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 [11]. For a more 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
CEPT population 2025	768 589 000		
ss devices operating in licence ot spectrum (remainder operating in licence um)	90%		
Hour factor	50%	62.7%	62.7%
factor (6GHz / (6GHz + 5GHz +2.4GHz))	48.17%		
t Adoption factor (6 GHz capable devices)	25%	32%	50%
tivity factor per person	1.97%		
taneously transmitting WAS/RLAN devices	820 521	1 317 034	2 057 866

4.2.1 **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 sub-sections set-out an explanation of inputs to the WAS/RLAN deployment model summarised in Table 13. Detailed material can be found in ANNEX 3:.

4.2.1.1 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 [12]. 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, these populations beyond Europe are divided by four. This is consistent with earlier studies in ITU-R WP 5A and accounts for assumed differences in 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 [13]. In order to support studies of RLAN interference into incumbent receivers, the spatial distribution of 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) [14]. Further explanation is given in Annex A3.2.

4.2.1.2 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.

4.2.1.3 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 RLAN studies [34] and ITU-R JTG 4-5-6-7 considered 62.7% to be the average busy hour factor over urban, suburban and rural areas.

4.2.1.4 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).

4.2.1.5 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.

4.2.1.6 RF activity factor

This 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 based on projected European data demand in 2025 and the duty cycle measurements for streaming video provided in ANNEX 6:. 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.

4.2.1.7 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.

4.2.2 Assignment of populations to urban, suburban and rural environments

The total population of Europe must be assigned to urban, suburban and rural environments. According to the study investigating interference from RLAN deployments into FSS receivers in the frequency band 5725-5850 MHz from ECC Report 244 [45], the appropriate distribution assignments for urban, suburban and rural in Europe are:

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

4.2.3 Busy hour data rate in the residential environment

Data rate demand during the busy hour is based on 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.

4.2.4 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 RLANs (98% and 2% respectively). Further explanation is given in Annex A3.6.

4.2.5 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 [16] which showed that transitions between active and non-active times in typical human activity patterns are rather steep (see Figure 3).

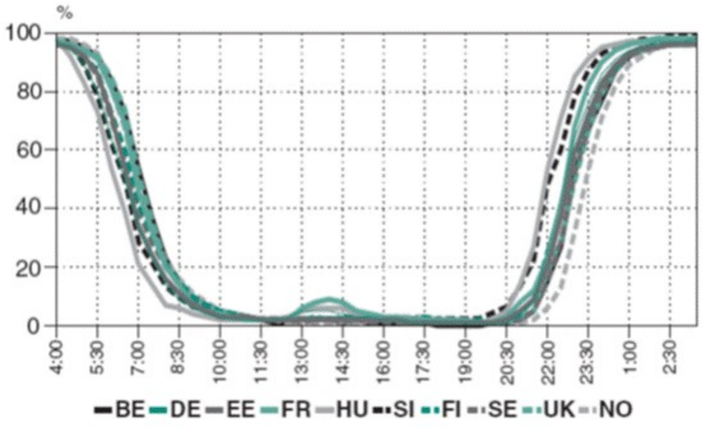


Figure 3: Sleep: Daily rhythm of persons aged 20 to 74 on weekdays [16]

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 4).

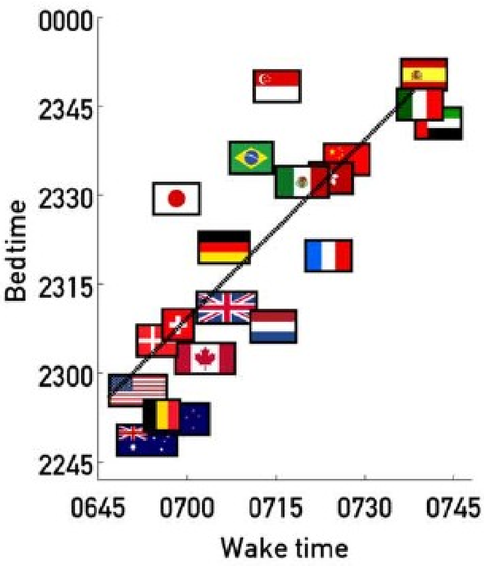


Figure 4: Wake and bed times in 20 surveyed countries [17]

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 p.m were chosen. It must be noted that "active" here does not mean that people are actively using RLAN or the Internet but simply that they are not sleeping. For RLAN sharing studies the RLAN market factors and busy hour patterns in the countries/regions within the respective time zones are taken into account.

4.2.5.1 Population distribution by time zone

A list of the world's countries and the corresponding time zone information was obtained from [18]. 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 [19]-[32]. 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 [33]. The following modifications of the UN source data were made in Table 15:

- 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 [16] 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 14, whereas the resulting values for total and active populations by continent are shown in Table 15. These tables provide calculations of the active population for a specific example, i.e. the start of the busy hour (8 p.m.) in the UTC+1 time zone.

Table 14: 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
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 15: 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[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
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.

1

5 OTHER SERVICES AND APPLICATIONS IN THE 6 GHZ FREQUENCY RANGE

5.1 FIXED SERVICE (FS)

5.1.1 FS system parameters and assumptions

The technical characteristics of point-to-point (PP) Fixed Service (FS) links are summarised in Table 16 for the lower 6 GHz band and in Table 17 for the upper 6 GHz band. The characteristics are derived from Recommendation ITU-R F.758 and Report ITU-R F.2326:

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," https://www.itu.int/rec/R-REC-F.758/en [35];

2 Report ITU-R F.2326-0: "Sharing and compatibility study between indoor International Mobile Telecommunication small cells and fixed service stations in the 5 925-6 425 MHz frequency band," http://www.itu.int/pub/R-REP-F.2326-2014 [35], [36].

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 (5 925 to 6 425 MHz) band," https://www.itu.int/rec/R-REC-F.383/en [37];

3 Recommendation ITU-R F.384-11: "Radio-frequency channel arrangements for medium- and high-capacity digital fixed wireless systems operating in the 6 425-7 125 MHz band," https://www.itu.int/rec/R-REC-F.384/en [38];

4 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," https://www.itu.int/rec/R-REC-F.699/en [39] (with peak side-lobe levels appropriate for single-entry interference studies);

5 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," https://www.itu.int/rec/R-REC-F.1245/en [40] (with average side-lobe levels appropriate for aggregate interference studies).

Table 16: 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[2]: −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 (Figure 5) Recommendation ITU-R F.1245 for aggregate interference (Figure 6)	
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)
Transmitter spectrum mask	Table 18, Figure 7	, Figure 9
Receiver noise figure typical (dB)	5	4
Receiver selectivity mask	Table 18, Figure 8	, Figure 10
Receiver noise power density typical N_{RX} (dBW/MHz)	−139	−140
Normalised RX input level for 1×10^{-6} BER (dBW/MHz)	−112.5	−110.5
Nominal long-term interference power density (dBW/MHz)	−139 + I/N	−140 + I/N
Protection requirement (dB)	I/N = −10 and −20 (Recommendation ITU-R F.758: Table 4)	

2 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 [35] and Report ITU-R F.2326-0 [36].

Link Length (km)	between 10 and 80 (Mode: 40)
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	

Table 17: 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[3]: -2)
TX output power density range (dBW/MHz)	between −31 and −13
Feeder/multiplexer loss range (dB)	between 0 and 6.3 (Mode: 1.8)
Antenna gain range (dBi)	between 32.6 and 47.4 (Mode: 38)
Antenna pattern	Recommendation ITU-R F.699 for single-entry interference (Figure 5) Recommendation ITU-R F.1245 for aggregate interference (Figure 6)
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)
Transmitter spectrum mask	Table 18, Figure 7
Receiver noise figure typical (dB)	between 4.5 and 5
Receiver selectivity mask	Table 18, Figure 8
Receiver noise power density typical N_{RX} (dBW/MHz)	−139.5
Normalised RX input level for 1 × 10^{-6} BER (dBW/MHz)	−113
Nominal long-term interference power density (dBW/MHz)	−139.5 + I/N
Protection requirement (dB)	I/N = −10 and −20 (Recommendation ITU-R F.758: Table 4)
Link Length (km)	between 10 and 80 (Mode: 40)
Note: This Report studies interference protection criteria of I/N = −10 dB and I/N = −20 dB to reflect that 15 CEPT administrations have a mobile allocation with a primary status in this band	

[3] 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.

and one CEPT administration has a mobile allocation with a secondary status

5.1.2 Fixed Service Point-to-Point narrow channels use in the band

In addition to the characteristics outlined in Section 5.1.1 for the FS with 40 and 29.65 MHz, it has to be noted that ECC Recommendation (14)06 [41] 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 ECC Recommendation (14)06 annexes [41].

5.1.3 FS antenna radiation patterns

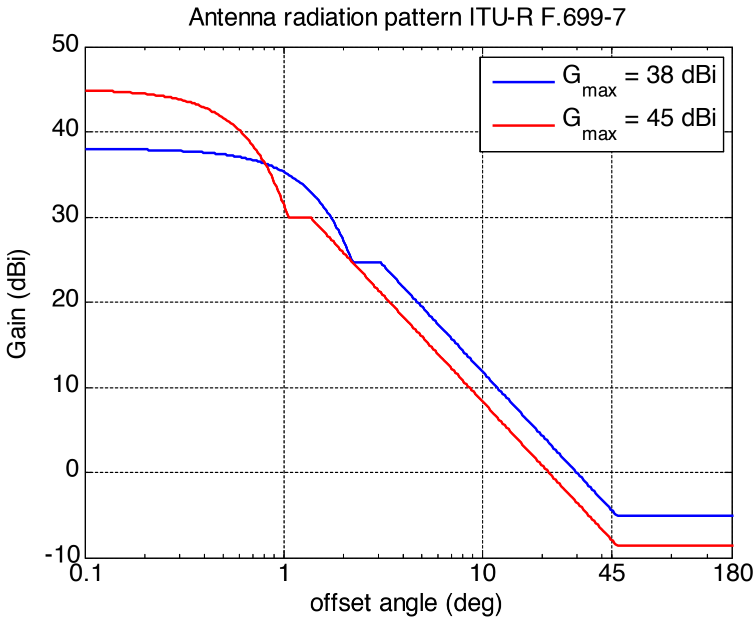


Figure 5: Antenna radiation pattern of PP FS system for single-entry interference according to Recommendation ITU-R F.699-7 at the band centre frequency of 6.175 GHz

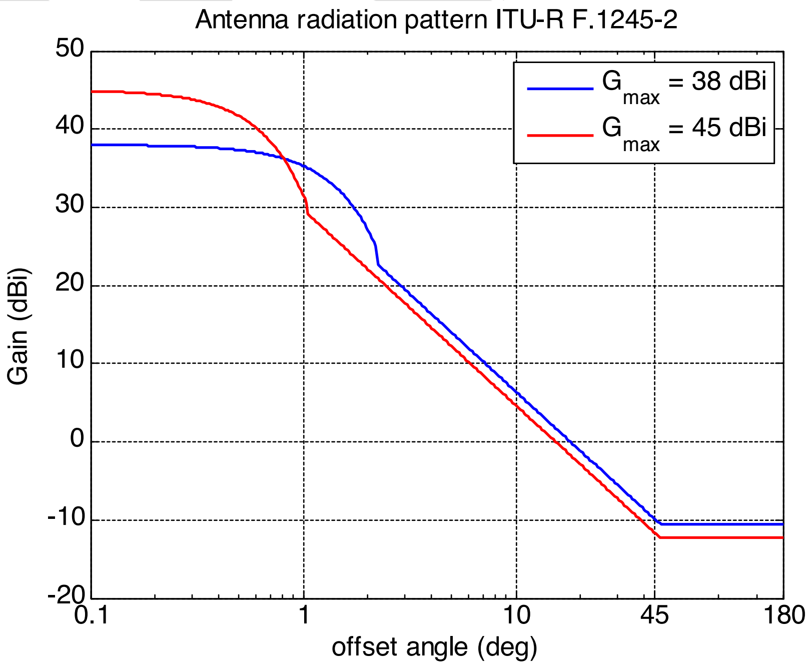


Figure 6: Antenna radiation pattern of PP FS system for aggregate interference according to Recommendation ITU-R F.1245-2 at the band centre frequency of 6.175 GHz

5.1.4 FS transmitter spectrum mask and receiver selectivity

Typical transmitter spectrum mask and typical receiver selectivity are calculated using the method described in ETSI TR 101 854, Annex F [42] for the values and corner points taken from ETSI EN 302 217-2 [43].

Table 18: Derivation of typical transmitter spectrum mask and typical receiver selectivity for FS systems with 40 MHz channel spacing

Parameter	Value	Reference
Modulation scheme 2^N	$64-QAM\ (N=6)$	Recommendation. ITU-R F.758
Channel spacing CS (MHz)	40	Recommendation ITU-R F.758
Payload (Mbit/s)	155	ETSI TR 101 854, Table F.1
Overhead factor (%)	10	ETSI TR 101 854, Table F.1
Gross bit rate (Mbit/s)	$GBR = payload \times \frac{100+overhead}{overhead} = 170.5$	ETSI TR 101 854, Equation (F.1)
Nyquist frequency (MHz)	$f_N = \frac{GBR}{2N} = 14.21$	ETSI TR 101 854, Equation (F.2)
Spectrum mask corner points $(f_i[MHz], K_i[dB])$	$(0,2),(17.2,2),(20.8,-10),(22.2,-32),(24$	EN 302 217-2 Table 3h, Figure 7(e)
Cosine roll-off factor r_{of}	0.562	ETSI TR 101 854 Annex F.2, Equation (F.4)
Typical TX spectrum mask $(f_i[MHz], t_i[dB])$	$(0,0),(7.358,-0.1),(14.709,-3.5),$ $(16.55,-5.6),(18.39,-8.7),(20.231,-14.3$ $(22.067,-38.1),(77,-57.0),(80,-57.0)$	ETSI TR 101 854, Annex F.5 Graphically shown in Figure 7
Typical RX selectivity $(f_i[MHz], r_i[dB])$	$(0,0),(7.385,-0.1),(14.793,-3.5),$ $(16.634,-5.7),(18.474,-8.9),(20.315,-1$ $(22.151,-47.6),(29.307,-63),(80,-63)$	ETSI TR 101 854, Annex F.5 Graphically shown in Figure 8

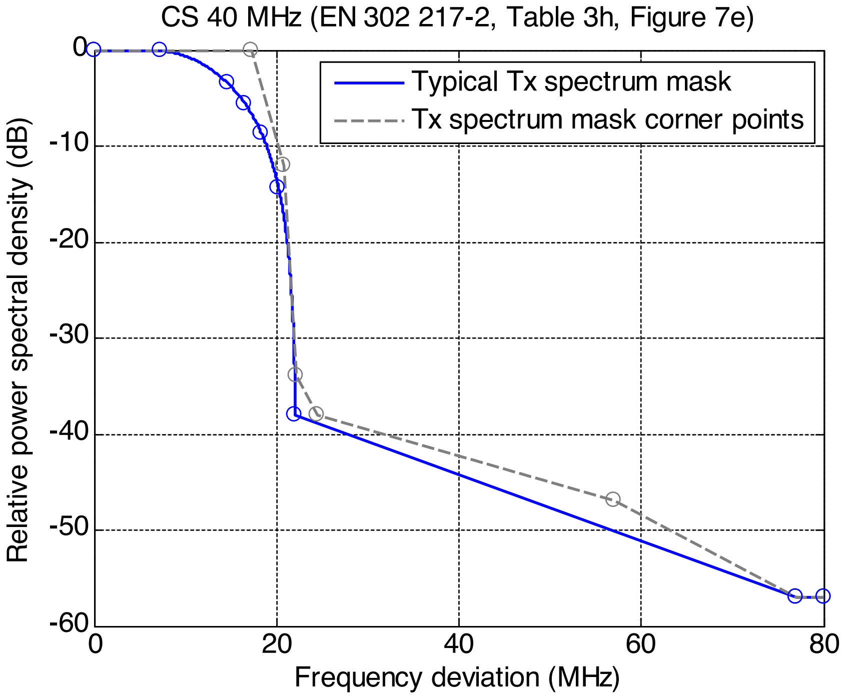


Figure 7: Typical transmitter spectrum mask for FS systems with channel spacing 40 MHz

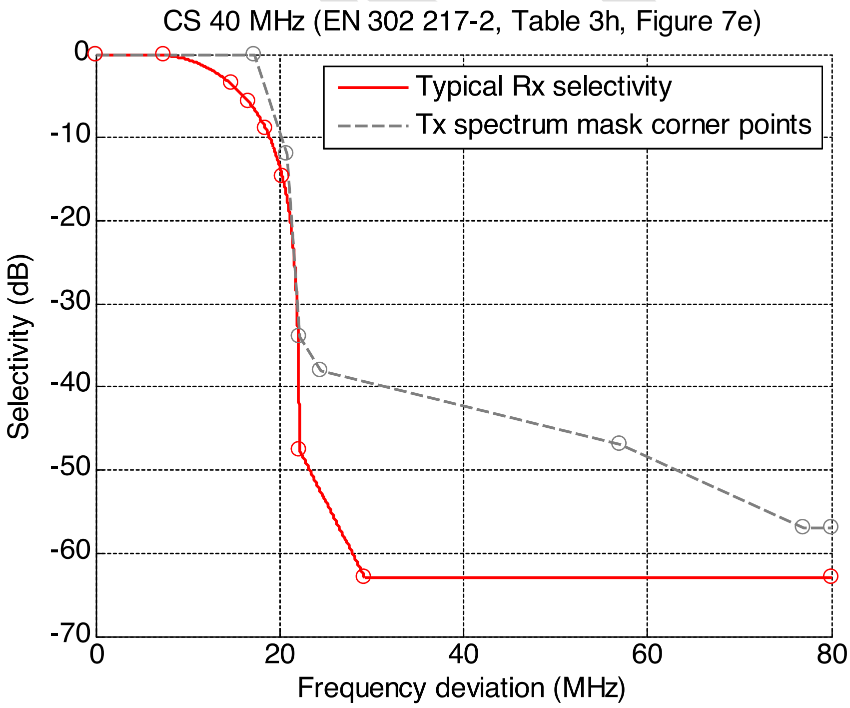


Figure 8: Typical receiver selectivity mask for FS systems with channel spacing 40 MHz

Table 19: Derivation of typical transmitter spectrum mask and typical receiver selectivity for FS systems with 29.65 MHz channel spacing

Parameter	Value	Reference
Modulation scheme 2^N	$128-QAM\ (N=7)$	Recommendation ITU-R F.758
Channel spacing CS (MHz)	29.65	Recommendation ITU-R F.758
Payload (Mbit/s)	155	ETSI TR 101 854, Table F.1
Overhead factor (%)	10	ETSI TR 101 854, Table F.1
Gross bit rate (Mbit/s)	$GBR = payload \times \frac{100+overhead}{overhead} = 170.5$	ETSI TR 101 854, Equation (F.1)
Nyquist frequency (MHz)	$f_N = \frac{GBR}{2N} = 12.179$	ETSI TR 101 854, Equation (F.2)
Spectrum mask corner points $(f_i[MHz], K_i[dB])$	$(0,2),(12,2),(14.5,-10),(15.5,-32),$ $(17,-36),(40,-45),(54,-55),(59.3,-$	EN 302 217-2 Table 3h, Figure 7(e)
Cosine roll-off factor r_{of}	0.25	ETSI TR 101 854 Annex F.2, Equation (F.4)
Typical TX spectrum mask $(f_i[MHz], t_i[dB])$	$(0,0),(5.06,0),(10.115,-0.3),$ $(11.381,-1.5),(12.648,-4.2),(13.914,-$ $(15.174,-38),(54,-57),(59.3,-57)$	ETSI TR 101 854, Annex F.5 Graphically shown in Figure 9
Typical RX selectivity $(f_i[MHz], r_i[dB])$	$(0,0),(5.071,0),(10.147,-0.3),$ $(11.414,-1.6),(12.68,-4.3),(13.947,-9$ $(15.207,-47.6),(20.294,-63),(59.3,-($	ETSI TR 101 854, Annex F.5 Graphically shown in Figure 10

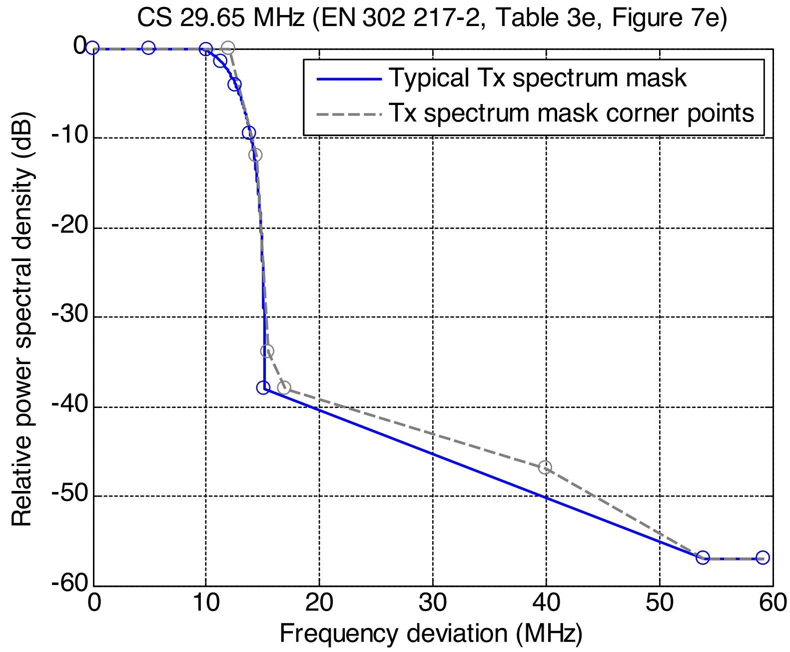


Figure 9: Typical transmitter spectrum mask for FS systems with channel spacing 29.65 MHz

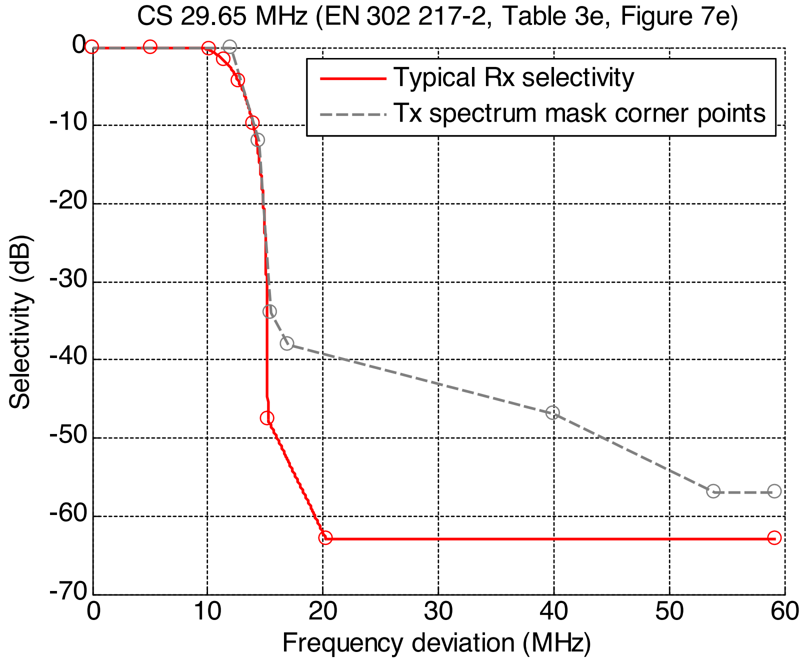


Figure 10: Typical receiver selectivity mask for FS systems with channel spacing 29.65 MHz

5.1.5 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 11 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 [44], 5 December 2017, Embedded Excel file “Draft Revised ECC Rep 173 - Below and Above 50 GHz in 2016.xlsw”

Figure 11: FS Link Lengths Reported by CEPT administrations (5925-7125 MHz)

5.2 FIXED SATELLITE SERVICE (FSS), EARTH-TO-SPACE

5.2.1 FSS system parameters and assumptions

The technical characteristics of Fixed Satellite Service (FSS) transmitters are summarised in Table 20. 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 RLANs in the 5725-5925 MHz band", January 2016, http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCREP244.PDF [45];

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", https://www.itu.int/rec/R-REC-S.672-4-199709-I/en [46] (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)

6 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" [47], https://www.itu.int/rec/R-REC-S.465/en

7 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" [48], https://www.itu.int/rec/R-REC-S.524/en

8 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" [49], https://www.itu.int/rec/R-REC-S.1432-1-200604-I/en

9 Recommendation ITU-R S.1587-3: "Technical characteristics of earth stations on board vessels (ESV) communicating with FSS satellites in the frequency bands 5 925 - 6 425 MHz and 14 - 14.5 GHz which are allocated to the fixed-satellite service" [50], https://www.itu.int/rec/R-REC-S.1587/en

10 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" [51], https://www.itu.int/rec/R-REC-S.731/en

Table 20: 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, 32
Antenna reference pattern	Recommendation ITU-R S.465
Range of emission bandwidths (MHz)	0.040-72
Earth station deployment	All regions, in all locations (rural, suburban, urban)
Earth station e.i.r.p. density towards the horizon	In accordance with RR No. **21.8** and Recommendation ITU-R S.524-9
Minimum earth station antenna elevation angle (degrees)	5

5.2.2 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 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 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.

5.2.3 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 & SES) have receive transponders. Table 21 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).

Table 21 is a snapshot of representative operational satellites while this Report is being written. 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.

Table 21: 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^o West	20.3	595	-7.44		
B	14^o West	26.5	1200			
C	31.5^o West	32.8	700			
D	3^o East	22.9	316	-2.09		
E	27.5^o West	34.2	565.76	6.67	832	5.00
F	53^o East	26.5	1200			
I	359^o East	28.67	340.68	3.35	501	1.67
J	40.5^o West	22	190	-0.8		
K	22^o West	28.2	190	5.4		
L	20^o West	31.8	250	7.8		
M	50.5^o East	32.4	250	8.4		
N	57^o East	27.9	190	5.1		
O	5^o East	32.5	700			
P	47.5^o West	20	190	-2.8		
Q	37.5^o West	30.5	190	7.7		
R	60^o East	37.29	201.28	14.25	296	12.58
R'	5^o East	37.29	201.28	14.25	296	12.58
T	34.5^o West	39.90	224.4	16.39	330	14.71
U	8^o West	27.2	428	0.88		
V	10^o East	24.2	412	-1.94		
W	66^o East	27.86	357	2.33	525	0.66
Y	45^o West	31.04	298.52	6.29	439	4.62
Z	72^o East	28.33	252.96	4.30	372	2.62

A list of representative satellites with coverage over Europe - which happen to be at specific orbital locations - is provided to be considered for sharing studies between RLAN and FSS, in Table 21. 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.

5.3 ROAD-INTELLIGENT TRANSPORTATION SYSTEMS (ITS) IN THE ADJACENT BAND

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

5.4 COMMUNICATION-BASED TRAIN CONTROL SYSTEMS (CBTC)

Technical characteristics of CBTC systems are outlined in Section 10.

5.5 RADIO ASTRONOMY

Technical characteristics for the Radio Astronomy Service are outlined in Section 11.

5.6 ULTRA WIDE BAND (UWB) SYSTEMS

Technical characteristics of UWB systems are outlined in Section 12.

6 METHODOLOGY AND APPROACH USED IN SHARING AND COMPATIBILITY STUDIES

6.1 METHODOLOGY

This Report has embraced both MCL and Monte Carlo simulation methodologies. 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 and this may lead to the calculation of azimuth dependent minimum separation distances. 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.

6.2 PROPAGATION MODELS

6.2.1 Terrestrial paths

When analysing interference into FS stations from a deployment of a large number of 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 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, RLANs are used at ground level and in upper floors of buildings, indoors and outdoors, such that the interference paths, through clutter, are from 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 RLAN usage, Recommendation ITU-R P.2109 [52] is used for computing indoor-to-outdoor interference path propagation losses as described in Section 6.4.

For near-in, out to 1 km, propagation loss including clutter, WINNER II (WII) [58] was used for suburban and urban areas.

For propagation loss beyond 1 km in suburban and urban areas, Recommendation ITU-R P.452 [54] terrain propagation or Recommendation ITU-R P.2001 [53] was used in combination with Recommendation ITU-R P.2108 [55]. ITU-R P.2108 is a suburban/urban endpoint clutter model used for long distance paths with the 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 or ITU-R P.2001 terrain propagation models are recommended in conjunction with the Recommendation ITU-R P.452 rural endpoint clutter model. By default, the rural clutter morphology is assumed to be village centre since RLANs are generally used within buildings. If the location is dominated by trees, a rural tree clutter morphology is assumed, instead.[4]

The P.452 assumes that for each rural clutter category there is an average clutter height and distance from

[4] 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 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 P.452 is used to calculate the clutter loss. Additionally, no clutter loss is added for cases where the distance from the RLAN to the FS station is less than 10 times the distance from the RLAN to the clutter.

6.2.1.1 Discussion of propagation models selected for terrestrial paths

The following was considered in recommending WINNER II (WII) over Recommendation ITU-R P.1411 [59], for propagation loss out to 1 km in urban and suburban areas.

- The WII 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 RLANs are below rooftop and assume that both the FS station and 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 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 RLAN on Earth randomly according to population density*
  b) *For each RLAN, calculate the distance to the FS:* d
  c) *For each RLAN, calculate* p_{LOS} *which is a function of distance* d *and the environment (RLAN can be in Urban, Suburban or Rural environment)*
  d) *For each RLAN, generate a random number* $r = rand(1)$ *with a uniform distribution over the interval* $[0,1]$
     if $r < p_{LOS}$*: 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 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 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 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 [60]) defines 3D macro cell models where the probability of LOS paths is calculated for 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.
- Recommendation ITU-R P.452 and Recommendation ITU-R P.2001 are both terrain propagation models. However, the ITU-R P.452 model is more conservative. It over predicts interference as it only models the lower half of the propagation time variability distribution. Therefore, it includes special

atmospheric conditions where the propagation loss can be less than free space loss. Conversely, it does not include multipath or rain fade. ITU-R P.2001 includes the full propagation loss time variability distribution (0 to 100 percent) and, therefore, will provide more realistic results.

6.2.1.2 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 [88]
  - A reference Excel implementation available on ITU-R Study Group 3 web page [89].

- Recommendation ITU-R P.2001-2: "A general purpose wide-range terrestrial propagation model in the frequency range 30 MHz to 50 GHz":
  - A reference MATLAB implementation available on ITU-R Study Group 3 web page [90].
- Recommendation ITU-R P.525 [57]: "Calculation of free-space attenuation";
- Recommendation ITU-R P.1411 [59]: "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 [58], 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.

6.2.2 Earth-to-air paths

For indoor RLAN usage, Recommendation ITU-R P.2109 is used for computing indoor-to-outdoor interference path propagation losses as described in Section 6.4.

For suburban and urban propagation areas, local end-point clutter is added using Recommendation ITU-R P.2108, Section 6.3 (for Earth-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 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 an RLAN with 1.5 m height. Therefore, in the simulations, when the rural RLAN height is 1.5 m, a clutter loss of 18.4 dB was added when the look angle to the FSS receiver was ≤ 2.86 degrees. When rural RLAN heights are above 1.5 m, the clutter loss is assumed to be negligible and is not calculated.

For each RLAN, a 4/3 earth model is used to determine whether the satellite is in view or over the horizon. 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 [63], from the RLAN position to the satellite orbital slot. Conservatively, atmospheric loss, which is small, was ignored in this calculation.

6.2.2.1 References and information on implementation

- Recommendation ITU-R P.525: "Calculation of free-space attenuation";
- Recommendation ITU-R P.528 [62]: "Propagation curves for aeronautical mobile and radionavigation services using the VHF, UHF and SHF bands";
- Recommendation ITU-R P.619 [63]: "Propagation data required for the evaluation of interference between stations in space and those on the surface of the Earth";
- Recommendation ITU-R P.2041 [61]: "Prediction of path attenuation on links between an airborne platform and Space and between an airborne platform and the surface of the Earth".

6.3 CLUTTER LOSS

Recommendation ITU-R P.2108 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, 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 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 [56] 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 RLAN to the FS station is less than 10 times the distance from the 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 [91].

6.4 BUILDING ENTRY LOSS

For indoor 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 [92].

6.5 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 RLAN access points and terminals of similar interference levels;
f) No single source of interference (or small number of sources with the same polarisation angle at the victim receiver) dominates the calculation;
g) 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 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 12 below shows the results of one simulation of 5000 samples.

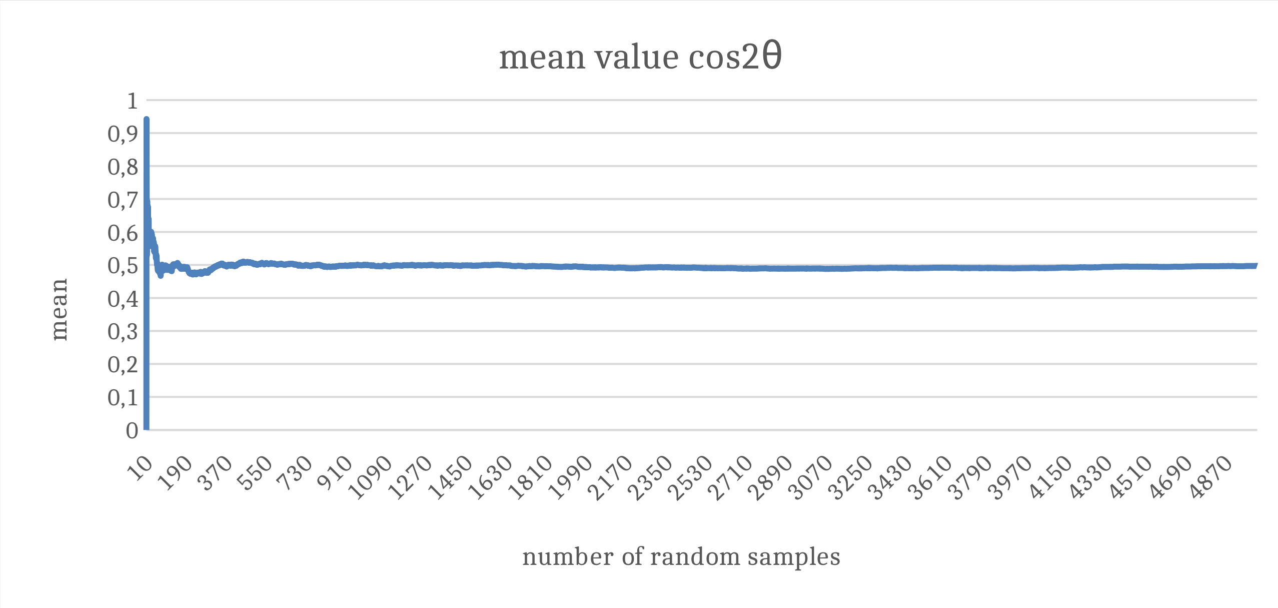


Figure 12: The mean value of $cos^2\theta$ as a function

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.

6.5.1 Applicability to 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 RLAN into FSS uplinks is 3 dB.

6.5.1.1 Arguments for randomness of RLAN polarisation as seen from the satellite

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

1 RLAN devices use linear polarisation, but polarisation mismatch is a known problem in RLAN networks;

11 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;

12 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;

13 Scattered energy from RLANs, e.g. from indoor to outdoor or from local clutter - is depolarised;

14 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.

6.5.2 **Applicability to RLAN - FS Studies**

The situation for 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 RLAN devices. However, the main beam of an FS receiver could equally see many RLANS 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.

6.6 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 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 4.1.1.4. 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 22 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 22: 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 %

7 SHARING BETWEEN RLAN AND FIXED SERVICE

7.1 INTRODUCTION

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

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

The output of the MCL is a theoretical minimum separation distance that is strongly dependent on the FS antenna pattern and on the propagation model assumptions. In all cases it is found that interference may theoretically occur (relative to the long-term threshold of the FS) unless there is a separation distance up to 47 km - depending on assumptions.

This result provides the motivation to consider a dynamic study, like the one presented in Studies B and C. The MCL study does not consider how the interference values vary with time nor how likely it is to find RLANs deployed at the specific locations needed to drive the interference levels above the threshold. It does not consider the very real-world distribution of RLAN e.i.r.p. and duty cycle or the significant off-boresight discrimination from real antennas. Nor does it consider the aggregation of interference from the population of RLANs.

The Monte Carlo analyses in Studies B and C find that interference levels above the -10 dB threshold occur in a very small percentage of the morphologies simulated - significantly less than the 20% time requirement for long-term interference in Recommendation ITU-R F.758-6. This is due to a combination of the fact that deployments where a high power RLAN is in line-of-sight of the FS in the main lobe of the antenna are rare and the fact that when such a deployment may be found the interference is intermittent due to the low activity factor of the RLAN.

Each study is described below in detail.

7.2 STUDY A: MCL ANALYSIS OF INTERFERENCE FROM RLAN INTO FS

7.2.1 Introduction

It is assumed that an FS station is the victim receiver and an RLAN AP 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 criteria of $I/N=-10$ dB and $I/N=-20$ dB are exceeded.

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

The following MCL formula is used:

$$P_{Tx_{EIRP}} - L_{Path} - L_{Clutter} - L_{BuildingEntry} + G_{Rx} \leq 10\log\left(k T_0 B\right) + NF_N + \frac{I}{N}$$

where:

- $P_{Tx_{EIRP}}$ is the e.i.r.p. of the RLAN transmitter;
- L_{Path} is the attenuation caused by the path of transmission;
- $L_{Clutter}$ is the attenuation caused by obstacles in the path of transmission;

- $L_{BuildingEntry}$ is the attenuation caused by walls when the RLAN transmitter is located inside a building;
- G_{Rx} is the antenna gain of the FS receiver in the direction of the 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 RLAN devices located indoors with e.i.r.p. power densities:
  - 1000 mW / 20 MHz = 17 dBm/MHz;
  - 250 mW / 20 MHz = 11 dBm/MHz.
- Urban scenario with RLAN devices located outdoors with e.i.r.p. power densities:
  - 1000 mW / 20 MHz = 17 dBm/MHz;
  - 25 mW / 20 MHz = 1 dBm/MHz;
  - 25 mW / 94 MHz = -6 dBm/MHz.
- Rural scenario with RLAN devices located indoors with e.i.r.p. power densities:
  - 1000 mW / 20 MHz = 17 dBm/MHz;
  - 250 mW / 20 MHz = 11 dBm/MHz.
- Rural scenario with RLAN devices located outdoors with e.i.r.p. power densities:
  - 1000 mW / 20 MHz = 17 dBm/MHz;
  - 25 mW / 20 MHz = 1 dBm/MHz;
  - 25 mW / 94 MHz = -6 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 (what results in peak separation distances only) are analysed.

Five scenarios are analysed, each with RLAN devices transmitting with e.i.r.p. of 1000 mW / 20 MHz = 17 dBm/MHz and with 240 mW / 160 MHz = 2 dBm/MHz:
- Urban scenario with outdoor 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) 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) 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) 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) RLAN devices at Tx height of 4.5 m;
  - Rx heights of 10 m, 25 m, 40 m and 55 m.

7.2.2 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 [59] is used with line of sight (LOS) conditions. From 1000 m, the model described in Recommendation ITU-R P.452-16 [54] is used with non-line of sight (NLOS) conditions. The model described in Recommendation ITU-R P.2108-0 [55] 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 (P.2109) 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).

7.2.3 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 23.

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 RLAN device inside of the first Fresnel zone of the FS link.

Table 23: MCL Parameters

Parameter	Value	Comment
Frequency	6.175 GHz	Centre frequency of the proposed band
FS Antenna Pattern	ITU-R F.699	Diagram is shown in Figure 5 of this Report, the elevation angle is assumed to be 0° for calculations
RLAN Antenna Pattern	Isotropical	Simplified assumption for single interferer case. e.i.r.p. values are used.
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, 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, 5 dB	Used for antenna height

		sensitivity analysis
RLAN e.i.r.p. max	14 dBm, 24 dBm, 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
RLAN Bandwidth min	20 MHz, 94 MHz	Used for power density sensitivity analysis
	20 MHz, 160 MHz	Used for antenna height 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	

7.2.4 Results for sensitivity analysis of power density levels

MCL calculations have been done for a flat terrain with terrain profile 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°. The 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 RLAN transmitter causes interference to the FS receiver corresponding to $I/N=-10$ dB and $I/N=-20$ dB.

7.2.4.1 Urban indoor scenario

Figure 13 shows the theoretical separation distance (bold blue line for $I/N=-10$ dB, bold red line for $I/N=-20$dB) for the urban indoor scenario, which was described in Section 7.2.1. The parameters used can also be seen in Figure 13. For an $I/N=-10$ dB, separation distances from 700 m up to 13500 m can be observed. For an $I/N=-20$ dB, the distances are between 900 m and 19900 m. These distances are strongly dependent on the antenna pattern 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 14 shows the theoretical separation distance for the urban indoor scenario with an RLAN power density of 11 dBm/MHz.

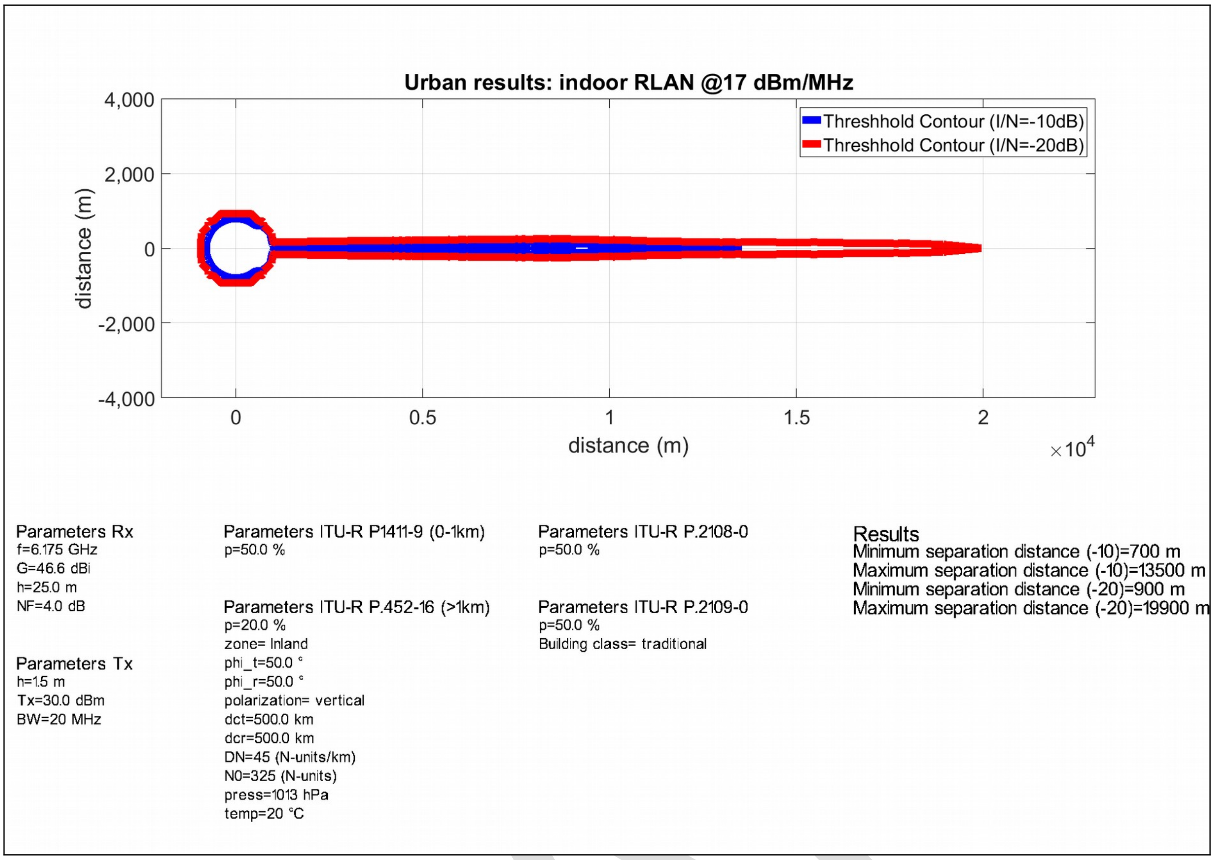


Figure 13: Urban results - indoor RLAN @ 17 dBm/MHz e.i.r.p.

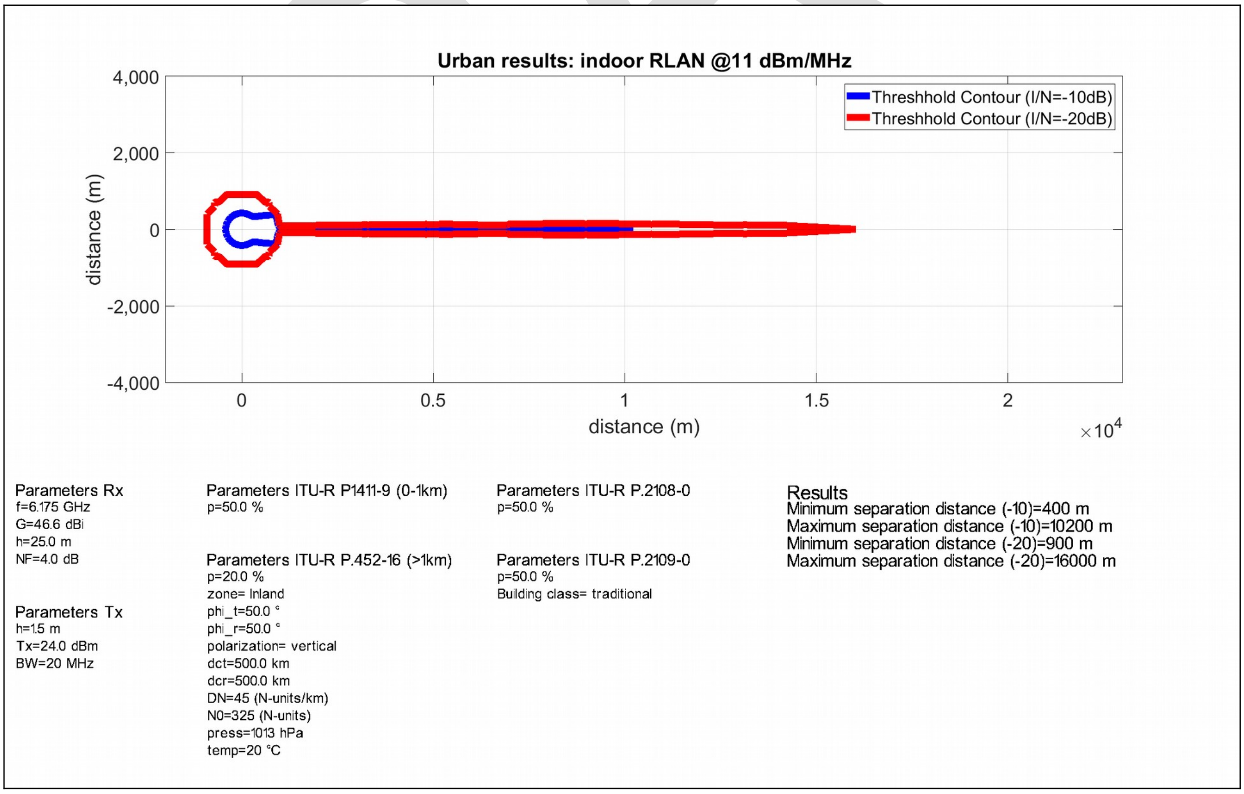


Figure 14: Urban results - indoor RLAN @ 11 dBm/MHz e.i.r.p.

7.2.4.2 Urban outdoor scenario

Figure 15 shows the theoretical separation distance (bold blue line for $I/N=-10$ dB, bold red line for $I/N=-20$ dB) for the urban outdoor scenario, which was described in Section 7.2.1. The parameters used are also provided in Figure 15.

For an $I/N=-10$ dB it can be seen in that in the urban outdoor scenario separation distances range between 900 m and 24200 m. For an $I/N=-20$ dB, the distances are between 900 m and 31700 m. These distances are strongly dependent on the antenna pattern of the FS receiver.

Figure 16 shows the theoretical separation distance for the urban outdoor scenario with an RLAN power density of $1\,dBm/MHz$.

Figure 17 shows the theoretical separation distance for the urban outdoor scenario with an RLAN power density of $-6\,dBm/MHz$.

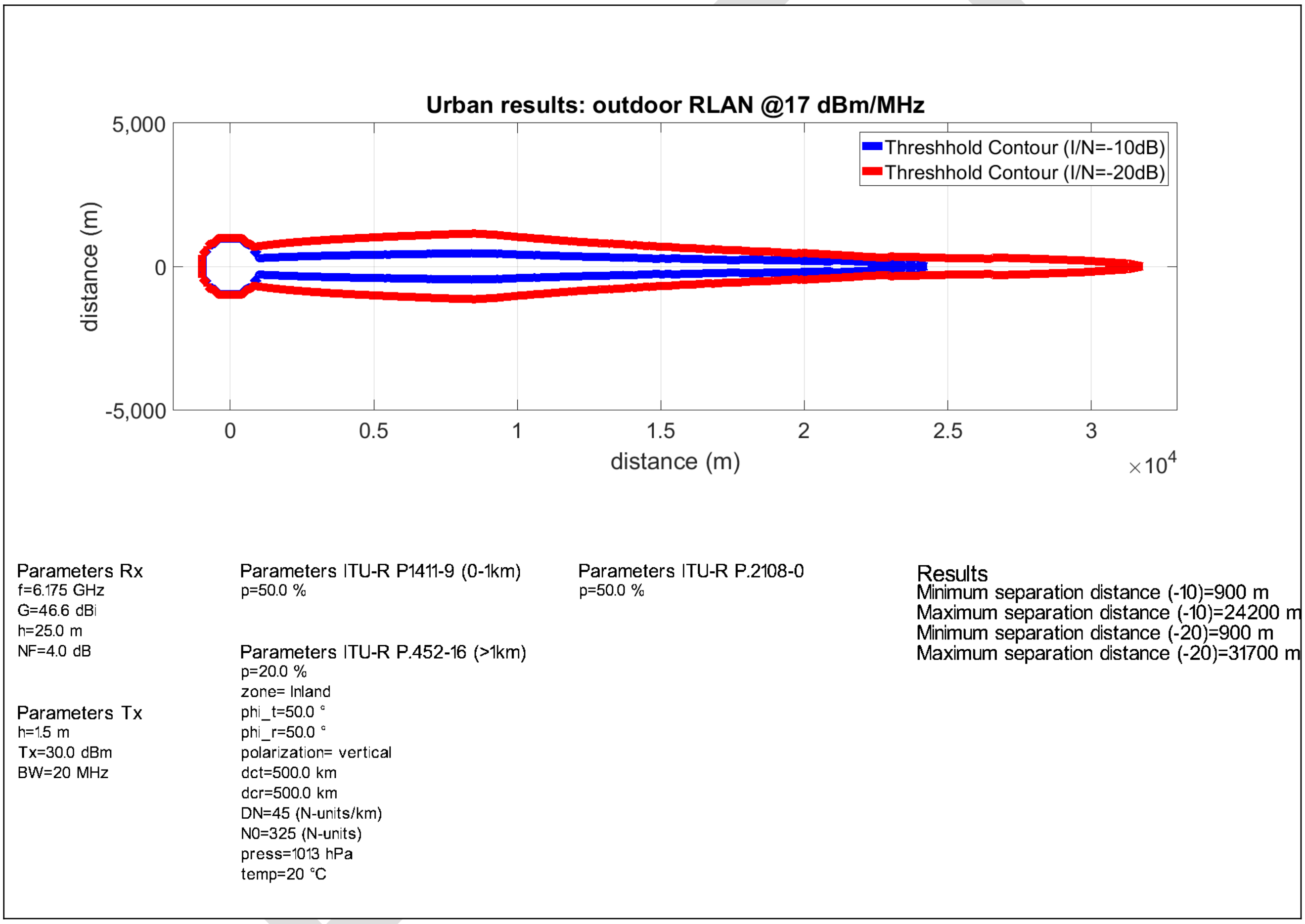


Figure 15: Urban results - outdoor RLAN @ 17 dBm/MHz e.i.r.p.

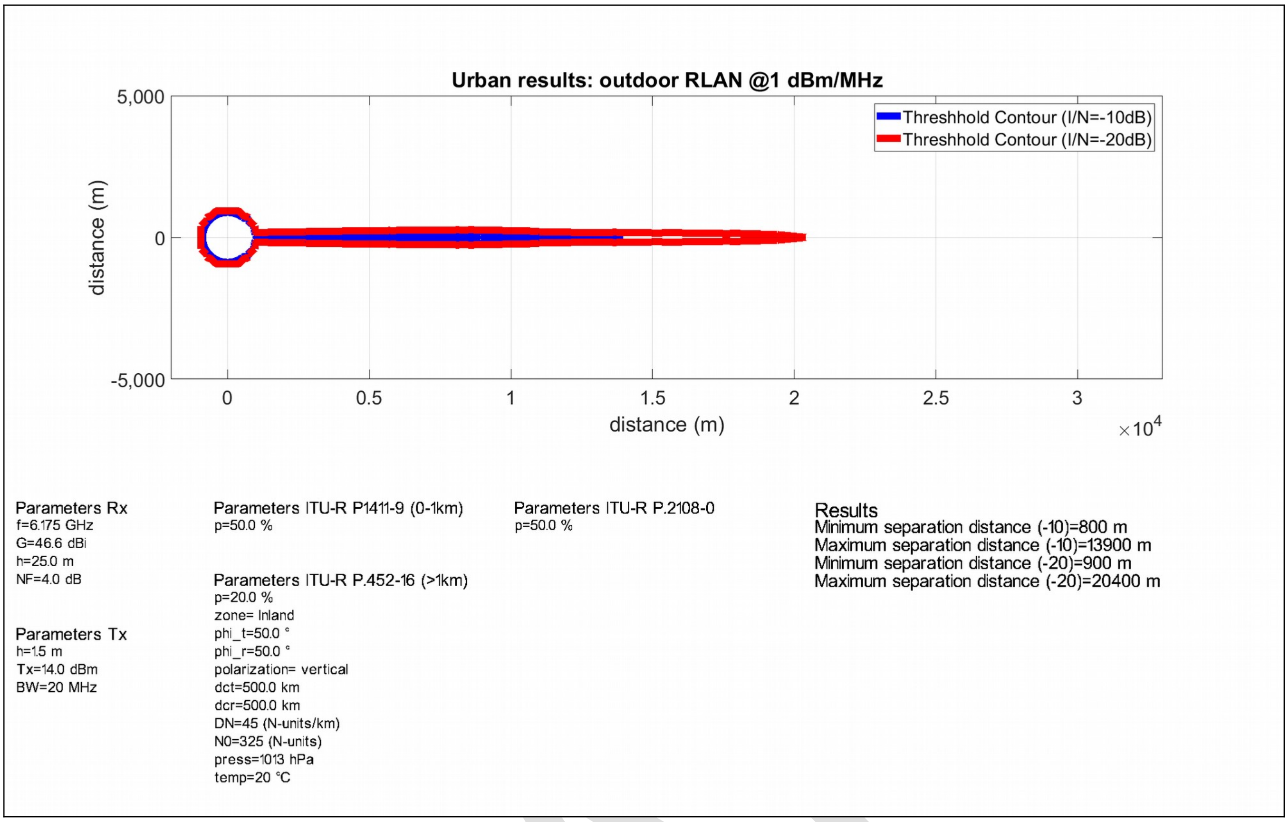


Figure 16: Urban results - outdoor RLAN @ 1 dBm/MHz e.i.r.p.

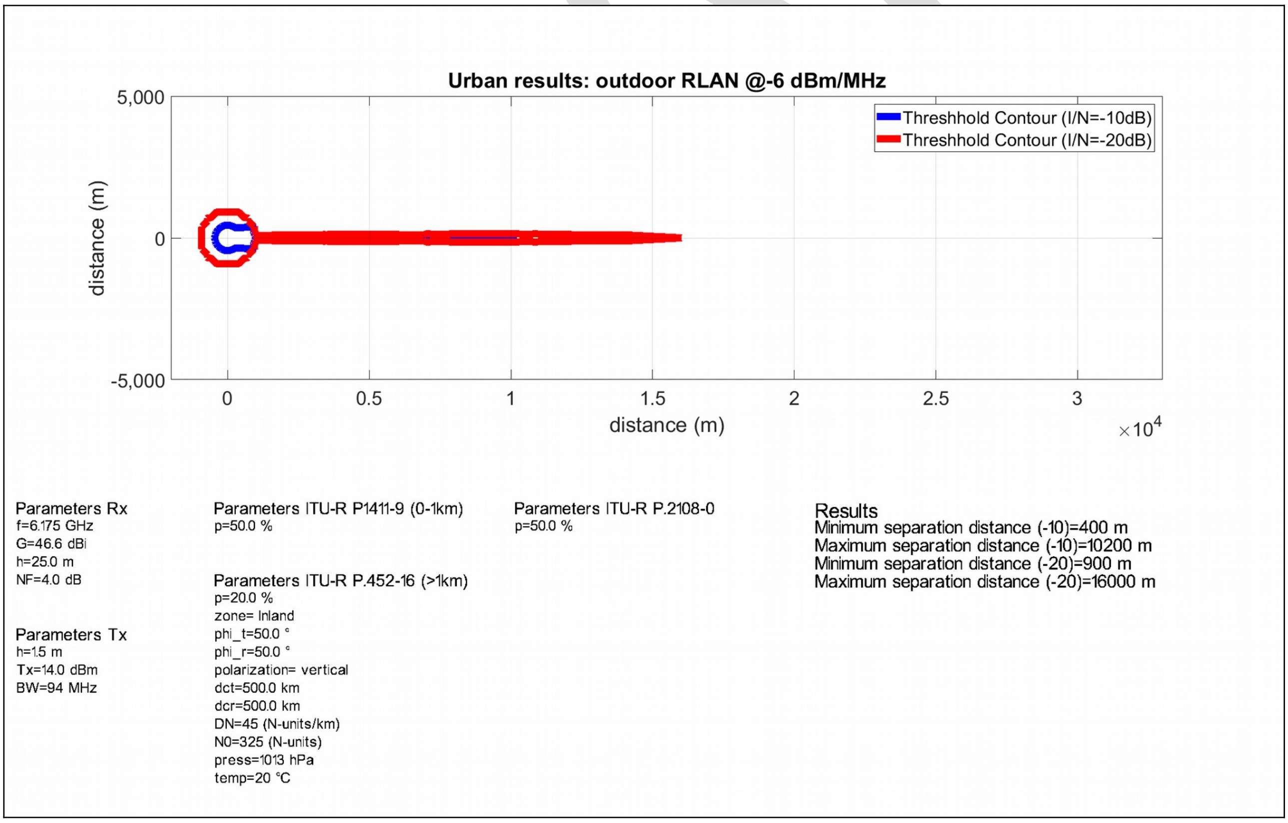


Figure 17: Urban results - outdoor RLAN @ -6 dBm/MHz e.i.r.p.

7.2.4.3 Rural indoor scenario

Figure 18 shows the theoretical separation distance (bold blue line for $I/N = -10$dB, bold red line for $I/N = -20$dB) for the rural indoor scenario which was described in Section 7.2.1. The used parameters are also given in Figure 18.

For an $I/N = -10$dB, it can be seen in Figure 18 that in the rural indoor scenario separation distances range between 1300 m up to 28200 m. For an $I/N = -20$ dB, the distances are between 4000 m and 36000 m. These distances are strongly dependent of the antenna pattern of the FS receiver. As described in Section 7.2.2, the shape of the threshold contour shown in Figure 18 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 19 shows the theoretical separation distance for the rural indoor scenario at an RLAN power density of 11 dBm/MHz.

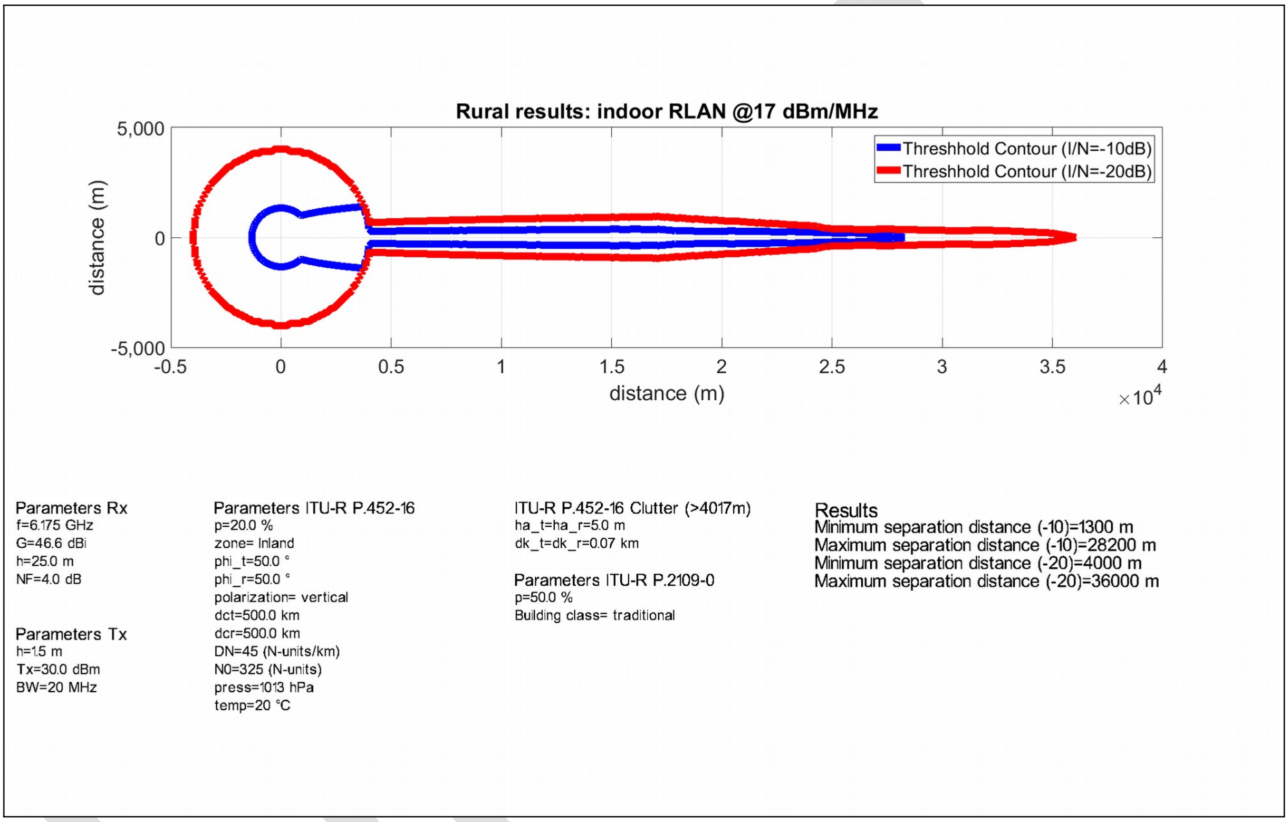


Figure 18: Rural results - indoor RLAN @ 17 dBm/MHz e.i.r.p.

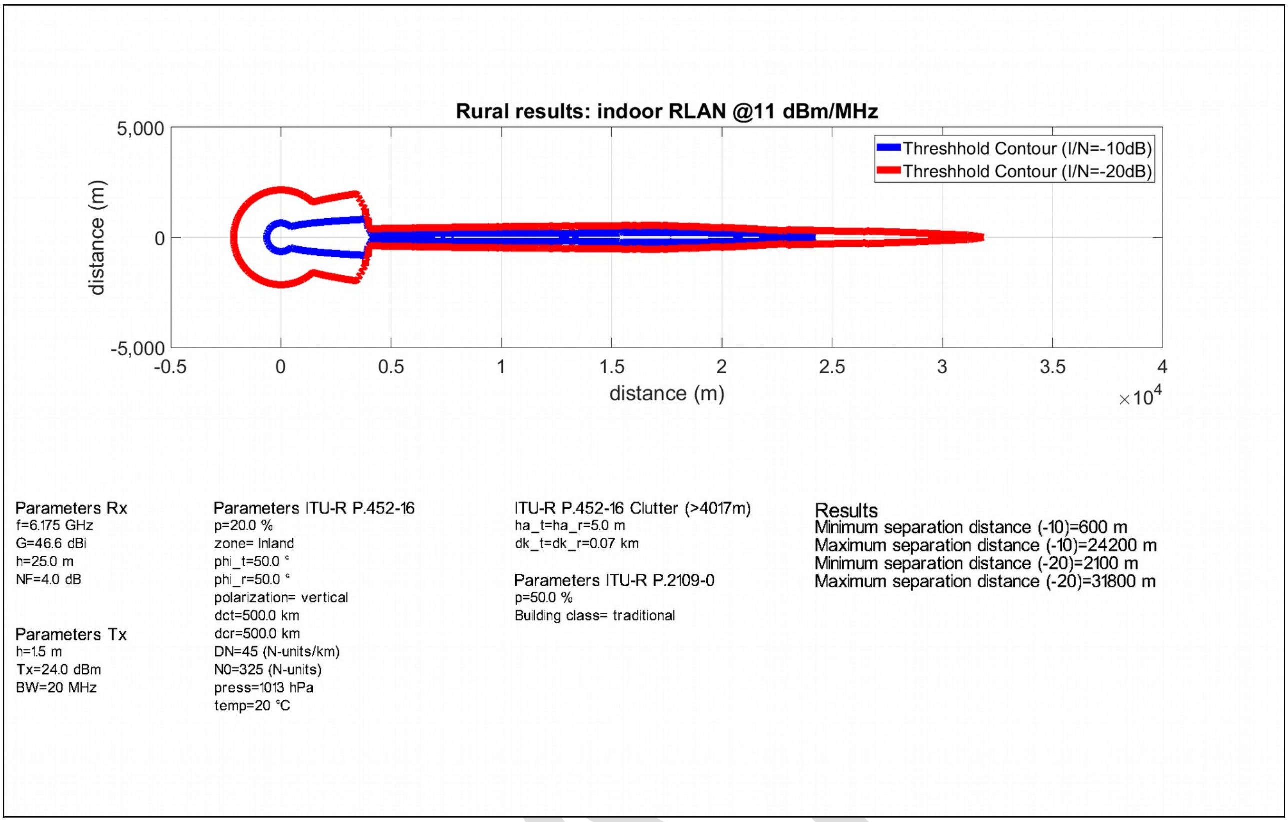


Figure 19: Rural results - indoor RLAN @ 11 dBm/MHz e.i.r.p.

7.2.4.4 Rural outdoor scenario

Figure 20 shows the theoretical separation distance (bold blue line for $I/N=-10$ dB, bold red line for $I/N=-20$dB) for the rural outdoor scenario which was described in Section 7.2.1. The parameters used are also provided in Figure 20.

As described in Section 7.2.2, the shape of the threshold contour shown in Figure 20 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 40400 m and for $I/N=-20$dB up to 47100 m.

Figure 21 shows the theoretical separation distance for the rural outdoor scenario for an RLAN power density of $1\,dBm/MHz$.

Figure 22 shows the theoretical separation distance for the rural outdoor scenario for an RLAN power density of $-6\,dBm/MHz$.

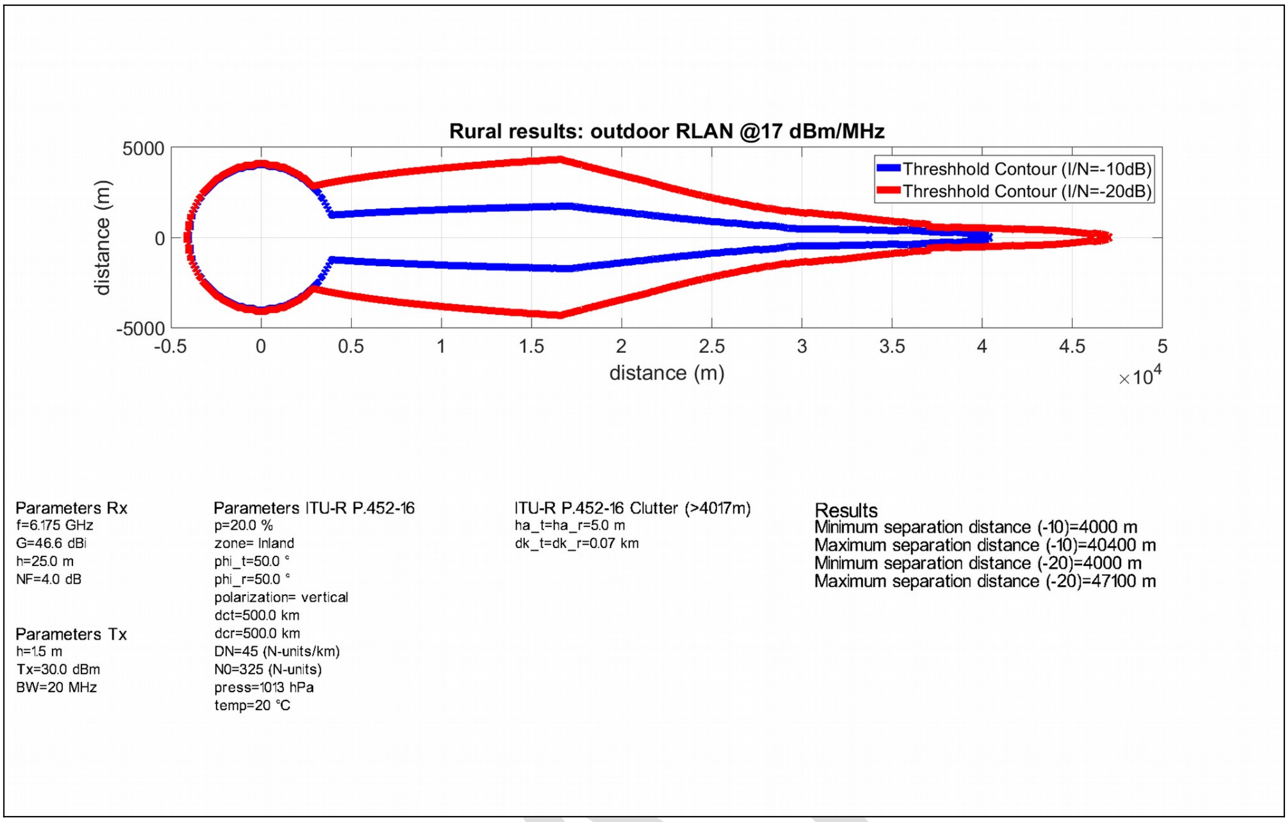


Figure 20: Rural results - outdoor RLAN @ 17 dBm/MHz e.i.r.p.

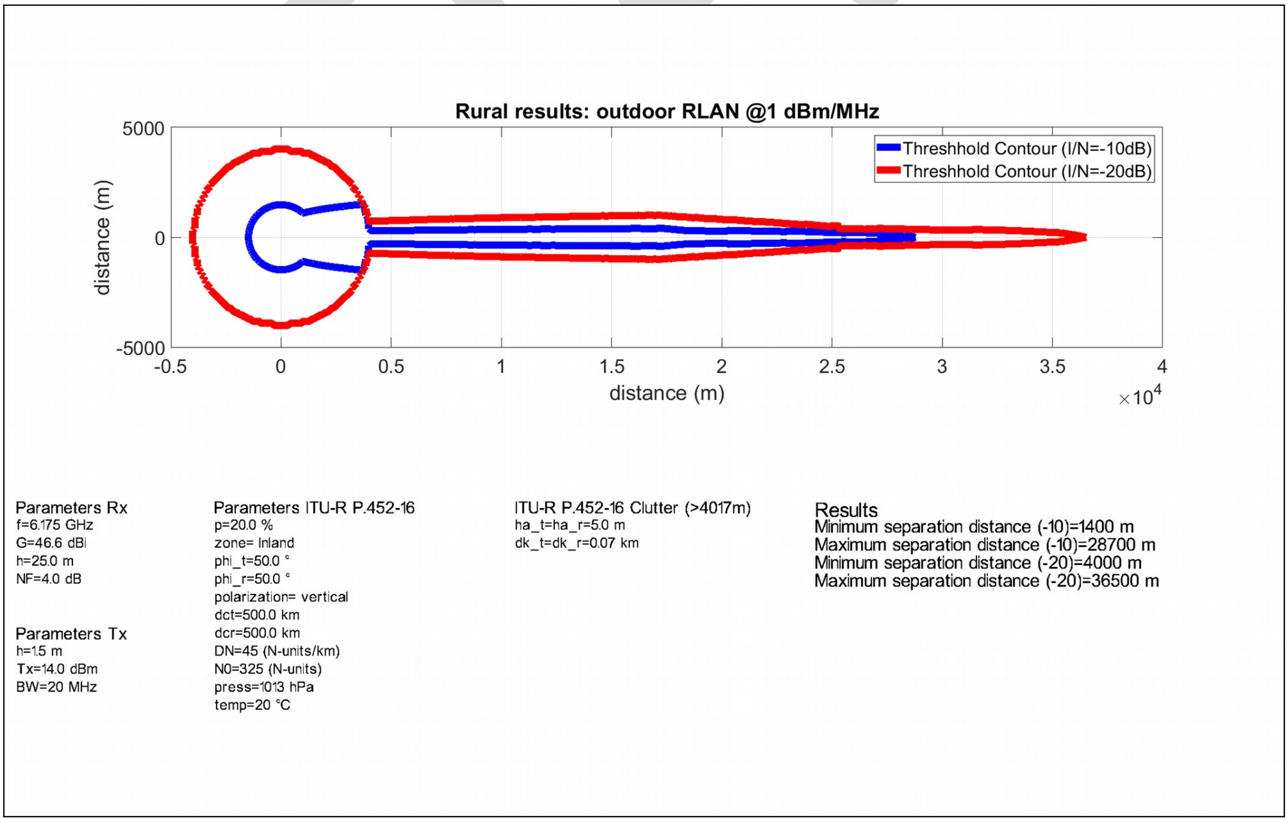


Figure 21: Rural results - outdoor RLAN @ 1 dBm/MHz e.i.r.p.

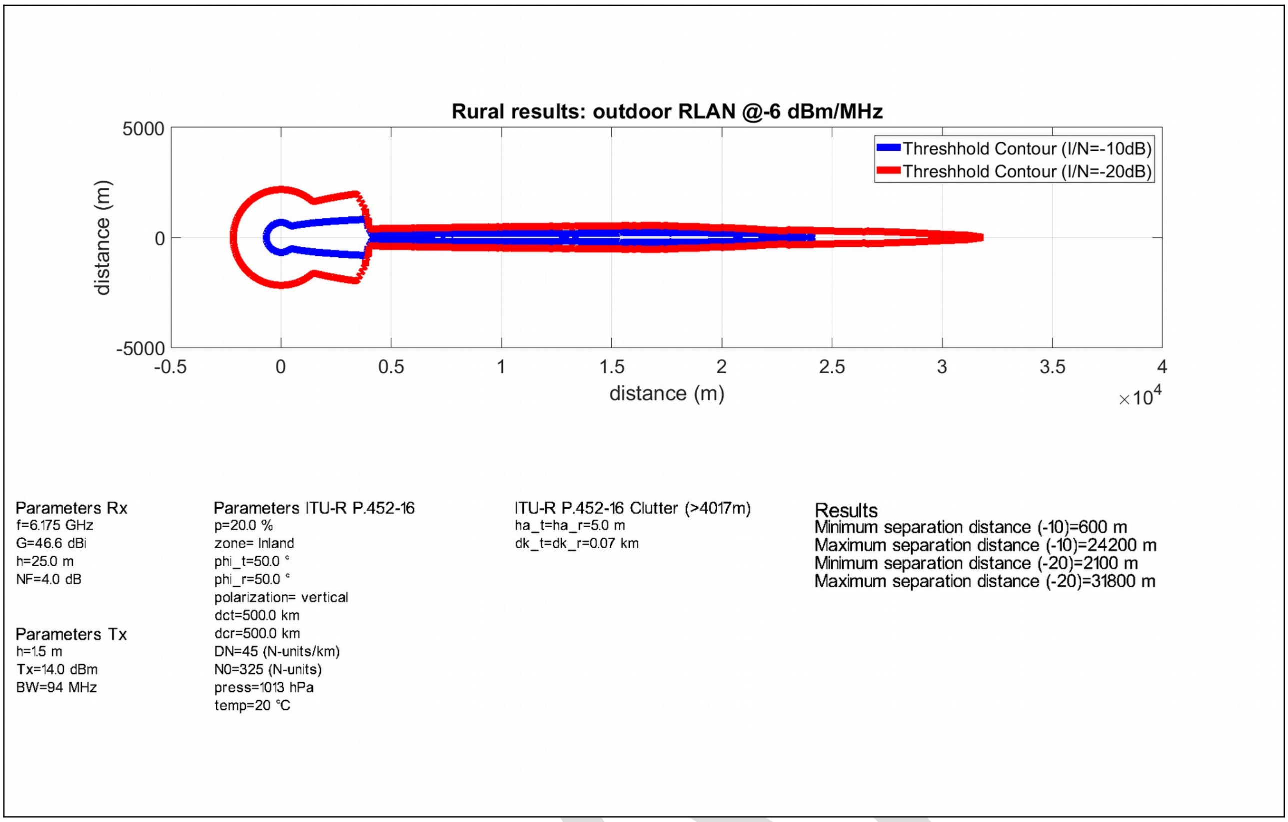


Figure 22: Rural results - outdoor RLAN @ -6 dBm/MHz e.i.r.p.

7.2.4.5 Summary of sensitivity analysis considering different power density levels

Single interferer MCL analyses have been conducted between Fixed Service and RLAN to derive the minimum separation distances between both systems, as summarised in Table 24 and Table 25.

Table 24: FS MCL results for $I/N = -10$ dB

RLAN Scenario	radiated power e.i.r.p.	Circle radius	Peak radius
Urban Indoor	17 dBm/MHz	700 m	13500 m
	11 dBm/MHz	400 m	10200 m
	-20 dBm/MHz	0 m	0 m
Urban Outdoor	17 dBm/MHz	1000 m *	24200 m
	1 dBm/MHz	800 m	13900 m
	-6 dBm/MHz	400 m	10200 m
	-37 dBm/MHz	0 m	0 m
Rural Indoor	17 dBm/MHz	1300 m	28200 m
	11 dBm/MHz	600 m	24200 m
	-30 dBm/MHz	0 m	0 m

Rural Outdoor	17 dBm/MHz	4017 m *	40400 m
	1 dBm/MHz	1400 m	28700 m
	-6 dBm/MHz	600 m	24200 m
	-46 dBm/MHz	0 m	m

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

Table 25: FS MCL results for $I/N=-20$ dB

RLAN Scenario	radiated power e.i.r.p.	Circle radius	Peak radius
Urban Indoor	17 dBm/MHz	1000 m *	19900 m
	11 dBm/MHz	1000 m *	16000 m
	-30 dBm/MHz	0 m	0 m
Urban Outdoor	17 dBm/MHz	1000 m *	31700 m
	1 dBm/MHz	1000 m *	20400 m
	-6 dBm/MHz	1000 m *	16000 m
	-46 dBm/MHz	0 m	0 m
Rural Indoor	17 dBm/MHz	4017 m *	36000 m
	11 dBm/MHz	2100 m	31800 m
	-40 dBm/MHz	0 m	0 m
Rural Outdoor	17 dBm/MHz	4017 m *	47100 m
	1 dBm/MHz	4017 m *	36500 m
	-6 dBm/MHz	2100 m	31800 m
	-56 dBm/MHz	0 m	0 m

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

7.2.5 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, 55 m) as well as of the RLAN location (outdoor, indoor) and RLAN antenna height (1.5 m and 4.5 m) onto the separation distances required to protect the FS receiver from RLAN interferences in a co-channel case is studied.

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

RLAN:

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

Fixed Service:

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

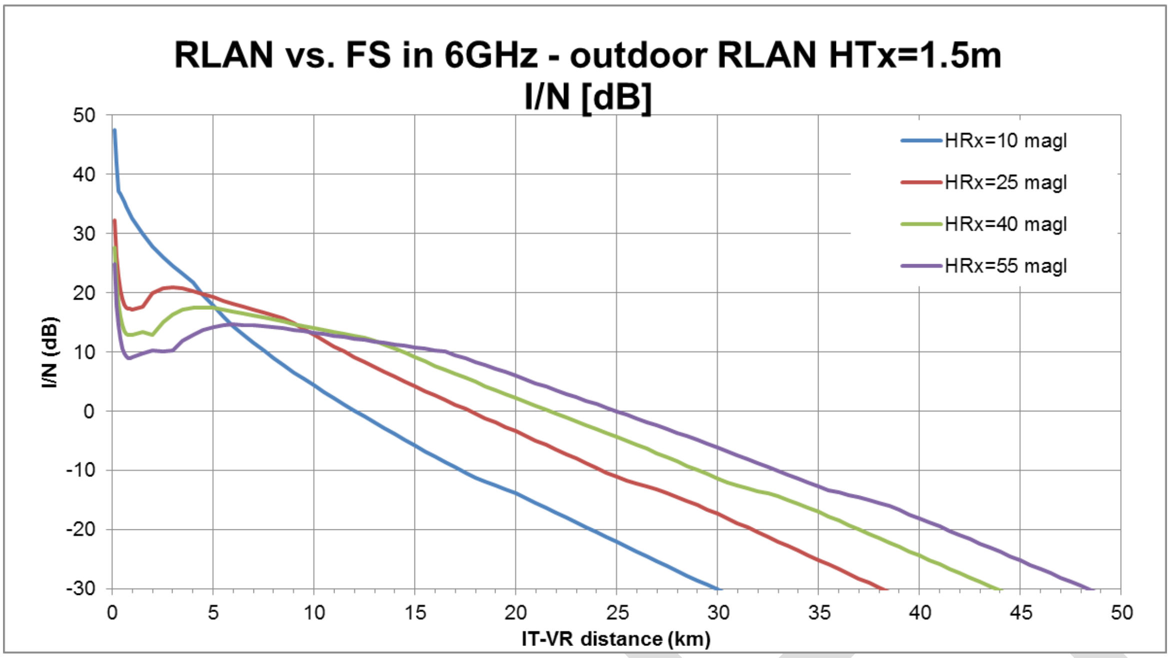


Figure 23: I/N at FS in dependence of RLAN distance in 0° azimuth direction of FS main beam (oudoor RLAN @ 1.5 m)

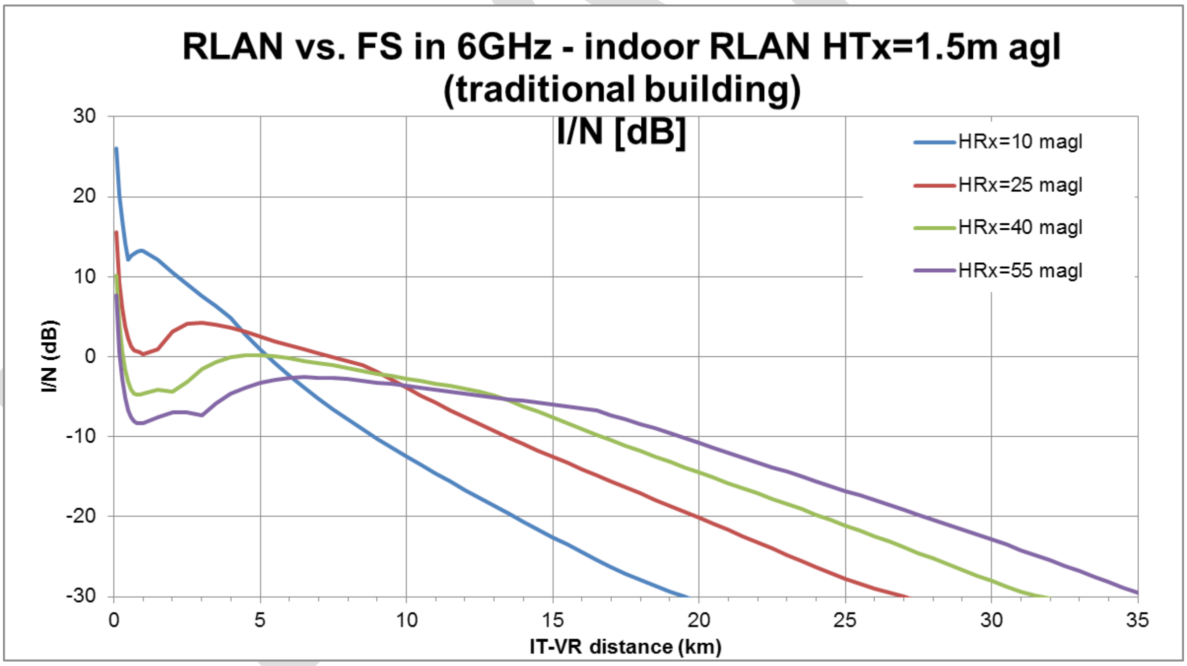


Figure 24: I/N at FS in dependence of RLAN distance in 0° azimuth direction of FS main beam (indoor RLAN @ 1.5 m, traditional building type)

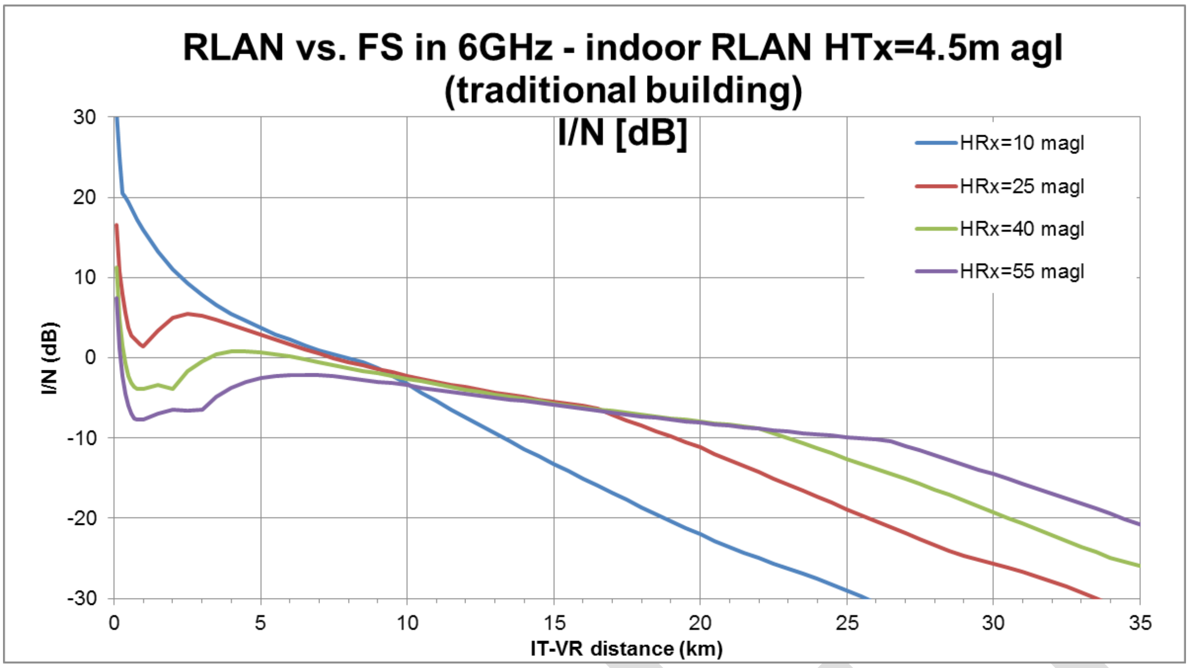


Figure 25: I/N at FS in dependence of RLAN distance in 0° azimuth direction of FS main beam (indoor RLAN @ 4.5 m, traditional building type)

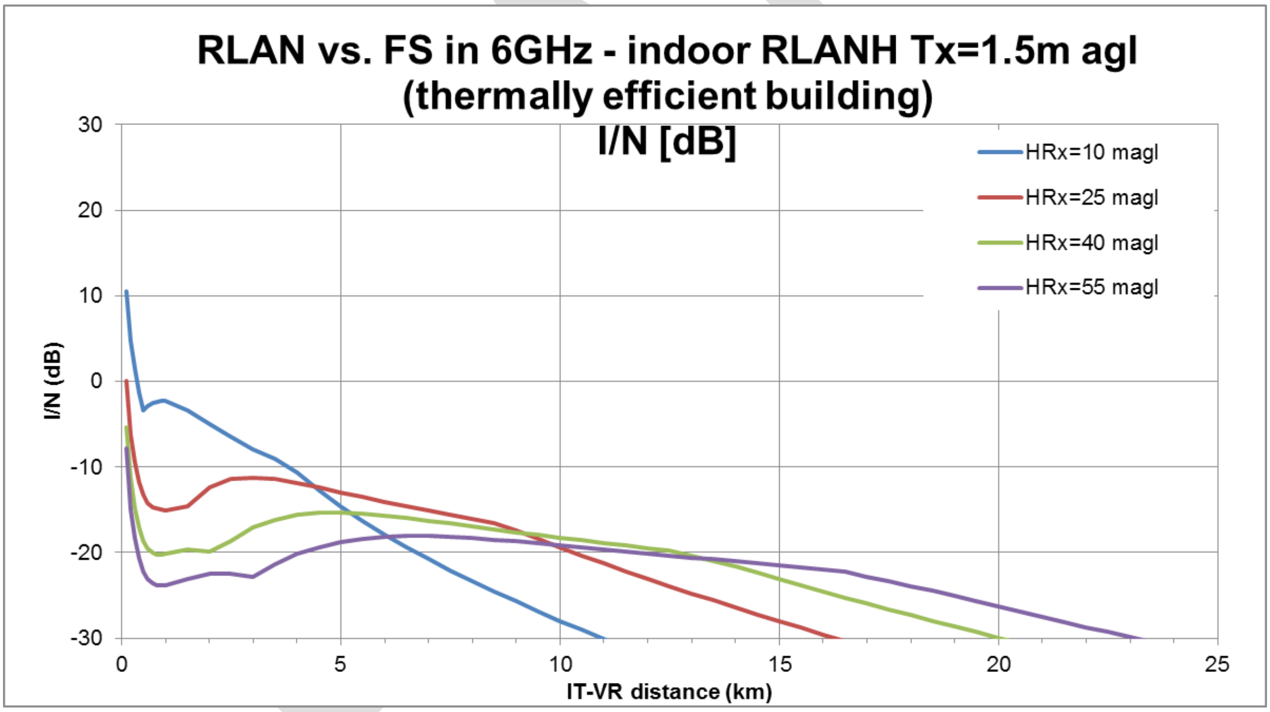


Figure 26: I/N at FS in dependence of RLAN distance in 0° azimuth direction of FS main beam (indoor RLAN @ 1.5 m, thermally efficient building type)

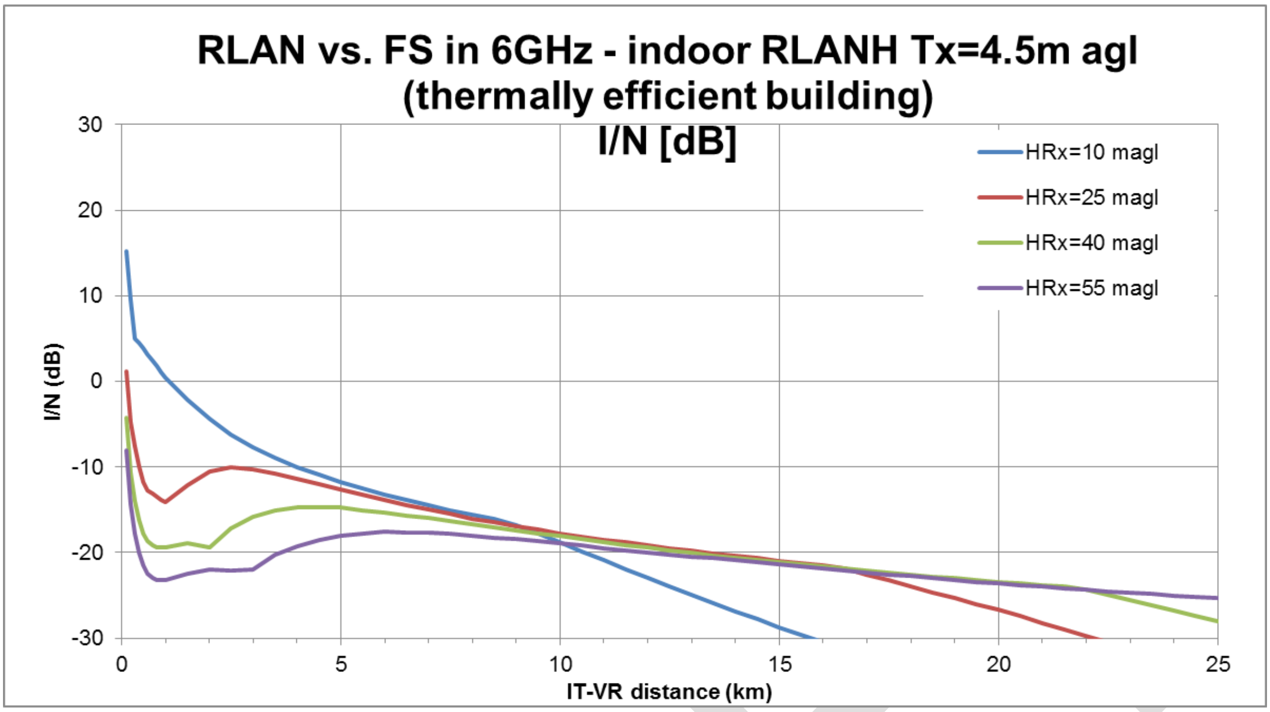


Figure 27: I/N at FS in dependence of RLAN distance in 0° azimuth direction of FS main beam (indoor RLAN @ 4.5 m, thermally efficient building type)

Table 26: Summary of the results for separation distance as a function of the FS antenna height for $I/N=-10$dB and maximum interference scenario

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

As can be seen from Table 26, the peak radii are much less when the RLAN transmitter is located indoor than when it is located outdoor as could be expected.

The largest distance (32.9 km) is when RLAN is outdoor and the fixed service receiver height is the highest (55 m). Some mitigation techniques should be considered to be able to avoid this kind of interference.

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

Table 27 gives peak radii of the critical area for an $I/N=-20$ dB and for a 1.5 m 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 26 for a 40 m fixed service antenna height).

Table 27: Results for separation distance as a function of the FS antenna height for $I/N=-20$ dB and maximum interference scenario

RLAN environment	$H_{Rx}=10$ magl [km]	$H_{Rx}=25$ magl [km]	$H_{Rx}=40$ magl [km]	$H_{Rx}=55$ magl [km]
Outdoor RLAN $H_{Tx}=1.5$ m	23.8	31.7	37	41.3
Indoor RLAN (traditional building) $H_{Tx}=1.5$ m	13.7	19.9	24.2	27.7
Indoor 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:

RLAN:

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

Fixed Service:

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

Table 28: Summary of the results for separation distance as a function of the FS antenna height for $I/N=-10$dB and minimum interference scenario

RLAN environment	$H_{Rx}=10$ magl [km]	$H_{Rx}=25$ magl [km]	$H_{Rx}=40$ magl [km]	$H_{Rx}=55$ magl [km]
Outdoor RLAN $H_{Tx}=1.5$m	5.97	9.3	10.1	9.9
Indoor RLAN (traditional building) $H_{Tx}=1.5$m	1.35	0.472	0.255	0.171
Indoor RLAN (thermally efficient buildings) $H_{Tx}=1.5$m	0.22	0.087	0.048	0.051
Indoor RLAN (traditional building) $H_{Tx}=4.5$m	1.39	0.472	0.283	0.181
Indoor 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 RLAN deployment for thermal efficient buildings. Note that the probability to have an indoor 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 29 presents the separation distances for an $I/N = -20$ dB and for a 1.5 m 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 27 (for example 0.103 km in Table 29 versus 0.051 km in Table 28 for a 55 m fixed service antenna height).

Table 29: Results for separation distance as a function of the FS antenna height for $I/N = -20$ dB and minimum interference scenario

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

7.2.6 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 RLAN power density is shown in Figure 28 for the urban indoor scenario. The dependency of the radii on the transmitted RLAN power density is shown in Figure 29 for the urban outdoor scenario. A decrease of transmitted power or an increase of bandwidth can reduce the size of critical areas.

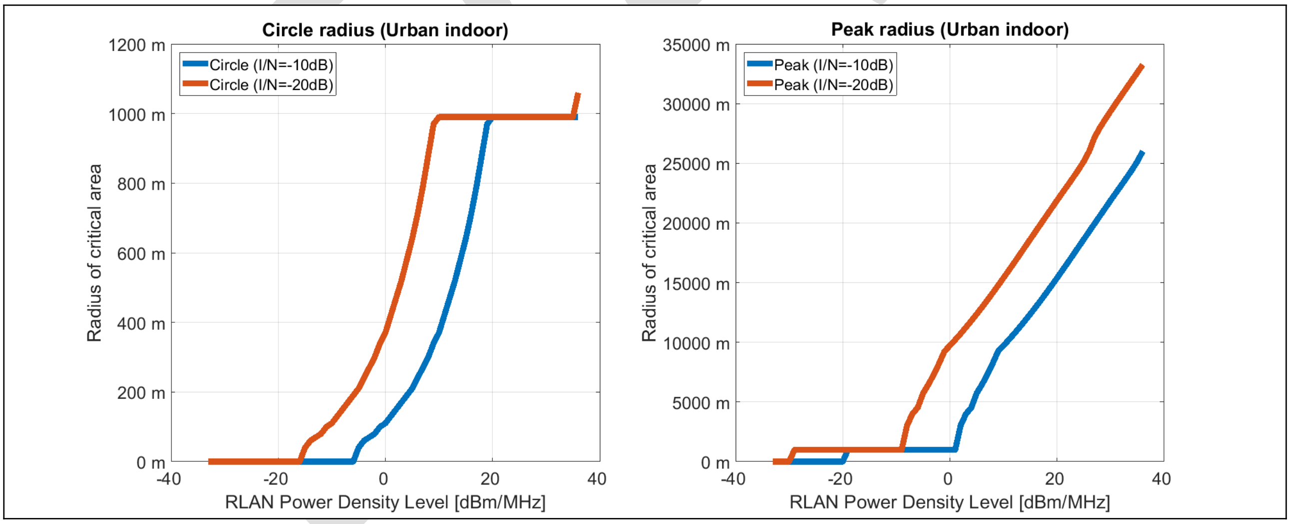


Figure 28: Dependency of critical radii on the RLAN power density indoors

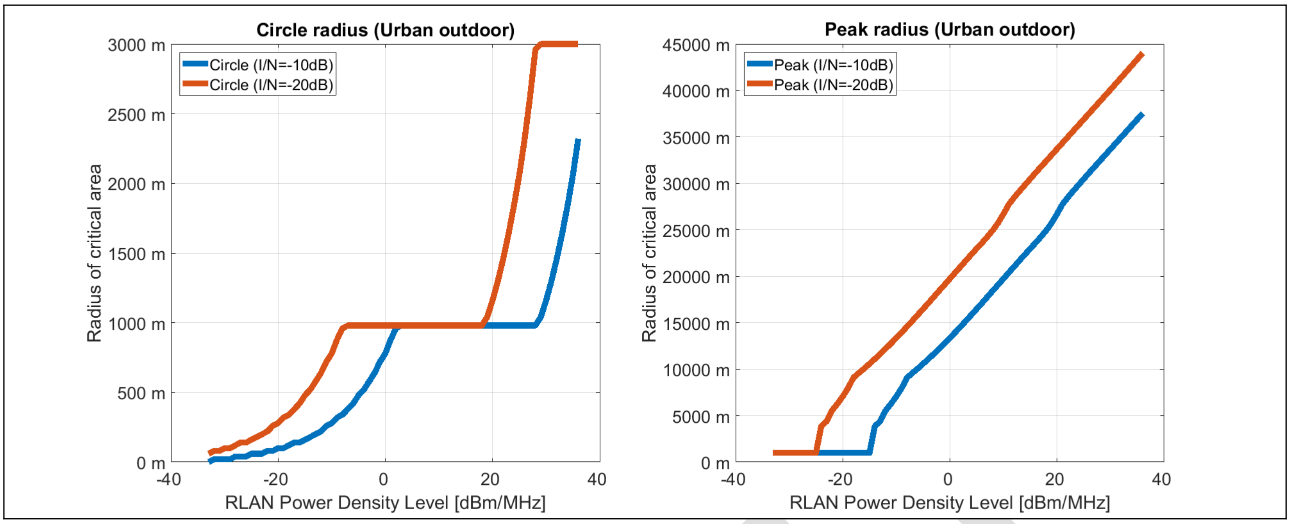


Figure 29: Dependency of critical radii on the RLAN power density outdoors

To achieve the same level of compatibility for outdoor 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 RLAN devices in those environments could compensate this for aggregated cases.

The impact from FS into RLAN has not been studied but it seems possible that 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 RLAN devices would have to share smaller bandwidths when one frequency is occupied by an FS station.

Figure 30 clearly shows that the peak radius between 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.

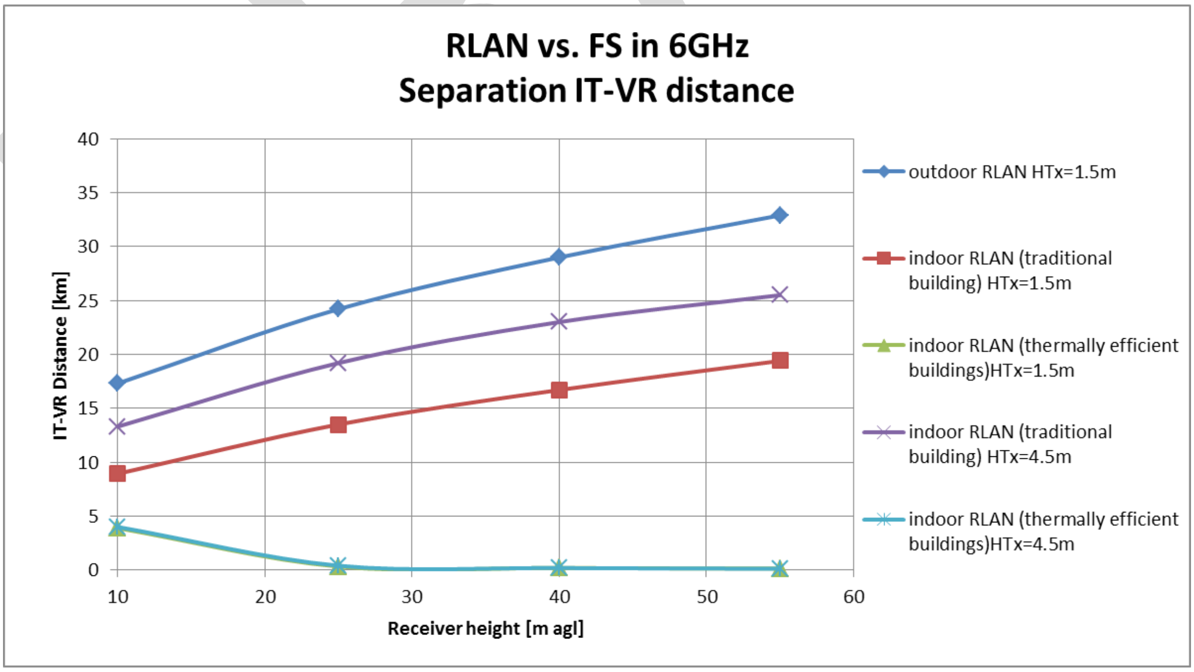


Figure 30: Dependency of critical peak radii on the FS receiver height and RLAN environment for $I/N=-10$ dB and maximum interference scenario

For minimum interference constellations, Figure 31 clearly shows that the required separation distance between RLAN interfering transmitter and FS receiver increases with the FS antenna height for the outdoor 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.

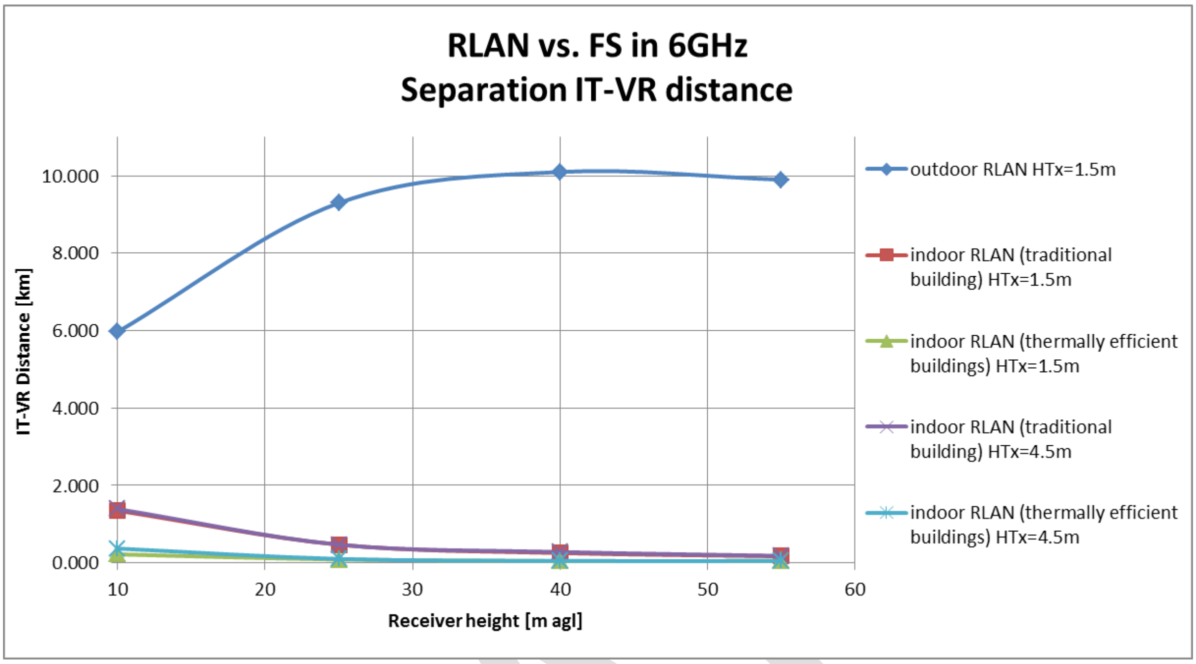


Figure 31: Dependency of critical peak radii on the FS receiver height and RLAN environment for $I/N=-10$dB and minimum interference scenario

7.3 STUDY B: MONTE CARLO ANALYSIS OF INTERFERENCE FROM RLAN INTO FS

The minimum coupling loss model (MCL) in Study A (Section 6.2) showed separation distances between an FS and a single worst-case RLAN interference into FS. Study A has shown that long term protection criteria can be exceeded by a single RLAN device if the duty cycle is higher than 20%. However, considering the 1.97% average duty cycle of this single device is lower than 20%, the long-term FS criterion will 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 RLAN interference by meeting FS defined short and long protection criteria. The Monte Carlo study B was carried out on two sets of real FS data in Europe.

The UK 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 [67], [68], [69]. Section 7.3.1 provides detail on the simulation methodology.

Next generation RLAN devices are going to achieve very high data rates thanks to higher channel bandwidths and improved spectral efficiencies. User applications generally require average application-layer data rates less than 1 Mbps, meaning that transmission bursts can be expected to be approximately one millisecond. Furthermore, even for bandwidth-intensive applications like video streaming, the high transmission rate results in very bursty transmissions.

This interference environment was modelled for each RLAN deployment iteration by randomly distributing active RLANs using the probability distribution for position and other relevant parameters such as centre frequency, bandwidth, e.i.r.p. and height as indicated in Section 7.3.1. Each RLAN deployment iteration was assumed to be independent.

Two-hundred-and-fifty-thousand (250 000) independent 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 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).
h) the *short-term* aggregate interference impact of the RLANs to the FS meets the Fractional Degradation of Performance (FDP) criteria per Recommendation ITU-R F.1094 [65]. FDP, as defined in Recommendation ITU-R F.1108-4 [70], is calculated for each FS receiver as follows:

$$FDP=\frac{1}{M}\sum_{i=1}^{M} ¿¿,$$

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.

7.3.1 Monte Carlo simulation methodology

Interference from 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 RLAN device population probability distribution over the simulation region.
2) Monte Carlo iterations
   a. Generate a random layout of RLANs using the device population probability distribution;
   b. Generate random path loss, clutter loss, building loss values between each RLAN and FS RX in accordance with the propagation modelling set out in Section 6.2.1. Also a random polarisation loss value is generated;
   c. Using the FS RX feeder loss, bandwidth and noise figure, compute the aggregate 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 Complimentary Cumulative Distribution Function (CDF) or Interference Graph.

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

Step 1) Data Setup:

A database of FS link entries that are used in the simulation is created. A CSV text file format is used that contains tabular data of the following parameters for each FS link in the simulation: Frequency, TX e.i.r.p., Channel Bandwidth, TX Longitude (LON)/Latitude (LAT), TX Antenna, TX Height, TX Gain, RX LON/LAT, RX Antenna, RX Height, RX Gain and RX Feeder loss.

For all FS RX antennas in the simulation, Ofcom UK antenna patterns (based on manufacturers' data) are used to create a tabular data file giving antenna gain as a function of angle off boresight. Values are computed from angle off boresight of 0 to 180 degrees in 0.1-degree increments. In the absence of an Ofcom antenna pattern, Recommendation ITU-R F.1245 is used (per Section 5.1.1).

A population density file is created as a textual CSV file. Each line of the file contains a LON/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 file 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 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 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 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 RLAN device count at that grid point divided by the total RLAN device count. A random 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 RLAN devices is generated 1 RLAN at a time. Each RLAN device is assigned a random LON/LAT position generated using the device population probability distribution described above. Each RLAN device is assigned a random height, e.i.r.p. and building type using discrete probability distributions that are input to the simulation. Building types are NO_BUILDING (outdoor RLAN), TRADITIONAL or THERMALLY_EFFICIENT. Each RLAN is assigned a random bandwidth using a discrete probability distribution that is input to the simulation and a random centre frequency. 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 RLANs is computed and aggregated. If the distance from an RLAN to the FS RX is larger than 150 km, the RLAN is assumed to contribute no interference to the FS RX. Next, the FS TX and FS RX locations are used with the RLAN position to determine if the RLAN is inside the first Fresnel zone of the FS link. If the RLAN is in fact inside the FS' first Fresnel zone, the 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 RLAN bandwidth and centre frequency along with the FS RX bandwidth and centre frequency are used to compute the fraction of the RLAN bandwidth that overlaps with the FX RX bandwidth. If there is no overlap, the RLAN is ignored in the interference calculation. To visualise the impact of those factors and the placement of RLANs within 150 km of FS Sections 7.3.2.1 and 7.3.3.1 provide more detail.

A random building penetration loss is computed using Recommendation ITU-R P.2109-0 and the building type and elevation angle from the RLAN to the FS RX. Note that for outdoor RLANs with building type equal NO_BUILDING, the building penetration loss is 0 dB. 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, θ, that is uniformly distributed from 0 to 360 degrees. The polarisation loss in dB is then given by:

$$Polarisation\,Loss = min\ ¿$$

Where B is the boresight angle from 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 degrees 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 RLAN is calculated considering the location of the FS RX, FS TX and the 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 RLAN.

In addition, a random body loss is generated using a discrete probability distribution provided in Section 6.6.

The interference power at the FS RX is computed by appropriately summing RLAN e.i.r.p., building penetration loss, path loss, path clutter, polarisation loss, body loss, FS RX gain in the direction of each RLAN, FS RX feeder loss and spectral overlap loss. This interference is aggregated over all 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:

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

where:

- N = FS RX noise power at receiver input (dBW);
- k = Boltzmann's constant = $1.3806488 \times 10^{-23}$ (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 [66].

7.3.2 The Netherlands FS analysis results

7.3.2.1 RLAN deployment model

To visualise the Monte Carlo methodology in the placement of RLANs within 150 km of an FS receiver, as detailed in Section 7.3.1, 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 [67].

Table 30 shows how the mid parameters outlined in Section 4.2 were implemented with respect to this simulation.

Table 30: Number of active RLAN devices simulated in a single iteration of 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 32 shows the location of FS 11 in Netherlands on a map. It also shows the RLANs operating at the farthest distance from the FS receiver that contribute to the aggregate interference.

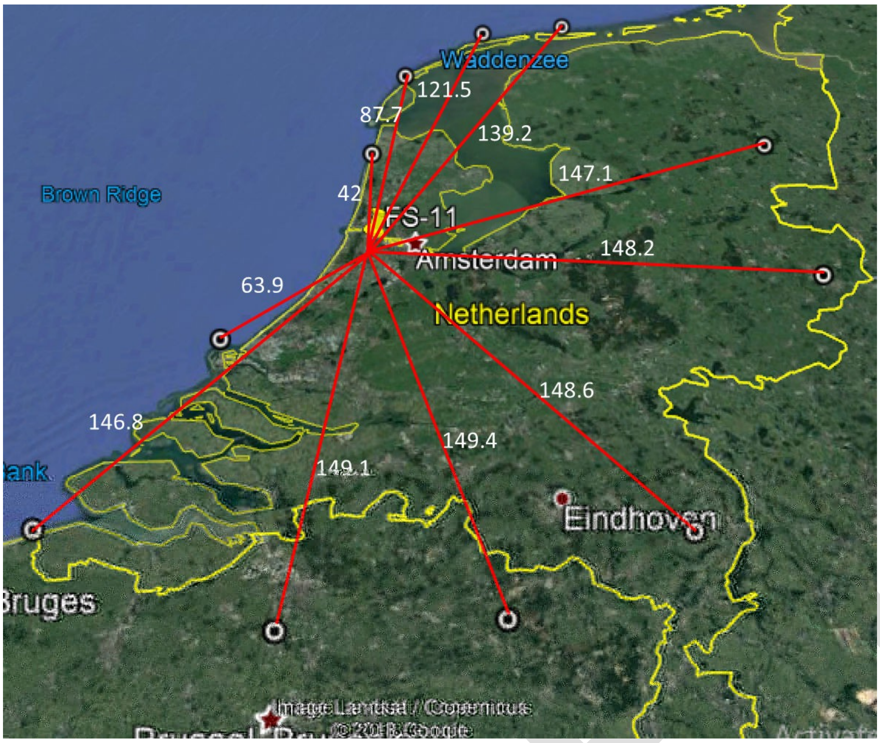


Figure 32: Geographic location of RLANs that overlap frequencies with Netherlands FS 11 at the perimeter of 150 km radius (distance, in km, of each RLAN to the FS is indicated)

Figure 33 shows the density of instantaneously transmitting devices that have nonzero spectral overlap with FS 11. Within a 150 km radius of FS 11, 30 229 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 RLAN device overlapping with the FS bandwidth. The red dots represent the RLANs in Figure 32. The larger orange dot is FS 11.

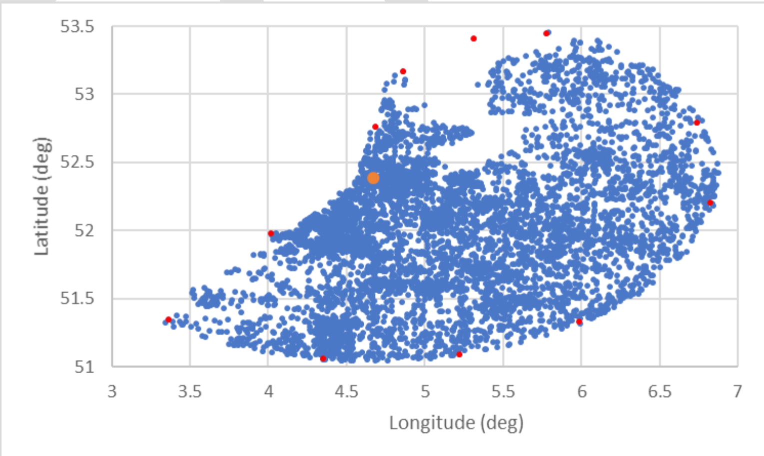


Figure 33: Density of 6249 instantaneously transmitting RLANs with frequency overlap in 150 km radius of Netherlands FS 11 receiver

7.3.2.2 Long-term interference

All 26 FS receivers in the Netherlands FS database per [67] were simulated. Ofcom UK antenna patterns (per [68]) 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 5.1.1).

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 RLANs were deployed randomly throughout Europe according to population density in accordance with Section 4.2. The "Mid" parameters from Table 13 (Section 4.2) were employed, based on a European population of 768 589 000. Together, these iterations represent 6 500 000 different RLAN-to-FS interference morphologies in the Netherlands, which represent an excellent statistical model of expected interference (temporally and spatially). Each iteration of the simulation models the set of instantaneously transmitting devices in the RLAN network.

Figure 34 and Figure 35 show the probability of aggregate I/N exceeding an I/N level (x-axis) due to the deployed active RLANs over all of the FS links considered[5]. Of the 6 500 000 different RLAN-FS morphologies simulated, 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 RLAN. Of these single-entry threshold exceedance cases:

- 36.4% were dominated by an RLAN device at an angle less than or equal to 2^0 off boresight from the FS receiver;
- 46.9% were dominated by an RLAN device at an angle greater than 2^0 off boresight from the FS receiver and distance from the FS receiver less than 1 km;
- Other topologies that resulted in a single RLAN device causing an I/N value greater than -10 dB included RLAN devices:
  - Being outdoors;
  - Statistically having very small building penetration loss;
  - Statistically having small path loss values and/or;
  - Having a height larger than buildings surrounding the FS receiver.

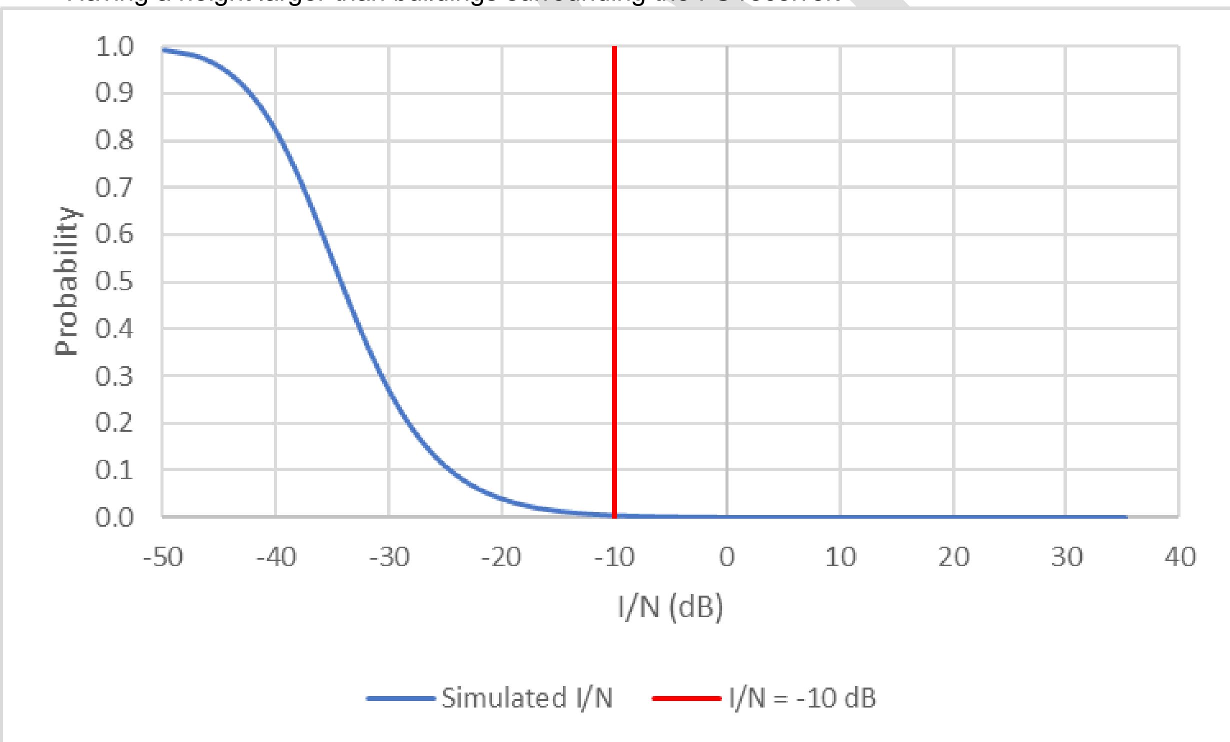


Figure 34: Netherlands FS Interference graph for 26 FS receivers

[5] This represents the aggregation of all the events across all the links. These plots are provided for information only and are not intended to be used for decision making.

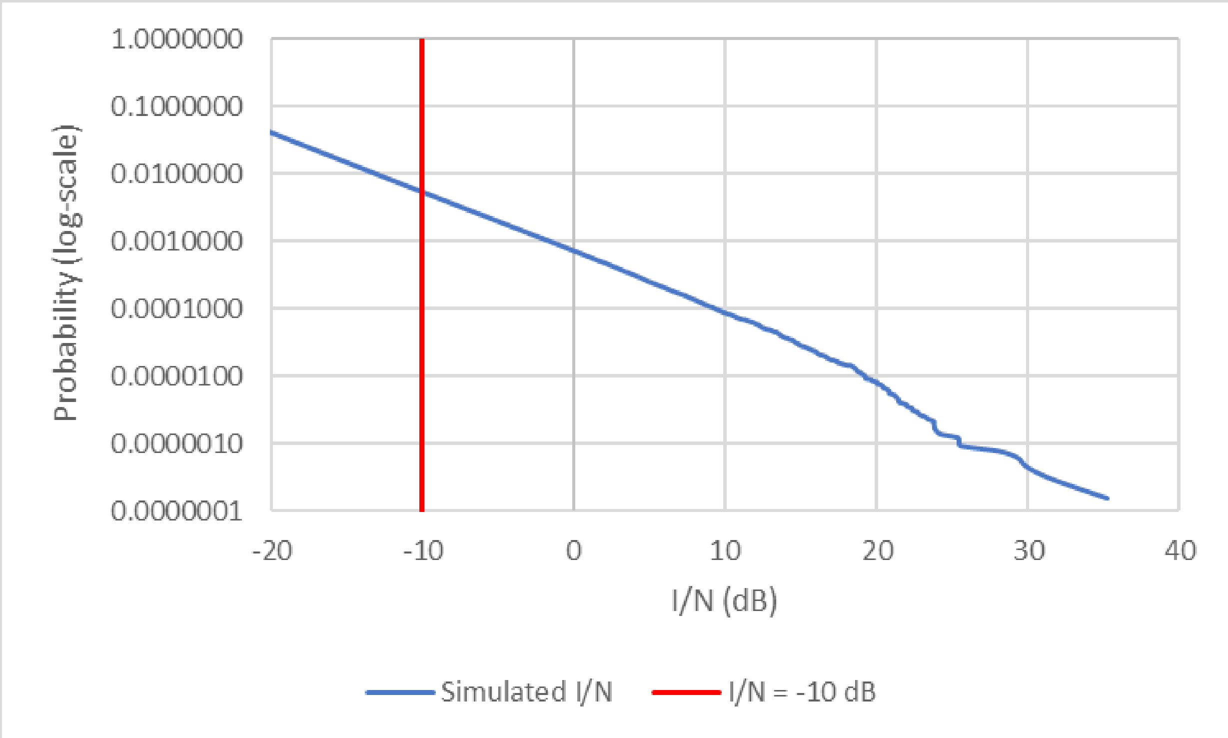


Figure 35: Netherlands FS: Interference graph for 26 FS receivers zoomed in

Figure 36 shows the percentage of the 250000 iterations for each of the 26 FS Receivers where the I/N from all RLANs (indoor and outdoor) exceeded -10 dB.

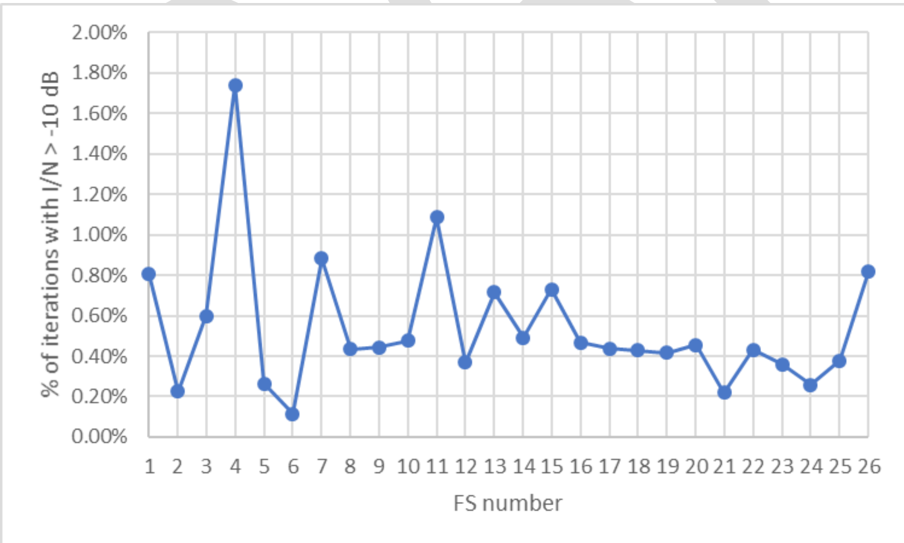


Figure 36: Statistics of aggregate I/N > -10 dB for each of the 26 FS receivers in the Netherlands

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 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 7.3.2.3.

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

The 250 000 simulation iterations, which dropped 1 317 034 instantaneously transmitting RLAN devices over the CEPT countries in each iteration (Mid value per Section 4.2), provided an excellent statistical analysis on the probability of I/N exceedance for any single 6 GHz RLAN operating in the Netherlands.

In the 250 000 iterations of the Monte Carlo simulation, there were 71 884 588 217 instantaneously transmitting RLAN-FS pairs for which RLAN transmit power was aggregated at the FS receiver. This corresponds to the 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 RLAN devices. Figure 37 shows the Complementary Cumulative Distribution Function (CCDF), or Interference Graph, for all the RLAN devices.

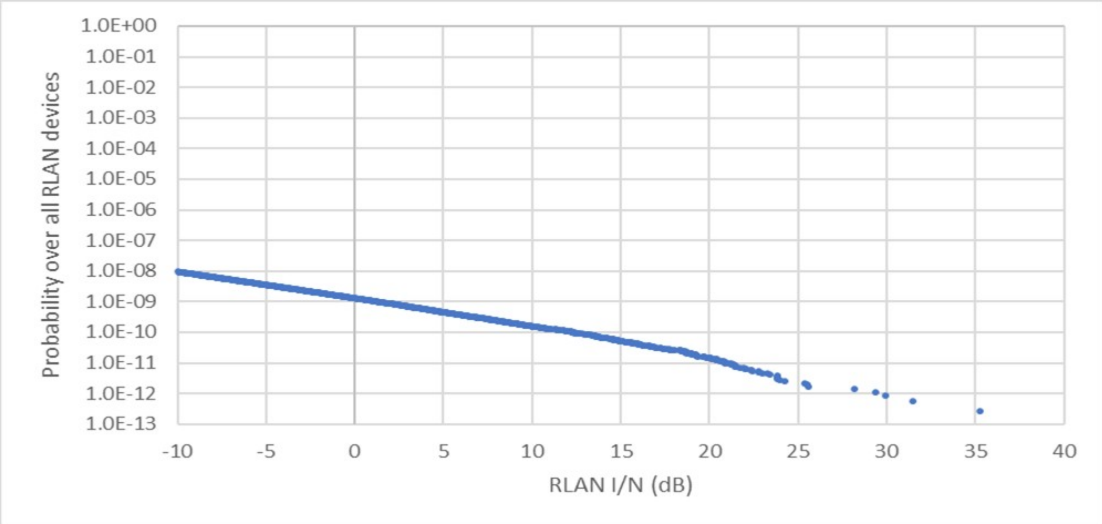


Figure 37: Netherlands FS single-RLAN Interference graph for 26 FS receivers

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

7.3.2.4 Short-term interference

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 38 below.

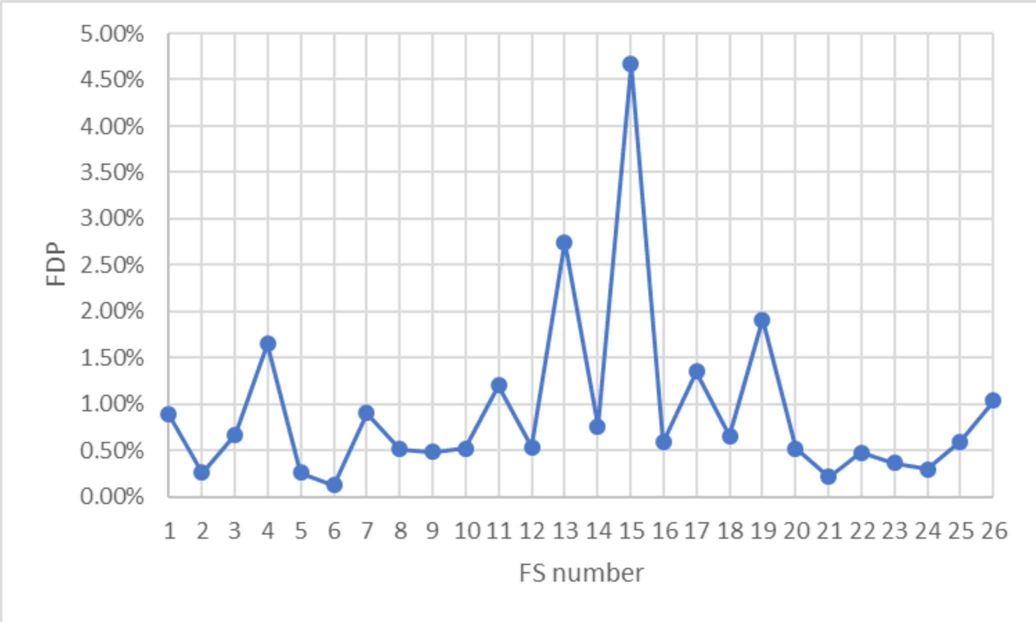


Figure 38: FDP for each of the 26 FS receivers in the Netherlands

The Monte Carlo results indicate that the short-term 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).

7.3.3 UK Fixed Service analysis results

7.3.3.1 RLAN deployment model

To visualise the Monte Carlo methodology in the placement of RLANs within 150 km of an FS receiver, as detailed in Section 7.3.1, 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 [69].

Table 31 shows how the parameters outlined in Section 4.2 were implemented with respect to this simulation.

Table 31: Number of active 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 39 shows the location of FS 477 with respect to London. It also shows the RLANs operating at the furthest distance from the FS receiver that contribute to the total aggregate interference.

Figure 39: Geographic location of RLANs that overlap frequencies with UK FS 477 at the perimeter of 150 km radius

Figure 40 shows the density of instantaneously transmitting devices that have frequency overlap with FS 477. Within a 150 km radius of FS 477, 43 904 RLAN devices are expected to be active every instant in time; 17066 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 RLAN device falling into the FS band. The red dots represent the RLANs in Figure 39. The larger orange dot is FS 477.

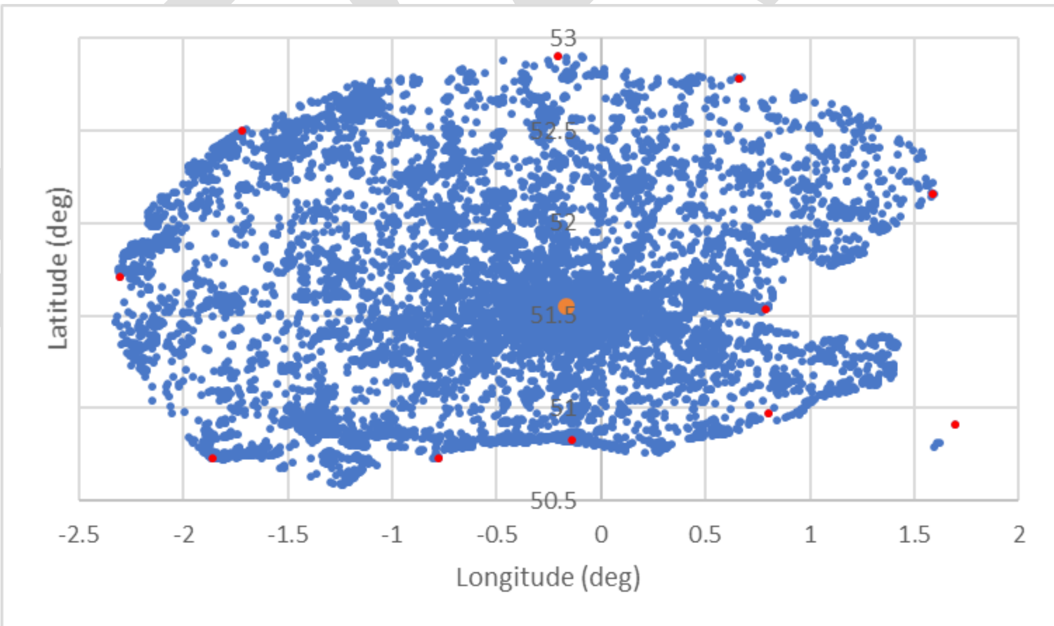


Figure 40: Density of 17 066 instantaneously transmitting RLANs with frequency overlap in 150 km radius of UK FS 477 receiver

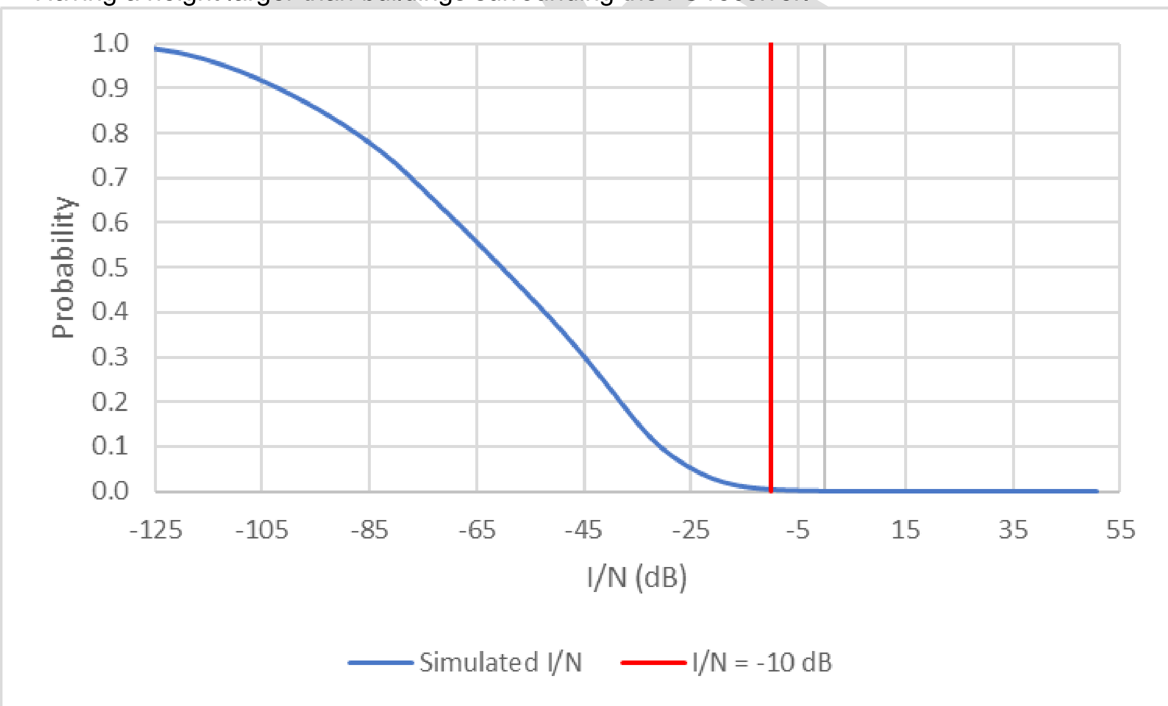
7.3.3.2 Long-term interference

The UK FS database per [69] 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 [68]were used for all 505 FS stations. For some of the FS, the RX feeder loss was 0 dB in the UK database [69], but this was assumed to be an error given the statement in Ofcom UK's OfW85 Point-to-Point Fixed Link licence Application Form[6] For these instances, a feeder loss of 1.1 dB was added (minimum value per Section 5.1.1).

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 RLANs were deployed randomly in accordance with Section 4.2. The "Mid" parameters from Table 13 were employed, based on a European population of 768 589 000. Together, these iterations represent 126 250000 different RLAN-to-FS interference morphologies in the UK, which represent an excellent statistical model of expected interference (temporally and spatially). Each iteration of the simulation models the set of instantaneously transmitting devices in the RLAN network.

Figure 41 and Figure 42 show the probability of aggregate I/N exceeding an I/N level (x-axis) due to the deployed active RLANs over all of the FS links considered[7]. Of the 126 250 000 different RLAN-FS morphologies simulated, 0.417% had aggregate I/N (due to indoor and outdoor RLANs) for an FS receiver exceeding -10 dB. Further investigation into these threshold exceedance instances revealed that 94.42% were dominated by a single RLAN. Of these single-entry threshold exceedance cases:

- 51.5% were due to an RLAN device at an angle less than or equal to 2^0 off boresight from the FS receiver;
- 32.8% were due to an RLAN device at an angle greater than 2^0 off boresight from the FS receiver and distance from the FS receiver less than 1 km;
- Other topologies that resulted in a single RLAN device causing an I/N value greater than -10 dB included RLAN devices:
  - Being outdoors;
  - Statistically having very small building penetration loss;
  - Statistically having small path loss values and/or
  - Having a height larger than buildings surrounding the FS receiver.



[6] "At lower frequencies, a value much greater than 0 dB is expected for feeder losses connecting the terminal indoor and outdoor units."

[7] This represents the aggregation of all the events across all the links. These plots are provided for information only and are not intended to be used for decision making.

Figure 41: UK FS: Interference graph for 505 UK FS receivers

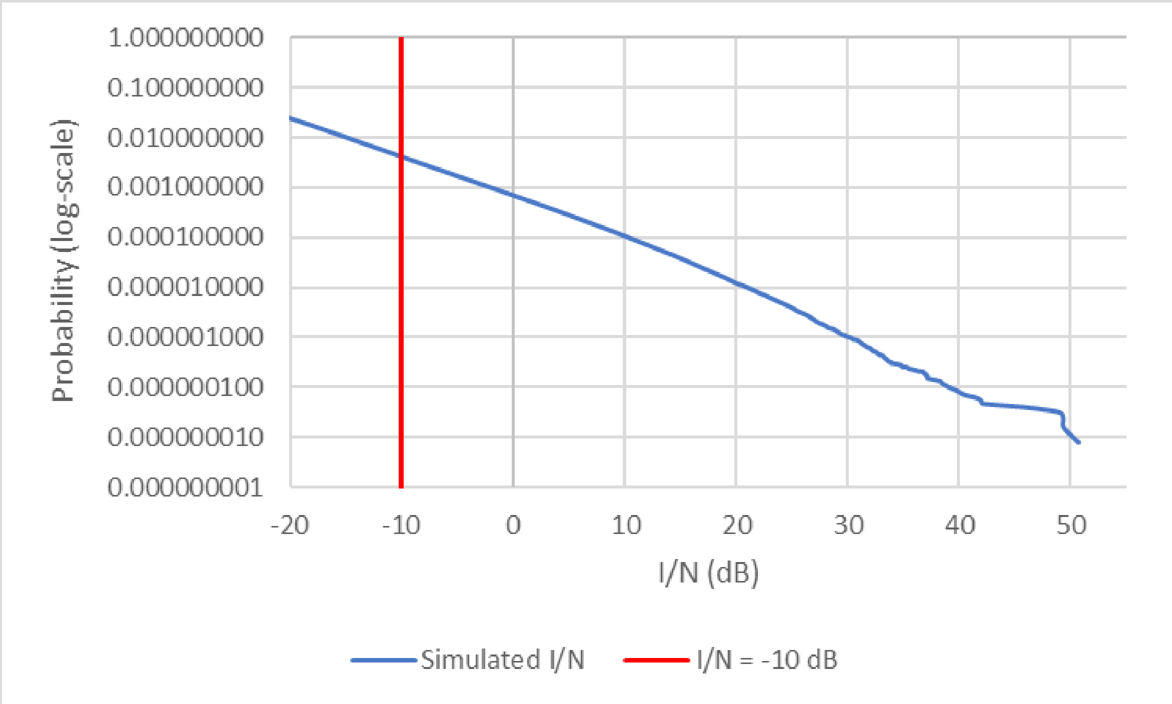


Figure 42: UK FS: Interference graph for 505 UK FS receivers zoomed in

Figure 43 shows the percentage of the 250000 iterations for each of the 505 FS Receivers where the I/N from all RLANs (indoor + outdoor) exceeded -10 dB.

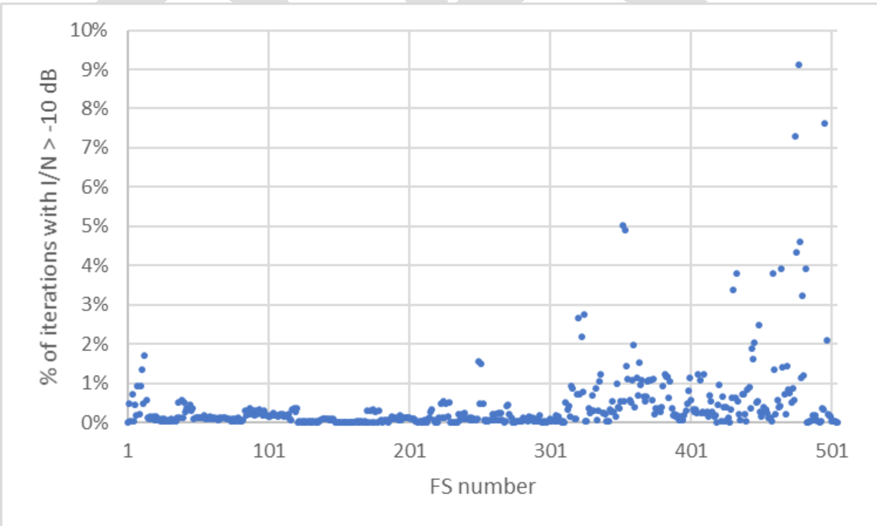


Figure 43: Statistics of aggregate I/N > -10 dB for each of the 505 FS receivers in UK

In the UK 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 UK 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 RLANs that are close (in terms of propagation loss) to the FS station. Short-term interference will be analysed in 7.3.3.4

7.3.3.3 Probability that a aingle RLAN in The UK will exceed -10 I/N at FS receiver

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

In the 250000 iterations of the Monte Carlo simulation, there were 353 687 421 941 instantaneously transmitting RLAN-FS pairs for which RLAN transmit power was aggregated at the FS receiver. This corresponds to the 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 17 953 676 240 660 total RLAN devices. Figure 44 shows the Complementary Cumulative Distribution Function (CCDF) or Interference Graph, for all the RLAN devices.

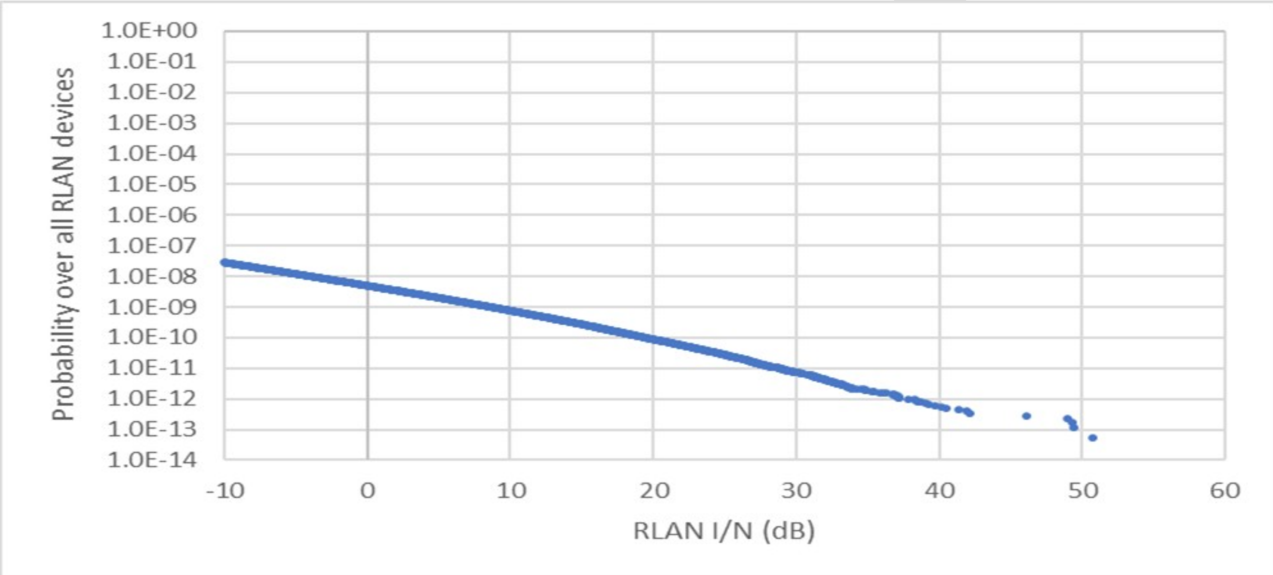


Figure 44: UK FS single-RLAN Interference graph for 505 FS receivers

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

7.3.3.4 Short-term interference

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 45 below.

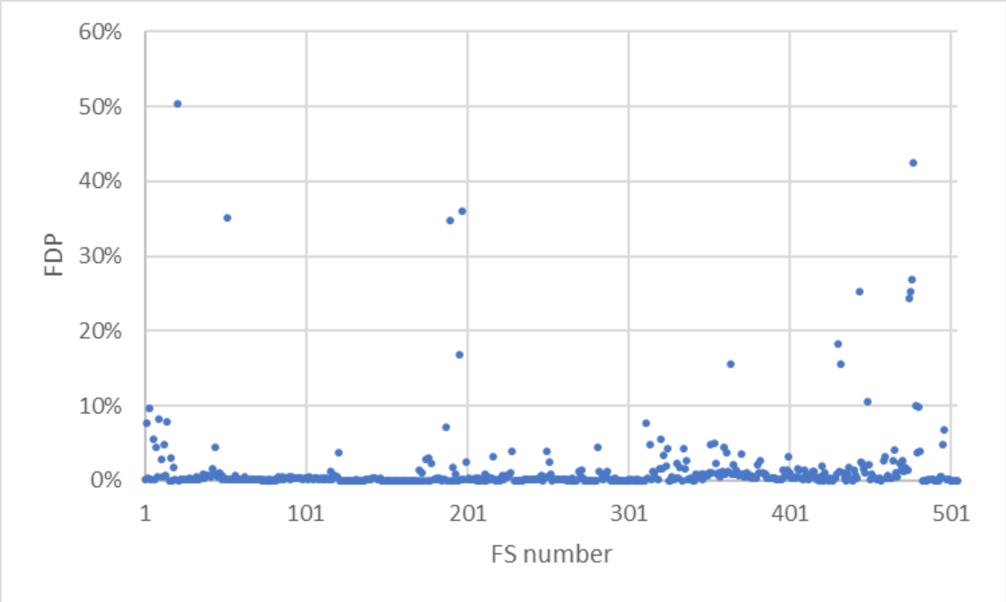


Figure 45: FDP for each of the 505 FS receivers in UK

Remarkably, the FDP was well below the short-term interference protection criteria threshold for the vast majority of the links without any mitigation. This indicates that the typical 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 RLANs at higher elevations than buildings in surrounding terrain leading to unrealistic geometries.

7.3.3.5 Applying 5 150-5 250 MHz RLAN requirements

In the following, the impact of applying 5 150-5 250 MHz band requirements (lower 5 GHz) is studied on long-term and short-term interference by removing all outdoor and 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 RLANs in the 126 250 000 different RLAN-FS morphologies simulated, as presented in Section 7.3.3.2, results in reducing the probability of interference exceeding -10 I/N by 50%, from 0.417% to 0.209%.

Figure 46 shows the reduction of I/N instances when applying the lower 5 GHz rules for each of the 505 FS Receivers.

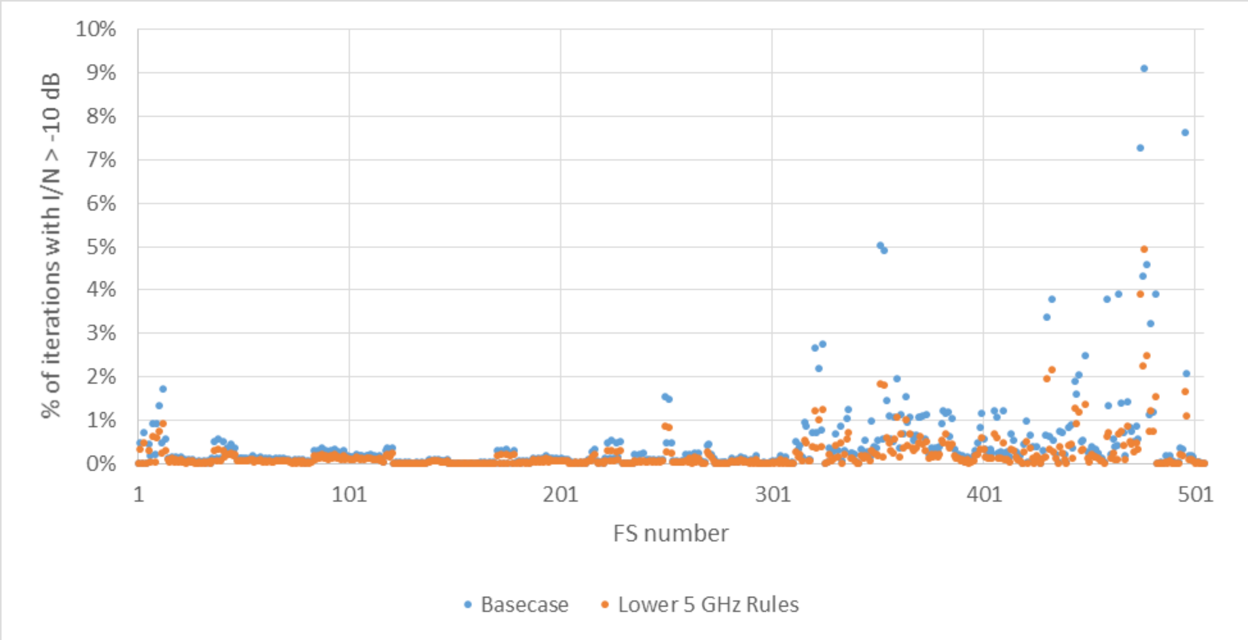


Figure 46: Statistics of aggregate I/N > -10 dB for each of the 505 FS receivers in the UK assuming lower 5 GHz rules

Impact on short-term interference:

Figure 47 shows the reduction of FDP results when applying the lower 5 GHz rules for each of the 505 FS Receivers.

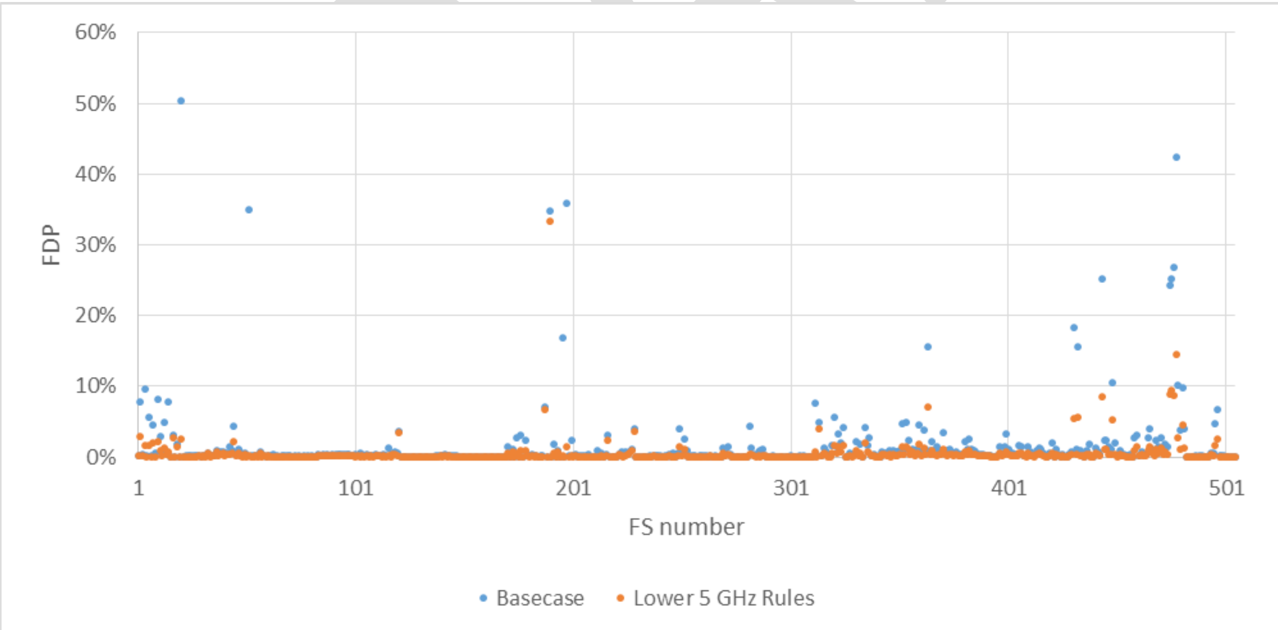


Figure 47: FDP for each of the 505 FS receivers in the UK with lower 5 GHz rules

After applying the lower 5 GHz rules, there are only two links out of 505 links that fail the short-term 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 48 and Figure 49 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 an RLAN that was 16 ms away and at 2.5 m higher than the FS (FS is 5 m and RLAN is 7.5 m) in an open field.

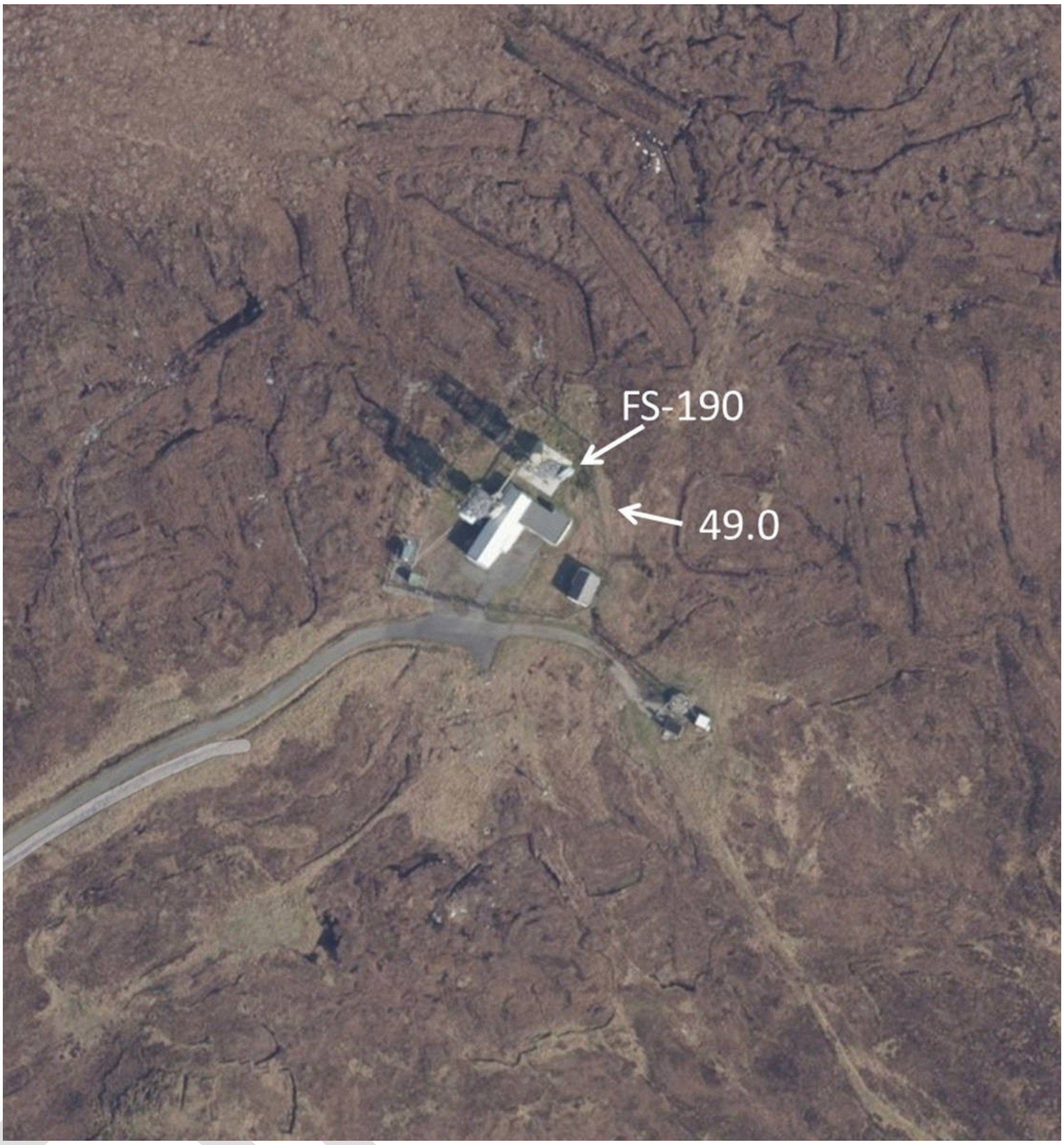


Figure 48: Geographic location of top RLAN interferer to UK FS 190 (0.016 km away)

FS 478 is at 15 m height and the RLAN is in an urban environment less than 8 m away from FS 478 and is at 12.5 m height. Figure 49 shows the location of this RLANs on a map. As shown, the height of this 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.

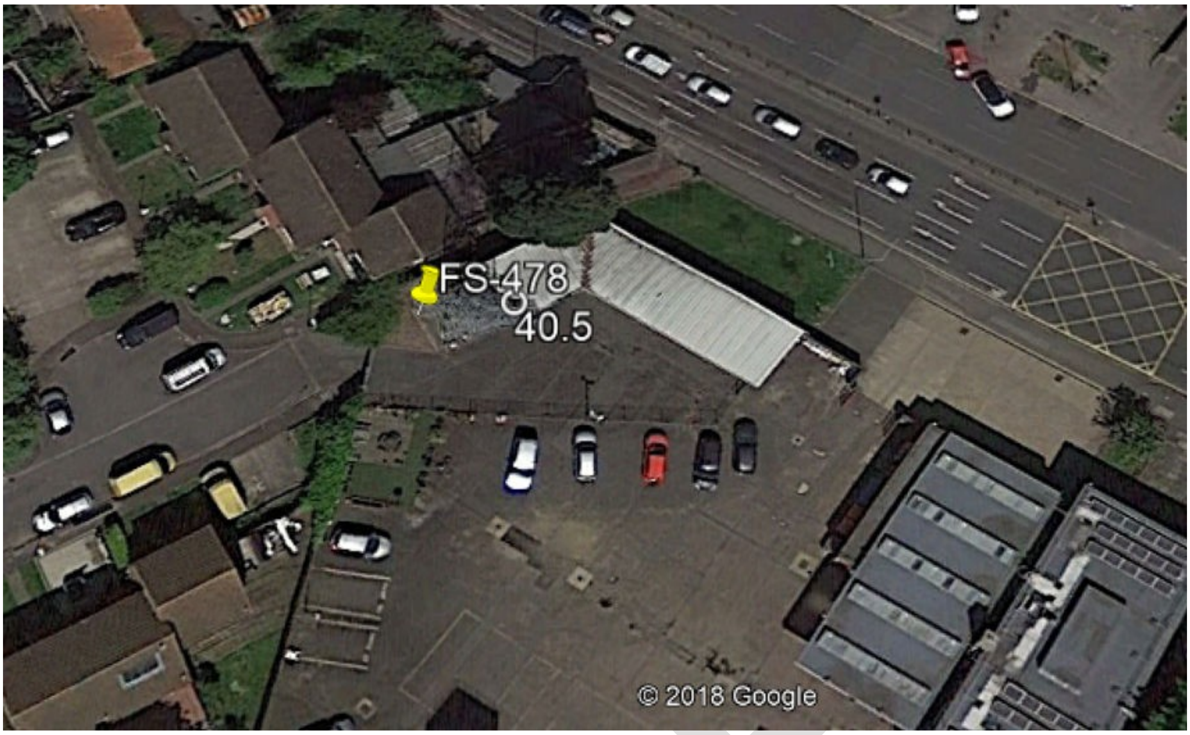


Figure 49: Geographic location of the top RLAN interferer to UK FS 478

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

7.3.4 Summary for Study B: Monte Carlo simulations

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

For an unconstrained deployment of RLAN, the short-term interference limit (FDP < 10%) is met for all FS links in the Netherlands whereas in the UK 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 short-term interference limit is met by 503 of the 505 UK links. Deeper analysis revealed that these exceedances were caused by combinations of RLAN parameters that resulted in unrealistic RLAN locations.

7.4 STUDY C: COVERAGE MAPPING AND MONTE CARLO ANALYSIS OF INTERFERENCE FROM RLAN INTO FS

7.4.1 Introduction

The third study assesses sharing between the fixed service and 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 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.

7.4.2 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 / or will be used in the near future.

7.4.3 Simulation methodology

7.4.3.1 Coverage mapping approach

In order to plot the potential interference created by an 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 an 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. RLAN height is chosen as 1.5 m, as it is the most probable one according to the distributions provided by the ETSI [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 RLAN and that neither the population density nor the RLAN duty cycle are taken into account.

7.4.3.2 Monte Carlo approach

The same methodology described in Section 7.3.1 is adopted in this Section, with the exception that only 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 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 characterize this phenomenon.

Table 32: Summary of WAS/RLAN deployment model

Parameter	Mid
otal Population of Europe 2025	768 589 000
/ireless devices operating in licence exempt spectrum emainder operating in licence spectrum)	90%
usy hour population	62.70%
GHz Factor	48.17%
larket Factor	32%
F activity factor	1.97%
verlap factor	21.25%
stantaneously Transmitting Devices within a 29.65 MHz	279 869.776

S channel	
umber of on-tune active RLAN within a 29.65 MHz FS hannel	0.0003

The antenna pattern used in the simulation is according UXA 10-59 A (RFS) [87] as it is one of the most used in France, with a gain of 38.7 dBi

7.4.3.3 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 33 were studied. These links are believed to be worst cases as they are situated in urban environment.

Table 33: Studied links

	Station A					Station B					Length (km)
Parameter	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

7.4.4 **Simulation results**

7.4.4.1 Coverage interference mapping

The obtained results are plotted in Figure 50, Figure 51 and Figure 52. In each figure, outdoor RLAN impact (left) is compared with indoor RLAN impact (right). All the coloured areas are the areas where the protection criterion I/N of -10 dB is exceeded at the FS receiver, because of an RLAN present at the coloured grid point. Areas where the RLANs will cause I/N values lower than -10 dB are not coloured deliberately.

Regarding the chosen FS stations, it is clear that for the links 1 and 2, outdoor RLAN will create interference to the FS within a large geographical area, while the indoor deployment seems to impact a smaller area.

For the third link, given the terrain profile the outdoor 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 km² and that the farthest interfering grid point is at 2.4 km from the FS station.

Based on the above elements, it can be concluded that the use of RLAN only indoor presents less risks for the FS than the outdoor high-power deployment

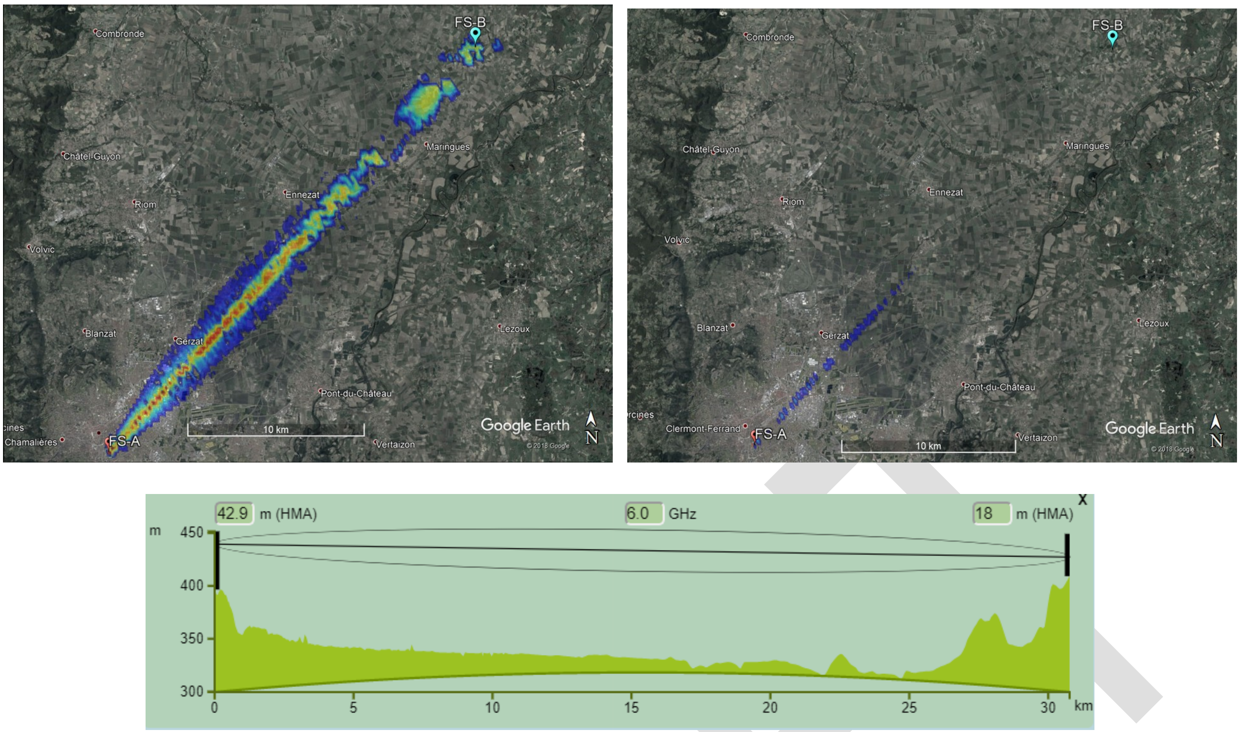


Figure 50: Fixed link 1 at Clermont-Ferrand. Top left: Outdoor RLAN impact on the fixed link, Top right: Indoor RLAN impact on the fixed link. Bottom: Fresnel zone and path profile

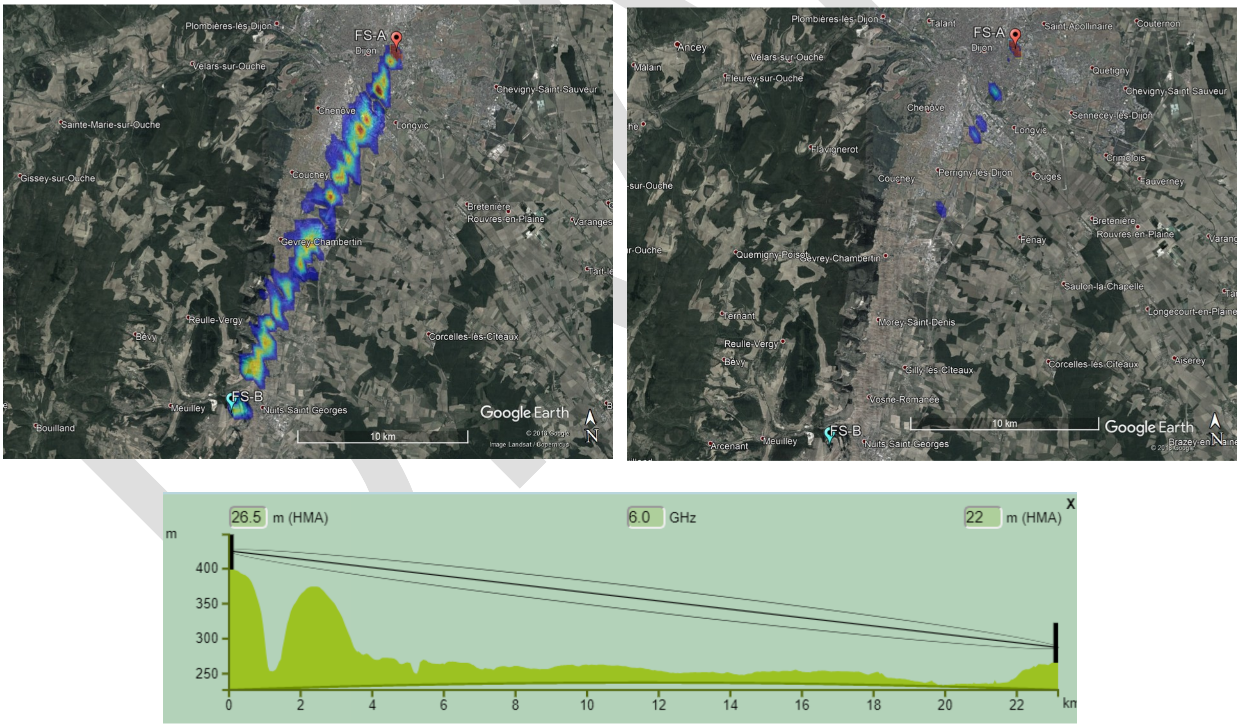


Figure 51: Fixed link 2 at Dijon. Top left: Outdoor RLAN impact on the fixed link, Top right: Indoor RLAN impact on the fixed link. Bottom: Fresnel zone and path profile

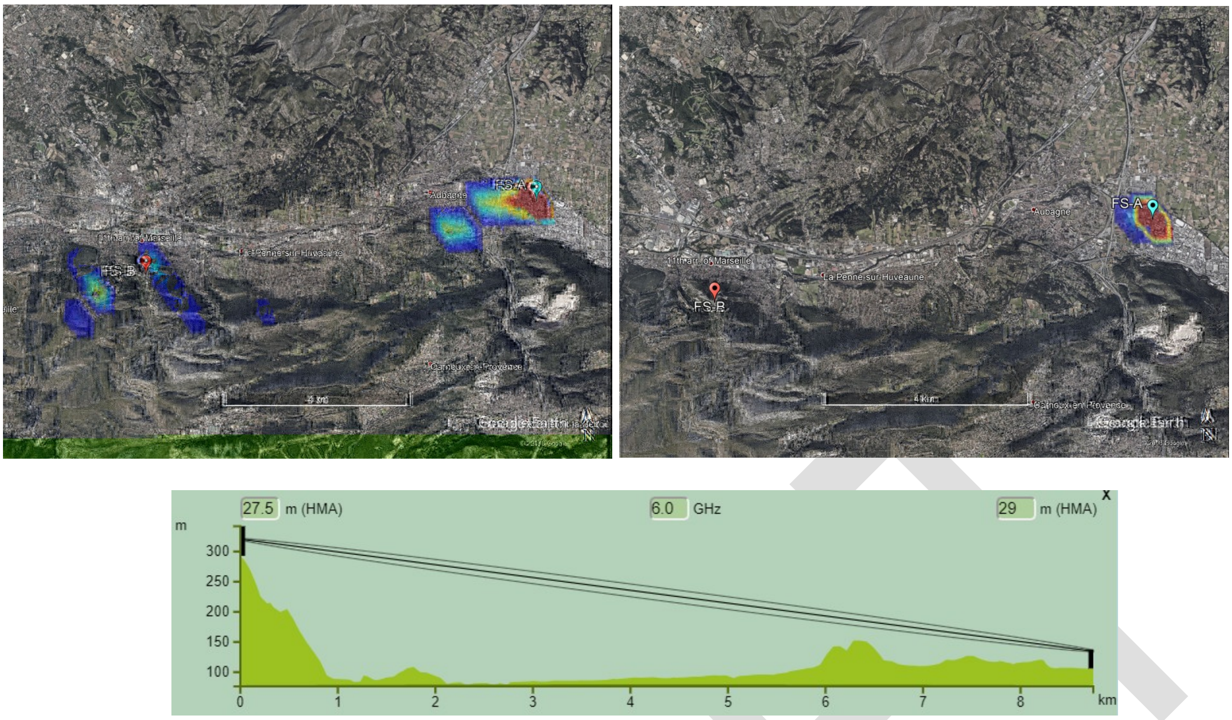


Figure 52: Fixed link 3 at Marseille. Top left: Outdoor RLAN impact on the fixed link, Top right: Indoor RLAN impact on the fixed link. Bottom: Fresnel zone and path profile

7.4.4.2 Monte Carlo simulation results

Monte Carlo simulation results are depicted in Figure 53 below. 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.

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.

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. Link 1and 2 are more subject to interference by RLANs given the terrain profile around it, while for link 2, the area where the RLAN could create interference is smaller (see Figure 52).

Again when combining the analysis with interference coverage map, regarding the cases where the I/N is exceeded, it is believed that they are due to high power outdoor usage.

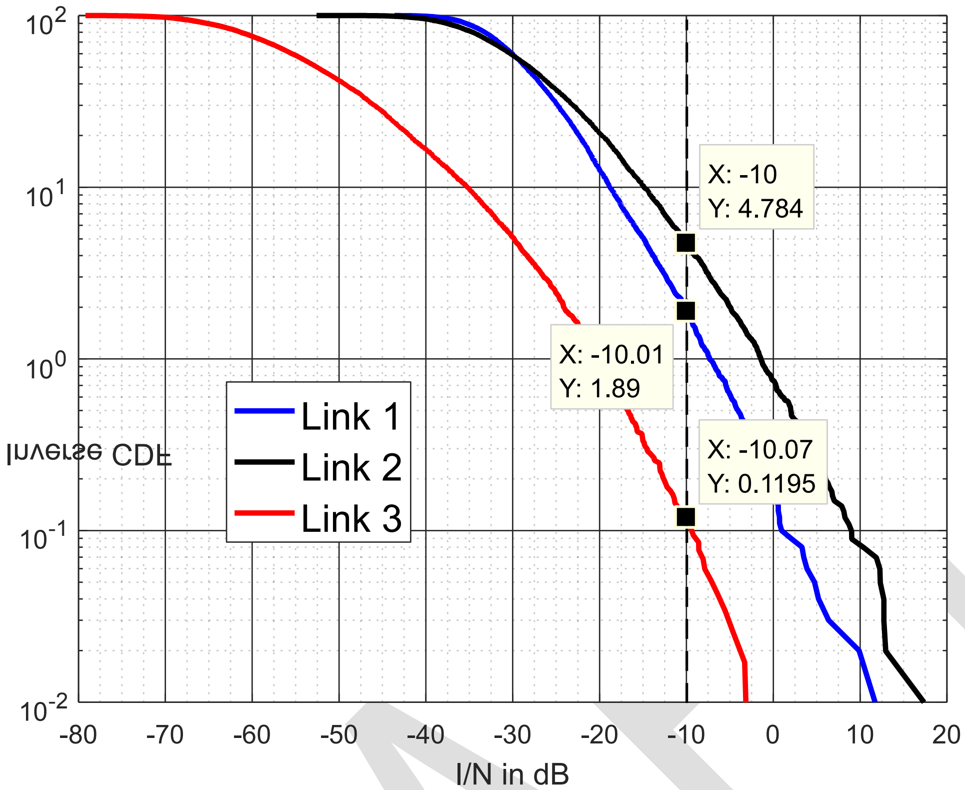


Figure 53: Monte Carlo simulations for the considered links

7.4.5 Summary for the Sharing Study C between RLAN and FS

Two set of complementary simulations have been run. The interference coverage mapping indicates that allowing outdoor 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.

Complementary statistical study based on a Monte Carlo approach, indicated that the I/N value of -10 dB was not exceeded for more than the 20% of the time as advised by Recommendation ITU-R F.758 for the long term protection criterion.

Taking into account the above elements, 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 its effect in case of accidental outdoor use, like: FS data base use for coordination, in particular, a geo-location methods that aims at detecting a spatial closeness between victim and interferer.

8 SHARING BETWEEN RLAN AND FSS

8.1 SHARING BETWEEN RLAN AND FSS STUDY A: MONTE CARLO ANALYSIS OF 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 RLAN deployment and available satellite G/T contours, related to the satellites in Table 21. Peak G/T levels using satellite thermal noise temperature per Table 21 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 RLAN deployments of a Monte Carlo simulation as detailed in the next Section.

Table 34 gives the worst I/N value found for each beam across all channels, under RLAN assumptions for the Mid scenario. The table shows that, in all cases, the I/N is more than 8.5 dB below the -10.5 dB threshold.

Table 34: Summary worst case I/N into FSS under RLAN assumptions for the Mid scenario

Satellite Reference (Table 20)	Satellite Longitude	Satellite Name	Beam Reference	Populations included in calculation	Worst I/N under Mid Active RLAN assumptions (dB)
J	40.5° West	SES-6	40.5W Hemispheric	Europe, Africa, Middle East	-30.45
K	22° West	SES-4	22W Hemispheric	Europe, Africa, Middle East, North and South Americas, Caribbean	-24.19
L	20° West		20W Zone	Europe, Africa, Middle East	-21.98
M	50.5° East		50.5E Zone	Europe, Africa, Middle East	-24.28
N	57° East		57E Hemispheric	Europe, Africa, Middle East	-24.42
Q	37.5° West		37.5W Hemispheric	Europe, Africa, Middle East	-24.19
R	60° East	IS-33e	C4A	Europe, Africa, Middle East	-19.64
T	34.5° West	IS-35e	C01	Europe, Africa, MiddleEast	-19.07
Y	45° West	IS-14	CEUH	Europe, Africa, Middle East	-27.96

Z	72° East	IS-22	WHLU	Europe, Africa, Middle East	-28.22

8.1.1 Simulation methodology

Interference from RLAN deployments into FSS satellite receiver is simulated using a Monte Carlo simulation of the 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 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 RLANs using the device population probability distribution;
i) Generate random clutter loss and building penetration loss values between each RLAN and FSS satellite receiver in accordance with the propagation modelling set out in Section 6.2;
j) Compute the aggregate interference from all co-channel 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 density file is created as a textual CSV file. Each line of the file 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 file 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 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 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 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 RLAN device count at that grid point divided by the total active RLAN device count. A random 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 either by a CSV file or a GXT file. For the CSV format, each line of the file 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 CSV file. 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 54 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 54: Representative FSS Transponder Frequency Plan (fc, Separation = 40 MHz)

Step 2) Monte Carlo Iterations:

For each iteration, a random layout of active RLAN devices is generated one RLAN at a time. Each RLAN device is assigned a random LON/LAT position generated using the device population probability distribution. Each RLAN device is assigned a random height, e.i.r.p. and building type using discrete probability distributions that are input to the simulation. Building types are NO_BUILDING (outdoor RLAN), TRADITIONAL or THERMALLY_EFFICIENT. Each RLAN is assigned a random bandwidth using a discrete probability distribution that is input to the simulation and a random centre frequency. The centre frequency is generated by considering all possible centre frequencies for the selected bandwidth and using a uniform distribution.

For each RLAN, a 4/3 earth model is used to determine whether the satellite is in view or over the horizon. 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 RLANs for which the satellite is in view is computed and aggregated. The RLAN bandwidth and centre frequency along with the FSS channel bandwidth and centre frequency are used to compute the fraction of the RLAN bandwidth that overlaps with the FSS channel. If there is no overlap, the RLAN contributes no interference to the FSS channel. In addition, a random body loss is generated using a discrete probability distribution described in Section 6.6.

A random building penetration loss is computed using Recommendation ITU-R P.2109-0 using the building type and elevation angle from the RLAN to the FSS satellite receiver orbital slot. Note that for outdoor RLANs with building type = NO_BUILDING, the building penetration loss is 0 dB. Random path clutter values are generated per Recommendation ITU-R P.2108 for urban and suburban RLANs and per Recommendation ITU-R P.452 for rural RLANs (as described in Section 6).

The path loss is computed using Free Space Path Loss (FSPL), per Recommendation ITU-R P.619-3, from the RLAN position to the FSS satellite orbital slot. Polarisation loss of 3 dB, per Section 6.5, is added. The FSS satellite Figure-of-Merit (G/T) is computed at the RLAN position as described above. The I/N contribution for a single RLAN into an FSS channel is computed by:

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

where:

- $EIRP$ = RLAN e.i.r.p. (dBW);
- L_{bldg} = Building Entry Loss (dB);
- L_{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 RLANs for each FSS channel in the simulation.

8.1.2 RLAN populations used in the simulations

The following total population projections for 2025, for each region, have been used in generating 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.

15 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).

16 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);

17 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 35 shows number of simultaneously transmitting RLAN devices that are simulated in each region within the satellite footprint. In addition, the number of active 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 RLANs deployment at 6 GHz.

Table 35: Number of active RLAN devices simulated

Region	2025 Population	Number of instantaneously transmitting RLAN devices

		Low	Mid	High
Europe	768 589 000	820 521	1 317 034	2 057 866
Africa	1 407 870 000	375 749	603 122	942 379
Middle East	396 751 000	105 890	169 966	265 571
North America, South America and the Caribbean	1 075 892 659	287 147	460 905	720 165

8.1.3 **Results by FSS satellite beam**

8.1.3.1 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.

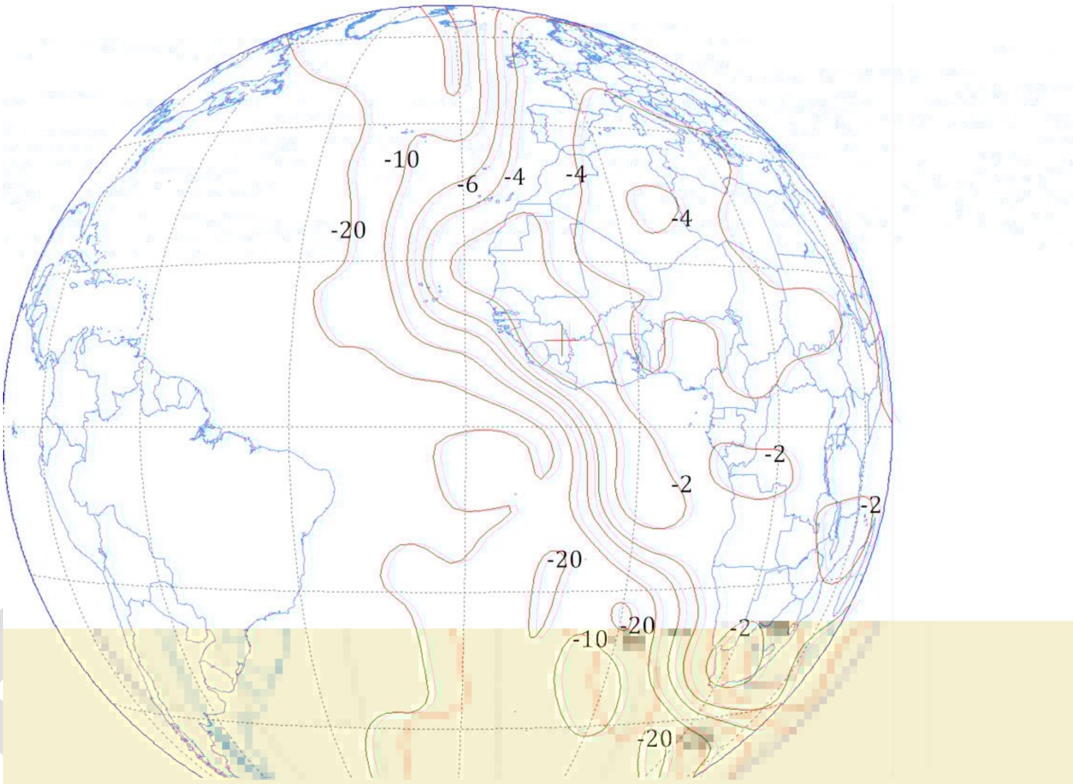


Figure 55: SES-4 G/T contours

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

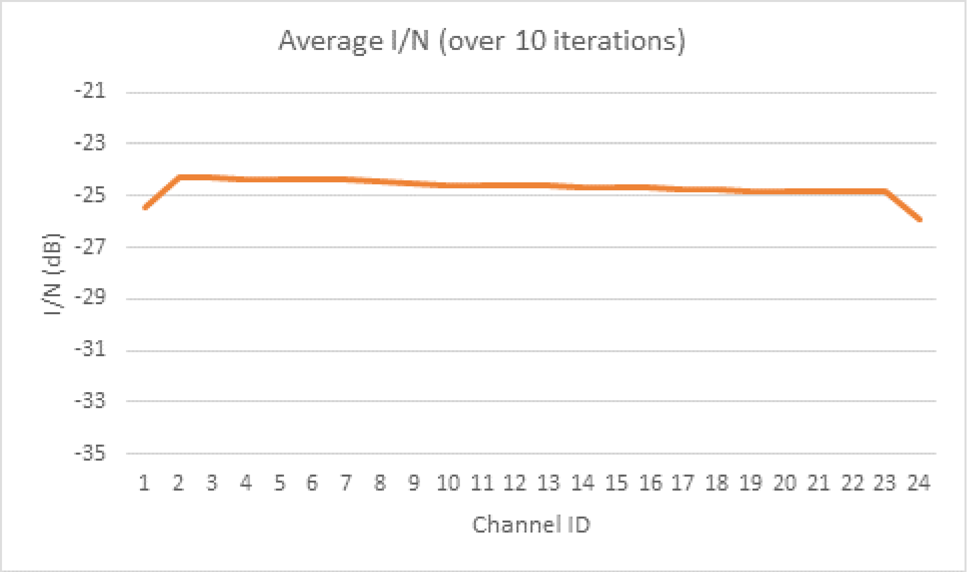


Figure 56: SES-4 I/N per channel under mid active RLAN assumptions

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

8.1.3.2 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 57.

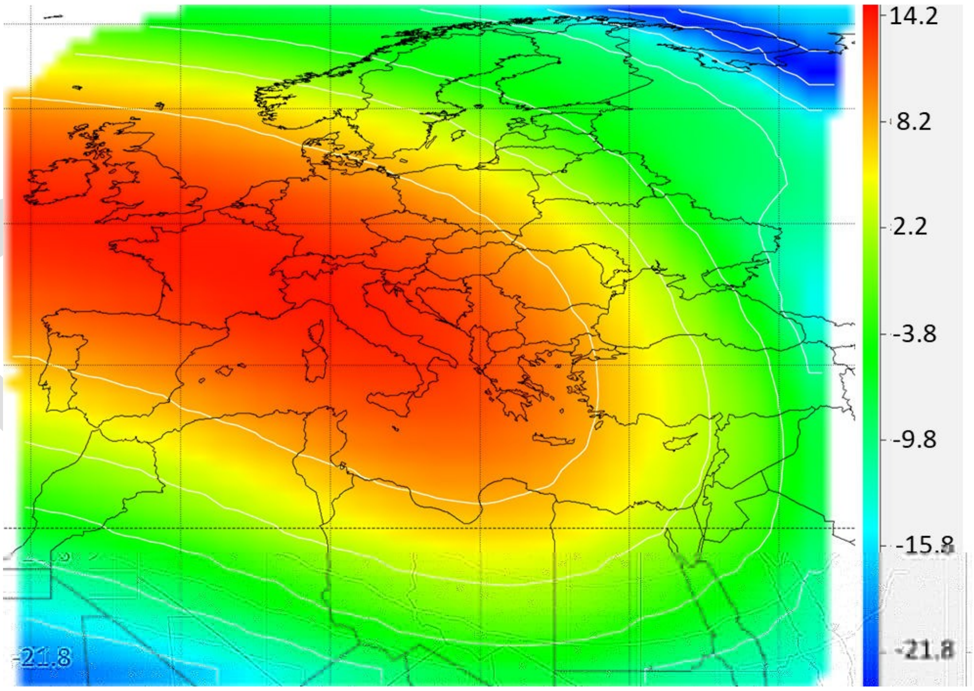


Figure 57: IS-33e G/T contours

The aggregate I/N under mid active RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown in Figure 58. The calculation includes RLANs in Europe, Africa and the Middle East.

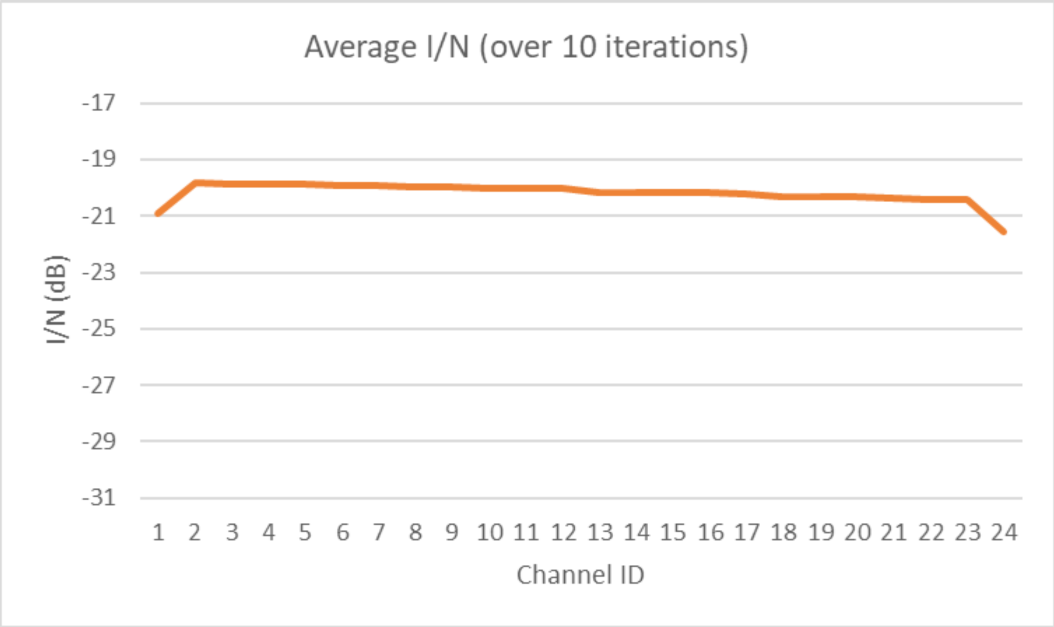


Figure 58: IS-33e I/N per channel under mid active RLAN assumptions

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

8.1.3.3 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 59. The other 16 contours provided do not cover Europe.

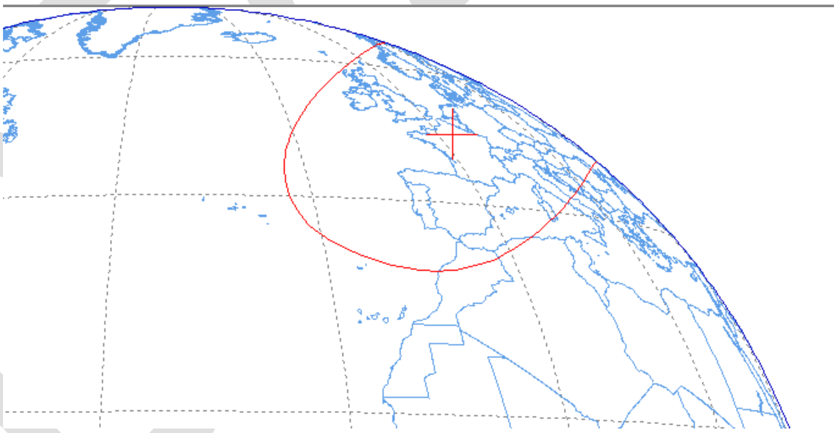


Figure 59: IS-35E G/T contours

The aggregate I/N under mid active RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown Figure 60. The calculation includes RLANs in Europe, Africa and the Middle East.

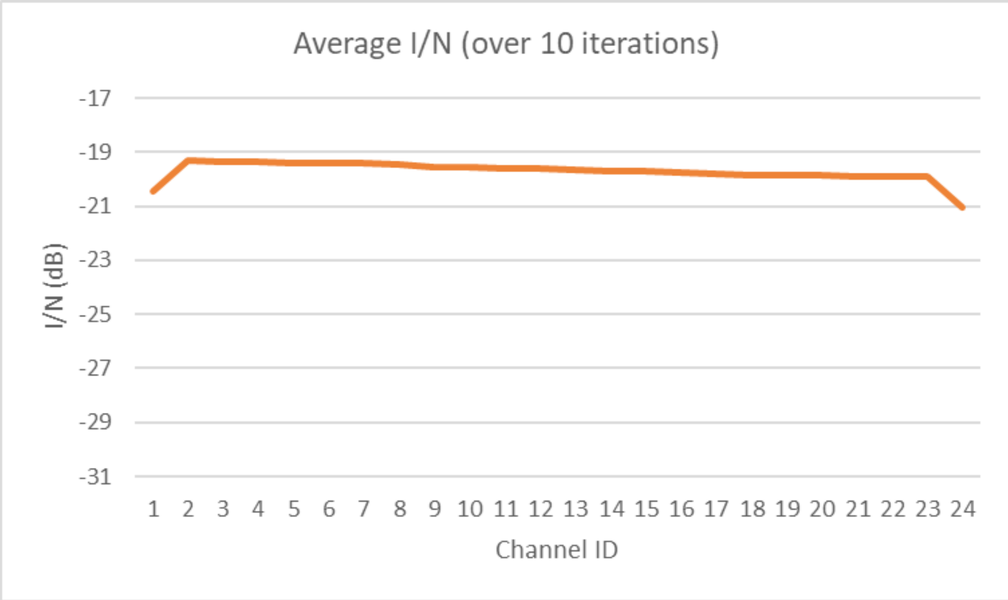


Figure 60: IS-35E I/N per channel under mid active RLAN assumptions

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

8.1.3.4 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 61.

Figure 61: IS-14 G/T contours

The aggregate I/N under mid active RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown in Figure 62. The calculation includes RLANs in Europe, Africa and the Middle East.

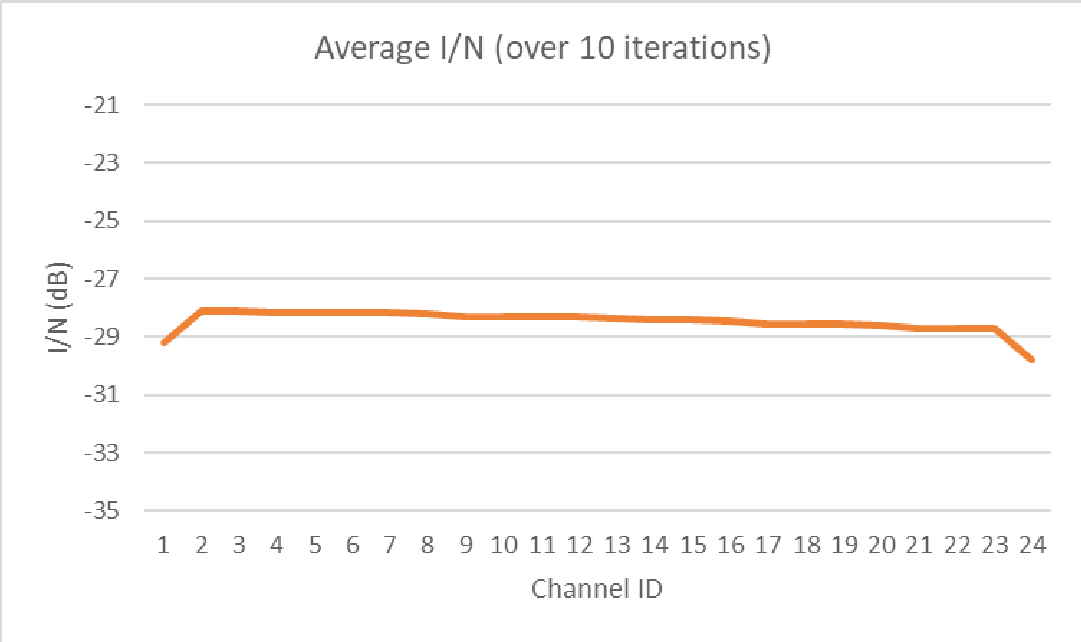


Figure 62: IS-14 I/N per channel under mid active RLAN assumptions

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

8.1.3.5 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 63.

Figure 63: IS-22 G/T contours

The aggregate I/N under mid active RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown in Figure 64. The calculation includes RLANs in Europe, Africa and the Middle East.

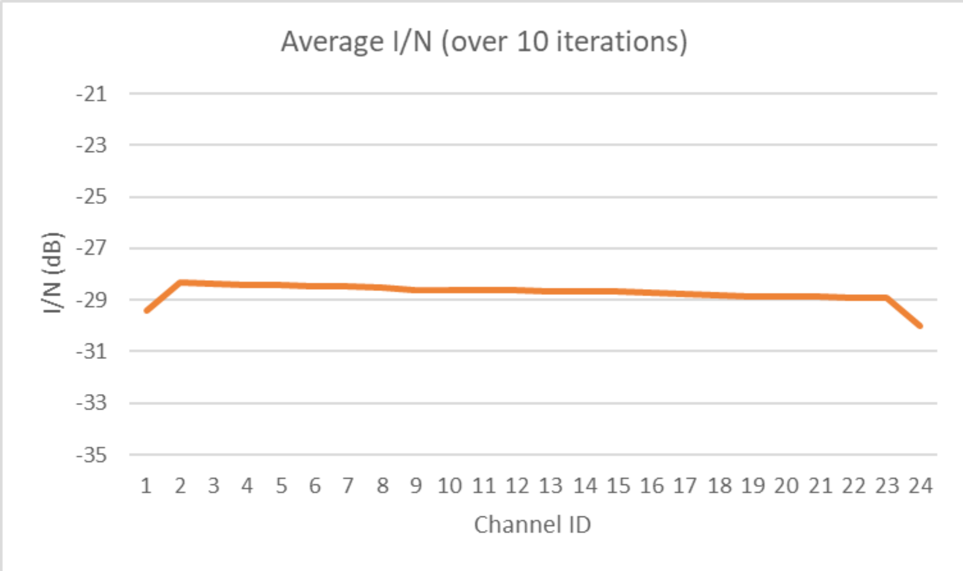


Figure 64: IS-22 I/N per channel under mid active RLAN assumptions

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

8.1.3.6 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 65.

Figure 65: SES 20W Zone G/T Contours

The aggregate I/N under mid active RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown in Figure 66. The calculation includes RLANs in Europe, Africa and the Middle East.

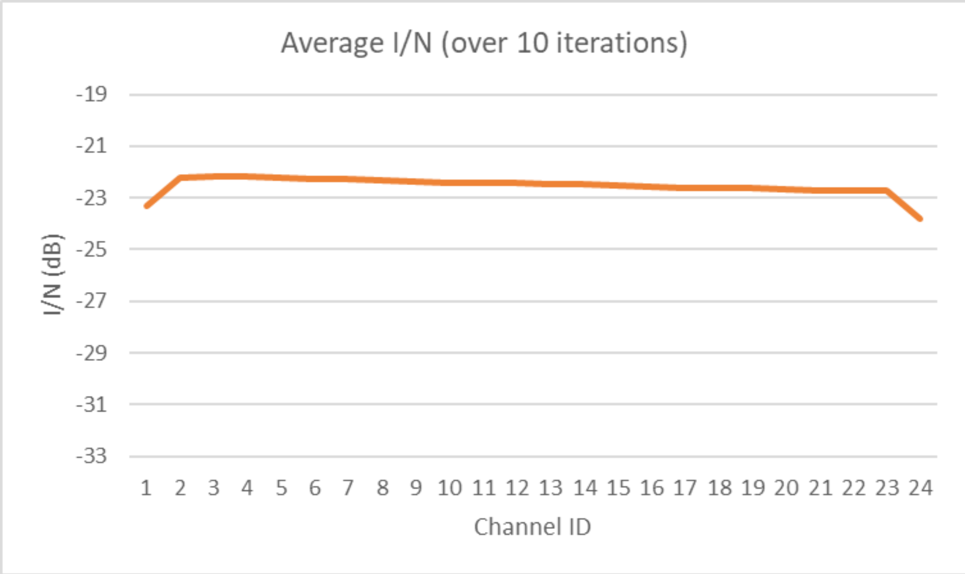


Figure 66: SES 20W I/N per channel under mid active RLAN assumptions

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

8.1.3.7 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 67.

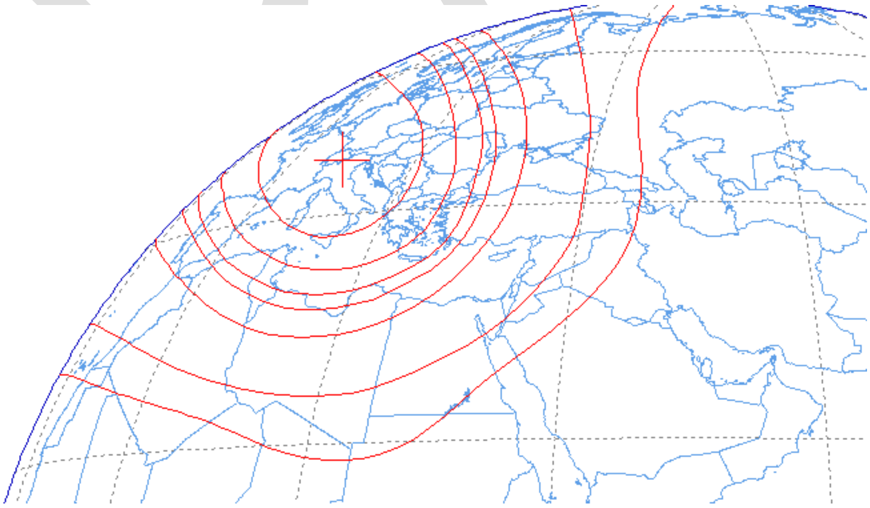


Figure 67: SES 50.5 E Zone G/T contours

The aggregate I/N under mid active RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown Figure 68. The calculation includes RLANs in Europe, Africa and the Middle East.

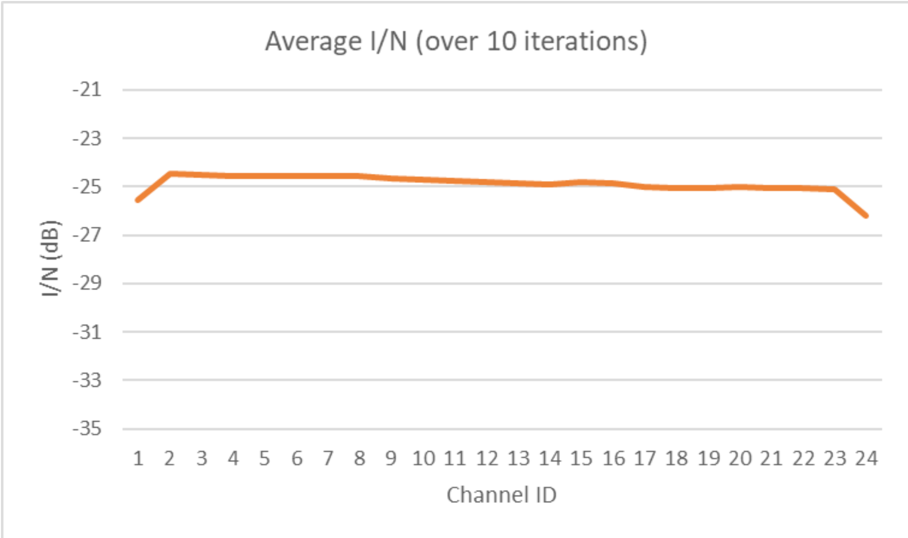


Figure 68: SES 50.5E I/N per channel under mid active RLAN assumptions.

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

8.1.3.8 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 69.

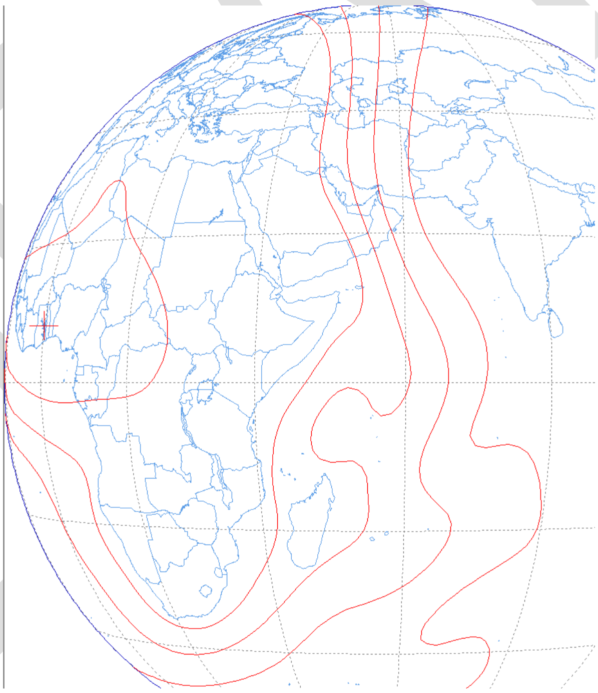


Figure 69: SES 57E 20W Zone G/T contours

The aggregate I/N under mid active RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown in Figure 70. The calculation includes RLANs in Europe, Africa and the Middle East.

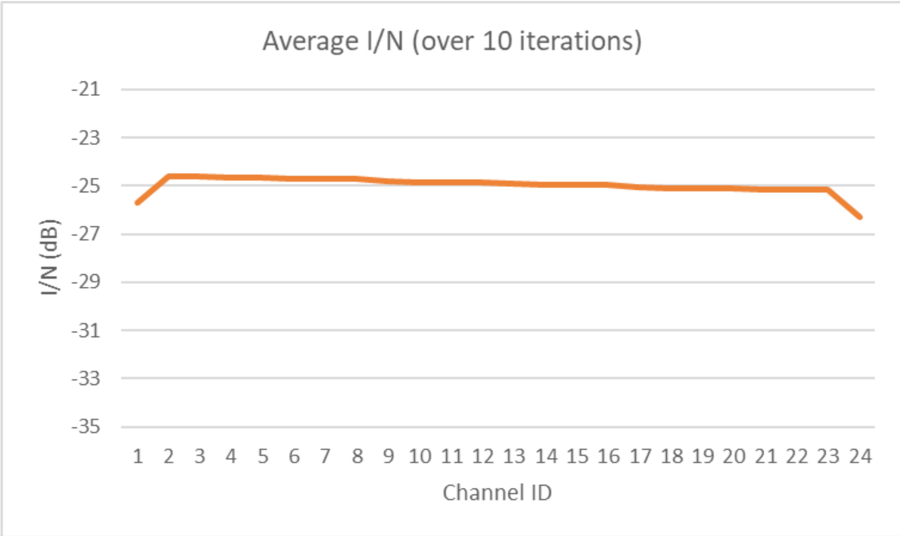


Figure 70: SES 57E I/N per channel under mid active RLAN assumptions

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

8.1.3.9 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 71.

Figure 71: SES 37.5W Zone G/T contours

The aggregate I/N under mid active RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown in Figure 72. The calculation includes RLANs in Europe, Africa and the Middle East.

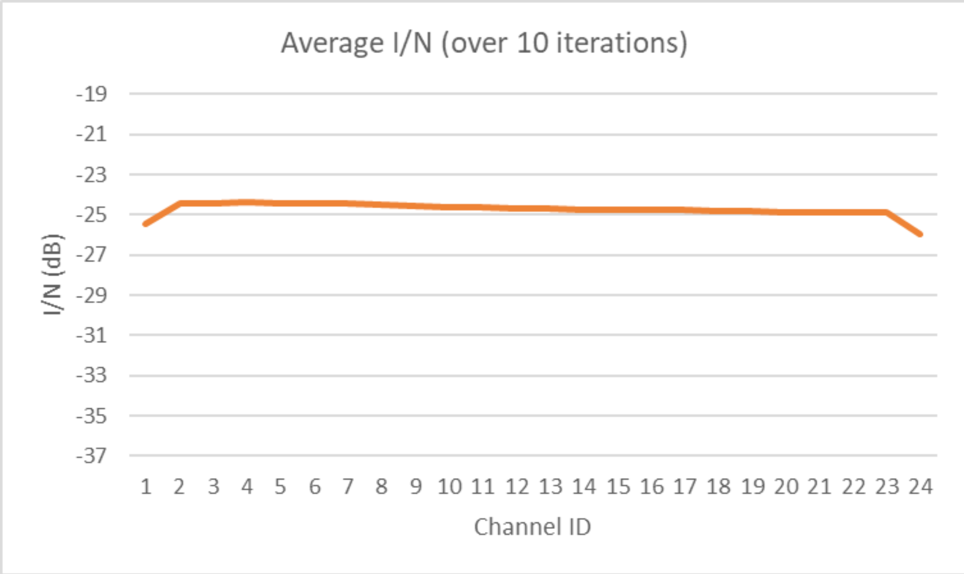


Figure 72: SES 37.5W I/N per channel under mid active RLAN assumptions

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

8.1.3.10 SES-6 40.5W

The satellite SES-6 at 40.5W has the global G/T contour per Figure 73. The peak G/T is -0.8 dB/K.

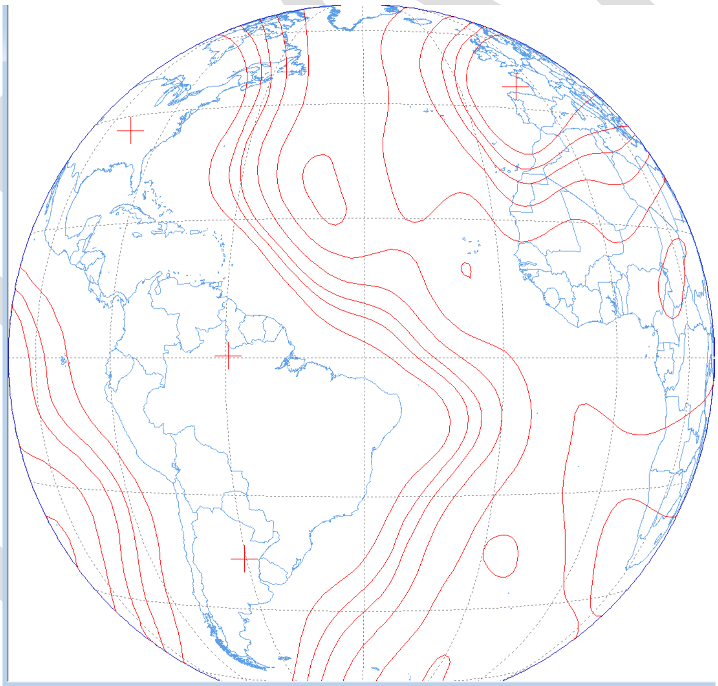


Figure 73: SES-6 40.5 W Global G/T contours

The aggregate I/N under mid active RLAN assumptions, across the 24 modelled FSS channels, averaged over 10 simulation iterations is shown in Figure 74. The calculation includes RLANS in Europe, Africa, the Middle East, North and South America and the Caribbean.

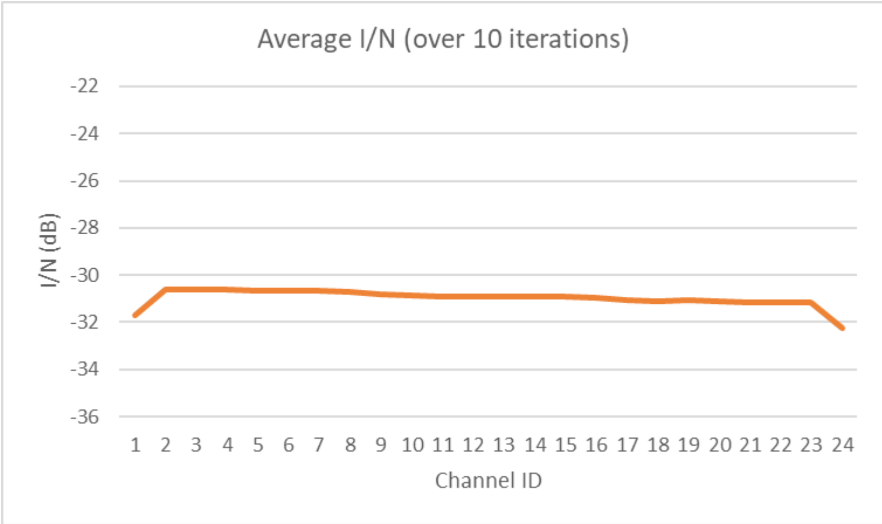


Figure 74: SES-6 40.5W I/N per channel under mid active RLAN assumptions

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

8.1.4 FSS link budgets

Table 36, Table 37, Table 38 and Error: Reference source not found 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 RLANs within the corresponding region. Averaging for the transmit powers and simulation parameters (building penetration losses, clutter losses and GT values) are done in linear domain. Note that this results in much lower building penetration and clutter losses than their mean values, i.e. 50th 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 36: IS-33e (at 60° East), Beam C4A, link budget for the Mid scenario

Parameter	Unit	Europe	Africa	Source
Number of Mid Active RLANs		1 317 034	603 122	Table 35
Number of Active RLANs contributing to I/N		1 314 896	604 121	RLANs within the coverage area
Total Average e.i.r.p. per RLAN	mW	50.42		Includes Body Loss per Table 22 (Section 6.6)
Average Building Entry Loss (Indoor 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 RLANs)	dBW	36	32	Includes Building Loss
Bandwidth Correction		0.075 (=36/480)		= Satellite Noise Bandwidth / Total 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 37: SES Satellite at 50.5° East, Zone Beam, link budget for the Mid scenario

Parameter	Unit	Europe	Africa	Source
Number of Mid Active RLANs		1 317 034	603 122	Table 35
Number of Active RLANs contributing to I/N		1 315 290	604 081	RLANs within Satellite View
Total Average e.i.r.p. per RLAN	mW	50.42		Includes Body Loss per Table 22 (Section 6.6)
Average Building Loss (Indoor 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 RLANs)	dBW	36	31	Includes Building Loss
Bandwidth Correction		0.075 (=36/480)		= Satellite Noise Bandwidth / Total RLAN Band (5935 to 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 38: SES Satellite at 57° East, Hemispheric Beam, link budget for the Mid scenario

Parameter	Unit	Europe	Africa	Middle East	Source
Number of Mid Active RLANs		1 317 034	603 122	169 966	Table 35
Number of Active RLANs contributing to I/N		1 314 430	604 449	170 188	RLANs within Satellite View
Total Average e.i.r.p. per RLAN	mW	50.42			Includes Body Loss per Table 22 (Section 6.6)
Average Building Loss (Indoor 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 RLANs)	dBW	36	31	25	Includes Building Loss
Bandwidth Correction		0.075 (=36/480)			= Satellite Noise Bandwidth / Total 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 39: 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 RLANs		1 317 034	603 122	169 966	Table 35
Number of Active RLANs contributing to I/N		1 314 430	604 449	170 188	RLANs within Satellite View
Total Average e.i.r.p. per RLAN	mW	50.42			Includes Body Loss per Table 22 (Section 6.6)
Total Aggregate Average e.i.r.p. (all RLANs)	dBW	36	32	25	Includes Building Loss
Bandwidth Correction		0.075 (=36/480)			= Satellite Noise Bandwidth / Total 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	

8.1.5 Summary for the sharing Study A between RLAN and FSS

Simulations show that, in all cases under RLAN assumptions for the Mid scenario, studied, 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 RLANs will not impact the operation of the FSS uplinks in the band 5925-6425 MHz.

8.2 STUDY B: AGGREGATE INTERFERENCE FROM RLAN INTO FSS SPACE STATIONS

8.2.1 Introduction

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

8.2.2 RLAN Parameters

8.2.2.1 RLAN e.i.r.p. distribution

Table 40: RLAN e.i.r.p. distribution for scenario 98% indoor & 2% outdoor

e.i.r.p. (mW)	1000	250	100	50	13	1	Total
Indoor (%)	0.70	8.97	6.09	25.27	51.42	5.57	98.01
Outdoor (%)	0.06	0.08	0.16	0.74	0.89	0.06	2.00

Table 41: RLAN e.i.r.p. distribution including body loss

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

A sensitivity analysis scenario for 95% indoor & 5% outdoor is provided in A5.3.

8.2.2.2 RLAN bandwidth distribution

Table 42: RLAN bandwidth distribution

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

8.2.2.3 RLAN antenna pattern

Only omnidirectional antennas are considered in the studies and no RLAN antenna discrimination is assumed.

8.2.2.4 RLAN deployment model for Europe

The population in Europe for the year 2025 is projected at 768 589 000.

Table 43: RLAN deployment models for Europe for the year 2025

	LOW	MID	HIGH
Devices Per Person	10	10	10
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 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 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 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
Effective High Activity 6 GHz Devices (10%)	41 650 799	66 854 530	104 460 203
Effective Low Activity 6 GHz Devices (90%)	374 857 188	601 690 769	940 141 827
RF Activity Factor for High Activity Devices	1.97%	1.97%	1.97%
Instantaneously Transmitting High Activity Devices	820 521	1 317 034	2 057 866
Instantaneously Transmitting Low Activity Devices (0.00022%)	82 469	132 372	206 831
Instantaneous Number of Transmitting 6 GHz Devices (total)	902 989	1 449 406	2 264 697
Percentage of Outdoor WAS/RLANs:	2.00%	2.00%	2.00%
Instantaneous Number of Outdoor Transmitting 6 GHz Devices (total)	18 060	28 988	45 294
Percentage of Indoor WAS/RLANs:	98.00%	98.00%	98.00%
Instantaneous Number of Indoor Transmitting 6 GHz Devices (total)	884 930	1 420 418	2 219 403

8.2.3 FSS Parameters

8.2.3.1 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 5.2.2).

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

It is proposed to also consider this value for the FSS protection criteria for studies between RLAN and FSS in the band 5925-6425 MHz, together with an apportionment of 3 dB of the interference allowance to take account of the Fixed Service (FS) in the band.

8.2.3.2 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

Table 44: FSS satellite parameters considered in this study

Satellite	Sub-satellite longitude	Maximum Receive Gain (dBi)	Coverage	Receiving Thermal Noise Temperature (K)	Figure of merit (dB/K) (using thermal noise)
L	20^o West	31.8	Zone beam over Europe	250	7.8
M	50.5^o East	32.4	Zone beam over Europe	250	8.4
R	60^o East	37.3	Spot beam over Europe	201	14.25
R'	5^oEast	37.3	Spot beam over Europe	201	14.25

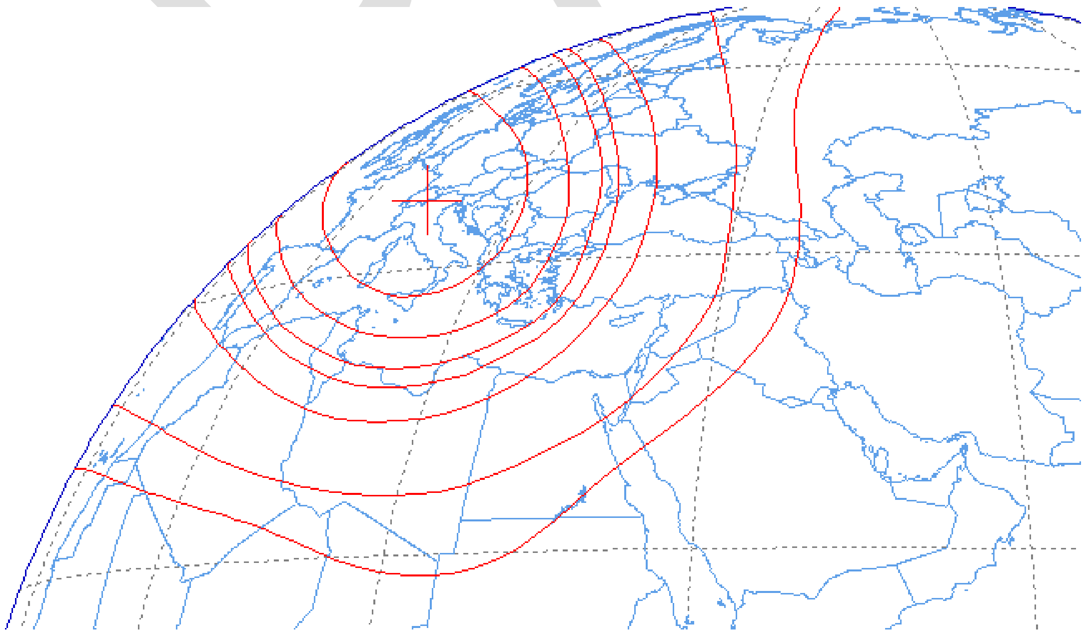


Figure 75: SES 50.5E (NSS-5) zone beam coverage over Europe in 5925-6425 MHz

Figure 76: SES 20W (NSS) zone beam coverage over Europe in 5925-6425 MHz

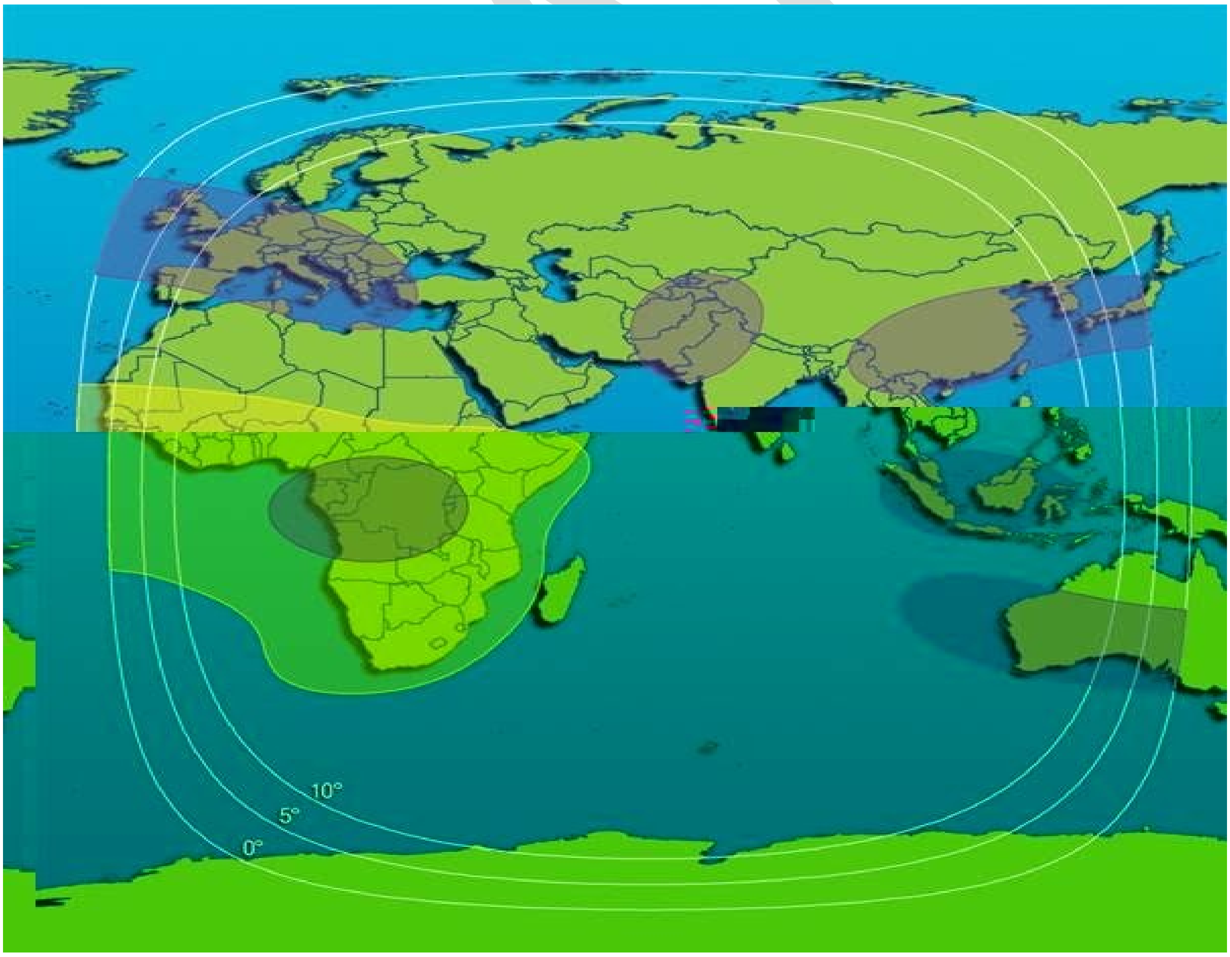


Figure 77: Intelsat 60E spot beam coverage over Europe in 5925-6425 MHz

8.2.3.3 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 RLAN devices).

8.2.4 Results of interference calculations

The scenario summarised in Table 45 is considered in the interference calculations.

Table 45: Scenario for Indoor & Outdoor (98% Indoor & 2% Outdoor)

e.i.r.p. and indoor-outdoor distributions							
e.i.r.p. (mW)	1000	250	100	50	13	1	Total
Indoor (%)	0.70	8.97	6.09	25.27	51.42	5.57	98.01
Outdoor (%)	0.06	0.08	0.16	0.74	0.89	0.06	2.00

Table 46: e.i.r.p. distribution with body loss (98% Indoor & 2% Outdoor)

e.i.r.p. distribution with body loss (98% Indoor & 2% Outdoor)										
e.i.r.p. (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

Table 47: Bandwidth distribution

Bandwidth distribution				
Bandwidth (MHz)	20	40	80	160
Distribution (%)	10.00	10.00	50.00	30.00

Table 48: Bandwidth correction

Bandwidth correction				
RLAN Bandwidth (MHz)	20	40	80	160
Average bandwidth correction factor (dB)	0.7	0.5	0.5	0.25

Calculations of the bandwidth correction factor are provided in A5.1

Detailed results of I/N interference calculations are provided in A5.2.

Table 49: Summary of I/N results for 98% indoor & 2% outdoor (BEL 17 dB)

BEL 17 dB	(duty cycle) RLAN deployment model	(1.97%) LOW	(1.97%) MID	(1.97%) HIGH
SES 50.5E (clutter 3 dB)	Max no. of simultaneously transmitting RLAN devices (6 GHz)	820 521	1 317 034	2 057 866
Zone beam Europe Gain 32.4 dB	I/N (dB)	-26.1	-24.0	-22.1
SES 20W (clutter 1.7 dB)	Max no. of simultaneously transmitting RLAN devices (6 GHz)	820 521	1 317 034	2 057 866
Zone beam Europe Gain 31.8 dB	I/N (dB)	-23.6	-21.5	-19.6
INT 60E (clutter 3 dB)	Max no. of simultaneously transmitting RLAN devices (6 GHz)	820 521	1 317 034	2 057 866
Spot beam Europe Gain 37.3 dB	I/N (dB)	-21.0	-19.0	-17.0
SAT 5E (clutter 1.5 dB)	Max no. of simultaneously transmitting RLAN devices (6 GHz)	820 521	1 317 034	2 057 866
Spot beam Europe Gain 37.3 dB	I/N (dB)	-19.5	-17.5	-15.5

Table 50: Summary of I/N results for 98% indoor & 2% outdoor (BEL 14 dB)

BEL 14 dB	(duty cycle) RLAN deployment model	(1.97%) LOW	(1.97%) MID	(1.97%) HIGH
SES 50.5E (clutter 3 dB)	Max no. of simultaneously transmitting RLAN devices (6 GHz)	820 521	1 317 034	2 057 866
Zone beam Europe Gain 32.4 dB	I/N (dB)	-24.5	-22.4	-20.5
SES 20W (clutter 1.7 dB)	Max no. of simultaneously transmitting RLAN devices (6 GHz)	820 521	1 317 034	2 057 866
Zone beam Europe Gain 31.8 dB	I/N (dB)	-22.0	-20.0	-18.0
INT 60E (clutter 3 dB)	Max no. of simultaneously transmitting RLAN devices (6 GHz)	820 521	1 317 034	2 057 866
Spot beam Europe Gain 37.3 dB	I/N (dB)	-19.5	-17.4	-15.5
SAT 5E (clutter 1.5 dB)	Max no. of simultaneously transmitting RLAN devices (6 GHz)	820 521	1 317 034	2 057 866
Spot beam Europe Gain 37.3 dB	I/N (dB)	-18.0	-15.9	-14.0

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 [45] 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 A5.3.

As can be seen from the results given in A5.3, 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.

8.2.5 Summary of the sharing Study B between 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 RLAN parameters and assumptions in the study, for example but not limited to the duty cycle of high activity RLAN devices (1.97% in this study).

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 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 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 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 RLAN devices, from “98% Indoor & 2% Outdoor” to “95% Indoor & 5% Outdoor” is provided in A5.3.

For several scenarios considered for the 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. Considering coexistence conditions for RLAN, such as limiting the use to indoor deployment and introducing an e.i.r.p. limit of 200 mW/20 MHz, would help ensuring long-term protection of FSS space stations from aggregate interference from RLAN devices in the band 5925-6425 MHz.

9 ADJACENT-BAND COMPATIBILITY BETWEEN RLAN AND ROAD-INTELLIGENT TRANSPORTATION SYSTEMS (ITS)

9.1 INTERFERENCE FROM RLAN INTO ROAD-ITS

9.2 DESCRIPTION OF SCENARIOS

The following scenarios established in ECC Report 244 [45] describe realistic, worst-case conditions applicable to both directions of interference between Road-ITS and RLAN.

Scenario A1: Indoor RLAN

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

Scenario A2: Outdoor RLAN

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

Scenario B1: In-car RLAN with external ITS antenna

One or more 6 GHz RLAN devices are situated inside the vehicle. 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 RLAN antenna is highly variable, dependent 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-car RLAN with in-car 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 car.

Scenario C: Portable outdoor RLAN devices

The ITS radio is mounted on the road side such as on a traffic light. One or several 6 GHz 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 RLAN.

9.3 PROPAGATION MODEL

Given the considered distances the free space model [57] is valid for this study. Additional 3 dB attenuation is considered to characterize the polarisation mismatch for all the scenarios.

9.4 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 RLAN out-of-band (OoB) emissions below 5925 MHz. Considering a protection criterion of -6 dB (as in ECC Report 244 [45] and ECC Report 277 [82]), the Interference over Noise criterion in dB is expressed as:

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

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

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

The radiation pattern of the ITS antenna is depicted in Figure 78 below with a maximum gain of 4 dBi and 10 dB side-lobe attenuation (as in ECC Report 244 [45]).

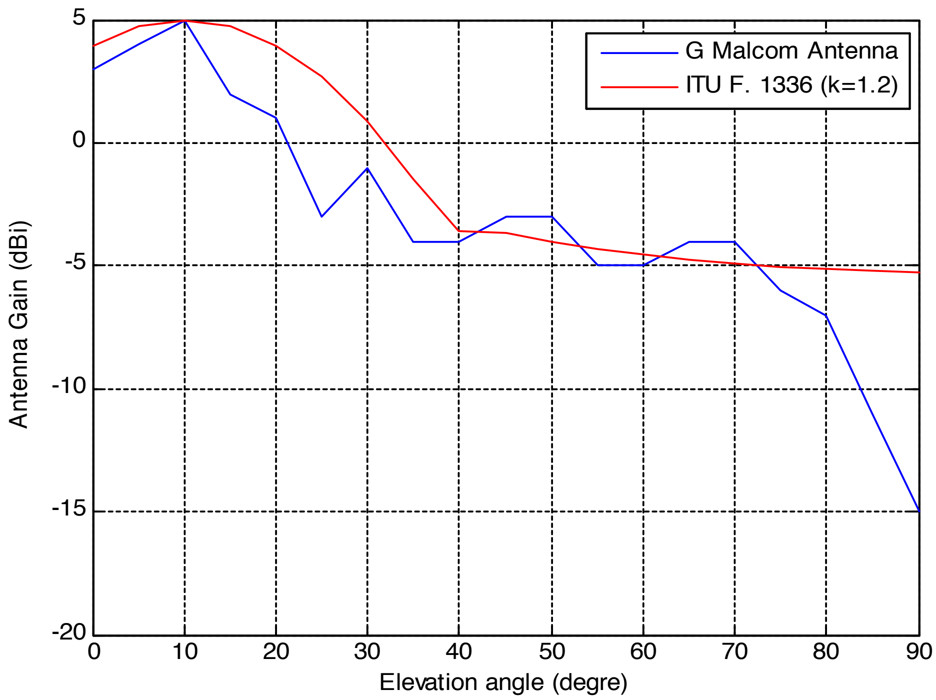


Figure 78: ITS OBU and RSU antenna pattern

9.5 RESULTS OF MCL CALCULATIONS FOR INTERFERENCE FROM RLAN INTO ROAD-ITS

For the scenarios described above, MCL calculations are performed to derive maximum RLAN out-of-band emissions below 5925 MHz. The results are summarised in Table 51 for the case where the RLAN signal is falling within the ITS main-lobe but also for the case where the 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 RLAN AP location elevation angles are within the side-lobe range.

Table 51: MCL calculations for interference from RLAN into Road-ITS - separation distances, main lobe and side-lobe

Parameter	Unit	Sc A1	Sc A2	Sc B1	Sc B2	Sc C
Transmitter part : RLAN						
Distance between 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
Car 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
Reception part: Road-ITS						
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
Results main lobe						
Maximum tolerable OoB RLAN incident in the 10 MHz ITS channel	dBm	-26.6	-45.2	-39.2	-59.2	-49.1
Maximum tolerable OoB RLAN density per MHz	dBm/MHz	-36.6	-55.2	-49.2	-69.2	-59.1
Results side-lobe						
Maximum tolerable OoB RLAN incident in the 10 MHz ITS channel	dBm	-16.6	-35.2	-29.2	-49.2	-39.1
Maximum tolerable OoB RLAN density per MHz	dBm/MHz	-26.6	-45.2	-39.2	-59.2	-49.1

9.6 SUMMARY OF ADJACENT-BAND COMPATIBILITY BETWEEN RLAN AND ROAD-ITS

Studies conducted between RLAN and Road-ITS below 5925 MHz shows that the 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 RLAN OoB emissions below 5925 MHz.

10 SHARING AND COMPATIBILITY BETWEEN RLAN AND COMMUNICATION-BASED TRAIN CONTROL (CBTC) SYSTEMS

10.1 ADJACENT BAND INTERFERENCE FROM RLAN INTO CBTC

10.1.1 CBTC characteristics

The CBTC characteristics considered in this study are summarised in Table 52.

Table 52: CBTC characteristics taken into account in the study

		IEEE 802.11 derived		TDMA/DSSS		TD-LTE	
	unit	BS	TU	BS	TU	BS[1]	TU[2]
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[6]	33[7]
		-	-			57.7[6]	43.7[7]
Adjacent Channel Rejection (ACR)	dB	16[4]	16[4]	-	-	-	-
		32[5]	32[5]				
Desensitization (D)[3]	dB	2	3	2	3	2	3

[1] cf. 3GPP TS 37.104 and TR 36.942
[2] cf. 3GPP TS 36.101 and TR 36.942
[3] Constructor information
[4] Valid in the first adjacent 5 MHz
[5] Beyond the first adjacent 5 MHz
[6] See ANNEX 7: (First value for the first 3 MHz and the second value is beyond)
[7] 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 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 7: for details).

10.1.2 Simulation methodology

RLAN and CBTC are to coexist in adjacent bands. The worst case coexistence is the one where an RLAN operating in the first channel dedicated to 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 (RLAN in our case) as well as blocking in the victim link receiver (CBTC). Figure 79 depicts these two interference mechanisms. The CBTC blocking is caused in our case by the RLAN in-band emissions. The interference inside the CBTC channel is, on the other hand, created by the RLAN unwanted emission.

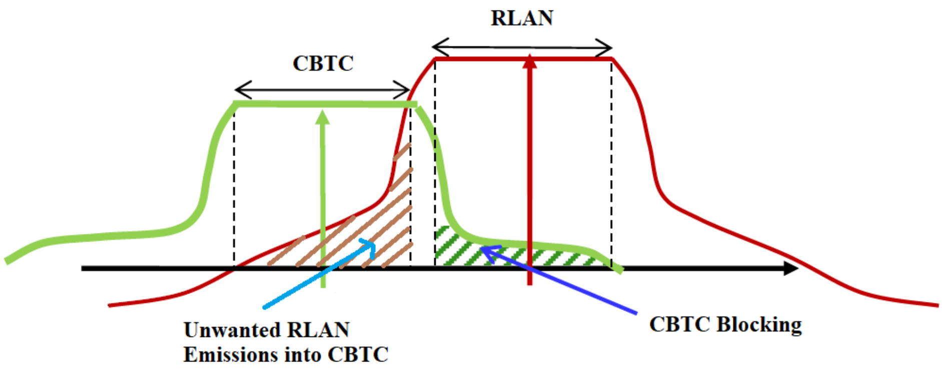


Figure 79: Unwanted emission from RLAN into the CBTC channel as well as the CBTC blocking

A two-step methodology is adopted here: first, maximum level of OoB RLAN emission tolerable by CBTC, as well as CBTC blocking are deduced given the characteristics depicted in Table 52. Secondly, a reverse engineering is performed in order to compute what are the RLAN e.i.r.p. densities and OoB emissions 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.

10.1.3 Maximum Out-of-Band emission from RLAN into the CBTC channel

This value represents the maximum tolerable amount of Interference energy falling from the 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:

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

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

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

10.1.4 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 RLAN signal received by CBTC within the 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

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

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:

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

10.1.5 **Results**

10.1.5.1 STEP 1: Maximum level of OoB RLAN emission and CBTC blocking

Table 53 depicts the achieved results for the first step computation.

Table 53: Results obtained for IEEE 802.11 derived CBTC and TDMA/DSS CBTC

		IEEE 802.11 derived		TDMA/DSSS		TD-LTE	
	unit	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	−¿	−¿	504	504	48.7	33
		−¿	−¿			57.7	43.7
ACR	dB	16[2]	16[2]	-	-	-	-
		32[3]	32[3]				
Target desensitization	dB	2	3	2	3	2	3
Maximum allowable unwanted emission from RLAN into the CBTC channel in the air[1]	dBm	−105.3	−102	−113.3	−110	−113.8	−106.5
Aggregated blocking level in the air, RLAN in 5935-5955 MHz	dBm	−70.3	−68.3	−63.3	−60	−60.4	−68.4
Aggregated blocking level in the air, RLAN in 5940-5960 MHz	dBm	−60	−58			−56.1	−62.8

[1] use eq.(1) - antenna gain + HW losses + boxing loss

[2] First floor of the ACS in the first adjacent 5 MHz

[3] Second floor of the ACS valid after 5940 MHz

The table above 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.

10.1.5.2 STEP 2: Required in-band and out-of-band emission for RLANS

The following scenarios are studied

- Scenario A: A fixed 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 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 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 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 54 describes the elements taken into account in the simulations. Given the small distances, the free space loss is considered as a propagation model.

Table 54: Considered propagation parameters

Parameter	Value			
	Sc#A	Sc#B	Sc#C	Sc#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[1]	5[2]	1[3]
Victim horizontal antenna discrimination (dB)	6[4]	3[5]	5[6]	3[7]
[1] At 10°, [2] at 11°, [3] at 10°, [4] at 11°, [5] at 17°, [6] at 10°, [7] at 17° Cf. CBTC antenna diagrams				

10.1.5.3 Maximum RLAN out-of-band emissions below 5935 MHz

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

$$I_{RLAN_{OOB}} = I_{CBTC} + \sum Losses + \sum Antenna_{discriminations}$$

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 55.

Table 55: Maximum RLAN out-of-band emission below 5935 MHz

Technology	Value						
	unit	Sc#A		Sc#B		Sc#C	Sc#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 RLAN below 5935 MHz are as follows:

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

10.1.5.4 Maximum RLAN in-band emission

In order to respect the CBTC blocking, appropriate levels of in-band emission for RLANs need to be derived. Using the same approach as in Section 10.1.5.3, is found:

$$P_{RLAN_{Inband}} = B_{CBTC} + \sum Losses + \sum Antenna_{discriminations}$$

Applying this equation, the results shown in Table 56 for RLAN first channel in 5935-5955 MHz are obtained.

Table 56: Maximum RLAN e.i.r.p. if operating in 5935-5955 MHz

Technology	Value						
	unit	Sc#A		Sc#B		Sc#C	Sc#D
		indoor	outdoor	indoor	outdoor		
IEEE 802.11 like	dBm/20MHz	14.5	-2.5	16.2	-0.8	7.6	-2.8
TDMA/DSSS	dBm/20MHz	21.5	4.5	24.5	7.5	14.6	7.5
TD-LTE	dBm/20MHz	24.4	7.4	16.1	-0.9	17.5	-0.9

If the first RLAN channel is to be configured above 5940 MHz, the results are shown in Table 57.

Table 57: Maximum RLAN e.i.r.p., in first adjacent channels, if operating above 5940 MHz

Technology	Value						
	unit	Sc#A		Sc#B		Sc#C	Sc#D
		indoor	outdoor	indoor	outdoor		
IEEE 802.11 like	dBm/20MHz	24.8	7.8	26.5	9.5	17.9	7.5
TDMA/DSSS	dBm/20MHz	21.5	4.5	24.5	7.5	14.6	7.5
TD-LTE	dBm/20MHz	28.7	11.7	21.7	4.7	21.8	4.7

10.1.6 **Summary for the CBTC Adjacent-Band Study**

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

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

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

10.2 INTERFERENCE FROM 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 RLAN band 5925-6425 MHz, as shown in Figure 80. 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 RLAN networks might thus severely impact the performance of the CBTC system.

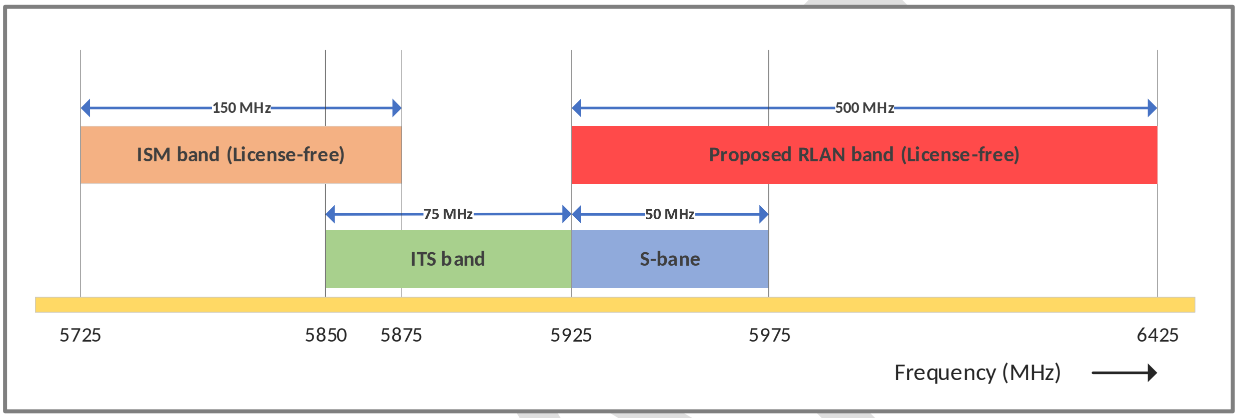


Figure 80: Overview of frequency bands

In this context, this Section evaluates the impact of the interference produced by an RLAN device on the operation of the Copenhagen S-train CBTC system.

10.2.1 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 350000 passengers a day. Table 58 lists the key figures of the Copenhagen S-train system.

Table 58: 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 [83].

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 [84] and [85].

- **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 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 RLAN device is less harmful compared to someone streaming videos or downloading large files on their RLAN device. The requirements listed in [84] 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 recognize 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 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 RLAN users are also using a channel of 20 MHz width and the same modulation and coding rate as S-train. For RLAN users using a wider channel (i.e. 40, 80 or 160 MHz) and/or a higher modulation and coding rate, the number of RLAN users that would prevent the train from transmitting would be greater, particularly given the short duty cycle of 1.97% (see Section 4.2) 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 [84] 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 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 [84]. 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 59 lists the key figures of the S-train CBTC system.

Table 59: 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 60 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 60: 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)

10.2.2 Experimental setup and methodology

The study in this Section shall be regarded more as an analytical study than as an empirical study. Furthermore, it is in part based on the MCL methodology [86]. 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.
- RLAN interferer: An RLAN interferer could either be an AP or a mobile device. While an RLAN AP could generally only be located at the wayside, an RLAN mobile device, typically carried by a passenger, could be located either at the wayside or inside the train.

10.2.2.1 Propagation model

The following propagation model originally presented in [34] has been used for this study.

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

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 61. 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 61: 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 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 RLAN interferer are defined and the impact of the RLAN interferer at a given distance “d” from the CBTC receiver is studied. The coordinate system is shown in Figure 81.

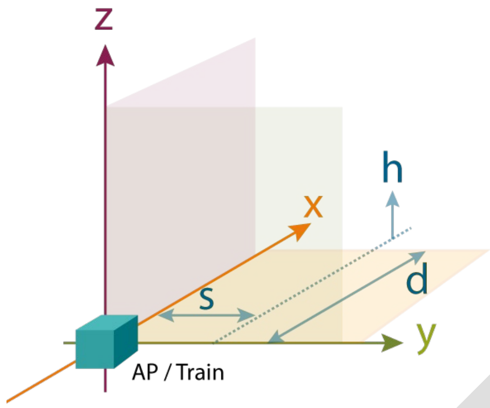


Figure 81: Coordinate system

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 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 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 RLAN device is not able to hear the transmissions from the CBTC unit, i.e. CBTC unit is hidden from the 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 RLAN device might not refrain from transmitting and thus produce interference for a CBTC unit that is already transmitting.

10.2.2.2 Experiment parameters

Table 62 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 62: 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 63 lists the generic parameter values used in this study, i.e. parameter values that are applicable for both CBTC and RLAN.

The e.i.r.p. values of 29.9 dBm and 18.5 dBm for RLAN AP and RLAN mobile device, respectively, have been used. These values have been adopted from in line with Section 4.1.1.1.

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

Table 63: Generic parameter values used in the study

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

10.2.3 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 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 RLAN interferer (i.e., “d” in Figure 81) is increased incrementally by moving the RLAN interferer.

10.2.3.1 Scenario A - CBTC AP vs RLAN AP close to track

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

- Height of the 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 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 82.

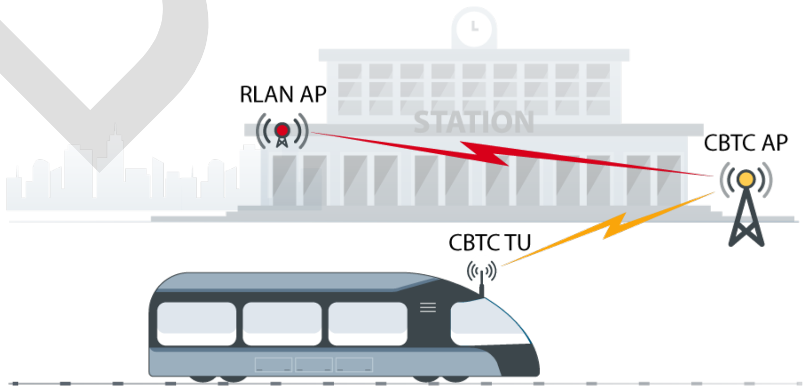


Figure 82: Scenario A

10.2.3.2 Scenario B - CBTC TU vs. RLAN AP close to track

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

- Height of the 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 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 83.

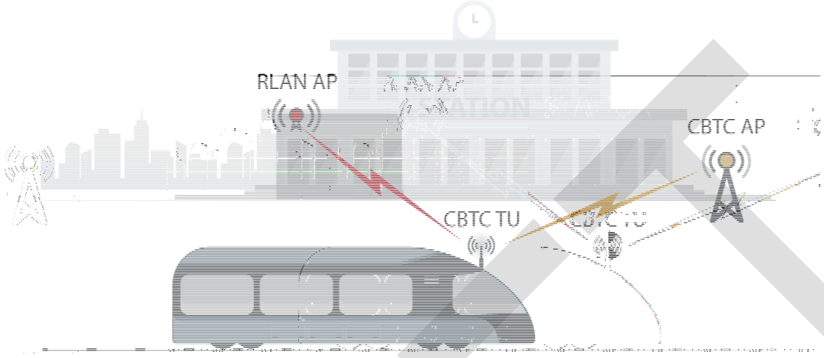


Figure 83: Scenario B

10.2.3.3 Scenario C - CBTC AP vs. RLAN mobile inside train

This scenario studies the impact on a CBTC AP from the transmissions of an 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 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 84.

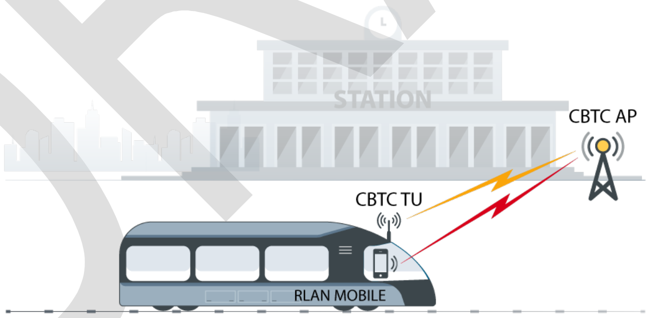


Figure 84: Scenario C

10.2.3.4 Scenario D - CBTC TU vs. RLAN mobile inside train

This scenario studies the impact on a CBTC TU from the transmissions of an 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 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 85.

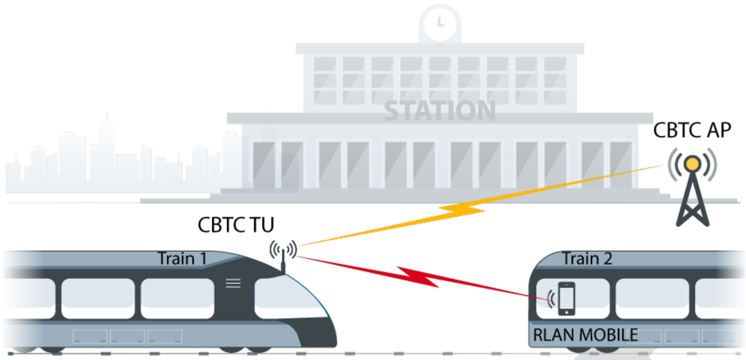


Figure 85: Scenario D

10.2.3.5 Scenario E - CBTC AP vs. RLAN mobile on platform

This scenario studies the impact on a CBTC AP from the transmissions of an 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 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 86.

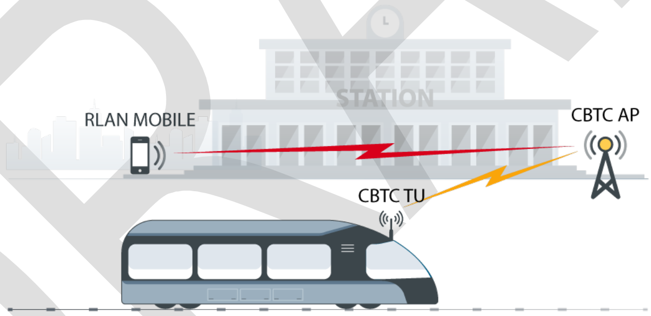


Figure 86: Scenario E

10.2.3.6 Scenario F - CBTC TU vs. RLAN mobile on platform

This scenario studies the impact on a CBTC TU from the transmissions of an 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 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 87.

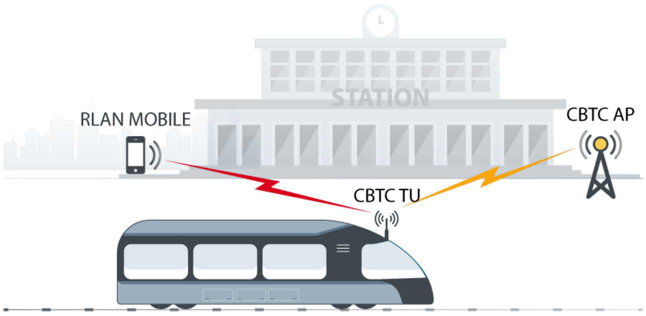


Figure 87: Scenario F

10.2.4 Results and Discussion

Figure 88 presents the results for the above described six scenarios. The x-axis shows the distance of the RLAN interferer from the CBTC receiver, i.e. “d” in Figure 81. The y-axis shows the received interfering signal power form an RLAN device.

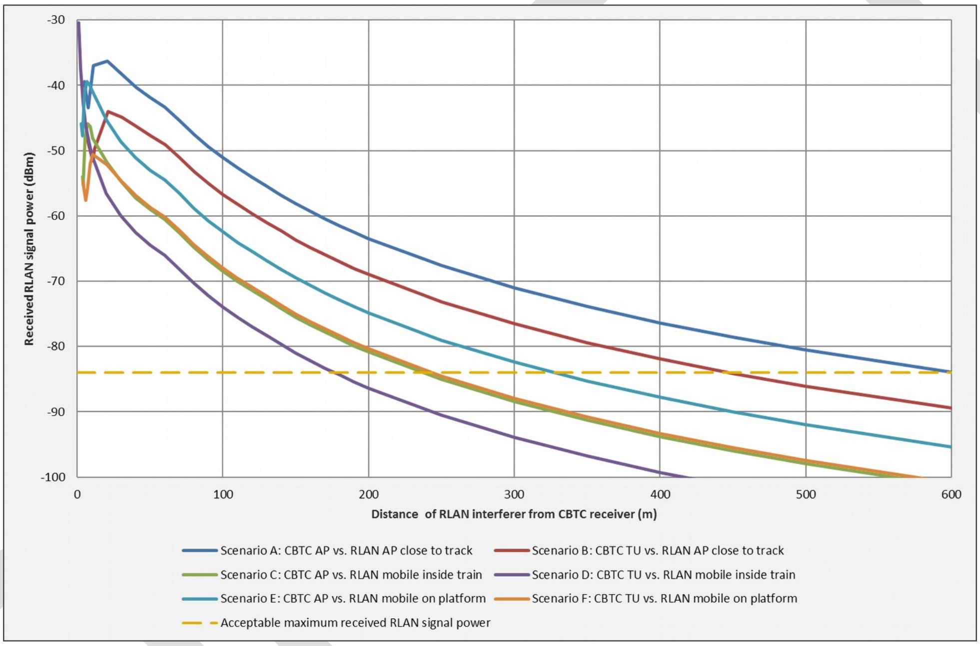


Figure 88: Interference from RLAN

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. 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 10.1.1). This implies that the power of the CBTC signal must be 9 dB above the power of the RLAN signal. Since the power of the CBTC signal is known in this case (i.e. -75 dBm), it means the power of the RLAN signal must be at least 9 dB less than -75 dBm. In other words, the power of the RLAN signal must be equal or less than $-75\,dBm - 9\,dB = -84\,dBm$. The horizontal yellow line in Figure 88 represents this value. Specifically, the received power from an RLAN interferer must be below this line to enable the CBTC receiver to correctly demodulate the signal. In short, anything in Figure 88 shown above this line is bad.

Figure 88 shows that for Scenario B, the 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 an RLAN AP close to the track and the receiver is a CBTC train (TU). In other words, the results show that if the 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 an RLAN AP close to the track and the receiver is a CBTC AP. The results show that the 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 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 an RLAN mobile device inside the train and the receiver is a CBTC AP. In Scenario F, the interferer is an 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 an RLAN mobile device inside another train. The main reason why the 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 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 88 have been summarised in Table 64. In the event that CBTC and RLAN have to share the same frequency band, it will not be possible to guarantee that no RLAN device will be present inside these distances from the S-train system. Thus, it can be concluded that RLAN will have a critically negative impact on the CBTC operation.

Table 64: Required minimum distance between CBTC receiver and 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 an 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 RLAN devices in the proximity and the data traffic characteristics of the applications used by them. Nonetheless, the case of a malicious “jammer” 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.

10.2.5 Summary on the study on interference from RLAN to CBTC operating in the same band

This Section presents the results from a study investigating the impact of RLAN devices coexisting in the same frequency band as the Copenhagen S-train CBTC system. Six worst-case scenarios are considered where the RLAN device is either functioning as a RLAN AP or an 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 an RLAN device. The distance of the 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 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 RLAN device and CBTC receiver to avoid the interference from the RLAN device. This distance ranges from the 180 m for Scenario D (minimum) to 600 m for Scenario A (maximum). If S-train and RLAN share the same frequency band eventually, it will not be feasible to reasonably assume that no 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 an RLAN device continuously interferes with a given CBTC receiver for 1 second, the train will stop.

It is, therefore, concluded that RLAN will have a critical impact on the operation of the S-train CBTC system. As mitigation, the design of the radio communication system, both for wayside and on-board, will have to be updated. The activities will involve one or more of the following: performing the link budget calculation and radio coverage survey again, installing additional APs at the wayside and, updating the radio equipment—including radio cards and antennas—as well as the radio communication software.

11 COMPATIBILITY BETWEEN WAS/RLAN AND RADIO ASTRONOMY

11.1 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 (CH_3OH). 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 [15] 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 [71] 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 [72].

Recommendation ITU-R RA 769 gives a threshold 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, for the Radio Astronomy site at Westerbork in the Netherlands it can been seen the plot in Figure 89 showing a contour based on a single 2000 second observation. 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 89: Contours based on a single 2000 second observation for the Radio Astronomy site at Westerbork, NL

Note that in Figure 89, 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 RAS, the local clutter loss being higher than the values derived from a general model or the 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 RLAN deployment on the operation of the RAS on a site-by-site basis.

12 COEXISTENCE BETWEEN RLAN AND ULTRA WIDE BAND (UWB) SYSTEMS

12.1 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 all currently legal radio devices 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.

12.2 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 [64].

The characteristics of UWB systems and use cases used here are based on:

- ETSI TR 103 181-1 [73];
- ETSI TR 103 181-2 [74].

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 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.

12.3 MCL STUDIES FOR A SINGLE INTERFERER

12.3.1 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 PMSE (Program making and special events) 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 [75] and described in System Reference Document ETSI TR 101 994-1 [76]. 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 [77] considered the compatibility of RLAN and UWB systems. A reference distance of 36 cm between the UWB device and the RLAN terminal was considered, in combination with free space propagation and omnidirectional antennas.

Table 65 lists the separation distances for the various proposed 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 RLAN transmitter at the UWB victim receiver and assumes that the highest 160 MHz channel, centred at 6335 MHz is used.

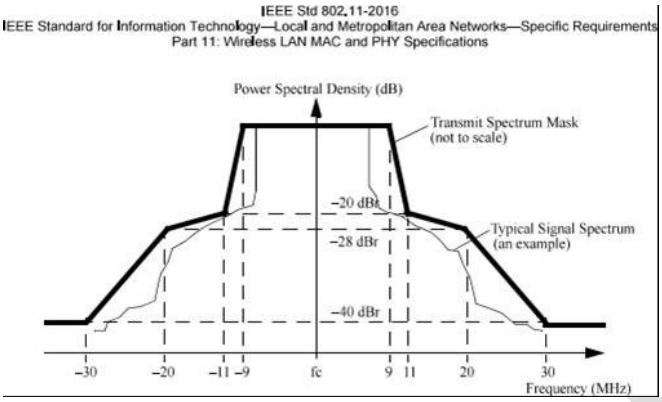
Table 65: Separation distances resulting in 3 dB loss to UWB communications systems from RLAN transmitter

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
Assumptions	
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 degradation of the UWB devices performance. To meet the separation distance of 36 cm results in an RLAN transmit power level of -38.4 dBm.

12.3.1.1 Example study regarding Wi-Fi out-of-band emissions impact on 6.5 GHz UWB signal

Figure 91 shows a spectrum analyser capture of a double-wide OTA Wi-Fi transmission at 5 GHz. Observed OoB emission is (barely) meeting IEEE 802.11 requirements, shown in Figure 90, 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 90: IEEE 802.11 Out-of-Band (OoB) emission requirement for OFDM transmissions

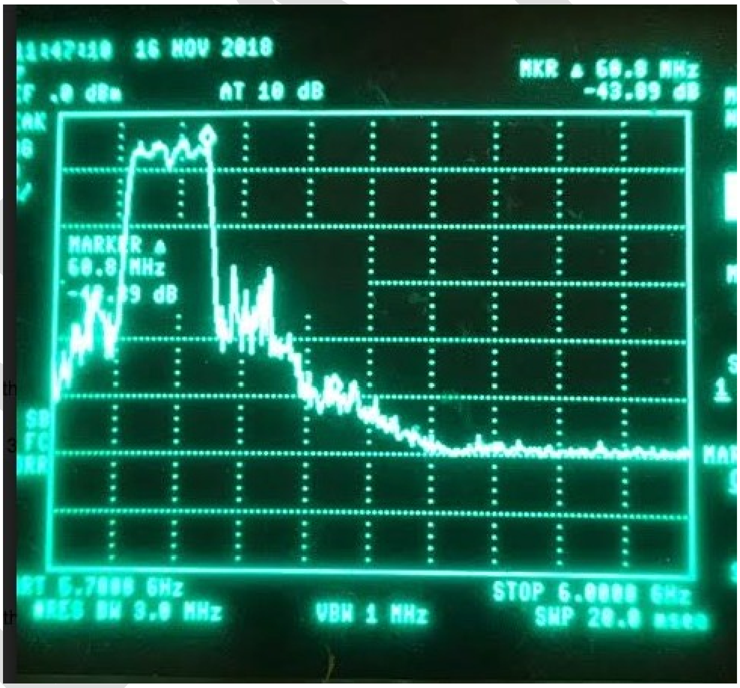


Figure 91: RLAN spectrum mask measurement

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 below)

It is also assumed (conservatively) that the shape of the noise 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 below)

A 6 dB UWB receiver noise figure and Tx + Rx antenna gains of 0 dB are also assumed.

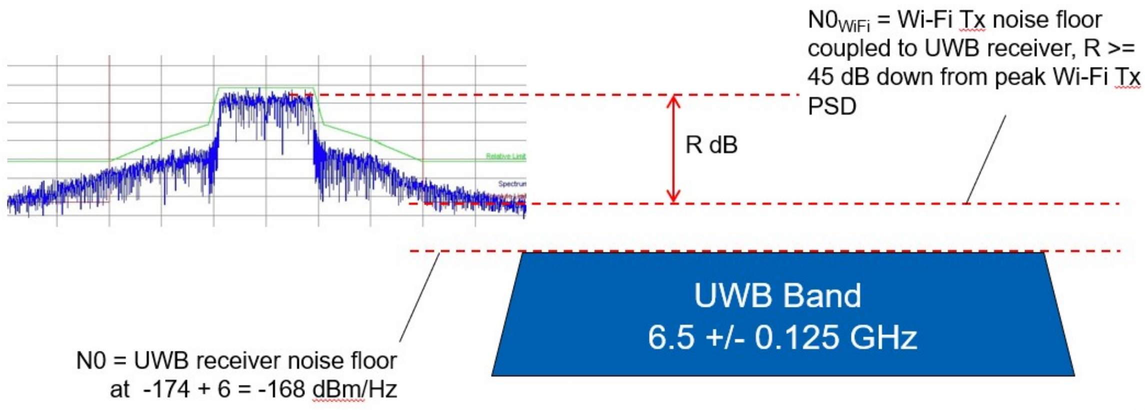


Figure 92: Noise floor analysis

The noise floor seen by UWB receiver due to an out-of-band Wi-Fi transmission is illustrated in Figure 92 and can be calculated as

$$N_{0\,WiFi}=P_{Tx}-10\log_{10}(BW)-R-P(d)$$

where

- P_{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 US. 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, defined 2 slides back. Per IEEE 802.11 spectrum mask requirement, R is at least 40 dB. Our spectrum analyser capture 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 using the Friis formula, using a path loss exponent of 2.0:

$$P(d)=20\log_{10}¿$$

And where d = distance in meters between UWB Rx and Wi-Fi transmitter and λ = Tx wavelength in meters = $c/6.5$ GHz.

How is a UWB receiver 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?

Solution: Path loss $P(10)$ between Wi-Fi transmitter and UWB receiver at distance 10 m is

$$P(10)=20\log_{10}\left(4\pi/(c/6.5\cdot10^{9})\right)+20\log_{10}(10)=48.7+20=68.7\,dB$$

Substituting $P(10)$into the above equation for $N_{0\,WiFi}$yields the following expression for the broadband noise level due to the Wi-Fi transmitter as seen by the UWB receiver:

$$N_{0\,WiFi}=14-10\log_{10}(33.3\,MHz)-R-P(10)=-130-R,(dBm/Hz)$$

If the Wi-Fi Tx OoB emission barely meets the IEEE 802.11 specs, then $R=40$ dB and $N_{0\,WiFi}=-175$ dBm/Hz.

The UWB receiver has a thermal noise floor of $N_0=-168$ dBm/Hz. The Wi-Fi OoB emission will add in RMS fashion to the thermal noise floor. Thus, the total noise floor is

$$N_{0Tot}=10\log_{10}\left[10^{\frac{-170}{10}}+10^{\frac{-168}{10}}\right]=-165.9\,dBm=-168+2.1\,dBm$$

Result: The Wi-Fi OoB emission coming from a 14 dBm Wi-Fi mobile device 10 m away will desensitize 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 characterize 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 93 below.

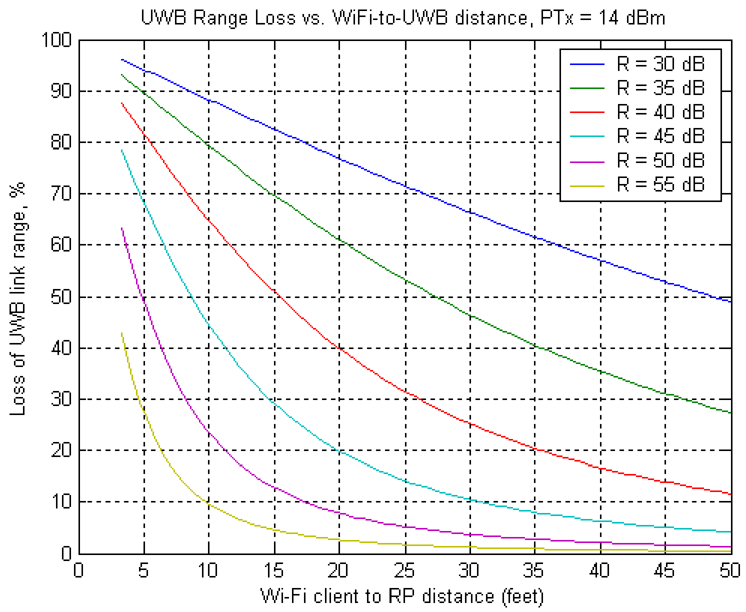


Figure 93: UWB range loss versus separation distance

Assuming 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 spec and
- in distance to at most 30 feet from a UWB receiver

Then the impact on UWB link range is less than 10%. Not particularly severe. Note that owners of co-deployed UWB and RLAN systems in professional settings control all three of these parameters for RLANs (e.g., e.i.r.p., channel selection and physical placement).

Looking back at how the analysis was performed, one can trade off PTx and R “dB for dB” to explore different scenarios, 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 30 feet.
- If Wi-Fi OoB emission is exactly 45 dB and Wi-Fi Tx power is increased to +24 dBm at 30 ft 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 $R\geq45$ dB attenuation it gets when Wi-Fi transmissions are kept out-of-band.

12.3.2 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, communicate 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 [78]. Passive keyless entry systems are described in System Reference Document ETSI TR 103 416 [79]. 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 showed the same -78 dBm total power coming from a single RLAN transmitter at the UWB receiver resulting in 3 dB sensitivity loss. Hence, the results from Table 65 are equally valid for location tracking systems.

12.3.3 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 [80] and ETSI TR 103 314 [81].

Table 66 lists the separation distances for the various proposed 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 RLAN transmitter at the UWB victim receiver.

Table 66: Separation distances resulting in 3 dB loss to UWB sensor systems from RLAN transmitter

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
Assumptions	
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 Table 65, a centre frequency of 6335 MHz for the RLAN system is used.

12.4 MONTE CARLO STUDIES FOR AGGREGATE INTERFERENCE

12.4.1 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 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 RLAN interferers are spread randomly throughout the building. Each person's 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 4.2 to give three resulting curves, corresponding to low, mid and high deployment.

RLAN power is randomly distributed according to weighted average RLAN e.i.r.p. from Section 4.1.1.4. The 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 wall penetration loss of 5 dB is used.

The results of the Monte Carlo simulations are shown in Figure 94 and Figure 95. Half a million iterations were run for every simulation.

Figure 94 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 95 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.

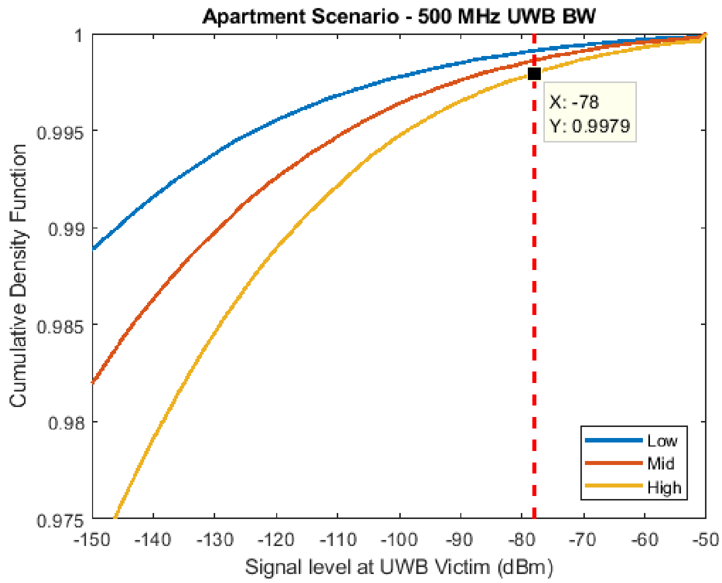


Figure 94: Monte Carlo results UWB apartment block scenario - 500 MHz UWB bandwidth

Table 67: Monte Carlo results UWB apartment block scenario - 500 MHz UWB bandwidth

Deployment Scenario	Probability of RLAN power > -65 dBm
Low	0.079%
Mid	0.13%
High	0.21%

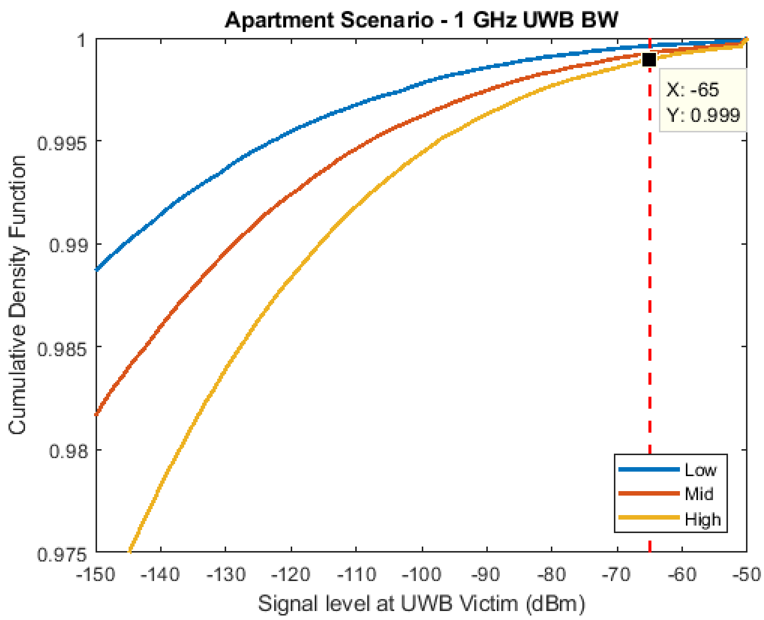


Figure 95: Monte Carlo results UWB apartment block scenario - 1 GHz UWB bandwidth

Table 68: Monte Carlo results UWB apartment block scenario - 1 GHz UWB bandwidth

Deployment Scenario	Probability of RLAN power > -65 dBm
Low	0.042%
Mid	0.067%
High	0.10%

12.4.2 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. 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 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 4.2 to give three resulting curves, corresponding to low, mid and high deployment.

RLAN power is randomly distributed according to weighted average RLAN e.i.r.p. from Section 4.1.1.4. The RLAN height distribution for sub-urban indoor homes from Section 4.2.2 is used to distribute the RLAN randomly in height. The RLAN bandwidth is chosen according to the distribution in Section 4.1.4. 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 ITU-R P.1411-9 is used in combination with building entry loss on both sites of the link, i.e. both the 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 96 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 1.7% probability that this value is exceeded. This result is very depended on the probability of having nearby RLAN transmitters. That can be seen from Figure 97, 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 3.3%.

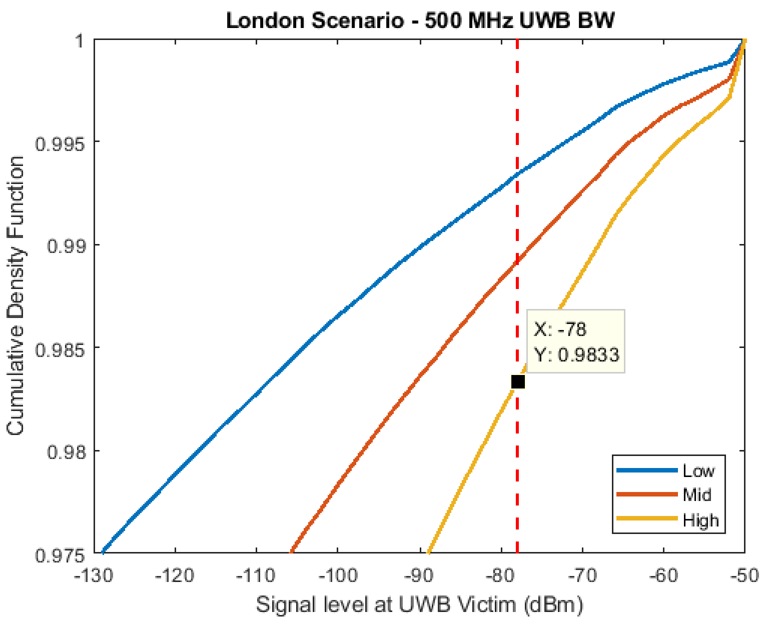


Figure 96: Monte Carlo results UWB London scenario - 500 MHz UWB bandwidth

Table 69: Monte Carlo results UWB London scenario - 500 MHz UWB bandwidth

Deployment Scenario	Probability of RLAN power > -78 dBm
Low	0.67%
Mid	1.0%
High	1.7%

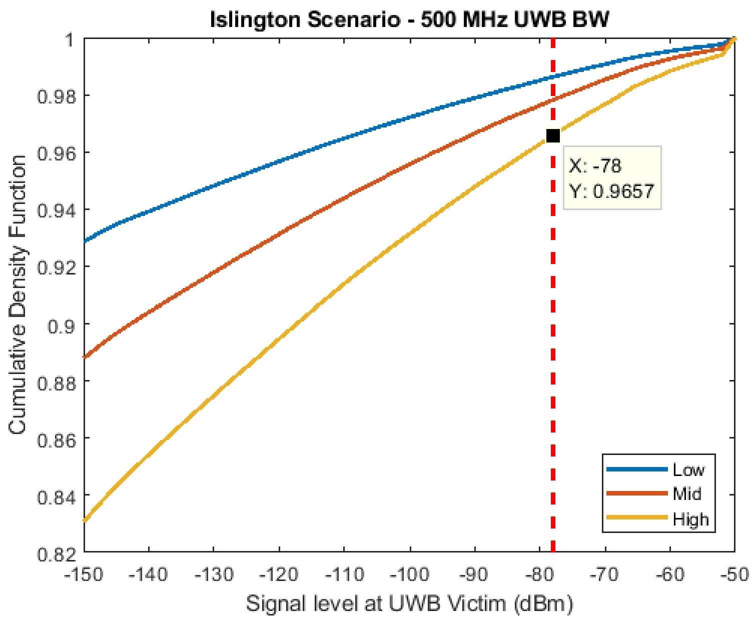


Figure 97: Monte Carlo results UWB Islington scenario - 500 MHz UWB bandwidth

Table 70: Monte Carlo results UWB Islington scenario - 500 MHz UWB bandwidth

Deployment Scenario	Probability of RLAN power > -78 dBm
Low	1.4%
Mid	2.2%
High	3.3%

The equivalent results for UWB system using 1 GHz bandwidth are shown in Figure 98 and Figure 99 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 0.8%. In the most densely populated borough of Islington, this probability doubles to 1.7% due to the increased chance of being closer to an RLAN transmitter.

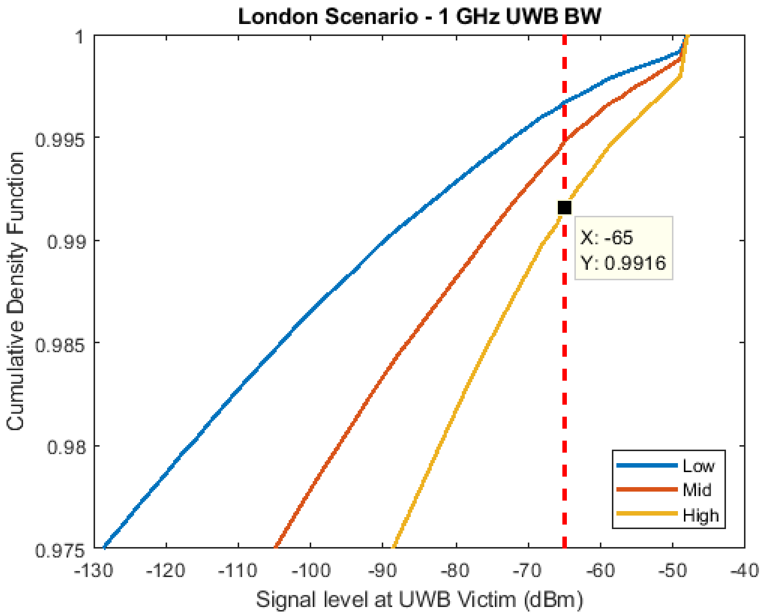


Figure 98: Monte Carlo results UWB London scenario - 1 GHz UWB bandwidth

Table 71: Monte Carlo results UWB London scenario - 1 GHz UWB bandwidth

Deployment Scenario	Probability of RLAN power > -65 dBm
Low	0.34%
Mid	0.54%
High	0.84%

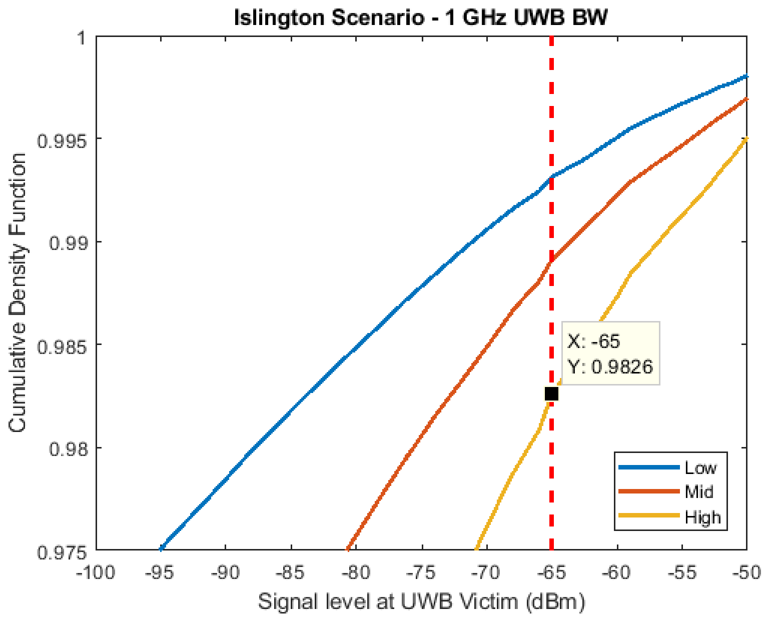


Figure 99: Monte Carlo results UWB Islington scenario - 1 GHz UWB bandwidth

Table 72: Monte Carlo results UWB Islington scenario - 1 GHz UWB bandwidth

Deployment Scenario	Probability of RLAN power > -65 dBm
Low	0.69%
Mid	1.1%
High	1.7%

12.4.3 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 12.4.1. The apartment block is assumed to be 100 m long, 16 m wide and 10 floors high. Each individual apartment is 10 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 RLAN interferers are spread randomly throughout the building. Each person's RLAN is active on average 1.97% of the time. Like before, a centre frequency of 6335 MHz for the RLAN system is used. RLAN power is randomly distributed according to weighted average RLAN e.i.r.p. from Section 4.1.1.4. This is combined with a license factor, busy hour factor, 6 GHz factor and market adoption factor as shown in Table 13 of Section 4.2 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 wall penetration 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 100, 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 100 shows that the probability that the sensitivity degradation is more than 3 dB is exceeded equals 0.01%.

Figure 100: Monte Carlo results UWB vehicular access scenario

Table 73: Monte Carlo results UWB vehicular access scenario

Deployment Scenario	Probability of RLAN power > -65 dBm
Low	0.0024%
Mid	0.003%
High	0.0048%

12.5 SUMMARY

Single interference scenario, minimum coupling loss study has shown that 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 RLAN duty cycle 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%[8].

[8] For simplicity, the Monte Carlo study assumes a constant duty cycle RLAN aggressor interfering with a constant duty cycle UWB receiver. It does not consider the probability of coincidence of real-world RLAN and UWB transmissions.

13 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 4 and 5 of the Report. The Report covers sharing and compatibility scenarios based on models of 2025 deployments.

Section 6 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 7-12 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. Further, note that for some of these inter-service sharing and compatibility problems, there have been no studies done and for others only very basic investigations have been performed, which do not identify the risk of interference as required in the EC Mandate on 6 GHz. However, the studies addressing the WAS/RLAN vs FS and WAS/RLAN vs FSS sharing problems, are fully developed allowing for conclusions to be drawn with regard to the feasibility of spectrum sharing.

13.1 SHARING BETWEEN RLAN AND FS

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

In the first study (A), two different types of areas have been shown in the MCL analysis where a single 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 based on the FS antenna pattern (here: ITU-R Recommendation F.699).

Sensitivity analyses have taken into account different RLAN e.i.r.p. density levels, indoor and outdoor deployments, population density types, FS and RLAN antenna heights, FS antenna gains and building types.

For the long term protection criterion $I/N=-10$ dB the range of required separation distances has been calculated:

- Circle distances are found to be varying from 400 m to 4017 m, peak distances are found to be varying from 48 m to 40400 m.

For the long term protection criterion $I/N=-20$ dB the range of required separation distances has been calculated:

- Circle distances are found to be varying from 1000 m to 4017 m, peak distances are found to be varying from 103 m to 47100 m.

Sensitivity analyses showed that reduction of power density level or indoor use are examples of measures reducing separation distances.

MCL calculations have revealed critical scenarios, but do not allow to conclude about the likelihood of these scenarios. Therefore, a statistical approach based on Monte Carlo studies is required.

A second study (B) analysed population of fixed links in 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 FDP < 10%, which is a complementary short term protection criterion, was exceeded in the UK due to highly improbable, even non-realisable, interference events that can occur in the Monte Carlo simulations. If only indoor deployment with a maximum e.i.r.p. of 200 mW is considered, it was shown that all but 2 cases of FDP exceedances were resolved. Under those conditions sharing is considered 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 an RLAN (indoor 250 mW and outdoor 1 W) would exceed the interference threshold of $I/N = -10$ dB. It indicated that allowing outdoor 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. Then a complementary statistical study based on a Monte Carlo approach, using the 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 for the long term protection criterion.

13.2 SHARING BETWEEN 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 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.

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

Two studies were conducted to assess aggregate interference from RLAN into FSS receivers in space, assuming RLAN deployment models in Europe by 2025. Study A employs a Monte Carlo methodology involving stochastic inputs to the 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.

Studies show that the calculated levels of interference are highly sensitive to some RLAN parameters and assumptions in the study, for example but not limited to the duty cycle of high activity RLAN devices.

Study A considers the Mid scenario for a representative set of FSS satellites. The results show that the protection criterion of $I/N = -10.5$ 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 RLAN systems, with no constraints on RLAN deployment or operations.

Study B considers a representative set of existing FSS satellites (as well as a potential future satellite) and the RLAN deployment model in Europe by 2025 in accordance with the Low, Mid and High scenarios. FSS protection criterion was satisfied in all cases for the baseline scenarios noting that the calculated levels of interference are close to the FSS protection criteria (i.e. -13.5 dB, including 3 dB service apportionment), with the smallest margin equal to 0.5 dB for the High scenario.

If the aggregate interference levels from RLAN deployments increase beyond those modelled for 2025, then the levels of interference from RLANs may result in an exceedance of the FSS protection criteria.

A sensitivity analysis on the distribution of Indoor and Outdoor RLAN devices with “95% Indoor & 5% Outdoor” is provided, in which case the protection criteria was exceeded in two cases for the High scenario.

Considering the need to address protection of FSS space receivers in long term (beyond 2025) from aggregate interference from RLANs, coexistence conditions, such as limiting RLAN use to indoor, introducing e.i.r.p. limits, etc. could be applied.

13.3 COMPATIBILITY BETWEEN RLAN AND ROAD-ITS

One adjacent-band coexistence study was conducted to assess the impact of RLAN OoB emission on Road-ITS below 5925 MHz, considering a protection criterion of -6 dB I/N. RLAN deployment scenarios of indoor, outdoor (fixed AP and portable device) and in-car were studied. The results of this co-existence study show that, depending on the scenario, the RLAN OoB emissions below 5925 MHz should meet a limit between -69dBm/MHz and -36dBm/MHz for the main-lobe case and between -59dBm/MHz and -26dBm/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 installed outside the car most of the time. The indoor usage scenario results in the least stringent requirement for RLAN OoB emissions below 5925 MHz.

13.4 SHARING AND COMPATIBILITY BETWEEN RLAN AND CBTC

A first study assesses the adjacent band coexistence between RLAN and CBTC below 5 935 MHz, both 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 RLAN OoB and In-band emissions.

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

When comparing the results achieved assuming RLAN operation starting at 5940 MHz and 5935 MHz, it is found that the RLAN operation above 5940 MHz is less restrictive for the RLAN emissions. In that case, an in-band e.i.r.p. of $21.5\,dBm/20\,MHz$ for indoor RLAN usage in adjacent channels 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 RLAN emission of $-42\,dBm/5\,MHz$ and an e.i.r.p. density of $4.7\,dBm/20\,MHz$ (RLAN first channel starting at 5940 MHz) are sufficient to ensure the CBTC operation.

Another study investigated the impact of RLAN devices coexisting in the same frequency band as the Copenhagen S-train CBTC system. The results present the required minimum distance between the RLAN device and CBTC receiver to avoid the interference from the RLAN device. This distance ranges from the 180 to 600 m. If S-train and RLAN share the same frequency band eventually, it will not be feasible to reasonably assume that no RLAN devices will be present within these distances. Dedicated mitigations techniques, to be locally applied, may need to be defined.

13.5 COMPATIBILITY BETWEEN RLAN AND RADIO ASTRONOMY

The number of RAS sites in Europe observing in this frequency range is small, possibly around 16. The local environment of each site is very well understood. Management of compatibility between RLAN and those sites could be addressed on a case by case basis at national level.

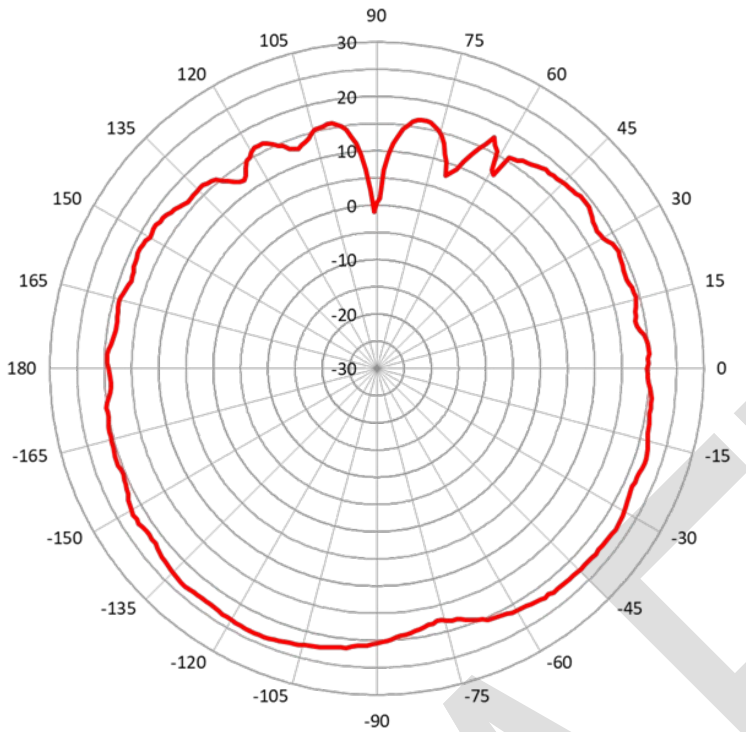
An I/N threshold can be used to derive a contour around the RAS site following applicable ITU-R Recommendations and taking into account the details of the site and possibly the typical observation schedule. The contours, which can be considered as a coordination zone or exclusion zone, represent a zone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

13.6 COEXISTENCE BETWEEN RLAN AND ULTRA WIDE BAND (UWB) SYSTEMS

UWB is designated as an underlay technology which cannot claim protection from interference nor cause interference to other services. 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 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, respectively.

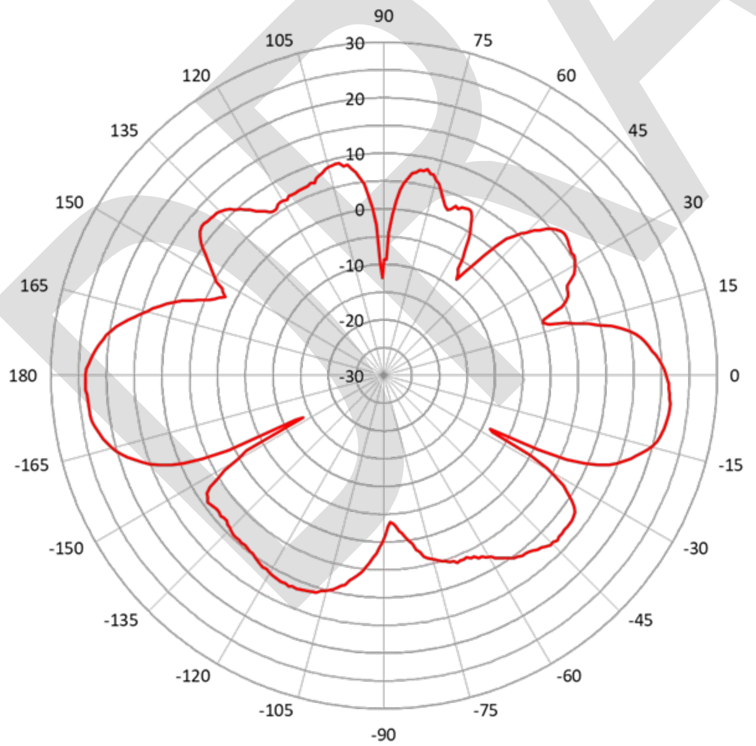
Aggregate interference evaluations with Monte Carlo simulations show that when taking the RLAN duty cycle into account, the probability that the sensitivity reduction to UWB communications and location tracking devices exceeds 3 dB ranges from 0.0024% to 3.3% depending on the scenario considered. For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

ANNEX 1: E-PLANE ANTENNA PATTERNS FOR WAS/RLAN ACESS POINTS



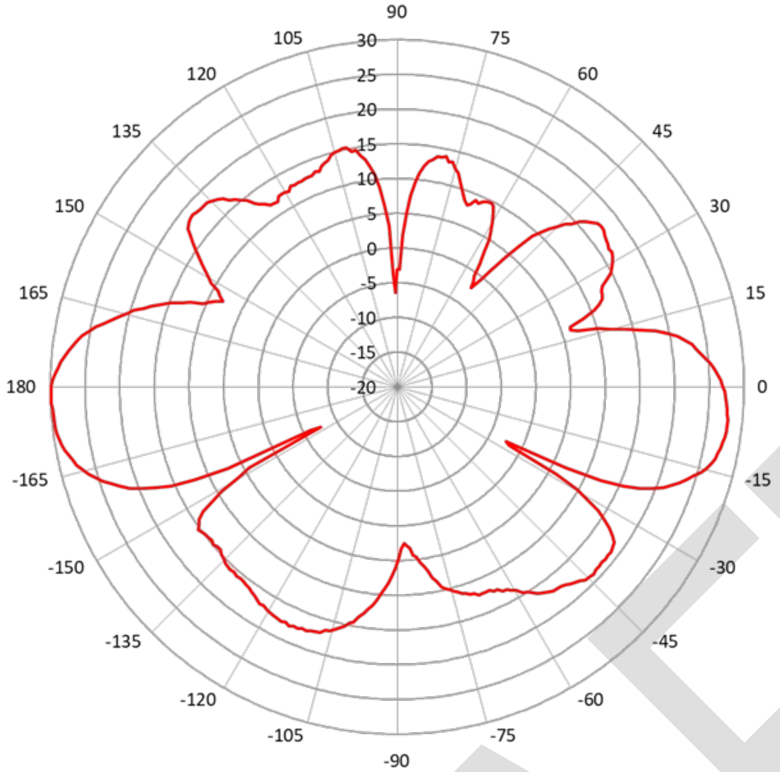
EIRP Probability based on E-Plane Directivity	
Indoor Enterprise AP	
>250 mW (24 dBm) and ≤ 1W (30 dBm)	0.00%
>100 mW (20 dBm) and ≤ 250 mW (24 dBm)	40.17%
>50 mW (17 dBm) and ≤ 100 mW (20 dBm)	34.07%
>13 mW (11 dBm) and ≤ 50 mW (17 dBm)	22.16%
>1 mW (0 dBm) and ≤ 13 mW (11 dBm)	3.32%
<1 mW (0 dBm)	0.28%
Total	100.00%

Figure 101: e.i.r.p. probability based on E-plane directivity for indoor enterprise AP



EIRP Probability based on E-Plane Directivity	
Indoor Consumer AP	
>250 mW (24 dBm) and ≤ 1W (30 dBm)	0.00%
>100 mW (20 dBm) and ≤ 250 mW (24 dBm)	11.91%
>50 mW (17 dBm) and ≤ 100 mW (20 dBm)	4.16%
>13 mW (11 dBm) and ≤ 50 mW (17 dBm)	16.90%
>1 mW (0 dBm) and ≤ 13 mW (11 dBm)	58.73%
<1 mW (0 dBm)	8.31%
Total	100.00%

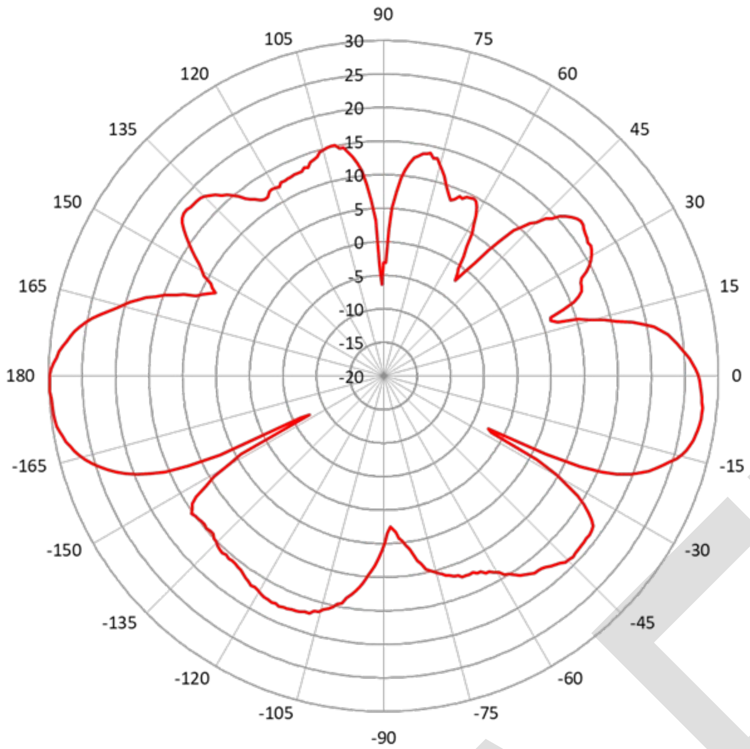
Figure 102: e.i.r.p. probability based on E-plane directivity for indoor consumer AP



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%

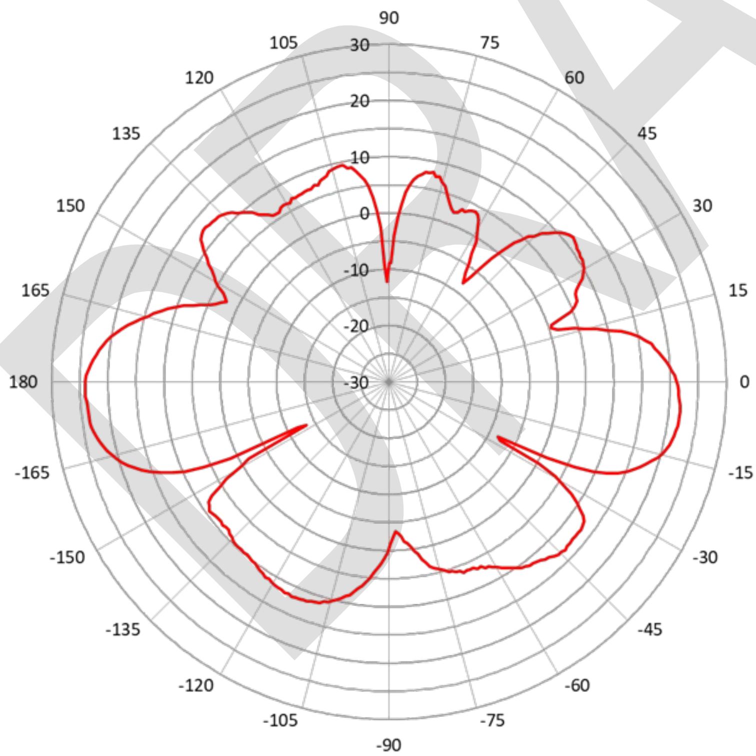
Figure 103: e.i.r.p. probability based on E-plane directivity for indoor high performance gaming router

Figure 104: e.i.r.p. probability based on E-plane directivity for indoor/outdoor client



EIRP Probability based on E-Plane Directivity	
Outdoor High Power AP	
>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)	15.24%
>13 mW (11 dBm) and ≤ 50 mW (17 dBm)	41.83%
>1 mW (0 dBm) and ≤ 13 mW (11 dBm)	20.50%
<1 mW (0 dBm)	3.32%
Total	100.00%

Figure 105: e.i.r.p. probability based on E-plane directivity for outdoor high power AP



EIRP Probability based on E-Plane Directivity	
Outdoor Low Power AP	
>250 mW (24 dBm) and ≤ 1W (30 dBm)	0.83%
>100 mW (20 dBm) and ≤ 250 mW (24 dBm)	11.36%
>50 mW (17 dBm) and ≤ 100 mW (20 dBm)	4.43%
>13 mW (11 dBm) and ≤ 50 mW (17 dBm)	19.11%
>1 mW (0 dBm) and ≤ 13 mW (11 dBm)	56.23%
<1 mW (0 dBm)	8.03%
Total	100.00%

Figure 106: 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 RLAN case can be depicted as follows (assuming an example of 10000 RLAN in the 6 GHz band considered in this Report, i.e. 5925 MHz to 6425 MHz:

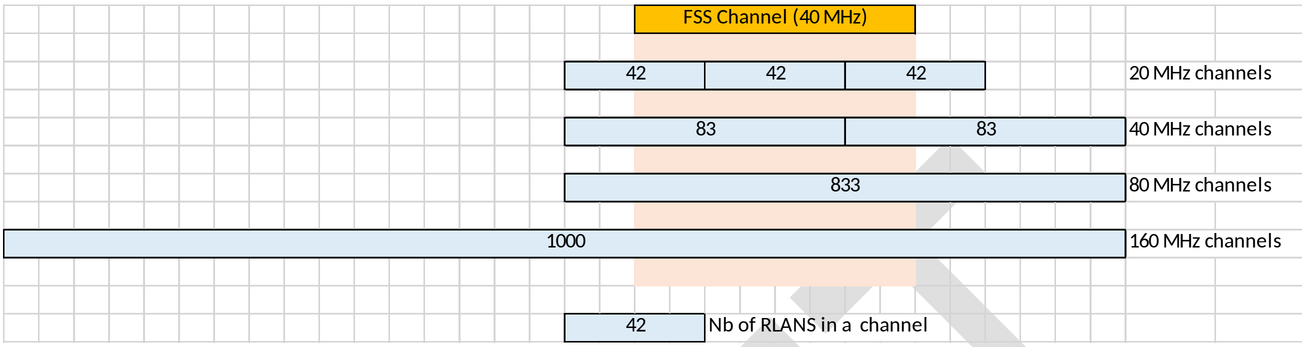


Figure 107: RLAN channels incident to a 40 MHz FSS receiver bandwidth

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 74.

Table 74 : Number of RLAN APs for different RLAN channels

RLAN Channels	# of channels	Percentage of RLAN	# of RLAN per bandwidth	# of 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
# of RLAN in the 6 GHz range				10000

The situation, therefore, represents a total of (3 x 42 + 2 x 83 + 1 x 883 + 1 x 1000) = 2125 RLAN overlapping the FSS channel.

There are 2 options to handle such situation and consider the effective aggregate e.i.r.p. produced by 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 RLAN within each channel

Option 2: to normalise the number of RLAN in each channel as an equivalent number of RLAN fully within the FSS channel

A2.1 OPTION 1

Step by step ach of the 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 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 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 RLAN with a bandwidth factor of 0.5 (linear).

In summary, this is, therefore, equivalent to having 126 RLAN using 20 MHz channels with an average bandwidth factor of ((0.5 x 42 + 1 x 42 + 0.5 x 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 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 RLAN with a bandwidth factor of 0.25 (linear).

In summary, this is, therefore, equivalent to having 166 RLAN that use 40 MHz channels with an average bandwidth factor of ((0.75 x 83 + 0.25 x 83)/166) = 0.5.

A2.1.3 For 80 MHz channel:

The 80 MHz channel overlaps 1/2 the FSS channel. Therefore, 833 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 RLAN with a bandwidth factor of 0.25 (linear).

Assuming the 80 mW (19 dBm) average e.i.r.p. per 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 75 : Option 1. Calculation of the aggregated e.i.r.p.

RLAN Channels	Average e.i.r.p. (mW)	Number of 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 - 10log(2125))=14.97 dBm per 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 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 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 RLAN fully in the FSS channel.

The second 20 MHz channel overlaps fully the FSS channel. This is, therefore, equivalent to having 42 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 RLAN fully in the FSS channel.

In summary, this is equivalent to (21 + 42 + 21) = 84 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 83x3/4 = 62.25 RLAN fully in the FSS channel.

The second 40 MHz channel overlaps 1/4 the FSS channel. This is, therefore, equivalent to having 83x1/4 = 30.75 RLAN fully in the FSS channel.

In summary, this is equivalent to (62.25 + 20.75) = 83 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 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 RLAN transmitting fully in the FSS channel.

Assuming the 80 mW (19 dBm) average e.i.r.p. per 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 76: Option 2. Calculation of the aggregated e.i.r.p.

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 RLAN in the FSS band with an average e.i.r.p. of 19 dBm.

A2.3 CONCLUSION

Both options handle the RLAN vs FSS from 2 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 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 4.2 of this Report.

A3.1 TOTAL POPULATION OF EUROPE 2025

Table 77 gives the human populations of CEPT Member countries in 2025. The population of the 48 CEPT Member Countries is expected to be 768 589 000 in 2025. This list excludes populations in Azerbaijan, Georgia and regions of the Russian Federation beyond the Moscow Time Zone shown in Figure 108.

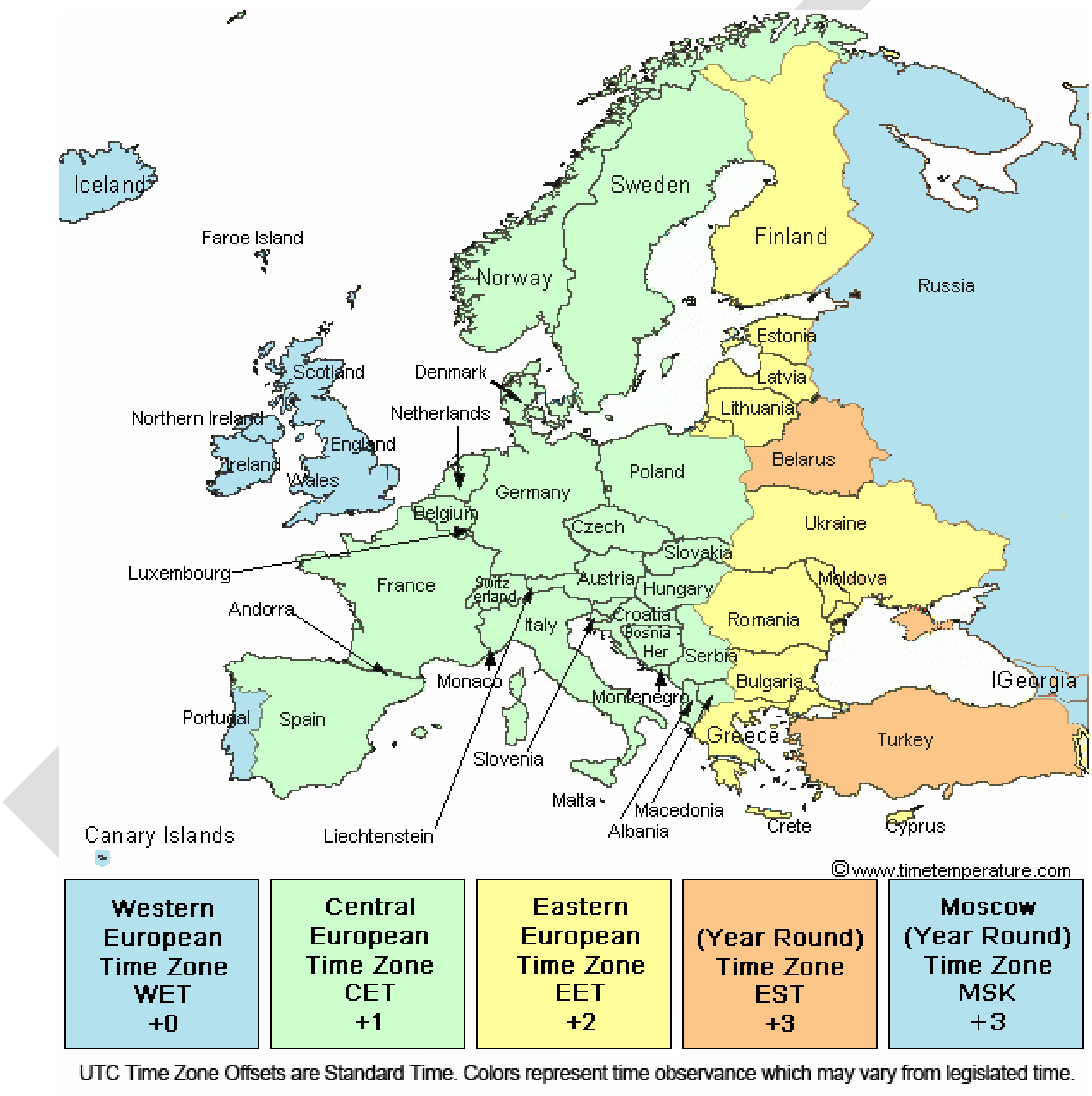


Figure 108: Time zone map

Table 77: The human populations (millions) of CEPT Member countries in 2025

Geo/Time	2025
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

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
The Former Yugoslav Republic of Macedonia	2 088
The Netherlands	17 414
Turkey	86 125
Ukraine	42 453
United Kingdom	69 074
Vatican	1

A3.2 SPATIAL DISTRIBUTION OF RLANS

To characterize the spatial characteristics of RLAN interference into other services such as FS, it is necessary to estimate the spatial distribution of 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 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 synthesize 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 109 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.

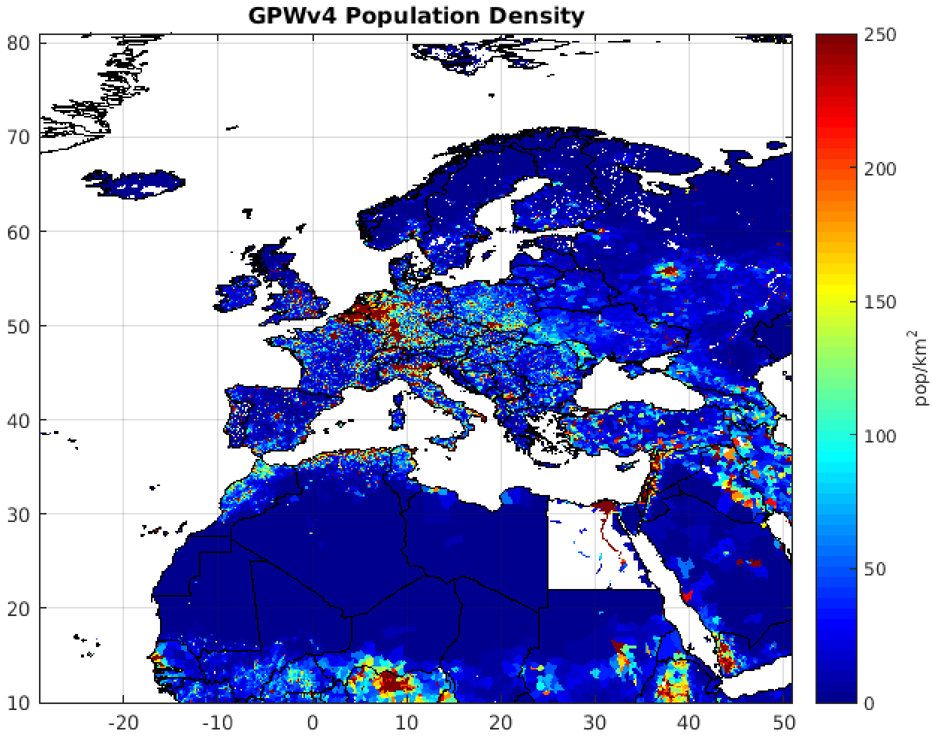


Figure 109: European population d map projected for 2020 (GPWv4 dataset)

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 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 duty cycle measurements for streaming video provided in ANNEX 6:. 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 found that the demand for high activity mode devices operating in a residence is going to be much higher than other use-cases. 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.[9] 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

[9] 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

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)[10].

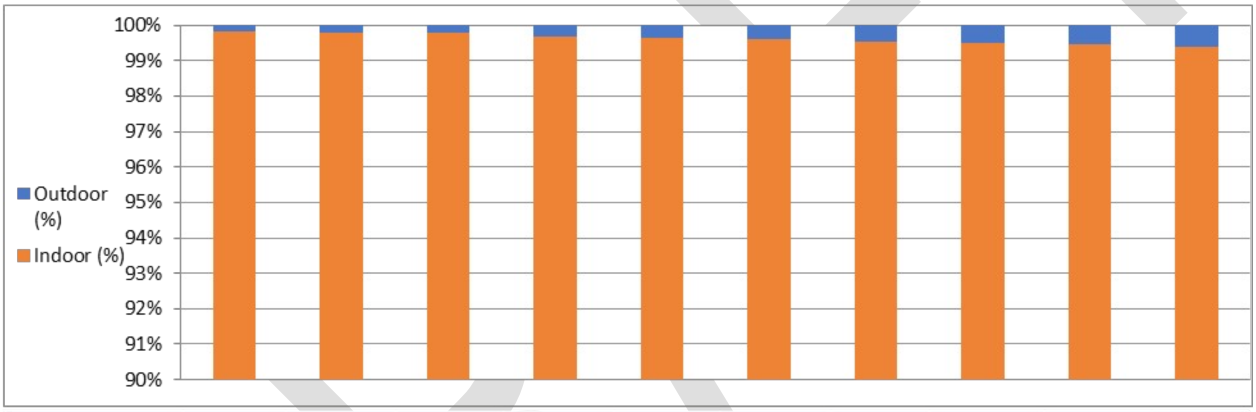
For public hotspot use, streaming video is an expected use case but it is more intermittent with average session length being shorter than the corporate and residential use-cases. Web browsing and other lower data rate activities are expected to consume activity time. It was assumed that 500 Mbytes/hour (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 110 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.



Deployment Type	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Indoor APs	99,750.2	112,676.0	123,414.7	122,463.5	140,000.1	147,825.7	159,546.9	171,540.1	182,602.2	189,331.7
Outdoor APs	171.7	229.3	245.5	375	477.1	609	726.8	860.4	1,002.8	1,152.1
Total	99,921.9	112,905.3	123,660.2	122,838.5	140,477.2	148,434.7	160,273.7	172,400.5	183,605.0	190,483.8

Figure 110: Worldwide indoor vs outdoor Wi-Fi shipments. Source Dell'Oro Group July 2017 Wireless LAN report (thousands)

Table 78 depicts a small cell forecast of 3GPP based technologies, such as License Assisted Access (LAA), of 1.5 million outdoor units in 2021.[11]

[10] 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 that we are forecasting for residential.

[11] 5G Americas and Small Cell Forum, Multi-operator and Neutral Host Small Cells: Drivers, Architectures, Planning and Regulation, Dec. 2016, http://www.5gamericas.org/files/4914/8193/1104/SCF191_Multi-operator_neutral_host_small_cells.pdf.

Table 78: 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 conservative ratio for indoor/outdoor RLANs of 98% indoor and 2% outdoor.

ANNEX 4: SELECTION OF PROPAGATION MODELS FOR MCL 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 [58] in Table 4-7 describes the probability for Line-of-Sight (LOS) situations. These formulas are given in Figure 111 and the probabilities have been plotted below in Figure 112 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 non-Line-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.

Scenario	LOS probability as a function of distance d [m]	Note
A1	$P_{LOS} = \begin{cases} 1 & ,d \le 2.5 \\ 1 - 0.9\left(1 - \left(1.24 - 0.61\log_{10}(d)\right)^3\right)^{1/3} & ,d > 2.5 \end{cases}$	
B1	$P_{LOS} = \min(18/d,1)\cdot\left(1 - \exp(-d/36)\right) + \exp(-d/36)$	
B3	$P_{LOS} = \begin{cases} 1 & ,d \le 10 \\ \exp\left(-\frac{d-10}{45}\right) & ,d > 10 \end{cases}$	For big factory halls, airport and train stations.
C1	$P_{LOS} = \exp\left(-\frac{d}{200}\right)$	
C2	$P_{LOS} = \min(18/d,1)\cdot\left(1 - \exp(-d/63)\right) + \exp(-d/63)$	
D1	$P_{LOS} = \exp\left(-\frac{d}{1000}\right)$	

Figure 111: Formulas for LOS probabilities

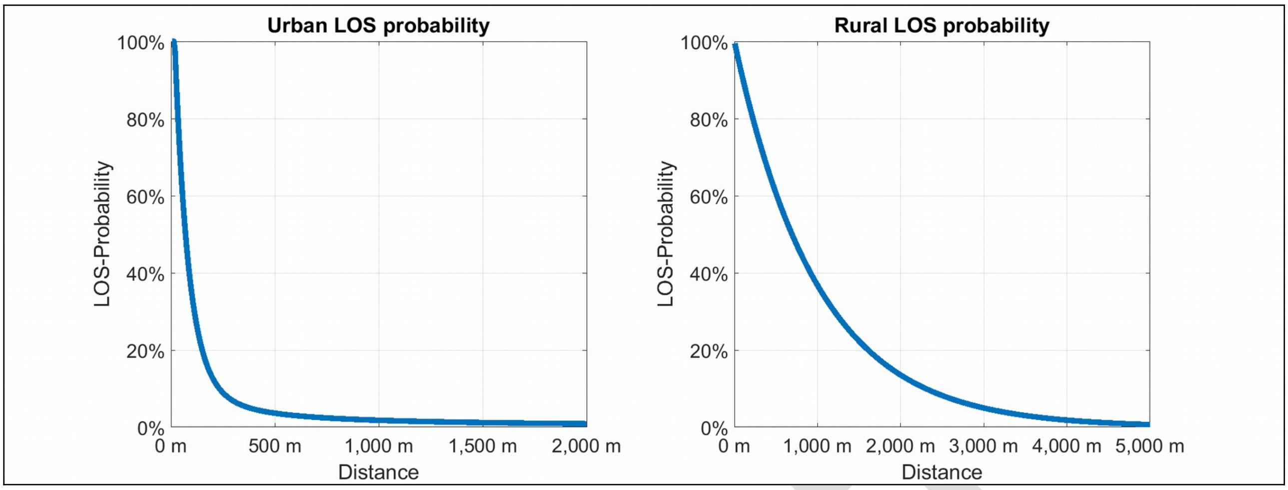


Figure 112: LOS probabilities for urban and rural scenarios

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 113.

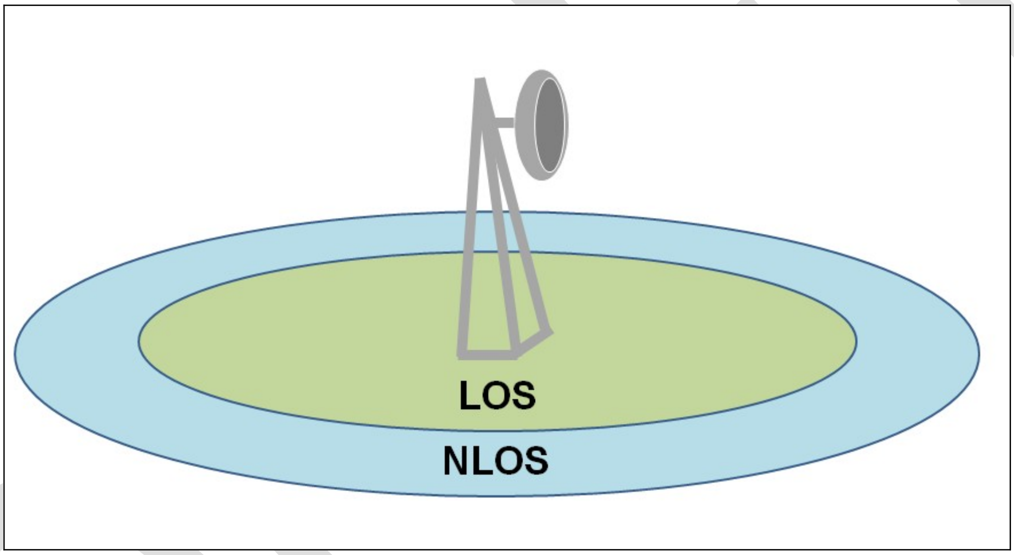


Figure 113: Illustration of LOS and NLOS areas

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 114) 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 M - 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 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 114.

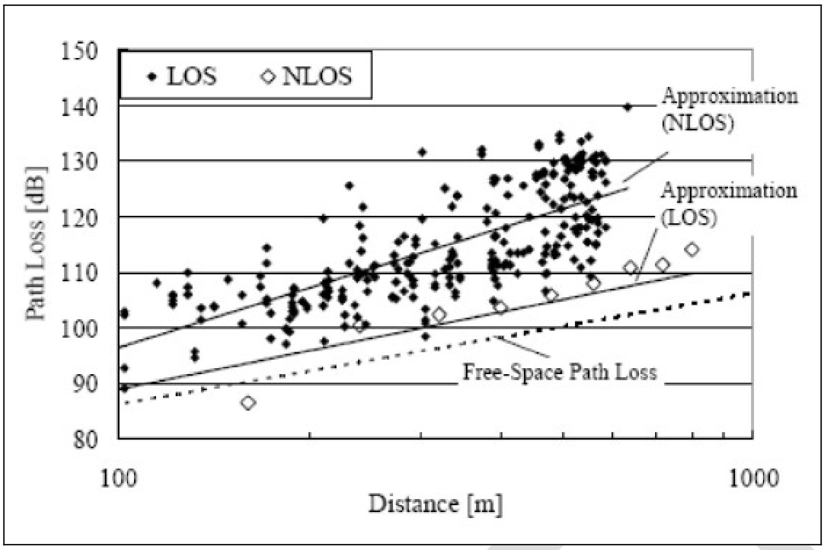


Figure 114: Measurements from WINNER II deliverable @4.95 GHz

It should be noted that in the legend of Figure 114 the markers for LOS and NLOS are swapped. In the plot itself the description is correct.

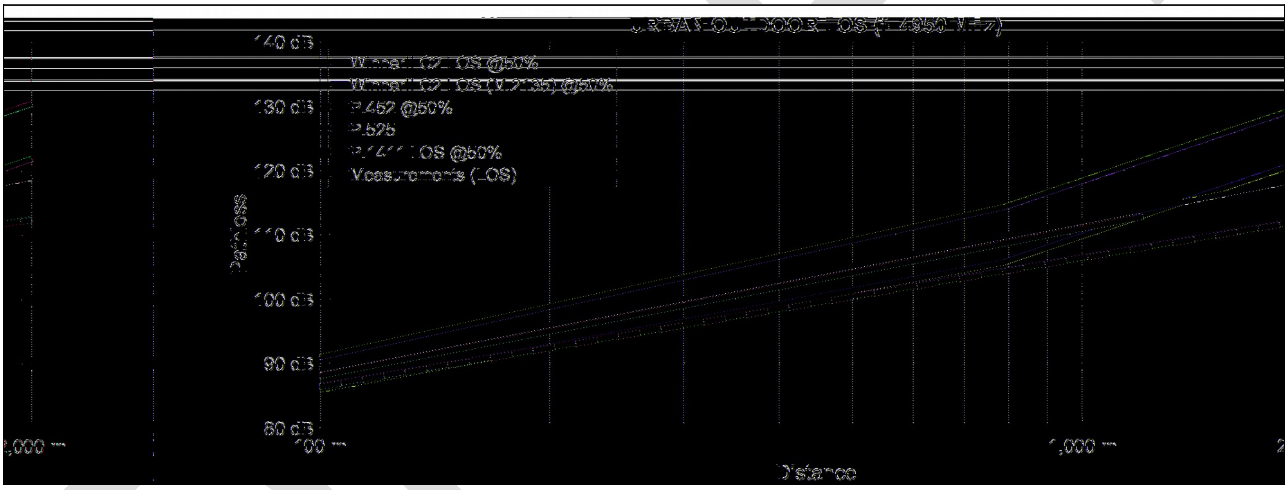


Figure 115: Comparison of propagation models

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 P.1411 (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 P.1411 (green line) estimate the measured values very good.

The same comparison for shorter distances is shown in Figure 116.

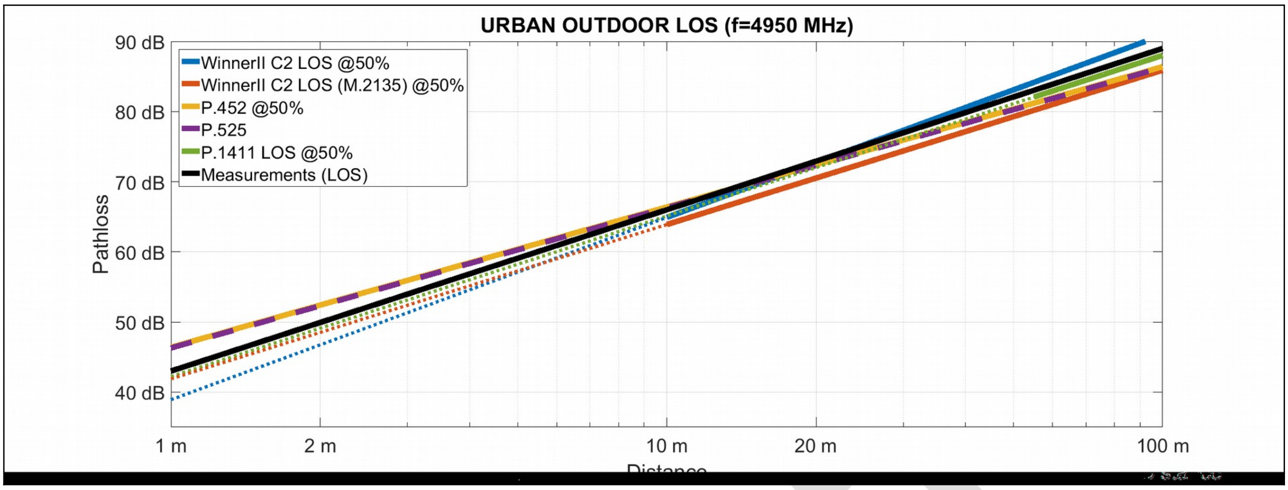


Figure 116: Comparison of propagation models

It should be noted that only for the free space loss model 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 P.452.

It can be seen that for short distances model 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 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 114 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 P.452 combined with P.2108 for clutter losses. If there is no description for NLOS conditions in a propagation model (e.g. P.525) P.2108 will also be used to generate additional clutter losses.

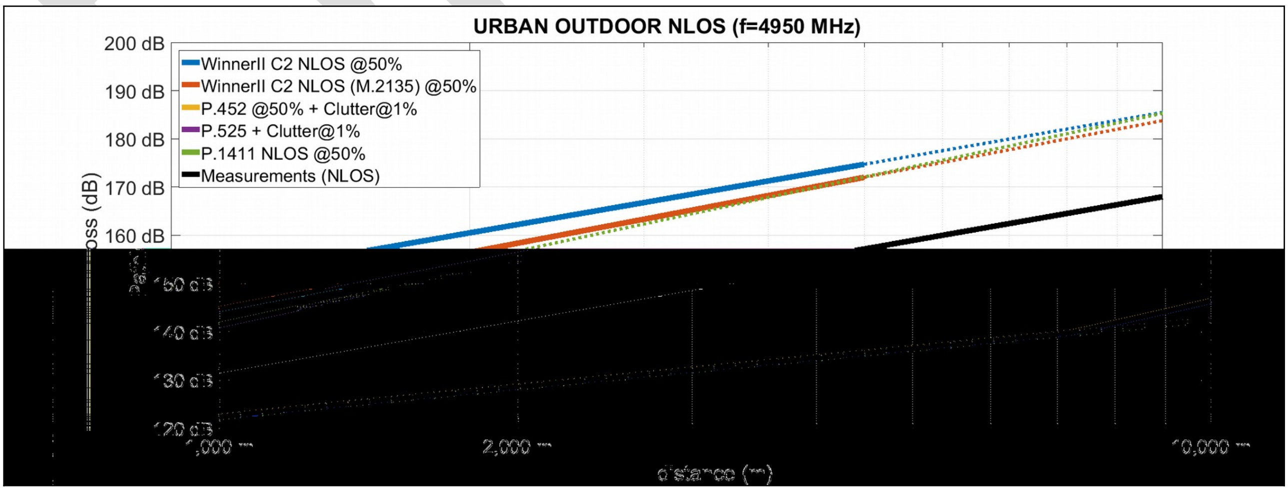


Figure 117: Comparison of propagation models @1% Clutter Loss percentage

Figure 118: Comparison of propagation models @50% Clutter Loss percentage.

It should be noted that model P.1411 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 P.452 in combination with clutter loss model P.2108 at a percentage of 50% describes values comparable to the measurements shown in Figure 114. The WINNER II models will overestimate the losses up to 20 dB. Model 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 P.1411. The WINNER II models do not show this behaviour.

Therefore, model P.452 combined with P.2108 at a percentage of 50% for clutter loss will be used for urban NLOS scenarios.

A4.4 PROPAGATION MODEL: RURAL LOS (0 M-4017 M)

For rural scenarios 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.

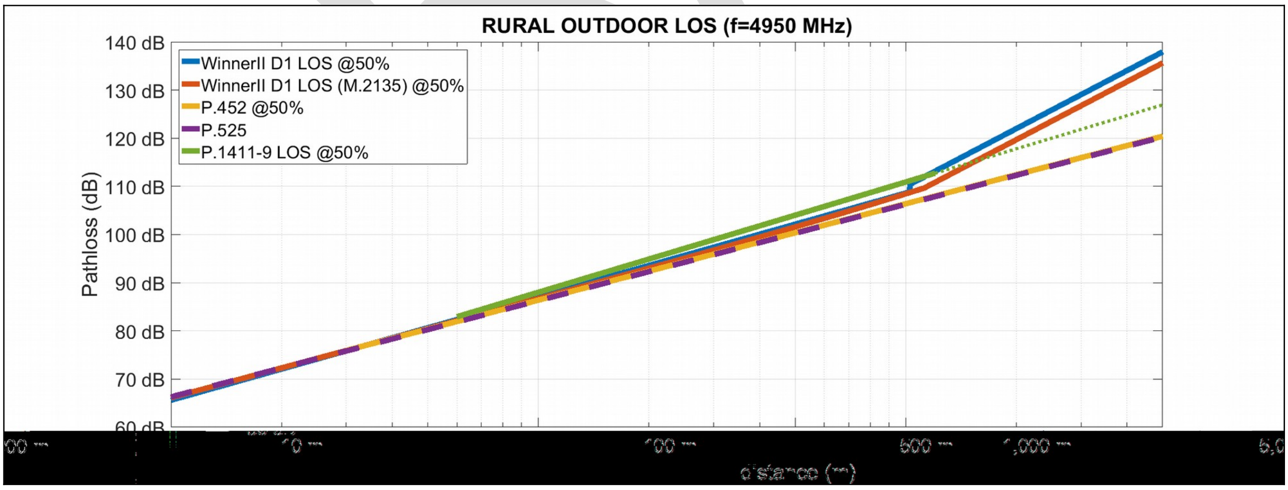


Figure 119: Comparison of propagation models

According to Figure 119, the WINNER II models generate higher losses at about 1200 m than P.1411. The results will very much depend on the antenna heights. WINNER II models are just valid for antenna heights of 32 m. Therefore, model P.452 will be used for rural LOS scenarios.

A4.5 PROPAGATION MODEL: RURAL NLOS (>4017M)

Figure 120: Comparison of propagation models

For distances greater than 5 km, neither 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 P.452 combined with its clutter implementation (e.g. $h_a = 5$ m, $d_k = 0.07$ km for rural village center) will be used for rural NLOS scenarios, although the WINNER II models would generate smaller losses than model P.1411.

A4.6 CONCLUSION ON PROPAGATION MODELS

Table 79: Urban propagation model

Distance	Propagation Model	Clutter	Building entry (applied in main study)
$0\,m \leq d < 1000\,m$ (LOS)	Recommendation ITU-R P.1411-9 (p=50%)		Recommendation ITU-R P.2109-0
$d \geq 1000\,m$(NLOS)	Recommendation ITU-R P.452-16 (p=50%)	Recommendation ITU-R P.2108-0 (p=50%)	Recommendation ITU-R P.2109-0

Figure 121: Proposed urban propagation model (outdoor)

For the proposed model under urban conditions as depicted in Figure 121, the assumed heights used by 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 80: Rural propagation model

Parameter	Propagation model	Clutter	Building entry (applied in main study)
$0\,m \le d < 4017\,m$ (LOS)	Recommendation ITU-R P.452-16		Recommendation ITU-R P.2109-0
$d \ge 4017\,m$ (NLOS)	Recommendation ITU-R P.452-16	Recommendation ITU-R P.452-16 (e.g. $h_a = 5\,m$, $d_k = 0.07\,km$ for rural village center)	Recommendation ITU-R P.2109-0

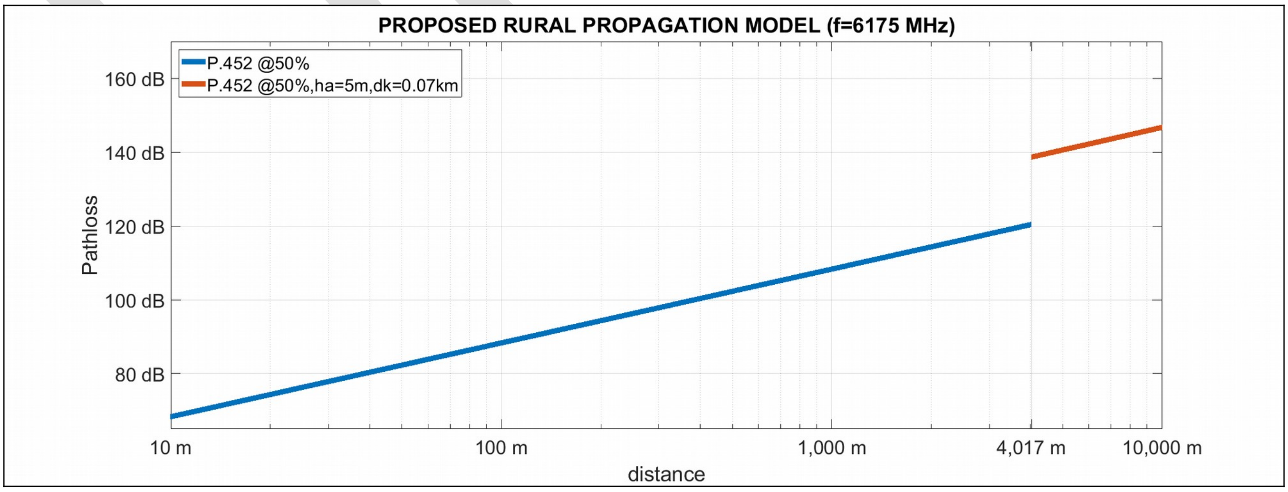


Figure 122: Proposed rural propagation model (outdoor)

It is obvious that the behaviour of the proposed rural propagation model as depicted in Figure 122 is not continuous. This sudden increase occurs because of the discrete change from LOS to NLOS conditions as described in Section 7.2.2. For the single interferer analysis this behaviour is not relevant since the targeted separation distances are less than 4017 m.

ANNEX 5: INTERFERENCE CALCULATIONS FOR STUDY C BETWEEN RLAN AND FSS

A5.1 PART 1: BANDWIDTH CORRECTION FACTOR

Table 81: Number of RLAN devices overlapping in the 40 MHz receiver - derivation

No. of channels overlapping with 40 MHz FSS	RLAN channels	No. of channels	% of RLAN	No. of RLAN per bandwidth	No. of 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 RLAN overlapping in the 40 MHz FSS receiver bandwidth

Application of the bandwidth correction factor leads to 21.2 % of RLAN devices overlapping in the 40 MHz FSS receiver, with an average e.i.r.p. level reduced by 3.55 dB.

A5.2 PART 2: RESULTS OF INTERFERENCE CALCULATIONS

Table 82: SES 50.5E - Results for scenario for indoor & outdoor (98% indoor & 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 RLAN in 40 MHz receiver (bandwidth factor 21.2%)	173 950	279 211	436 268
Aggregate e.i.r.p. (mainbeam) (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
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
ΔT/T (%)	0.2	0.4	0.6
I/N (dB)	-26.1	-24.0	-22.1
I/N criteria for interference from all co-primary services	-10.5 dB		
Apportionment between FS and RLAN	3		
I/N criteria for interference from RLAN	-13.5 dB		

Table 83: SES 50.5E - Results for scenario for indoor & outdoor (98% indoor & 2% outdoor) (Building Entry Loss 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 RLAN in 40 MHz receiver (bandwidth factor 21.2%)	173 950	279 211	436 268
Aggregate e.i.r.p. (mainbeam) (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
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
ΔT/T (%)	0.4	0.6	0.9
I/N (dB)	-24.5	-22.4	-20.5
I/N criteria for interference from all co-primary services	-10.5 dB		
Apportionment between FS and RLAN	3		
I/N criteria for interference from RLAN	-13.5 dB		

Table 84: SES 20W - Results for scenario for indoor & outdoor (98% indoor & 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 RLAN in 40 MHz receiver (bandwidth factor 21.2%)	173 950	279 211	436 268
Aggregate e.i.r.p. (mainbeam) (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
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
ΔT/T (%)	0.4	0.7	1.1
I/N (dB)	-23.6	-21.5	-19.6
I/N criteria for interference from all co-primary services	-10.5 dB		
Apportionment between FS and RLAN	3		
I/N criteria for interference from RLAN	-13.5 dB		

Table 85: SES 20W - Results for scenario for indoor & outdoor (98% indoor & 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 RLAN in 40 MHz receiver (bandwidth factor 21.2%)	173 950	279 211	436 268
Aggregate e.i.r.p. (mainbeam) (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
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
ΔT/T (%)	0.6	1.0	1.6
I/N (dB)	-22.0	-20.0	-18.0
I/N criteria for interference from all co-primary services	-10.5 dB		
Apportionment between FS and RLAN	3		
I/N criteria for interference from RLAN	-13.5 dB		

Table 86: INT 60E - Results for scenario for indoor & outdoor (98% indoor & 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 RLAN in 40 MHz receiver (bandwidth factor 21.2%)	173 950	279 211	436 268
Aggregate e.i.r.p. (mainbeam) (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
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
ΔT/T (%)	0.8	1.3	2.0
I/N (dB)	-21.0	-19.0	-17.0
I/N criteria for interference from all co-primary services	-10.5 dB		
Apportionment between FS and RLAN	3		
I/N criteria for interference from RLAN	-13.5 dB		

Table 87: INT 60E - Results for scenario for indoor & outdoor (98% indoor & 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 RLAN in 40 MHz receiver (bandwidth factor 21.2%)	173 950	279 211	436 268
Aggregate e.i.r.p. (mainbeam) (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
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
ΔT/T (%)	1.1	1.8	2.8
I/N (dB)	-19.5	-17.4	-15.5
I/N criteria for interference from all co-primary services	-10.5 dB		
Apportionment between FS and RLAN	3		
I/N criteria for interference from RLAN	-13.5 dB		

Table 88: Satellite similar to INT 60E positioned at 5E - Results for scenario for indoor & outdoor (98% indoor & 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 RLAN in 40 MHz receiver (bandwidth factor 21.2%)	173 950	279 211	436 268
Aggregate e.i.r.p. (mainbeam) (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
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
ΔT/T (%)	1.1	1.8	2.8
I/N (dB)	-19.5	-17.5	-15.5
I/N criteria for interference from all co-primary services	-10.5 dB		
Apportionment between FS and RLAN	3		
I/N criteria for interference from RLAN	-13.5 dB		

Table 89: Satellite similar to INT 60E positioned at 5E - Results for scenario for indoor & outdoor (98% indoor & 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 RLAN in 40 MHz receiver (bandwidth factor 21.2%)	173 950	279 211	436 268
Aggregate e.i.r.p. (mainbeam) (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
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
ΔT/T (%)	1.6	2.6	4.0
I/N (dB)	-18.0	-15.9	-14.0
I/N criteria for interference from all co-primary services	-10.5 dB		
Apportionment between FS and RLAN	3		
I/N criteria for interference from RLAN	-13.5 dB		

A5.3 SENSITIVITY ANALYSIS FOR 95% INDOOR & 5% OUTDOOR

Table 90: Sensitivity scenario for indoor & outdoor (95% indoor & 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

Bandwidth distribution				
Bandwidth (MHz)	20	40	80	160
Distribution (%)	10.00	10.00	50.00	30.00

Bandwidth correction				
RLAN Bandwidth (MHz)	20	40	80	160
Average bandwidth correction factor (dB)	0.7	0.5	0.5	0.25

Table 91: Summary of the sensitivity analysis (BEL 17 dB)

BEL 17 dB	(duty cycle) RLAN deployment model	(1.97%) LOW	(1.97%) MID	(1.97%) HIGH
SES 50.5E (clutter 3 dB) Zone beam Europe Gain 32.4 dB	Max number of simultaneously transmitting RLAN devices (6 GHz)	820 521	1 317 034	2 057 866
	I/N (dB)	-23.4	-21.4	-19.4
SES 20W (clutter 1.7 dB) Zone beam Europe Gain 31.8 dB	Max number of simultaneously transmitting RLAN devices (6 GHz)	820 521	1 317 034	2 057 866
	I/N (dB)	-20.9	-18.9	-16.9
INT 60E (clutter 3 dB) Spot beam Europe Gain 37.3 dB	Max number of simultaneously transmitting RLAN devices (6 GHz)	820 521	1 317 034	2 057 866
	I/N (dB)	-18.4	-16.3	-14.4

SAT 5E (clutter 1.5 dB) Spot beam Europe Gain 37.3 dB	Max number of simultaneously transmitting RLAN devices (6 GHz)	820 521	1 317 034	2 057 866
	I/N (dB)	-16.9	-14.8	-12.9

Table 92: Summary of the sensitivity analysis (BEL 14 dB)

BEL 14 dB	(duty cycle) RLAN deployment model	(1.97%) LOW	(1.97%) MID	(1.97%) HIGH
SES 50.5E (clutter 3 dB) Zone beam Europe Gain 32.4 dB	Max number of simultaneously transmitting RLAN devices (6 GHz)	820 521	1 317 034	2 057 866
	I/N (dB)	-22.5	-20.5	-18.5
SES 20W (clutter 1.7 dB) Zone beam Europe Gain 31.8 dB	Max number of simultaneously transmitting RLAN devices (6 GHz)	820 521	1 317 034	2 057 866
	I/N (dB)	-20.0	-18.0	-16.0
INT 60E (clutter 3 dB) Spot beam Europe Gain 37.3 dB	Max number of simultaneously transmitting RLAN devices (6 GHz)	820 521	1 317 034	2 057 866
	I/N (dB)	-17.5	-15.4	-13.5
SAT 5E (clutter 1.5 dB) Spot beam Europe Gain 37.3 dB	Max number of simultaneously transmitting RLAN devices (6 GHz)	820 521	1 317 034	2 057 866
	I/N (dB)	-16.0	-13.9	-12.0

ANNEX 6: RLAN DUTY CYCLE GENESIS

A6.1 THE RELEVANCE OF DUTY CYCLE

To utilise the radio spectrum as efficiently as possible, digital RLAN systems do not transmit data continuously, but in bursts. In spectrum sharing studies, the "burstiness" of a signal, expressed through its duty cycle (DC), is generally accepted to provide a realistic estimate of its interference potential.

Duty Cycle is generally defined as the ratio:

$$\frac{\sum T_{ON}}{T_{OBS}}$$

where:

- T_{ON} is the duration of time the level of a transmit signal exceeds a certain defined threshold;
- T_{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 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 RLAN systems such as those based on emerging IEEE 802.11ax technology are expected to achieve very high data rates whilst maintaining a low duty cycle.

The next Section describes the evolution of a technical approach adopted to make a reliable estimation of duty cycle for future 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.

A6.2 ESTIMATING THE DUTY CYCLE OF FUTURE 6 GHZ RLAN SYSTEMS

To evaluate the coexistence scenarios studied in the current Report, a duty cycle representative of the RLAN deployment situation in the year 2025 had to be determined.

It is noted that 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 123 shows the general process applied to estimate the duty cycle for RLAN devices deployed in CEPT countries in 2025.

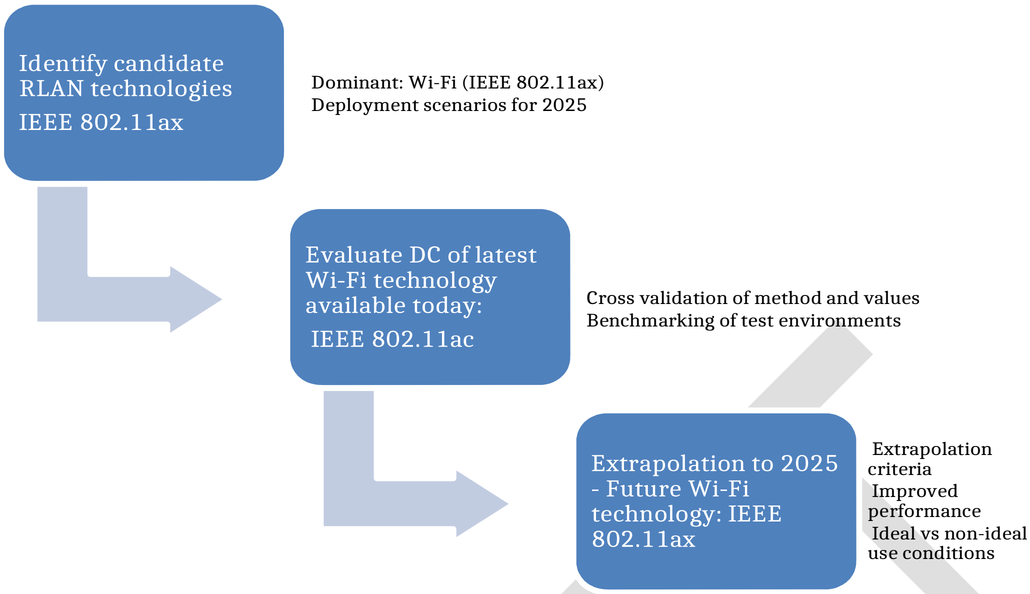


Figure 123: Process applied to estimate the 6 GHz RLAN duty cycle

Initially, this duty cycle had been calculated on the basis of the projected 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 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 duty cycle (also referred to as “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 duty cycles 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 duty cycles for IEEE 802.11ax equipment were 0.97% (one client) and 0.72% (three clients).

The JRC presented a proposal to measure the duty cycle 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 duty cycles 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 duty cycle 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 duty cycle 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 duty cycles 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 duty cycles between 1.16% and 1.78%, which correspond, after conversion to IEEE 802.11ax, to duty cycles 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 duty cycle calculations.

After reviewing above results the group eventually reached a consensus on a single representative duty cycle value of 1.97%. This value was derived from the maximum duty cycle 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 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 RLAN systems in practice.

The conversion factor is summarised in the formula below:

$$DC_{802.11ax} = DC_{802.11ac} \cdot \left(\frac{BW_{802.11ac}}{BW_{802.11ax}} \right) = 2.32\% \cdot \left(\frac{80\,MHz}{94\,MHz} \right) = 1.97\%$$

where:

- $DC_{802.11ax}$ is the IEEE 802.11ax duty cycle,
- $DC_{802.11ac}$ is the IEEE 802.11ac duty cycle,
- $BW_{802.11ac}$ is the IEEE 802.11ac channel bandwidth and
- $BW_{802.11ax}$ is the IEEE 802.11ax channel bandwidth.

Figure 124 summarises the steps followed in the evolution of an agreed DC value for 6 GHz RLAN for 2025.

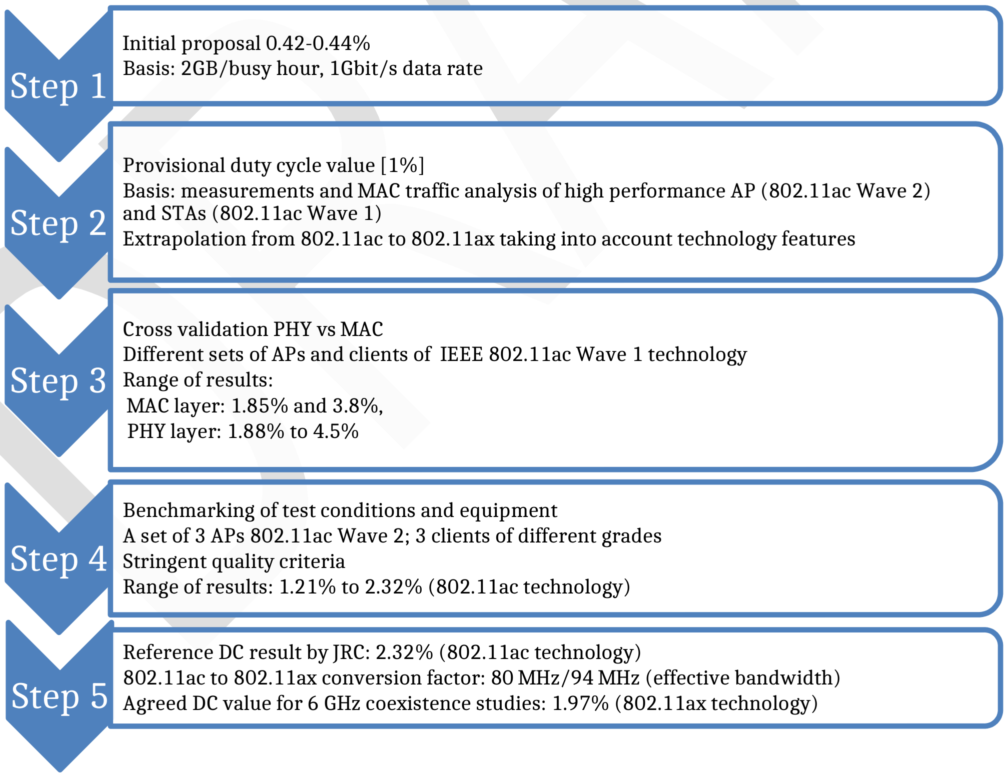


Figure 124: Steps followed in the evolution of an agreed DC value

ANNEX 7: COMPUTING THE 2 DB DESENSITISATION EQUIVALENT ACS FOR LTE CBTC BS

Documents 3GPP TS 37.104 and TR 36.942 do not specify the ACS values for LTS BS. Only blocking levels associated with a 6 dB desensitization are specified. Therefore, the ACS has been computed first and then deduce the blocking levels associated with a 2 dB desensitisation, since the relationship is not linear.

The input parameters for LTE CBTC Base Station are given in Table 93.

Table 93: 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 94) using the equations for the maximum tolerable interference and the maximum blocking level from Sections 10.1.3-10.1.4:

$$ACS = B_{CBTC} - I_{max}$$

$$ACS = B_{CBTC} - 10\log_{10}\left(10^{\frac{D}{10}} - 1\right) - N$$

Table 94: 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 52 in Section 10.1.1.

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