CEPT ECC
Electronic Communications Committee

ECC Report 206

Compatibility studies in the band 5725-5875 MHz between SRD equipment for wireless industrial applications and other systems

Approved 31 January 2014

0 EXECUTIVE SUMMARY

This report investigates the possible deployment of Wireless Industrial Applications (WIA) using technologies different from Ultra-Wide Band in the frequency range 5725 to 5875 MHz and their possible impact on the others systems and services allocated/identified in this and adjacent frequency ranges. Those wireless industrial applications are intended to be operated in the frequency range 5725 to 5875 MHz and are further described in ETSI TR 102 889-2 0.

Industrial applications require "robust" wireless technologies to be used for their critical wireless links in industrial environments. Wireless applications allow savings of often complex and expensive cables, cable protection and plugs, and offer an increased mobility and flexibility as well as the wear and tear free transmission medium. These advantages are particularly high in the area of:

- monitoring and mobile worker communication;
- wireless sensors and actuators at moving parts;
- setups that require flexibility in terms of tool or machine reconfigurations.

The current regulations allow the deployment of SRDs in the frequency range from 5725 to 5875 MHz but limited to 25 mW while WIA are planned to be operated at 400 mW.

Relating to the channel utilization, it was noted that a factory using WIA would need 76 MHz to operate on a given site, however since part of this 76 MHz may not be available for WIA usage due to other possible users (RTTT, BFWA…), there would be a need to identify more than 76 MHz for WIA in order to ensure that they can be operated. Therefore, for some of the compatibility studies, the WIA was assumed to have access to the whole spectrum 5725 to 5875 MHz.

It should be noted that WIA with a maximum e.i.r.p. of 400 mW limited to indoor deployment (assuming 15 dB attenuation for the wall loss and similar device quantities) would have an impact on the others services/systems similar to the impact resulting from SRD devices deployed outdoor according to the existing regulations (25 mW). Therefore, an indoor restriction may be seen as equivalent to the existing regulations and thus sufficient for the protection of others services/systems.

Independent on the above consideration, the Table below provides an overview of the conducted study results.

Table 1: Summary of the compatibility studies

Service/Systems	Results	Comments
Radiolocation 5.725-5.850 GHz	Large separation distances are required under worst case assumptions without mitigation technique. Thus, DFS/DAA is required with the following detection thresholds: ▪ -65 dBm in 1 MHz ▪ -60.5 dBm in 3 MHz ▪ -52 dBm in 20 MHz The adjacent band coexistence appears possible. Note 1, Note 4	A DAA mitigation technique that is fully in operation at all times is mandatory. This must be ensured by the manufacturers of the WIA devices. Moreover, as the frequency band in question is dedicated to military services in some European countries, thus further reaching restrictions may apply. DFS as developed for WLAN and BFWA does not allow detecting all types of radars (cf. e.g. ECC Report 192 [34]).

Service/Systems	Results	Comments
		Recommendation ITU-R M.1638 [6], which lists the radar characteristics for the 5 GHz range, is under revision in ITU WP 5B. Due to the ongoing process this report at hand does not encompass all types of radars. Part of the spectrum may be blocked by radars
RTTT 5.795-5.805 GHz, 5.805-5.815 GHz (used by some administrations)	No interference is expected in the case of OBU RTTT. In the case of RTTT RSU the separation distances without DAA mitigation techniques are depending on the environment: ▪ Urban environment 100 m ▪ Suburban environment 1000 m ▪ Rural environment 2500 m DAA mitigation techniques were not studied but the same threshold as for ITS may be considered. Note 2, Note 4	
BFWA 5.725-5.875 GHz	The separation distances without DAA mitigation techniques are depending on the environment: ▪ Urban environment no separation distance required ▪ Suburban environment less than 3 km ▪ Rural environment between 3 km (C/I criterion) and 10 km (I/N criterion) Thus, DAA with a threshold of -99 dBm on WIA device level is required in suburban and rural environments. Note 1, Note 2, Note 3, Note 4, Note 5	
FSS 5725-5875 MHz	The deployment of WIA is compatible with FSS if TPC (based on a minimum power strategy) is implemented and the assumptions on the number of devices are met (see Table 52)	
Radio Amateur Service 5725-5850 MHz	Under worst case assumptions, separation distances may be needed. Considering more realistic cases, the separation distances are significantly reduced. Note 2	It should be noted that the most sensitive amateur service operations are globally harmonised at 5760-5762 MHz
Radio Amateur Satellite Service 5830-5850 MHz	No interference is expected. Note 2.	
ITS 5855-5875 MHz	Required separation distances without DAA mitigation techniques are depending on the environment: ▪ Urban environment 100 m ▪ Rural environment 2500 m	

Service/Systems	Results	Comments
	Thus, DAA with a threshold of -85 dBm on WIA device level is required. Note 1, Note 2, Note 3, Note 4, Note 5	
Non Specific SRD 5725-5875 MHz	Under worst cases assumptions, separation distances may be needed. Considering a realistic case, no separation distance is needed	Limited information on the SRDs deployed in the band was provided

Note 1: DFS/DAA on device level may not be possible for all WIA applications. Further developments may show automated solutions so that a sensing procedure may be able to coordinate centralized the spectrum.

Note 2: Due to the fact that TPC was found necessary to meet the FSS protection criterion, TPC was assumed when conducting the compatibility studies.

Note 3: Higher threshold would be possible with the use of centralized sensing.

Note 4: A registration/ notification / light licensing procedure for WIA could help in enforcing the required separation distances (e.g. to tolling bridges, RTTT).

Note 5: If both systems (interferer and victim) are based on IEEE 802.11, coexistence between those systems might be possible using an updated CSMA/CA protocol. However, this is still to be demonstrated.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
APC	Adaptive Power Control
AS	Amateur Service
BFWA	Broadband Fixed Wireless Access
BPSK	Binary Phase Shift Keying
CENELEC	French: Comité Européen de Normalisation Électrotechnique; English: European Committee for Electrotechnical Standardization
CEPT	European Conference of Postal and Telecommunications Administrations
CS	Central Station
CW	Contiguous Wave
DC	Duty Cycle
DAA	Detect And Avoid
DFS	Dynamic Frequency Selection
dRSS	desired Received Signal Strength
E-s	Earth to space
EC	European Commission
ECC	Electronic Communications Committee
ECCM	Electronic Counter-Counter Measures
e.i.r.p.	equivalent isotropically radiated power
ERP	Effective Radiated Power
ETSI	European Telecommunications Standards Institute
EU	European Union
FHSS	Frequency Hopping Spread Spectrum
FM	Frequency Modulation
FSS	Fixed Satellite Service
GFSK	Gaussian Frequency Shift Keying
IARU	International Amateur Radio Union
IEEE	Institute of Electrical and Electronic Engineers
ILR	Interference Link Receiver
ILT	Interference Link Transmitter
iRSS	Interfering Received Signal Strength
ITS	Intelligent Transport System
IVC	Inter-Vehicles Communications
LEO	Low Earth Orbits
MCL	Minimum Coupling Loss
OBU	On Board Unit
P-MP	Point-MultiPoint
QPSK	Quaternary Phase Shift Keying
R2V	Roadside to Vehicle
RSU	Road Side Unit
RTTT DSRC	Road Transport and Traffic Telematics, Dedicated Short-Range Communications
s-E	Space to Earth
SEAMCAT	Spectrum Engineering Advanced Monte Carlo Analysis Tool

SRD	Short Range Device
SRdoc	System Reference document
SSB	Single Side Band
StdDev	Standard Deviation
TDMA	Time Duplex Multiple Access
TLPR	Tank Level Probing Radar
TPC	Transmit Power Control
TS	Terminal Station
UWB	Ultra Wide Band
VLR	Victim Link Receiver
VLT	Victim Link Transmitter
V2R	Vehicle to Roadside
WG FM	Working Group Frequency Management
WIA	Wireless Industrial Applications
WLAN	Wireless Local Area Network

1 INTRODUCTION

This report investigates the possible deployment of Wireless Industrial Applications (WIA) using technologies different from Ultra-Wide Band in the frequency range 5725 to 5875 MHz and their possible impact on the others systems and services allocated/identified in this and adjacent frequency ranges. Those wireless industrial applications are intended to be operated in the frequency range 5725 to 5875 MHz and are further described in ETSI TR 102 889-2 [1].

Industrial applications require "robust" wireless technologies to be used for their critical wireless links in industrial environments. Wireless applications allow savings of often complex and expensive cables, cable protection and plugs, and offer an increased mobility and flexibility as well as the wear and tear free transmission medium. These advantages are particularly high in the area of:

- monitoring and mobile worker communication;
- wireless sensors and actuators at moving parts;
- setups that require flexibility in terms of tool or machine reconfigurations.

Different functions can be mastered substantially more efficient by a wireless network of data acquisition terminals, robotic type equipment or automated guided vehicles.

The current regulations allow the deployment of SRDs in the frequency range from 5725 to 5875 MHz but limited to 25 mW (see Table 2).

Table 2: Regulatory parameters related to Annex 1 to ERC/REC 70-03 [2]

Frequency Band	Power / Magnetic Field	Spectrum access and mitigation requirement	Channel spacing	ECC/ERC Decision	Notes
i: 5725-5875 MHz	25 mW (14 dBm) e.i.r.p	No requirements	No spacing	-	-

Part of the WIA in a factory may be deployed trough the existing regulatory framework.

2 OVERVIEW OF INDUSTRIAL APPLICATIONS USING TECHNOLOGIES DIFFERENT FROM ULTRA-WIDEBAND (UWB)

In a larger industrial plant, if a chemical or oil-/and gas industry process plant ("process automation") or e.g. an automotive discrete manufacturing plant (discrete or "factory automation"), there are and will be always many different wireless systems and technologies for different purposes in parallel to each other (partly or completely overlapping).

The subdivision of such systems into three main classes can be typically done into:

- Manufacturing cell or sub-unit automation;
- factory hall or plant sub-unit automation and
- plant level automation.

The classes are described below in more details.

2.1 MANUFACTURING CELL OR SUBUNIT AUTOMATION

The lowest control system level can be a part of a line in an automotive plant or a normal discrete manufacturing cell or a subunit in process automation (e.g. a reactor with a local control to which sensors and actuators are connected). Typically lower range (e.g. 10 m to 30 m range) but most demanding for latency and robustness, are capable to live with fast movements, integrated antennas and many obstacles (nearly complete shielding).

One such cell unit has one wireless system with in average 30 devices.

Up to 10 such units/manufacturing cells can be in close proximity, so that their interference area overlaps.

The area related local device density at 10 m range therefore is typically 10x30 devices per 10x10 m² or 0,33 to 3 devices per m² (at 30 m to 10 m range respectively).

The cell automation data packets as such are typically quite small and have 16 octets on air (e.g. 4 octets of user data, 12 octets for addressing, control and error protection) and have to be sent every 50 ms in each direction.

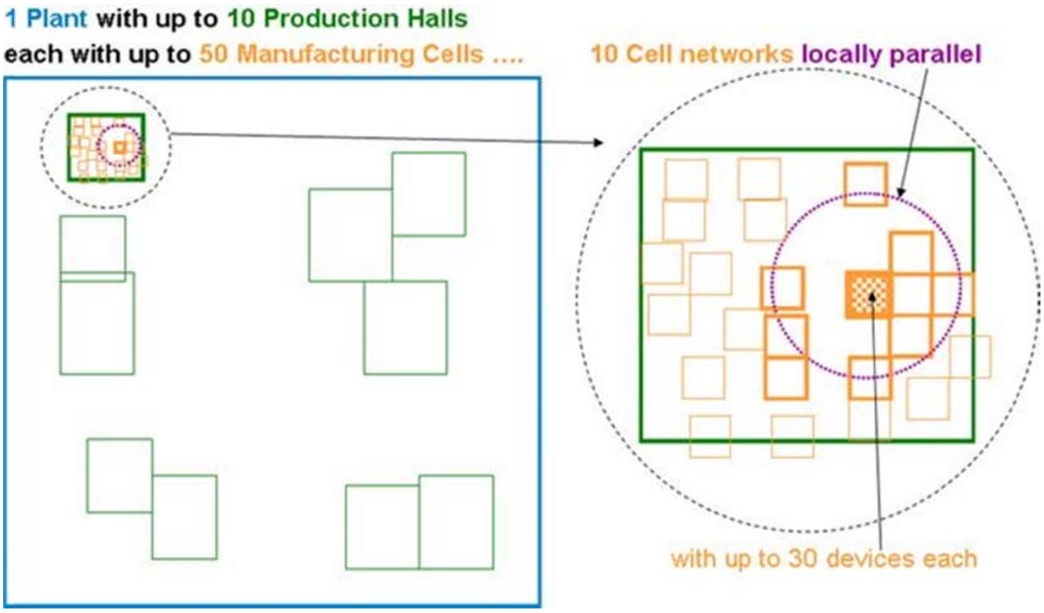


Figure 1: Example of a 1 plant with 10 production halls and 50 manufacturing cells

2.2 FACTORY HALL (OR PLANT SUBUNIT) AUTOMATION

Medium Control System level, where e.g.:

a) whole production lines or moving applications (e.g. moving through a factory hall in discrete manufacturing e.g. automated guided vehicles, rail hanging power screwdrivers), or
b) whole production units in process automation:
   - Cover a larger area (e.g. 100 m x 100 m). This is solved by an industrial WLAN or a mesh type technology (TDMA schemes used) to safely cover a larger area with.
   - In average 100 devices and still low latencies.

Also here the master is in need of higher duty cycles and high power to cover the range without line of sight:

Up to 5 such independent systems can be within range of each other (are within "interference" range).
The area related local device density at 100 m range therefore is approx. 5 x 100 devices per 100 x 100 m² or 0,022 per m² at 100 m range.

The hall/subunit automation data packets as such are typically medium size with 200 octets on air (e.g. 140 octets of user data, 60 octets for addressing, networking, control and error protection) and have to be sent every 200 ms in each direction.

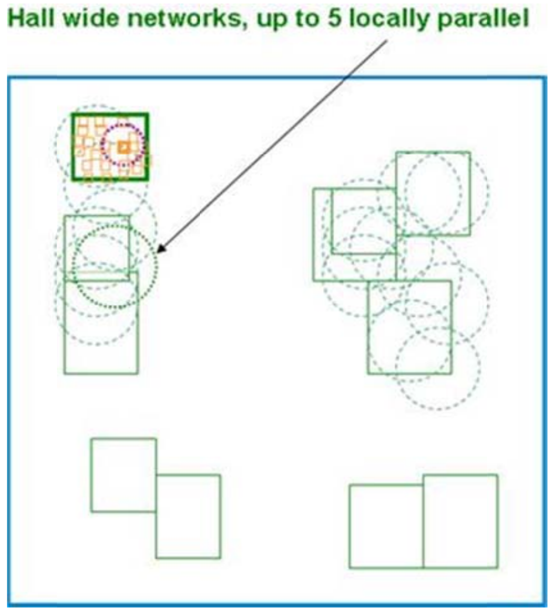


Figure 2: Example of hall wide networks, up to locally parallel

2.3 PLANT LEVEL WIDE APPLICATIONS

Control system level covering up to the whole plant, typically an industrial mesh technology:

Able to cover e.g. 1 km x 1 km but typically with mesh technology to increase robustness against typical industrial influences (moving obstacles, interference/coexistence).

One such mesh system can have up to 1000 connected devices, but each device only having to cover a smaller range (100 m) and the mesh covers the larger distances needed, without excessive power needs.

There may be up to 3 independent such mesh networks operating in parallel in the whole plant.

Up to max. 50 devices of the 3 clusters can be within range of each other (are within "interference" range).

The area related local device density at 100 m range therefore is approx. 50 devices per 100x100 m² or 0.025 per m² at 100 m range.

The plant level automation data packets are typically medium size with 105 octets on air (e.g. 50 octets of user data, 55 octets for addressing, networking, control and error protection) and have to be sent every 500 ms in each direction.

2.4 OPERATION OF THE THREE CLASSES

All of these 3 levels are operated in parallel (partially or completely overlapping interference area), and often by different operators and connected to different Control Systems. Each of the many wireless systems has to be allowed to switch on and off and vary the number of connected active devices and data amount transferred, depending of the needs of the many different production cells/subunits/ lines in order to maximise individually production, quality, safety and do service, troubleshooting and installation work on the productions units.

Parallel means that at most parts of the plant, the three "wireless" classes operate overlapping, preferably in the same frequency band for maximal flexibility of coexistence management reasons, to increase spectrum efficiency and to have the same needed spectrum properties like industrial-interference-free, power efficiency (range) and bending/damping by obstacles.

Normally, in total about 76 MHz of preferably continuous spectrum would be required to support applications from the 3 classes to operate seamless within a given environment without any restriction. This would still require a clever site planning which is not always possible as the different wireless solutions are from different vendors. However, recent and future developments of more intelligent sharing mechanisms will facilitate automatic seamless operation of these 3 classes even if less spectrum is made available.

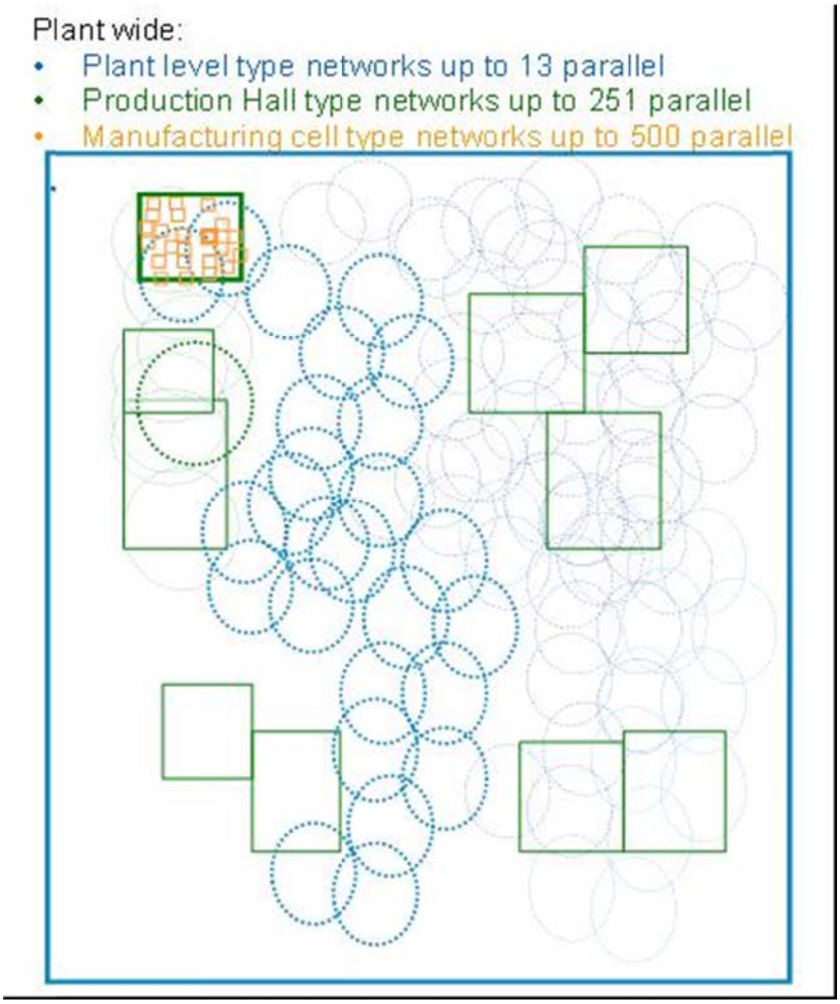


Figure 3: Example of a combination of 3 classes

Table 3 shows the extreme low latency and application availability requirements of many industrial wireless applications.

Table 3: Industrial application

Characteristic	Manufacturing cell	Factory hall	Plant level
Indoor/outdoor application	Indoor	Mostly indoor	Mostly outdoor
Spatial dimension LxWxH [m³]	10 x 10 x 3	100x100x10	1000 x 1000 x 50
Number of devices (typically)	30	100	1000
Number of parallel networks (= clusters)	10	5	5
Number of such clusters per plant	50	10	1
Typical Number of locally parallel devices	300	500	250
Network type	Star	Star/Mesh	Mesh
S, Typ. packet size [on air, byte]	16	200	105
Maximum allowable latency (end-to-end) incl. jitter/retransmits [ms]	5 ± 10 %	20 ± 10 %	20 ± 10 %
T, Update Time [ms]	50 ± 10 %	200 ± 10 %	500 ± 10 %

Characteristic	Manufacturing cell	Factory hall	Plant level
Packet Loss Rate (involved outside latency)	10^{-9}	10^{-9}	10^{-9}
Application availability	Exceeds 99,999 % (less than 300 s accumulated outage per annum).		
Typical operational distance	Depends on individual use case and frequency of operation.		
Note: To account for up and downlink information, 2 telegrams have been assumed.			

Additional technical details are provided in ANNEX 1: (see also the ETSI SRdoc [1]).

Relating to the spectrum requirements, it was noted that the WIA system would need 76 MHz to operate on a given site, however since part of this 76 MHz may not be available locally for WIA usage due to other possible users (RTTT, BFWA…), there would be a need to identify more than 76 MHz for WIA systems in order to ensure that they can operate. This would mean that toward Europe, WIA would be spread over more than 76 MHz, resulting in a decrease of the possible number of WIA systems operating per channel and at the same time as given in the previous section.

3 SERVICES AND SYSTEMS IN THE BAND 5725-5875 MHz

Table 4 provides the extract from the ITU Radio Regulations [3] for the bands used through this report.

Table 4: Extract of Article 5 of the ITU Radio Regulations

Region 1	Region 2	Region 3
5 725-5 830 FIXED-SATELLITE (Earth-to-space) RADIOLOCATION Amateur 5.150 5.451 5.453 5.455 5.456	5 725-5 830 RADIOLOCATION Amateur 5.150 5.453 5.455	
5 830-5 850 FIXED-SATELLITE (Earth-to-space) RADIOLOCATION Amateur Amateur-satellite (space-to-Earth) 5.150 5.451 5.453 5.455 5.456	5 830-5 850 RADIOLOCATION Amateur Amateur-satellite (space-to-Earth) 5.150 5.453 5.455	
5 850-5 925 FIXED FIXED-SATELLITE (Earth-to-space) MOBILE 5.150	5 850-5 925 FIXED FIXED-SATELLITE (Earth-to-space) MOBILE Amateur Radiolocation 5.150	5 850-5 925 FIXED FIXED-SATELLITE (Earth-to-space) MOBILE Radiolocation 5.150

Footnotes of RR Art. 5 relevant for CEPT countries:

5.150 The following bands: 5 725-5 875 MHz (centre frequency 5 800 MHz), and ... are also designated for industrial, scientific and medical (ISM) applications. Radio communication services operating within these bands must accept harmful interference which may be caused by these applications. ISM equipment operating in these bands is subject to the provisions of No. 15.13.

5.451 Additional allocation: in the United Kingdom, the band 5 470-5 850 MHz is also allocated to the land mobile service on a secondary basis. The power limits specified in Nos. 21.2, 21.3, 21.4 and 21.5 shall apply in the band 5 725-5 850 MHz.

5.455 Additional allocation: in Armenia, Azerbaijan, Belarus, Cuba, the Russian Federation, Georgia, Hungary, Kazakhstan, Latvia, Moldova, Mongolia, Uzbekistan, Kyrgyzstan, Tajikistan, Turkmenistan and Ukraine, the band 5 670-5 850 MHz is also allocated to the fixed service on a primary basis. (WRC-03)

The following table provides an overview ERC Report 25 [4] for the bands 5725 to 5875 MHz.

Table 5: Allocation / Identification of spectrum according to ERC Report 25 [4]

Frequency range	European Common Allocation	ECC/ERC harmonisation measures	Application	European footnotes	Standard	Notes
5725-5830 MHz	FIXED-SATELLITE (E/S) RADIOLOCATION Amateur Mobile 5.150 EU2 EU22		Amateur		EN 301 783	
		ECC/REC/(06)04	BFWA		EN 302 502	Within the band 5725-5875 MHz
			Defence systems			Tactical and weapon system radars
			ISM			Within the band 5725-5875 MHz

Frequency range	European Common Allocation	ECC/ERC harmonisation measures	Application	European footnotes	Standard	Notes
		ERC/REC 70-03	Non-Specific SRD		EN 300 440	Within the band 5725-5875 MHz
		ERC/REC 70-03	Radiodeterminatio n applications		EN 302 372	Within the band 4500-7000 MHz for TLPR application
		ERC/REC 70-03	RTTT		EN 300 674	Within the band 5795-5805 MHz. RTTT in the band 5805-5815 MHz on a national basis
			Weather Radars			Ground based and airborne
5830-5850 MHz	FIXED-SATELLITE (E/S) RADIOLOCATION Amateur Amateur Satellite (S/E) Mobile 5.150 EU2 EU22		Amateur Satellite (S/E)	EU23		Within the band 5830-5850 MHz
		ECC/REC/(06)04	BFWA		EN 302 502	Within the band 5725-5875 MHz
			Defence systems			Tactical and weapon system radars
			ISM			Within the band 5725-5875 MHz
		ERC/REC 70-03	Non-Specifics SRDs		EN 300 440	Within the band 5725-5875 MHz
		ERC/REC 70-03	Radiodeterminatio n applications		EN 302 372	Within the band 4500-7000 MHz for TLPR application
			Weather radars			Ground based and airborne
5850-5925 MHz	FIXED FIXED-SATELLITE (E/S) MOBILE 5.250	ECC/REC/(06)04	BFWA		EN 302 502	Within the band 5725-5875 MHz
			FSS		EN 301 443	Priority for civil networks
			ISM			Within the band 5725-5875 MHz
		ECC/DEC/(08)01 ECC/REC(08)01	ITS		EN 302 571	Within the band 5875-5925 MHz. Within the band 5855-5875 MHz
		ERC/REC 70-03	Non-Specific SRDs		EN 300 440	Within the band 5725-5875 MHz
		ERC/REC 70-03	Radiodeterminatio n applications		EN 302 372	Within the band 4500-7000 MHz for TLPR application

EU2: Civil-military sharing.

EU22: The band 5250-5850 MHz is utilised for a variety of radiodetermination applications falling within the radionavigation and radiolocation services. This band will be subject to further detailed consideration.

EU23 In the sub-bands 5660-5670 MHz (earth to space), 5830-5850 MHz (space to earth) and 10.45-10.50 GHz the amateur-satellite additionally operates on a secondary and non-interference basis to other services. In making assignments to other services, CEPT administrations are requested wherever possible to maintain these allocations in such a way as to facilitate the reception of amateur emissions with minimal power flux densities.

The following services and systems are covered within this study following the approach considered in previous ECC Reports (see for example [5]):

- Section 3.1: Radiolocation Service
- Section 3.2: Road Transport and Traffic Telematic (RTTT) Systems
- Section 3.3: Fixed Service (Point-to-Point Links) and Broadband Fixed Wireless Access (BFWA)
- Section 3.4: Fixed-Satellite (E-s) Service (FSS)
- Section 3.5: Amateur Service, Amateur-satellite (s-E) Service
- Section 3.6: Intelligent Transport Systems (ITS)
- Section 3.7: Short Range Devices including:Non-specific Short Range Devices and Tank Level Probing Radar (TLPR) applications

It should be noted that at the date of finalization of this report, CEPT was conducting studies relating to the possible introduction of Digital Air To Ground Communications (DA2GC) system in the frequency bands 1900-1920 MHz, 2010-2025 MHz and 5855-5875 MHz. However, those studies were not completed at the time this report was finalised; therefore, this case was not considered in this report.

In addition, the EC has issued a Mandate calling for studies to consider additional bands for RLANs in the 5 GHz frequency range. Since those studies were at initial stage when this Report was approved, this case was not considered.

3.1 RADIOLOCATION SERVICE

The bands between 5725 MHz and 5850 MHz are allocated to the Radiolocation service on a primary basis.

3.1.1 Technical characteristics

Recommendation ITU-R M.1638 [6] provides characteristics of radars operating under the Radiolocation services in the frequency range 5250-5850 MHz. Within this range, the band between 5725 MHz and 5850 MHz is used by many different types of radars on fixed land-based, ship borne and transportable platforms. It should be noted that most of these radars are designed to operate not only in the 5725-5850 MHz band but in a larger portion of the band 5250-5850 MHz.

The following table contains technical characteristics of representative systems deployed in this band. This includes a subset of the radars contained in Recommendation ITU-R M.1638 [6], which are relevant for the frequency band 5725-5850 MHz (radars L, M, N, O and Q) and three additional radars operated by administrations within CEPT (X, Y and Z). This information is generally sufficient for calculation to assess the compatibility between these radars and other systems.

Frequency hopping is one of the most common Electronic-Counter-Counter-Measures (ECCM). Radar systems that are designed to operate in hostile electronic attack environments use frequency hopping as one of its ECCM techniques. This type of radar typically divides its allocated frequency band into channels. The radar then randomly selects a channel from all available channels for transmission. This random occupation of a channel can occur on a per beam position basis where many pulses on the same channel are transmitted or on a per pulse basis. This important aspect of radar systems should be considered and the potential impact of frequency hopping radar should be taken into account in sharing studies.

It should be emphasized, that the Recommendation ITU-R M.1638 is under revision in ITU WP 5B, and that the new radars proposed to be added in a revised version of Recommendation ITU-R M.1638 [6] are not accounted for in this report (e.g. bi-static radars).

3.1.2 Operational characteristics of Radiolocation systems

There are numerous radar types, accomplishing various missions, operating within the Radiolocation service throughout the whole range 5250- 5850 MHz, and specifically within the 5725-5850 MHz band. Test range instrumentation radars are used to provide highly accurate position data on space launch vehicles and aeronautical vehicles undergoing developmental and operational testing. These radars are typified by high transmitter powers and large aperture parabolic reflector antennas with very narrow pencil beams. The radars have auto-tracking antennas which either skin-track or beacon-track the object of interest. Periods of operation can last from minutes up to 4-5 hours, depending upon the test program. Operations are conducted at scheduled times 24 hours/day, 7 days/week.

Shipboard sea and air surveillance radars are used for ship protection and operate continuously while the ship is underway as well as entering and leaving port areas. These surveillance radars usually employ moderately high transmitter powers and antennas which scan electronically in elevation and mechanically a full 360 degrees in azimuth. Operations can be such that multiple ships are operating these radars simultaneously in a given geographical area. Other special-purpose radars are also operated in the band 5250-5850 MHz.

Also, in this band operate tactical radar mounted on mobile vehicles used for providing airspace surveillance.

It shall be emphasized that some radar systems are designed such that they are robust against interference however this was designed in order to encompass any problems during their operations and not to cope with possible interference resulting from underlay technology.

3.1.3 Protection criteria

The desensitising effect on radars operated in this band from other services of a CW or noise-like type modulation is predictably related to its intensity. In any azimuth sectors in which such interference arrives, its power spectral density can simply be added to the power spectral density of the radar receiver thermal noise, to within a reasonable approximation. If power spectral density of radar-receiver noise in the absence of interference is denoted by N_0 and that of noise-like interference by I_0, the resultant effective noise power spectral density becomes simply I_0+N_0. An increase of about 1 dB for the Radiolocation radar would constitute significant degradation. Such an increase corresponds to an (I+N)/N ratio of 1.26, or an I/N ratio of about –6 dB. These protection criteria represent the aggregate effects of multiple interferers, when present. The tolerable I/N ratio for an individual interferer depends on the number of interferers and their geometry, and needs to be assessed in the course of analysis of a given scenario. The aggregation factor can be very substantial in the case of certain communication systems, in which a great number of stations can be deployed.

Table 6: Characteristics of Radiolocation systems

Characteristics	Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X (Note 1)	Radar Y (Note 1)	Radar Z
Function	Instrumentation			Surface and air search				Search
Platform type	Ground				Ship	Ground /Vehicle		
Tuning range (MHz)	5350-5850		5400-5850		5450-5825	5400-5850		5250-5850
Modulation	None		Pulse / chirp pulse	Chirp pulse	None			Non-Linear FM
Tx power into antenna (kW)	2800	1200	1000	165	285	12	12	70
Pulse width (µs)	0.25, 1.0, 5.0	0.25, 0.5, 1.0	0.25-1 (plain) 3.1-50 (chirp)	100	0.1, 0.25, 1.0	4-20	4-20	3.5, 6, 10
Pulse rise/fall time (µs)	0.02-0.5	0.02-0.05	0.02-0.1	0.5	0.03/0.05 / 0.1	No detail	No detail	N/A
Pulse repetition rate (pps)	160, 640	160, 640	20-1280	320	2400/1200 / 750	1000-7800	1000-7800	2500/3750

Characteristics	Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X (Note 1)	Radar Y (Note 1)	Radar Z
Chirp bandwidth (MHz)	N/A	N/A	4.0	8.33	N/A	No detail	No detail	
RF emission bandwidth –3 dB –20 dB (MHz)	0.5-5	0.9-3.6 6.4-18	0.9-3.6 6.4-18	8.33 9.9	5.0/4.0/1.2 16.5/12.5/7.0	5	5	
Antenna pattern type	Pencil				Fan	N/A		
Antenna type	Parabolic		Phased Array		Travelling wave feed horn array	N/A		Phased Array
Antenna polarization	Vertical/Left-hand circular				Horizontal	Vertical		Horizontal
Antenna main beam gain (dBi)	54	47	45.9	42	30.0	35	35	31.5
Antenna elevation beam width (degrees)	0.4	0.8	1.0	1.0	28.0	N/A	N/A	43.8
Antenna azimuthal beam width (degrees)	0.4	0.8	1.0	1.0	1.6	N/A	N/A	1.75
Antenna horizontal scan rate (degrees/s)	N/A (Tracking)				90	N/A (tracking)	180/360	120/180
Antenna horizontal scan type	N/A (Tracking)				30-270 ° Sector	N/A		
Antenna vertical scan rate (degrees/s)	N/A (Tracking)				N/A			
Antenna vertical scan type (degrees)	N/A (Tracking)				Fixed	N/A		
Antenna side-lobe (SL) levels (dB)	-20	-20	-22	-22	-25	-40	-40	N/A
Antenna height (m)	20	8-20	20	20	40	10	10	6 – 13
Receiver IF 3 dB bandwidth (MHz)	4.8, 2.4, 0.25	4, 2, 1	2-8	8	1.2, 10	4	4	N/A
Receiver noise figure (dB)	5	5	11	5	10	5	5	≤ 13
Minimum discernable signal (dBm)	–107	–100	–107,–117	–100	-94 (short) -102 (wide)	-103	-103	-108

Note 1: Radars X and Y can operate both in fixed frequency and in hopping mode: the following parameters have to be taken into account in the different compatibility studies in the band 5725-5875 between industrial applications using technologies different from UWB and Radiolocation service.

Frequency hopping characteristics

Frequency band:	5250 to 5850 MHz or 5470 to 5850 MHz
type of frequency hopping:	random
hopping rate:	300 to 1500 Hz
number of frequency:	1 frequency /10 MHz

3.2 ROAD TRANSPORT AND TRAFFIC TELEMATICS (RTTT) SYSTEMS

ECC/DEC/(02)01 [7] has identified the frequencies for RTTT applications in the band 5.795-5.815 GHz, ECC/DEC(02)01 has been withdrawn by ECC/DEC/(12)04**Error! Reference source not found.**. The band 5795-5805 MHz is for use by initial road-to-vehicle systems, in particular road toll systems, with an additional sub-band, 5805-5815 MHz, to be used on a national basis to meet the requirements of multi-lane road junctions.

3.2.1 Parameters

The regulatory parameters (maximum power levels) for RTTT are given in Annex 5 of ERC/REC 70-03 [2]. The RTTT parameters used in this Report are taken from the EN 300 674 [8] developed by ETSI and the BS EN 12253 [9] developed by CENELEC. It should be noted that the EN 300 674 deals with both Road Side Units (RSU) and On-Board Units (OBU) and is divided in two parts, the part 1 providing general characteristics and test methods, the part 2 containing the essential requirements under article 3.2 of the R&TTE Directive [10].

Table 7: Summary of characteristics of the RTTT systems

	Road Side Units	On Board Units
Frequency range (MHz)	5795 and 5815	
e.i.r.p.	2 W (33 dBm) standard for -35° ≤ θ ≤ 35° 18 dBm for θ > 35° 8 W (39 dBm) optional	Maximum re-radiated sub-carrier e.i.r.p.: -24 dBm (Medium data rate) -14 dBm (High data rate)
Antenna gain	Left circular polarised 13 dBi Linear polarised 10 dBi (assumed front-to-back ratio of 15 dB)	1 – 10 dBi (see Figure 6)
Transmitter Bandwidth	1 MHz	500 kHz
Receiver bandwidth	500 kHz	200 MHz – 1.4 GHz (not used)
Polarization	left circular	left circular
Receiver sensitivity (at the receiver input)	-104 dBm (BPSK)	-60 dBm
Co-channel C/I (dB)	6 for 2-PSK, 9 for 4-PSK, 12 for 8-PSK	Not defined

The following figure depicts the RTTT frequency utilization for 1.5 MHz sub-carrier frequency, according the ETSI EN 300 674 [8]. The location of downlink channels from RSU to OBU and the location of uplink channels from OBU to RSU become visible.

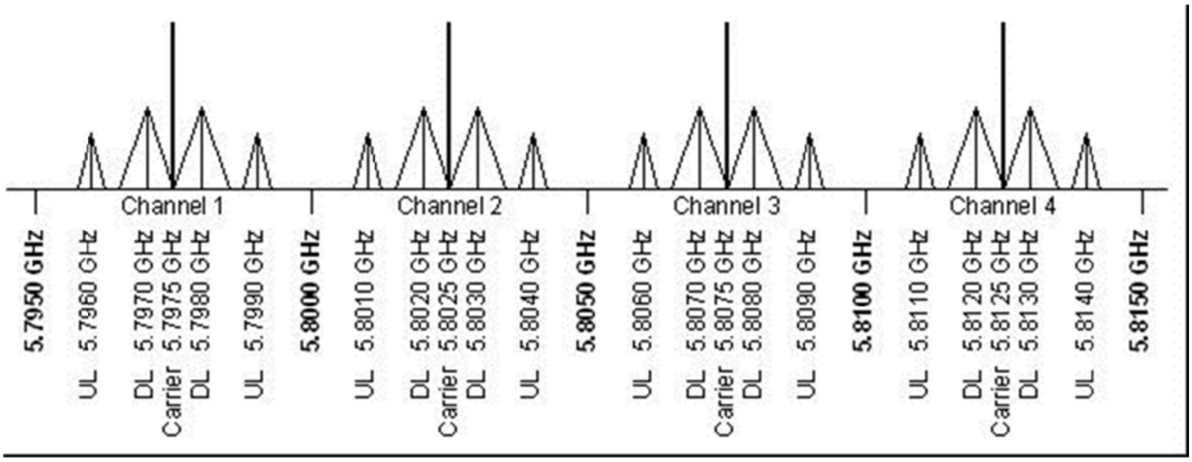


Figure 4: RTTT frequency utilization for 1.5 MHz sub-carrier frequency, according the EN 300 674

The transmit power limits of RTTT downlink, uplink and out of band emissions are depicted in the following Figure.

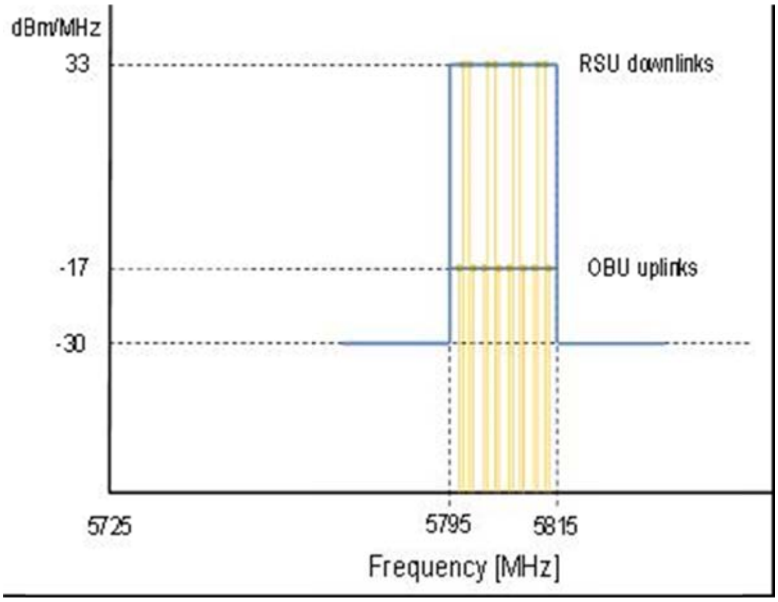


Figure 5: e.i.r.p. limits of RTTT

It is proposed to use as a typical antenna pattern of RSU an antenna gain of -5 dBi Vert.Lin.Pol. for all azimuth directions for RTTT RSU. The gain will be higher when within the RTTT communication zone however it is not likely the WIA radio will be located within the communication zone.

The gain in the horizontal plane is roughly the same in all directions since the RSU antennas are tilted down, (typically 45 to 55 degree). Therefore, the difference of gain is varying not much in different directions when the considered station is far enough from the antenna. There are some differences depending on azimuth angle however these differences are smaller than the differences because of different RSU types.

For the OBU antenna model, the following model is proposed:

Gain [dB] = -4.5-(0.004*Az)-(0,0002*Az*Az)

This is illustrated in the following figure.

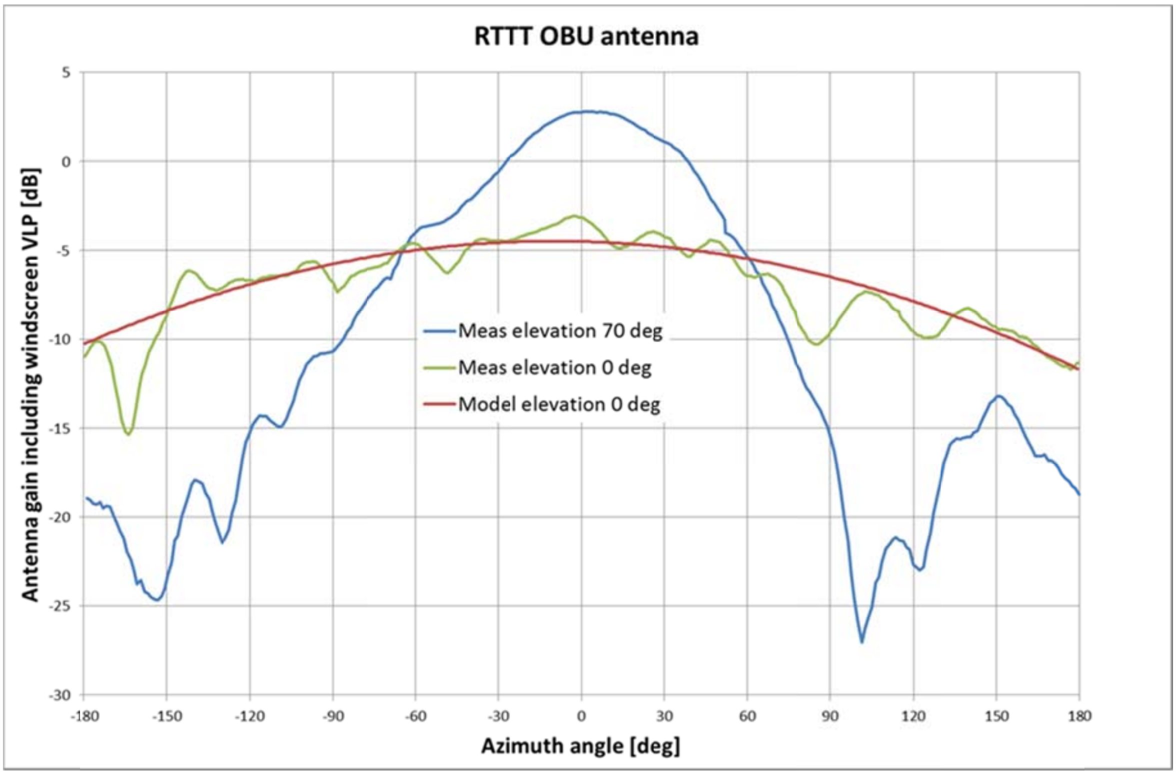


Figure 6: Antenna pattern OBU

3.2.2 Protection Criteria

On Board Unit (OBU)

The OBU requires a -60 dBm signal in order to function at all and to understand commands from the RSU. Assuming negligible re-radiation loss and a signalling distance of 8 m, the received signal strength at the OBU should be -59 dBm or higher . This corresponds to power density of -56 dBm/MHz. Assuming that simple BPSK is used, the required margin is 6 dB and thus the protection criterion in term of the maximum acceptable interference power at the OBU would be -62 dBm/MHz on-axis.

Road Side Unit (RSU)

The RSU, when operating in BPSK mode requires a 6 dB margin over its receiver sensitivity: this gives -107 dBm at the receiver input or density of -98 dBm/MHz at the input to an antenna with a -9 dB off-axis gain. Since the RSU antenna points at the road surface, noon-axis gain is taken into consideration.

3.3 FIXED SERVICE

In this frequency range, two types of Fixed Service links may be deployed: Point-to-Point links and Point-to-Multipoint links as Broadband Fixed Wireless Access (BFWA) systems.

ECC Report 173 [11] indicates that in “the lightly licensed 5.8 GHz frequency band FWA (fixed and nomadic) operation continues to be possible on a national basis under the framework set by ECC Recommendation ECC/REC(06)04 [12] and ETSI Harmonised Standard EN 302 502 [13]. Coexistence considerations result in a low e.i.r.p. constraints and a need to implement a demanding Dynamic Frequency Selection (DFS) feature for the protection of primary Radiodetermination service.”

“The band is unlicensed/light licensed, from 5.725 to 5.850 GHz.

From 5.85 to 5.95, some use is indicated, mostly for P-MP. The licensing regime appears to be mostly link-based. Few countries indicated a significant use, including the Russian Federation (1400 P-P links, 600 P-MP Base Stations, infrastructure and broadcasting).

National frequency plans have been declared in majority of answers.”

3.3.1 Point-to-Point Links

Recommendation ITU-R F.383-7 [14] defines the channel arrangements for the lower 6 GHz band. Depending on which channel arrangements are chosen, the frequency range may extend from 5850-6425 MHz. ERC/REC 14-01 [15] defines the CEPT harmonised channel plans for Radio-frequency channel arrangements for high capacity analogue and digital radio-relay systems operating in the band 5925-6425 MHz.

The harmonised CEPT arrangements are based on recommends 1 of Recommendation ITU-R F.383-7 [14], which does not extend below 5925 MHz. There is a limited deployment of Point-to-point links, therefore this case is not considered in the compatibility studies.

3.3.2 Broadband Fixed Wireless Access (BFWA) Systems

ECC Report 101 [5] indicated that Broadband Fixed Wireless Access (BFWA) refers to wireless systems that provide local connectivity for a variety of applications and using a variety of architectures, including combinations of access as well as interconnection. ECC Report 068 [16] depicts the different architectures of BFWA and provides the relevant information on these different kinds of networks including technical parameters to ensure compatibility with other systems. The following section provides the main parameters for one BFWA architecture, Point to Multipoint (P-MP).

3.3.2.1 BFWA Parameters

The technical parameters of the BFWA systems were provided by a BFWA operator in Germany. A P-MP system with a Central Station (sector antenna 120°) and a Terminal Station (direction antenna, 22dBi) was assumed to be representative for the majority of BFWA systems

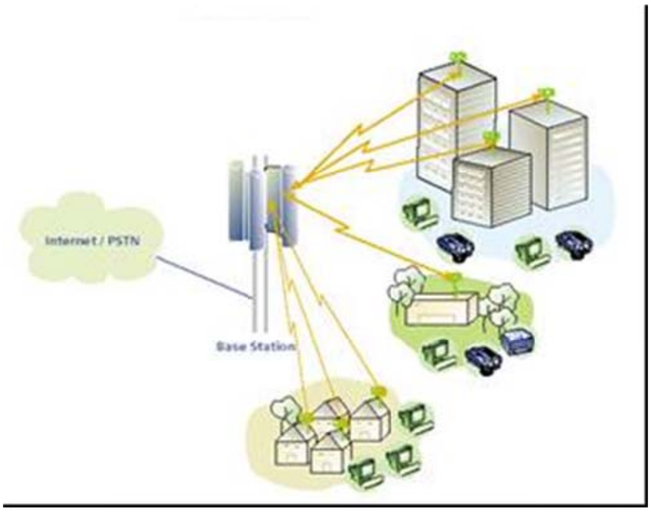


Figure 7: Typical BFWA P-MP deployment scenario (from ECC Report 068 [16])

The technical parameters of the BFWA system used in this study can be found in the following table.

Table 8: BFWA system parameters

Parameter	BFWA P-MP
Topology	Receiver Sectored Central Station (CS) Transmitter Terminal Stations (TS)
Channel bandwidth	20 MHz
Duplex/ Access scheme	TDD/TDMA
Max Tx power dBm TS (conducted)	14 dBm
Max e.i.r.p.	36 dBm
Max Power density spectral (dBm/MHz) e.i.r.p.	23 dBm/MHz
Adaptive power control dB	12 dB
Antenna CS (Rx antenna-> Victim Link Receiver)	16 dBi, sector antenna 120°, 4° down tilt See Figure 8.
Antenna height CS	30 m
Antenna TS (Tx antenna-> Victim Link Transmitter)	22 dBi (see Figure 9 below)
Antenna height TS	10 m
Receiver sensitivity 64-QAM	-68 dBm
Fading Margin	10 dB
Minimum wanted power at TS and BS (Sensitivity – fade margin)	-58 dBm
Protection ratio 64 QAM	C/(I+N) 24 dB C/N=C/I=27 dB
I/N	0 dB
Receiver Noise floor	-95 dBm
Link lenght	Typical 1 km
Path loss model	Spherical diffraction (outdoor, outdoor) see ANNEX 3:

The following figures provide an overview of the BFWA antenna pattern.

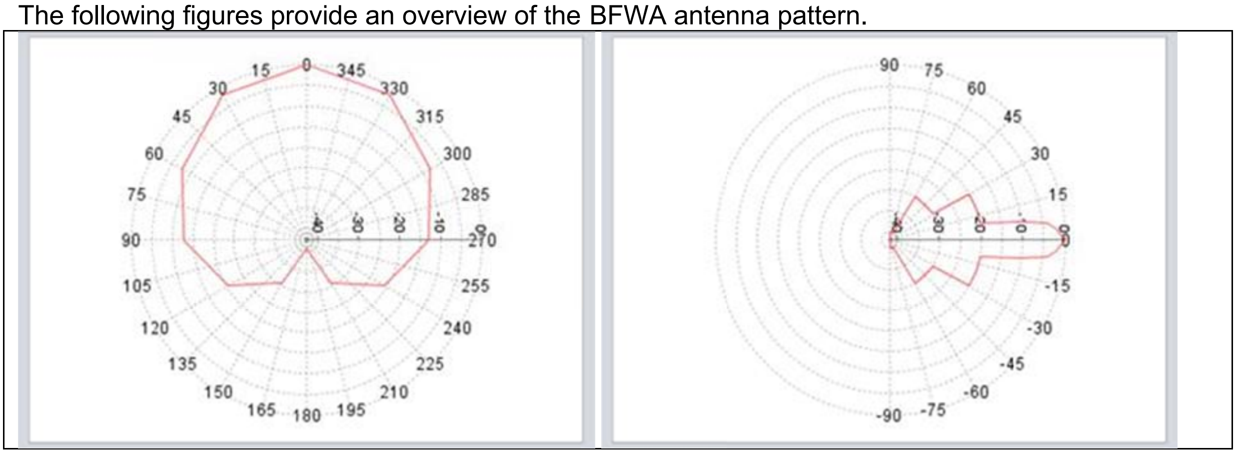


Figure 8: Horizontal and Vertical Pattern of BFWA CS Rx

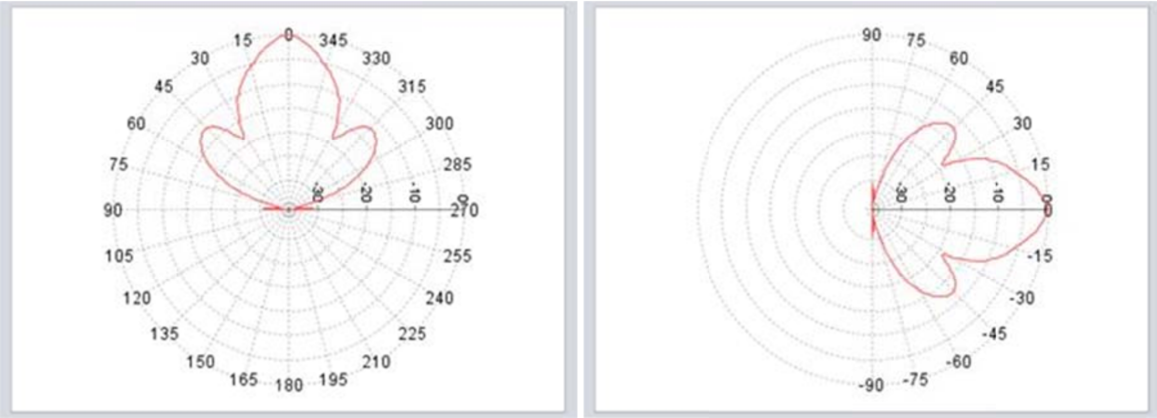


Figure 9: Horizontal and Vertical Pattern of BFWA Ts

Mid-Gain Airmax Sector 5G-120-16

Antenna and Electrical Characteristics

Frequency Range	5.10-5.85 GHz
Gain	15.0-16.0dBi
Polarization	Dual Linear
Cross-pol Isolation	22dB min
Max VSWR	1.5:1
Hpol Beamwidth (6dB)	137 deg.
Vpol Beamwidth (6dB)	118 deg.
Elevation Beamwidth	8 deg.
Electrical Downtilt	4 deg.
ETSI Specification	EN 302 326 DN2
Dimensions	367x63x41mm
Weight	1.1 kg
Windloading	120 mph

Figure 10: Typical P-MP Central station (Ubiquiti Networks, www.ubnt.com)

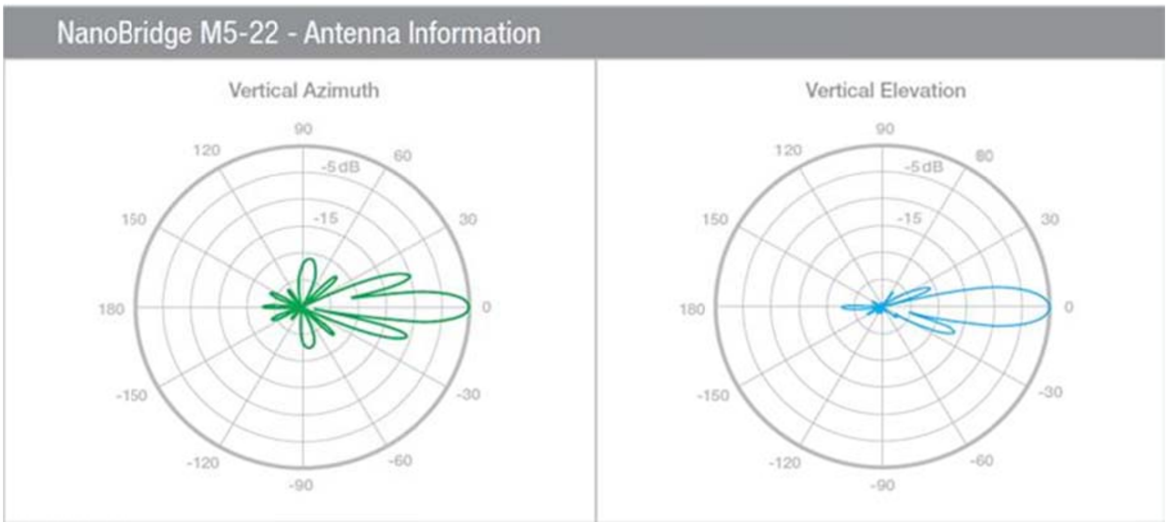


Figure 11: Typical BFWA Terminal Station antenna pattern (Ubiquiti Networks, www.ubnt.com)

Figure 12: Typical BFWA TS antenna (Ubiquiti Networks, www.ubnt.com)

3.4 FIXED SATELLITE (E-S) SERVICE (FSS)

FSS deployments use the whole band 5725-5925 MHz and it is used by transmitting earth stations in the Earth-to-space direction operating only to satellites in geostationary orbits. In the 125 MHz portion of the band up to 5850 MHz, this is a Region 1 allocation only (i.e. only Europe, Africa, and some of the northernmost countries in Asia). Above 5850 MHz the band is part of the heavily utilised FSS global uplink band and most of the currently operating satellites (INTELSAT & New Skies for instance) have receive transponders in this upper portion of the band.

The following table 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. The parameters shown are those required in sharing studies with the WIA systems. In these frequency bands, the satellite beams cover very large areas of the Earth (using global, hemispherical, zonal or regional beams) as can be seen by the satellite footprint coverage plots in Annex 6 of ECC Report 68 [16].

Table 9: Sample Satellite Data taken from ITU filings for the band 5725-5875MHz

Satellite	Sub-satellite longitude	Part of Frequency range 5725-5875 MHz used	Satellite Maximum Receive Gain G_{sat}(dBi)	Space Station Receiving System Noise Temperature T_{sat} (Kelvin)
A	5° West	Whole band	34	773
B	14° West	Whole band	26.5	1200
C	31.5° West	> 5850 MHz	32.8	700
D	3° East	Whole band	34	773
E	18° West	>5850MHz	32.8	700
F	53° East	Whole band	26.5	1200
G	59.5° East	Whole band	34	1200
H	66° East	>5850 MHz	34.7	700
I	359° East	>5850 MHz	32.8	700

The following figure shows the basic sharing scenario between WIA terminals and the FSS service. The studies reported in the following section address the aggregate emissions of a large number of WIA terminals into the main beam of satellite receivers.

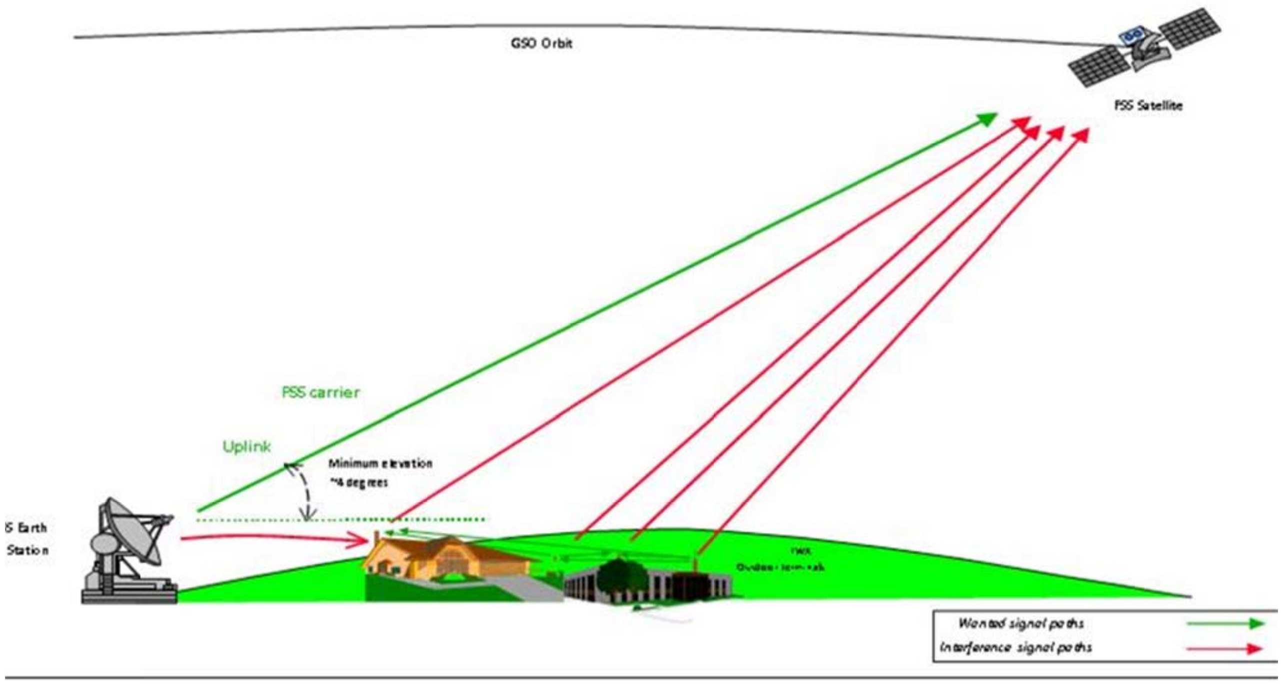


Figure 13: FSS/WIA Sharing Scenario in the band 5725-5875 MHz

3.5 AMATEUR AND AMATEUR-SATELLITE (s-E) SERVICES

The amateur and amateur-satellite (s-E) services have harmonised allocations in all three ITU Regions in the frequency range 5725-5850 MHz with secondary status as follows:

Table 10: Allocations for Amateur Services

Frequency	Service
5725-5830 MHz	Amateur
5830-5850 MHz	Amateur Amateur Satellite (space-to-Earth)

The operational characteristics of amateur stations and amateur-satellite stations vary significantly. However based on the IARU Region-1 VHF Managers Handbook they can be categorised as:

- Weak signal reception of Narrowband Terrestrial and EME (Moonbounce) operation in the sub-band 5760-5762 MHz, including propagation beacons.
- Data and multimedia systems (point to-point links and area repeaters) in other parts of the band.
- Low-power satellite downlinks within 5830-5850 MHz (typically from LEO Cubesat satellites).

3.5.1 Characteristics for the Amateur Service

Recommendation ITU-R M.1732-1 [17] provides characteristics of stations operating in the amateur service for use in sharing studies:

Table 11: Examples of Amateur Service characteristics in the band 5725-5850 MHz

Parameter	CW-Morse, EME	SSB Voice	FM Voice	Digital Voice and Multimedia
Transmitter Power(1) (dBW)	3 – 20 (typically: 13)	3 – 20 (typically: 13)	3 – 20 (typically: 10)	1-10 (typically: 6)
Transmitter Feeder Loss (dB)	1 – 2 (typically: 1)	0 – 10 (typically: 1)	0 – 10 (typically: 1)	1 – 6 (typically: 1)
Antenna gain (dBi)	0 – 40 (typically: 33)	0 – 40 (typically: 33)	0 – 40 (typically: 33)	0 – 30 (typically: 27)
Typical e.i.r.p.(dBW)	1 – 45 (typically: 45)	1 – 45 (typically: 45)	1 – 45 (typically: 42)	10 – 40 (typically: 32)
Antenna polarisation	Horizontal, Vertical,	Horizontal, Vertical	Horizontal, Vertical	Horizontal, Vertical.
Receiver IF bandwidth (kHz)	0.4	2.7	9 15	2.7, 6, 16, 130, 10500
Receiver Noise Figure(2) (dB)	1 – 7 (typically 1	1 – 7 (typically 1)	1 – 3 (typically 2)	2

(1) Maximum powers are determined by each administration.
(2) Receiver noise figures for bands above 50 MHz assume the use of low-noise preamplifiers.

In order to simplify studies[1], it is assumed a typical terrestrial CW/SSB amateur station uses a 0.9 m (33 dBi) dish directional antenna, 13 dBW (20 Watt transmitter), and has a 1 dB NF receiver optimised for the 5760-5762 MHz band. The receiver LNA is assumed to be at the antenna feedpoint, so feeder losses for the receiver situation can be ignored (i.e. assumed to be 0dB).

The determination of the maximum tolerable interference level from emissions of a single WIA device at the Amateur Service (AS) receiver is based on ECC Report 172 [18], where it is said that this level should be lower than N + (I/N) where N is the AS receiver inherent noise level and I/N the interference to noise ratio. The interference to noise ratio can be taken as –10 dB as given in ECC Report 172 [18].

3.5.2 Characteristics for the Amateur-Satellite Service

In the 5GHz bands the Amateur Satellite service has two distinct ITU secondary allocations:

- 5650-5670 MHz Earth-to-Space only (i.e. for uplinks);
- 5830-5850 MHz space-to-Earth only (i.e. for downlinks).

As Wireless Industrial Applications are being studied for the frequency range 5725-5875 MHz, only sharing with reception of amateur satellite space-to-Earth downlinks need be considered, as the uplink allocation is outside of the WIA frequency range.

Recommendation ITU-R M.1732-1 [17] provides characteristics of stations operating in the amateur-satellite service for use in sharing studies:

[1] In Recommendation ITU-R M.1732-1 [17] the specific 5.7GHz band is combined with other amateur bands. Therefore some adjustments have been made in order to be more representative of 5.7GHz equipment

Table 12: Characteristics of Amateur-Satellite systems in the space-to-Earth direction

Parameter	CW-Morse	SSB, FM, Digital Voice, Data
Transmitter Power [(1)] (dBW)	10	10
Transmitter Feeder Loss (dB)	0.2 – 1	0.2 – 1
Transmitting antenna gain (dBi).	0 – 6	0
Typical e.i.r.p.(dBW)	0 – 15	9 – 15
Antenna polarisation	Horizontal, Vertical, LHCP, RHCP	Horizontal, Vertical, LHCP, RHCP
Receiver IF bandwidth (kHz)	0.4	2.7, 16, 50, 100
Receiver Noise Figure [(2)] (dB)	1 – 3 (typically: 1)	1 – 3 (typically: 2)

[(1)] Maximum powers are determined by each administration.
[(2)] Receiver noise figures for bands above 50 MHz assume the use of low-noise preamplifiers.

Most current amateur satellites are typically nano or picosats (also called ‘cubesats’) that occupy slightly elliptical Sun-Synchronous low earth orbits (LEO) of 600-800km altitude. These smaller satellites have relatively low power and antenna gain.

As geostationary systems are generally not in use, it may be noted that for CW systems, therefore, a practical issue arises due to LEO Doppler shift that requires slightly wider Rx rf bandwidth. Therefore, many amateurs would in practice stick to a single 2.4 kHz BW using the SSB-Voice system. Therefore, for the purpose of this report, only the SSB-Voice case is considered in the sharing studies.

For sharing studies 0 dBW Tx Power, 0.5 dB feeder loss and 3 dB antenna gain for a patch antenna are assumed for the satellite; and the amateur receiving ground station is assumed to be similar to the Amateur Service (see section 4.5).

It should be noted that most amateur satellite downlinks are coordinated and harmonised in a sub-band at 5840-5842 MHz.

3.6 INTELLIGENT TRANSPORT SYSTEMS (ITS)

Administrations are recommended to make the frequency band 5855-5875 MHz available for ITS non-safety applications in order to support and enhance ITS all over Europe (see ECC/REC/ (08)01 [33]). Non-safety applications means Inter Vehicle Communication (IVC) and Roadside to Vehicle (R2V) communication. Examples of non-safety applications includes:

- Internet access;
- Points of interest notification;
- Traffic control.

Safety related ITS applications are intended to be used in the band 5.875 to 5.925 GHz (ECC/DEC/(08)01 [36] and Commission Decision 2008/671/EC [37]).

ITS applications can be summarized as follows:

1. Inter-Vehicles Communications (IVC) (this includes multi-hop routing involving several vehicles):
    - Linear (e.g. for convoys of vehicles);
    - Vehicle cluster covering several lanes (e.g. for lane management, overtaking assist).
2. Vehicle to Roadside (uplink) V2R and Roadside to Vehicle R2V (downlink):
    - One vehicle to beacon;

- Beacon to one vehicle;
- Beacon to many vehicles (broadcast, short range and long range);
- Beacon to selected vehicles.

3. Cluster of vehicles communication, including to roadside beacon.

More details can be found in ECC Report 101 [5].

3.6.1 Parameters

ECC Report 101 [5] considers the following list of parameters for ITS systems (see also SRdoc ETSI TR 102 492-1 [19]).

Table 13: Systems parameters

Parameter	Value	Comments
Frequency stability	1ppm	This figure takes account of the frequency tolerance allowed by IEEE 802.11 [20], together with the expected Doppler variation from a vehicle closing speed of 400 km/h.
Maximum radiated power (e.i.r.p.)	Equipment classes: A 10 dBm B 20 dBm C 33 dBm	Transmitter power control (TPC) with a 30 dB range.
Antenna beam shape/gain	RSU: 10 dBi OBU: 5; 8 dBi	See Figure 14 and Figure 15
Modulation scheme	BPSK QPSK 16QAM 64QAM	This is the standard set within IEEE 802.11 [20]
Data rates	3/4.5 /6/9/ 12/18 /24/27 Mbit/s	This is the standard set within IEEE 802.11 [20]. As an option two channels may be combined to produce double data rates (up to 54 Mbit/s). Default data rate is 6Mbit/s.
Channel Bandwidth	10 MHz, option 20 MHz	This is the standard set within EEE 802.11 [20].
Communication mode	Half-duplex, broadcast	Half-duplex and broadcast are believed to be adequate for the applications considered to date.
Receiver sensitivity	-92dBm/MHz	Based on -82 dBm for a bandwidth of 10 MHz
Protection criterion	C/I=6dB	For a classical BPSK signal

Communication channels will be open for the applications within the respective usage category (either road safety related or not, i.e. used for traffic management).

The required power levels (e.i.r.p.) range from 3 dBm to 33 dBm to achieve communication distances of up to 1000 m.

The technical parameters used for interference assessment are given in the following table.

Table 14: Technical parameters of ITS devices used for compatibility study

Characteristics	Value	Unit
Receiver bandwidth	10	MHz
Receiver sensitivity	-82	dBm
Receiver sensitivity	-92	dBm/MHz
Antenna gain	8	dBi
Receiver sensitivity at antenna	-100	dBm/MHz
C/I	6	dB
Allowable Interfering Power at receiver	-98	dBm/MHz
Allowable Interfering Power at receiver antenna	-106	dBm/MHz
Transmitter Characteristics		
Bandwidth	10	MHz
Tx_{out}, e.i.r.p	33	dBm
Tx_{out} e.i.r.p per MHz	23	dBm/MHz
Assumed value for TPC	8	dB
Net Tx_{out} e.i.r.p	15	dBm/MHz
Antenna Gain	8	dBi

Table 15: ITS Channel utilization

Channel type	Centre frequency	CH No.	Channel spacing	Default data rate	TX power limit	TX power density limit
G5CC	5 900 MHz	180	10 MHz	6 Mbit/s	33 dBm e.i.r.p	23 dBm/MHz
G5SC2	5 890 MHz	178	10 MHz	12 Mbit/s	23 dBm e.i.r.p	13 dBm/MHz
G5SC1	5 880 MHz	176	10 MHz	6 Mbit/s	33 dBm e.i.r.p	23 dBm/MHz
G5SC3	5 870 MHz	174	10 MHz	6 Mbit/s	23 dBm e.i.r.p	13 dBm/MHz
G5SC4	5 860 MHz	172	10 MHz	6 Mbit/s	0 dBm e.i.r.p	-10 dBm/MHz
G5SC5	As required in EN 302 571 for the band 5470-5725 MHz		several	dependent on channel spacing	30 dBm e.i.r.p (DFS master)	17 dBm/MHz
					23 dBm e.i.r.p (DFS slave)	10 dBm/MHz

The e.i.r.p. given in Table 15 are based on the values given in EN 302 571. However, the calculations are provided based on an e.i.r.p of 33 dBm since it is allowed by the regulations (see ECC Recommendation (08)01 and Commission decision 2008/671/EC).

Typical antenna pattern for the two ITS devices RSU and OBU are shown in Figure 14 and Figure 15. It is an essential design feature of communications between vehicles, or between vehicles and local infrastructure beacons, that they are directed more or less horizontally in a typical omni-directional pattern with typically 8 dBi gain in the horizontal plane.

The RSU and OBU antenna gain is 5 dBi vertical linear (8 dBi left circular) with an elevation angle of 10° see Figure 15.

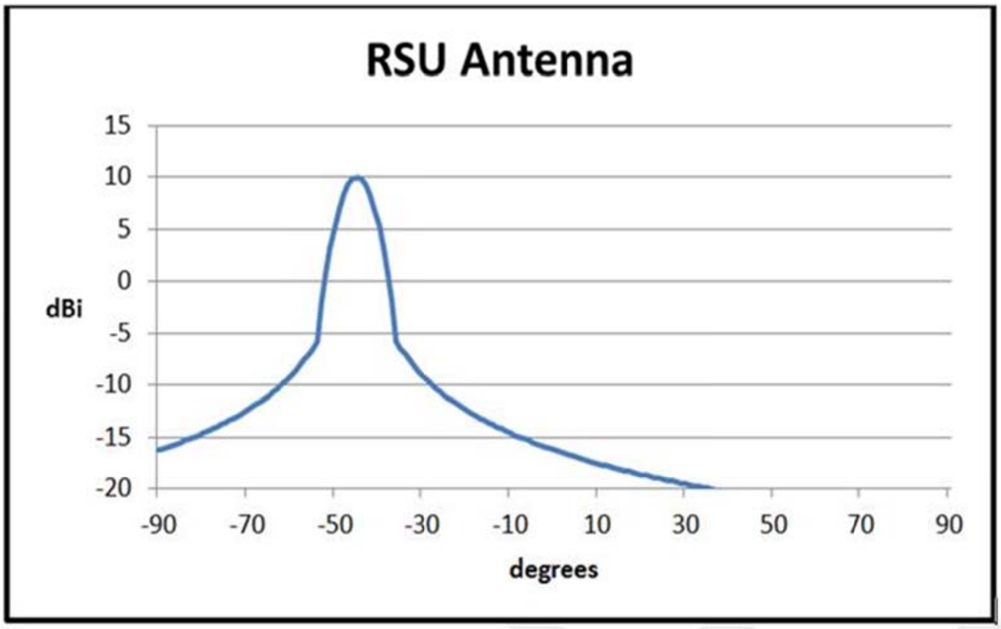


Figure 14: Horizontal antenna pattern RSU (antenna gain: 10 dBi)

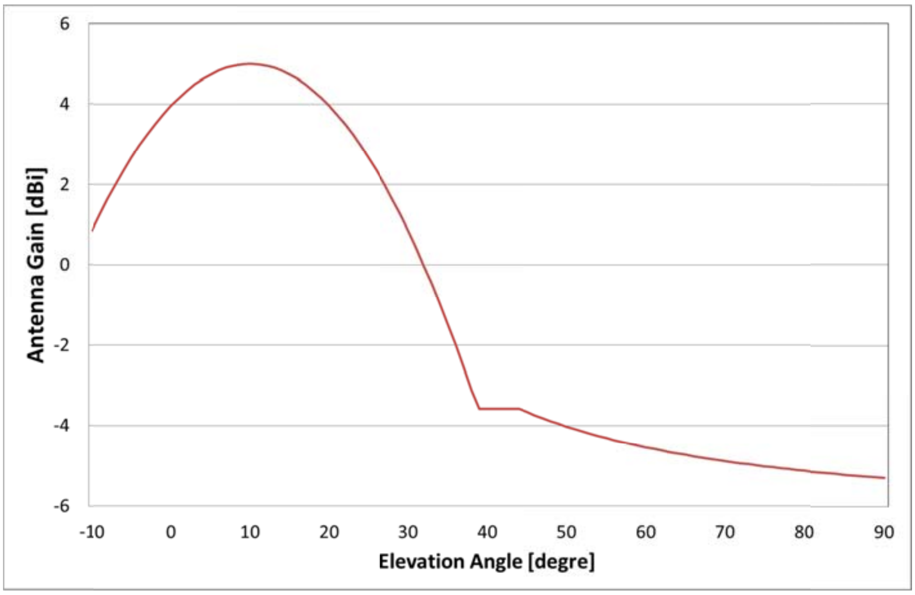


Figure 15: Horizontal antenna pattern OBU (antenna gain: 5 dBi)

The antenna pattern from Figure 14 has been used in this report for RSU and the antenna pattern from Figure 15 has been used in this report for OBU.

3.7 SHORT RANGE DEVICES (SRD)

3.7.1 General (non-specific) SRD

As specified in Annex 1 of ERC/REC 70-03 [2], the frequency band 5725-5875 MHz is used by non-specific SRD. This use should comply with the technical characteristics as shown below.

Table 16: Technical characteristics of SRD

Frequency Band	Power	Antenna	Channel Spacing	Duty Cycle (%)
5725-5875 MHz	25 mW e.i.r.p	Integral (no external antenna socket) or dedicated	No channel spacing - the whole stated frequency band may be used	No duty cycle restriction

In addition to these regulatory technical characteristics, assumptions on some parameters had to be made in order to carry out compatibility studies. Three kinds of SRD were considered for the interference assessment (see the following table) as in previous CEPT studies (see for example [5]). Updated system parameters and examples of real existing equipment were not available at the time this report has been created.

Table 17: SRD parameters

Parameter	SRD I	SRD II	SRD III	Comments
Typical bandwidth BW (MHz)	0.25 MHz	20 MHz	8MHz	Note 1, Note 2.
TX Power, dBm e.i.r.p.	+14	+14	+14	
Ant. Gain, dBi	2 to 20	2 to 24	2	
Ant. Polarization	Circular	Circular	Vertical	
Receiver sensitivity, dBm	-110	-91	-84	
Protection criterion, dB	I/N=0dB	C/I=8dB	C/I=20dB	
FkTB	-105 dBm/MHz	N/A	N/A	
Max OoB RX interference, dBm	-35	-35	-35	E.g. limit for Rx blocking
Duty cycle : %	Up to 100%	Up to 100%	100%	
RX wake-up time (if applicable)	1 sec	1 sec	N/A	For battery operated equipment

Note 1: The given bandwidths are for non-spread spectrum modulation.

Note 2: For spread spectrum modulation (FHSS, DSSS and other types) the bandwidth can be up to 100 MHz

3.7.2 Tank Level Probing Radar (TLPR)

Tank Level Probing Radar (TLPR) are installed in closed metallic tanks or reinforced concrete tanks, or similar enclosure structures made of comparable attenuating material, holding a substance, liquid or powder. TLPR utilizes bandwidths that extend over multiple frequency bands allocated to numerous radio services. The emission limits for TLPR are specified outside the tank (see EN 302 372 [22]).

Given the attenuation resulting from the tank of TLPRs and their low susceptibility to interference to narrow band signals, it is considered that compatibility studies for the protection of TLPR are not necessary (see CEPT Report 26 [23]).

The power limits for these bands are -41.3 dBm/MHz e.i.r.p. outside the tank but in reality the power levels outside the actual tank are much lower than this maximum value. The value of -41.3 dBm/MHz e.i.r.p. is based on a standard test tank of 500 litres. The reason for doing so is as follows. Levels outside an installed tank are in many cases difficult if not impossible to measure because average is ranging from 8 to 100,000 cubic meters. In practice therefore a test tank of 500 litre is used that fits for example in an anechoic chamber. The practical outside levels of an installed tank however are lower (varying from 20dB to 30dB thanks the cavity attenuation) than the -41.3 dBm/MHz limit the test tank emits. Therefore no interference is expected from TLPR on WIA.

It was also considered in the past that compatibility studies for TLPR are not necessary (see CEPT Report 26 [23]).

4 COMPATIBILITY STUDIES

The section details the compatibility studies between the industrial applications using other technologies different from UWB (WIA) systems (see section 2 and ANNEX 1:) and other radio communications services and systems (see section 3).

The following table provides an overview of the WIA systems considered for the compatibility studies.

Table 18: WIA characteristics

Characteristic	WIA I	WIA II	WIA III	WIA IV
Indoor/Outdoor	Indoor	Indoor	Outdoor	Outdoor
Transmit power (dBm)	26	26	26	26
Bandwidth (MHz)	1	20	3	20
Transmit power (dBm/MHz)	26	13	21	13

4.1 RADIOLOCATION SERVICE

This section of the report examines the prospects of co-channel sharing between radar systems and the industrial applications using other technologies different from UWB operating in frequency band 5725-5850 MHz. Information and technical characteristics of the considered radars can be found in section 3.1. This section provides basic calculations of the interference level from a single WIA device into radars and identifies the need for mitigation techniques which are described in subsequent sections.

4.1.1 MCL Calculations

4.1.1.1 Methodology for calculating interference from WIA into Radar

The determination of the maximum tolerable interference level from emissions of a single WIA device at the radar receiver is based on Recommendation ITU-R M.1461 [24], where it is said that this level should be lower than N + (I/N) where N is the radar receiver inherent noise level and I/N the interference to noise ratio. The interference to noise ratio can be taken as –6 dB as given in Recommendations ITU-R M.1461 and ITU-R M.1638 [6].

Interference from WIA into Radars

In this section, the method used to calculate the potential interference to Radiolocation devices is based on the Minimum Coupling Loss (MCL) required between radars and WIA systems. The separation distances can be calculated using the free space propagation model.

$$MCL = P_{T\_WIA} + Corr - I_{Radar}$$

where

MCL	*Minimum Coupling Loss in dB*
P_{T_WIA}	*Maximum Transmit Power, before antenna and feeders (WIA) in dBW*
$Corr$	*Bandwidth correction factor:*

if BW_{Radar} *smaller than* BW_{WIA} : $10log\left(\frac{BW_{Radar}}{BW_{WIA}}\right)$

if BW_{Radar} *larger than* BW_{WIA}: *0*

and where:

BW_{Radar}	*Receiver Noise Bandwidth (Radar) in Hz*
BW_{WIA}	*Transmitter Bandwidth (WIA) in Hz*

I_{Radar} *Maximum Permissible Interference at Receiver after antenna and feeder (Radar) in dB*

The MCL is then converted into the required propagation loss L_P as follows:

$$L_P = MCL + G_{T\_WIA} - L_{T\_WIA} + G_{R\_Radar} - L_{R\_Radar} - L_{Wall\ Loss}$$

where

G_{T_WIA}	*Gain of the WIA antenna in dBi*
L_{T_WIA}	*WIA feeder loss in dB*
G_{R_Radar}	*Gain of Radar antenna in dBi*
L_{R_Radar}	*Radar feeder loss in dB*
$L_{Wall\ Loss}$	*Wall loss in dB, 15 dB for indoor systems and 0 dB for outdoor systems*

The required separation distances d (in meters) were calculated, assuming free space propagation, from:

$$d = \frac{\lambda}{4\pi} \cdot 10^{\left(\frac{L_P}{20}\right)}$$

where λ *is the wavelength given in meters.*

For these calculations, basic assumptions have been chosen for the WIA parameters transmit power and antenna gain, leading to an e.i.r.p. of 26 dBm:

- in a bandwidth of 1 MHz and 20 MHz for the indoor case (WIA I and WIA II)
- In a bandwidth of 3 MHz and 20 MHz for the outdoor case (WIA III and WIA IV)

Table 19: Separation distances WIA I (1 MHz – indoor) – Radar systems

Parameter		Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X & Y	Radar Z
Radar	Receiver IF3dB bandwidth B (MHz)	4.8	4	8	8	10	4	1
	Antenna main beam gain	54	47	45.9	42	30	35	31.5
	Antenna height (m)	20	15	20	20	40	10	10
	Radar feeder loss (dB)	0	0	0	0	0	0	0
	Minimum discernible signal (dBm)	-107	-100	-107	-100	-102	-103	-108
	Receiver noise figure F (dB)	5	5	11	5	10	5	13
	Noise level kTB (dBm)	-107.2	-108.0	-104.9	-104.9	-104.0	-108.0	-114.0
	Noise level kTBF(dBm)	-102.2	-103.0	-93.9	-99.9	-94.0	-103.0	-101.0
	Max acceptable interference level with I/N -6dB (dBm)	-108.2	-109.0	-99.9	-105.9	-100.0	-109.0	-107.0
WIA I	WIA e.i.r.p (dBm) outdoor	26	26	26	26	26	26	26
	WIA feeder loss	0	0	0	0	0	0	0
	Antenna Gain (dBi)	0	0	0	0	0	0	0
	Bandwidth (MHz)	1	1	1	1	1	1	1
Calculations	Bandwidth correction factor (dB)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Minimum coupling loss (dB)	134.2	135.0	125.9	131.9	126.0	135.0	133.0
	Wall Loss (dB)	15.0	15.0	15.0	15.0	15.0	15.0	15.0
	Required propagation loss (dB)	173.2	167.0	156.8	158.9	141.0	155.0	149.5
	Frequency (MHz)	5800	5800	5800	5800	5800	5800	5800
	Wavelength (m)	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Free space distance (km)	1873	916	286	364	46	230	122

Table 20: Separation distances WIA II (20 MHz – indoor) – Radar systems

	Parameter	Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X & Y	Radar Z
Radar	Receiver IF3dB bandwidth B (MHz)	4.8	4	8	8	10	4	1
	Antenna main beam gain	54	47	45.9	42	30	35	31.5
	Antenna height (m)	20	15	20	20	40	10	10
	Radar feeder loss (dB)	0	0	0	0	0	0	0
	Minimum discernible signal (dBm)	-107	-100	-107	-100	-102	-103	-108
	Receiver noise figure F (dB)	5	5	11	5	10	5	13
	Noise level kTB (dBm)	-107.2	-108.0	-104.9	-104.9	-104.0	-108.0	-114.0
	Noise level kTBF (dBm)	-102.2	-103.0	-93.9	-99.9	-94.0	-103.0	-101.0
	Max acceptable interference level with I/N -6dB (dBm)	-108.2	-109.0	-99.9	-105.9	-100.0	-109.0	-107.0
WIA II	WIA e.i.r.p (dBm) outdoor	26	26	26	26	26	26	26
	WIA feeder loss	0	0	0	0	0	0	0
	Antenna Gain (dBi)	0	0	0	0	0	0	0
	Bandwidth (MHz)	20	20	20	20	20	20	20
Calculations	Bandwidth correction factor (dB)	-6.2	-7.0	-4.0	-4.0	-3.0	-7.0	-13.0
	Minimum coupling loss (dB)	128.0	128.0	122.0	128.0	123.0	128.0	120.0
	Wall Loss (dB)	15.0	15.0	15.0	15.0	15.0	15.0	15.0
	Required propagation loss (dB)	167.0	160.0	152.9	155.0	138.0	148.0	136.5
	Frequency (MHz)	5800	5800	5800	5800	5800	5800	5800
	Wavelength (m)	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Free space distance (km)	917	410	181	230	33	103	27

Table 21: Separation distances WIA III (3 MHz – outdoor) – Radar systems

	Parameter	Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X & Y	Radar Z
Radar	Receiver IF3dB bandwidth B (MHz)	4.8	4	8	8	10	4	1
	Antenna main beam gain	54	47	45.9	42	30	35	31.5
	Antenna height (m)	20	15	20	20	40	10	10
	Radar feeder loss (dB)	0	0	0	0	0	0	0
	Minimum discernible signal (dBm)	-107	-100	-107	-100	-102	-103	-108
	Receiver noise figure F (dB)	5	5	11	5	10	5	13
	Noise level kTB (dBm)	-107.2	-108.0	-104.9	-104.9	-104.0	-108.0	-114.0
	Noise level kTBF (dBm)	-102.2	-103.0	-93.9	-99.9	-94.0	-103.0	-101.0
	Max acceptable interference level with I/N -6dB (dBm)	-108.2	-109.0	-99.9	-105.9	-100.0	-109.0	-107.0
WIA III	WIA e.i.r.p (dBm) outdoor	26	26	26	26	26	26	26
	WIA feeder loss	0	0	0	0	0	0	0
	Antenna Gain (dBi)	0	0	0	0	0	0	0
	Bandwidth (MHz)	3	3	3	3	3	3	3
C	Bandwidth correction factor (dB)	0.0	0.0	0.0	0.0	0.0	0.0	-4.8

Parameter		Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X & Y	Radar Z
	Minimum coupling loss (dB)	134.2	135.0	125.9	131.9	126.0	135.0	128.2
	Wall Loss (dB)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Required propagation loss (dB)	188.2	182.0	171.8	173.9	156.0	170.0	159.7
	Frequency (MHz)	5800	5800	5800	5800	5800	5800	5800
	Wavelength (m)	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Free space distance (km)	10530	5152	1609	2049	259	1294	398

Table 22: Separation distances WIA IV (20 MHz – outdoor) – Radar systems

Parameter		Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X & Y	Radar Z
Radar	Receiver IF3dB bandwidth B (MHz)	4.8	4	8	8	10	4	1
	Antenna main beam gain	54	47	45.9	42	30	35	31.5
	Antenna height (m)	20	15	20	20	40	10	10
	Radar feeder loss (dB)	0	0	0	0	0	0	0
	Minimum discernible signal (dBm)	-107	-100	-107	-100	-102	-103	-108
	Receiver noise figure F (dB)	5	5	11	5	10	5	13
	Noise level kTB (dBm)	-107.2	-108.0	-104.9	-104.9	-104.0	-108.0	-114.0
	Noise level kTBF (dBm)	-102.2	-103.0	-93.9	-99.9	-94.0	-103.0	-101.0
	Macceptable interference level with I/N -6dB (dBm)	-108.2	-109.0	-99.9	-105.9	-100.0	-109.0	-107.0
WIA IV	WIA e.i.r.p (dBm) outdoor	26	26	26	26	26	26	26
	WIA feeder loss	0	0	0	0	0	0	0
	Antenna Gain (dBi)	0	0	0	0	0	0	0
	Bandwidth (MHz)	20	20	20	20	20	20	20
Calculations	Bandwidth correction factor (dB)	-6.2	-7.0	-4.0	-4.0	-3.0	-7.0	-13.0
	Minimum coupling loss (dB)	128.0	128.0	122.0	128.0	123.0	128.0	120.0
	Wall Loss (dB)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Required propagation loss (dB)	182.0	175.0	167.9	170.0	153.0	163.0	151.5
	Frequency (MHz)	5800	5800	5800	5800	5800	5800	5800
	Wavelength (m)	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Free space distance (km)	5159	2304	1017	1296	183	579	154

4.1.1.2 Determination of required separation distance

Although the above calculations are showing large separation distances, it is expected that the necessary separation distances are limited by the value of the radio-horizon H_e which is calculated with the following formula:

$$H_e[km] = 4.12 \cdot (\sqrt{h_{WIA}} + \sqrt{h_{Radar}})$$

where h_{WIA} and h_{Radar} correspond to the antenna heights of the WIA and radar respectively.

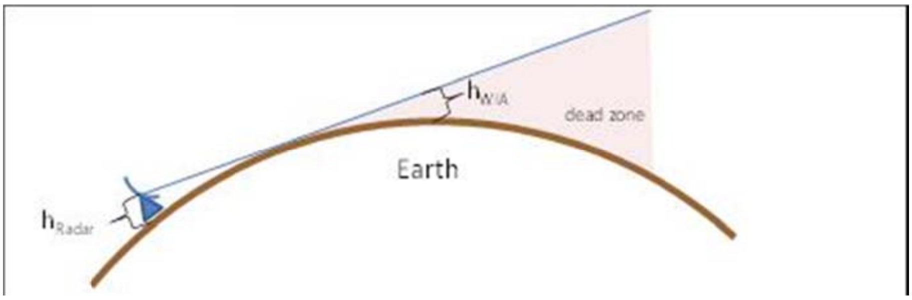


Figure 16: Radar and WIA horizon

Table 23: Separation distance - horizon

Characteristic	Factory hall	Plant level
Range of antenna high WIA	2 to 6 m	1.5 to 50 m
Typical Antenna high WIA	4 m	2 m to 50 m
He (hRadar=10 m)	21.2 km	18.9 km to 42.2 km
He (hRadar=15 m)	24.2 km	21.8 km to 45.1 km
He (hRadar=20 m)	26.7 km	24.3 km to 47.6 km
He (hRadar=40 m)	34.3 km	31.9 km to 55.2 km

In case, radars are installed on top of terrain relieves to improve their range by setting them over ground clutter, the effective radar height should be considered and the separation distance increased accordingly.

With the assumed antenna heights for h_{WIA} and h_{Radar}, the required separation distance is in the order of 20 to 55 km.

4.1.2 Aggregated impact

This section provides considerations on the aggregated impact.

The number of WIA seen by a radar is a function of the distance between radar and WIA location and the radar antenna beam width. If the radar is located far away, all the active transmitters of a factory can be visible (see Annex 1). The below figures are aimed to illustrate the situation.

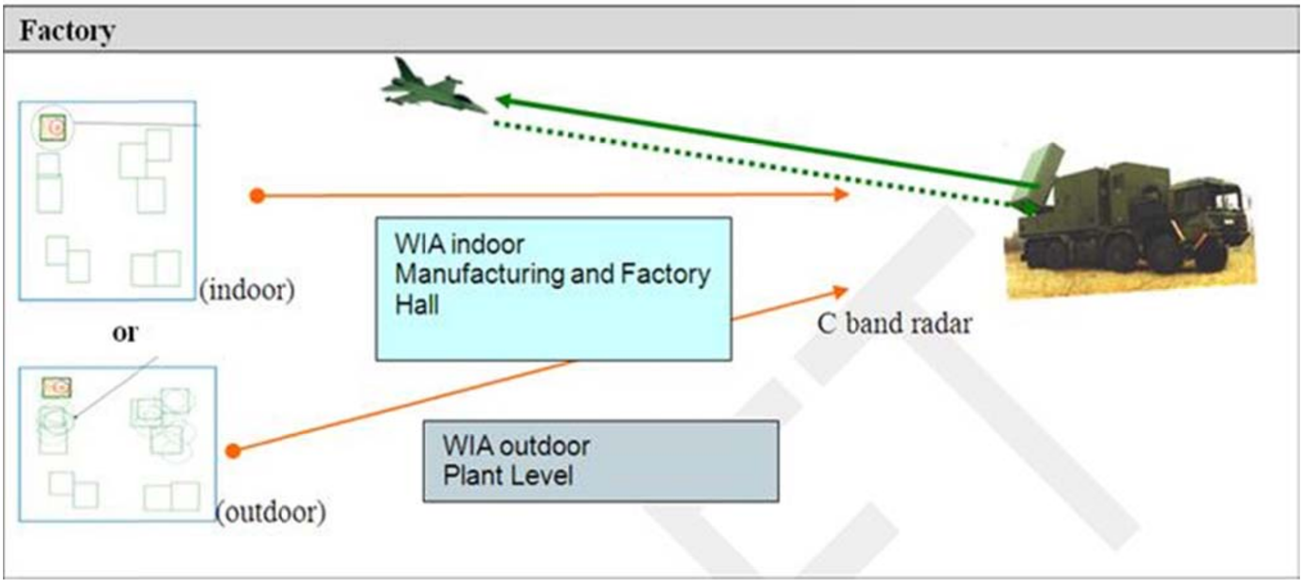


Figure 17: Cohabitation synoptic of WIA and military radar

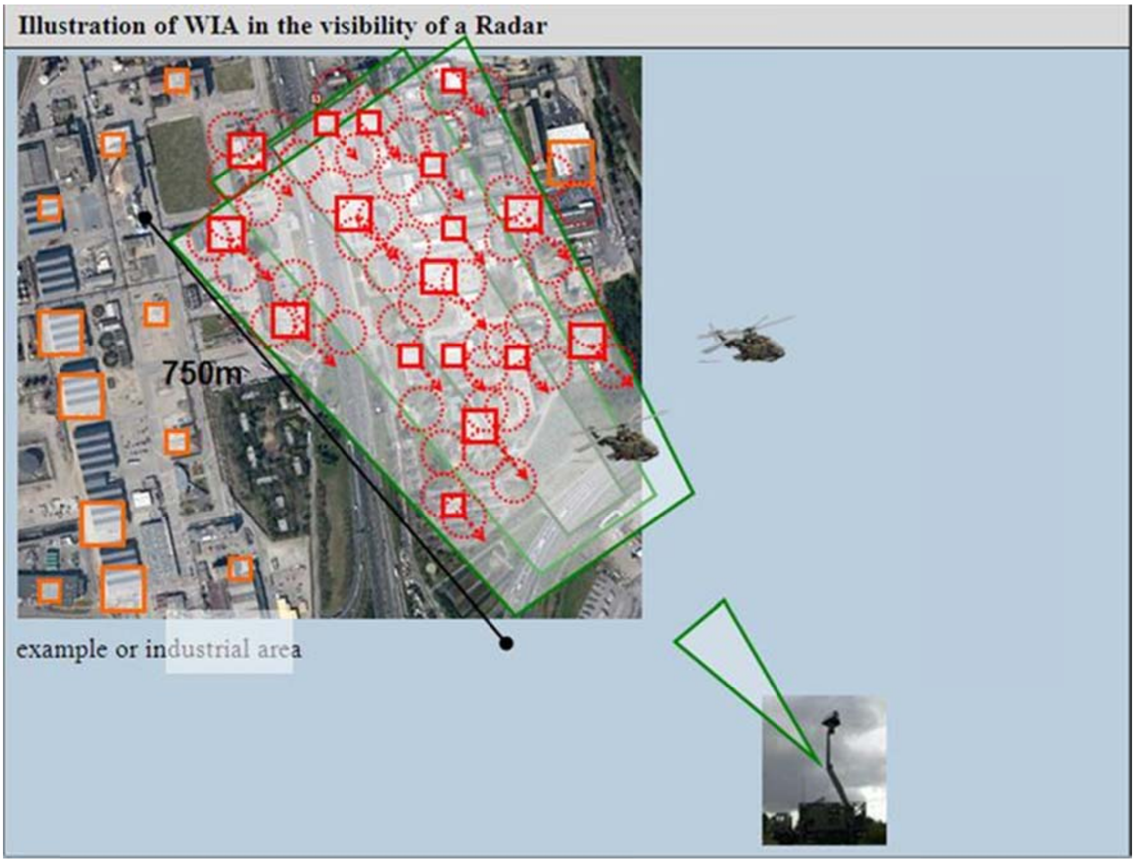


Figure 18: cohabitation synoptic of WIA in an industrial area and military radar

The aggregated impact has not been considered in this report. Further analysis may be required to assess the aggregated impact on the radar.

4.1.3 DFS consideration

Dynamic Frequency Selection (DFS) is a mechanism which may allow WIA to detect radar in order to operate without causing undue interference to radar operating in the 5725 to 5850 MHz bands. The same mechanism also enables BFWA systems to operate in the 5725 to 5850 MHz band, at least in those countries that have implemented the ECC/REC/(06)04 [12]. DFS is a mitigation technique, intended to sense the presence of radar signals in a given channel and prevent WIA signals from transmitting on that channel.

ANNEX 5: provides the methodology to determine the threshold to detect radar systems. Such a methodology has been used to determine DFS detection thresholds for RLAN, BBDR and BFWA at 5 GHz.

The following table provides an overview of the calculated threshold depending on the WIA under consideration.

Table 24: DFS thresholds

Characteristics of the Radars	Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X & Y	Radar Z
DFS Detection threshold Th (dBm) – WIA 1 MHz	-39.51	-46.19	-48.68	-55.80	-53.43	**-65.19**	-49.53
DFS Detection threshold Th (dBm) – WIA 3 MHz	-34.73	-41.41	-43.91	-51.03	-48.66	**-60.41**	-44.76
DFS Detection threshold Th (dBm) – WIA 20 MHz	-26.50	-33.18	-35.67	-42.79	-40.42	**-52.18**	-36.52

4.1.4 Conclusion

It can be concluded that mitigation techniques are required to enable the sharing between WIA systems and fixed frequency radars.

In the co-channel interference assessment with radiolocation (i.e. below 5850 MHz), mitigation techniques such as an efficient DFS mechanism may improve the compatibility issue noting that frequency hopping radars may trigger on all available channels.

DFS may not allow detecting all types of radars. In particular, some incompatibility may remain with frequency hopping radars. However, this issue has already been identified for other radio systems using DFS.

The Recommendation ITU-R M.1638 [6] is under revision in ITU WP 5B. The report at hand is based on only those radars which are already described in Recommendation ITU-R M.1638 that is in force. The report at hand does not encompass the newly introduced types of radars in the ITU working document.

4.2 ROAD TRANSPORT AND TRAFFIC TELEMATICS (RTTT) SYSTEMS

The RTTT characteristics and parameters are provided in section 3.3.2. WIA and RTTT systems can operate on the same channel, therefore coexistence problems can be expected at both sites. Two main types of potential interference situation have been identified:

- interference from WIA (indoor / outdoor) on the RTTT Road Side Unit (RSU) and vice versa.
- interference from WIA (indoor / outdoor) on the RTTT On Board Unit (OBU) and vice versa.

Section 4.2.1 contains MCL calculations, and section 4.2.2 SEAMCAT simulations.

4.2.1 MCL Calculations

The calculations developed in this section used the same propagation model as in ECC Report 101 [9] (see ANNEX 4:).

4.2.1.1 MCL calculations - RTTT RSU

4.2.1.1.1 *Separation distances between WIA interferer and RTTT RSU victim*

The antenna main beam of RTTT RSU is directed to the lane. Therefore, only the RTTT side lobe is considered relevant in the below calculations.

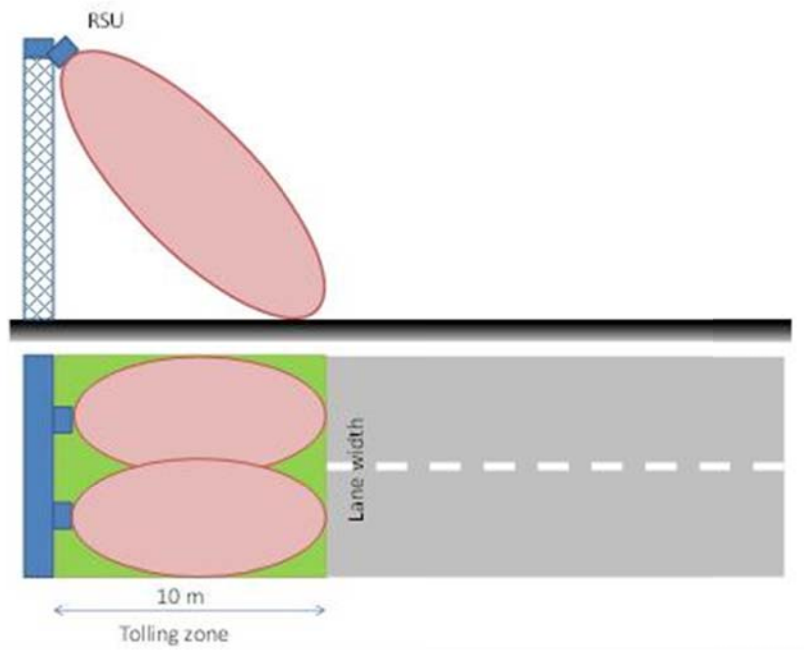


Figure 19: Sharing RSU on the road

The results of calculations for the separation distances between interferer WIA (indoor) with 1 MHz bandwidth and the victim RTTT RSU are provided in the following table.

Table 25: Interferer WIA I (bandwidth 1 MHz – indoor) - Victim RTTT RSU

LINK BUDGET	Units	Propagation model (see Annex 5)			
		Urban	Suburban	Rural	ETSI TR 102- 492
Emission part: WIA-I (1 MHz – indoor)					
Bandwidth	MHz	1	1	1	1
Tx out, e.i.r.p.	dBm	26	26	26	26
Effect of TPC (dB)	dB	0	0	0	0
Wall loss	dB	15	15	15	15
Antenna Gain	dBi	0	0	0	0
Net Tx power density	**dBm/MHz**	**11**	**11**	**11**	**11**

LINK BUDGET	Units	Propagation model (see Annex 5)			
		Urban	Suburban	Rural	ETSI TR 102- 492
Reception part: RSU RTTT					
Receiver bandwidth	MHz	0.5	0.5	0.5	0.5
Receiver sensitivity	dBm	-104	-104	-104	-104
Antenna gain	dBi	10	10	10	10
C min per MHz at antenna input	**dBm/MHz**	**-111**	**-111**	**-111**	**-111**
Protection criterion					
Criterion C/I	dB	6	6	6	6
Acceptable interfering power at receiver	**dBm/MHz**	**-107**	**-107**	**-107**	**-107**
Allowable Interfering power level 'I' at receiver antenna input	**dBm/MHz**	**-117**	**-117**	**-117**	**-117**
MAIN LOBE WIA - SIDE LOBE RTTT					
Sidelobe attenuation	dB	15	15	15	15
Required Attenuation	**dB**	**113**	**113**	**113**	**113**
Separation distance WIA → RTTT	**m**	**329**	**567**	**1037**	**525**

The following table provides an overview of the separation distances for the RTTT RSU as a victim.

Table 26: Separation distances (m) – WIA Interferer - RTTT RSU Victim (Side lobe)

WIA type	Propagation model (see Annex 5)			
	Urban	Suburban	Rural	ETSI TR 102- 492
WIA I – 1 MHz indoor	329	567	1037	525
WIA II – 20 MHz indoor	164	258	357	173
WIA III – 3 MHz outdoor	569	1054	2117	1255
WIA IV – 20 MHz outdoor	366	640	1192	622

4.2.1.1.2 Separation distances between RTTT RSU interferer and WIA victim

The results of calculations for the separation distances between interferer RTTT RSU and the victim WIA are provided in the following table.

Table 27: Separation distances (m) - RTTT RSU Interferer (Side lobe) - WIA Victim

WIA type	Propagation model (see Annex 5)			
	Urban	Suburban	Rural	ETSI TR 102- 492
WIA I – 1 MHz indoor	111	159	182	95
WIA II – 20 MHz indoor	140	210	279	134
WIA III – 3 MHz outdoor	387	681	1280	678
WIA IV – 20 MHz outdoor	312	534	958	482

4.2.1.2 MCL calculations - RTTT OBU

4.2.1.2.1 *Separation distances between WIA interferer and RTTT OBU victim*

The below Table provides the main parameters for the OBU

Table 28: parameters Victim RTTT OBU

Reception part: OBU RTTT	Unit	Value
Receiver bandwidth	MHz	200
Receiver sensitivity	dBm	-60
Antenna gain	dBi	10
Protection criterion C/I	dB	6
Sidelobe attenuation	dB	15

The results of calculations for the separation distances between interferer WIA and the victim RTTT OBU are provided in the following table.

Table 29: Separation distances (m) - WIA Interferer - RTTT OBU Victim

WIA type	Antenna gain	Propagation model (see Annex 5)			
		Urban	Suburban	Rural	ETSI TR 102- 492
WIA I – 1 MHz and WIA II – 20 MHz indoor	Main lobe	77	91	91	57
	Side lobe	16	16	16	16
WIA III – 3 MHz and WIA IV – 20 MHz outdoor	Main lobe	183	291	421	206
	Side lobe	77	91	91	57

4.2.1.2.2 *Separation distances between RTTT OBU interferer and WIA victim*

The results of calculations for the separation distances between interferer RTTT OBU and the victim WIA are provided in the following table.

Table 30: Separation distances (m) - RTTT OBU Interferer – WIA Victim

WIA type	Antenna gain	Propagation model (see Annex 5)			
		Urban	Suburban	Rural	ETSI TR 102- 492
WIA I – 1 MHz indoor	Main lobe	5	5	5	5
	Side lobe	1	1	1	1
WIA II – 20 MHz indoor	Main lobe	7	7	7	7
	Side lobe	1	1	1	1
WIA III – 3 MHz outdoor	Main lobe	64	65	65	44
	Side lobe	12	12	12	12
WIA IV – 20 MHz outdoor	Main lobe	41	41	41	31
	Side lobe	7	7	7	7

4.2.2 SEAMCAT simulations

4.2.2.1 Scenario Outline

The following figure depicts the scenario outline, which is valid for victim link receiver (VLR) RSU. Extra scenario outlines are depicted, if this simulation case varies from the following scenario outline.

The offset between victim link (RTTT) and interfering link (WIA) is used as a variable in the simulations to show the required separation distance. Mostly the distance between road and closest WIA is shown.

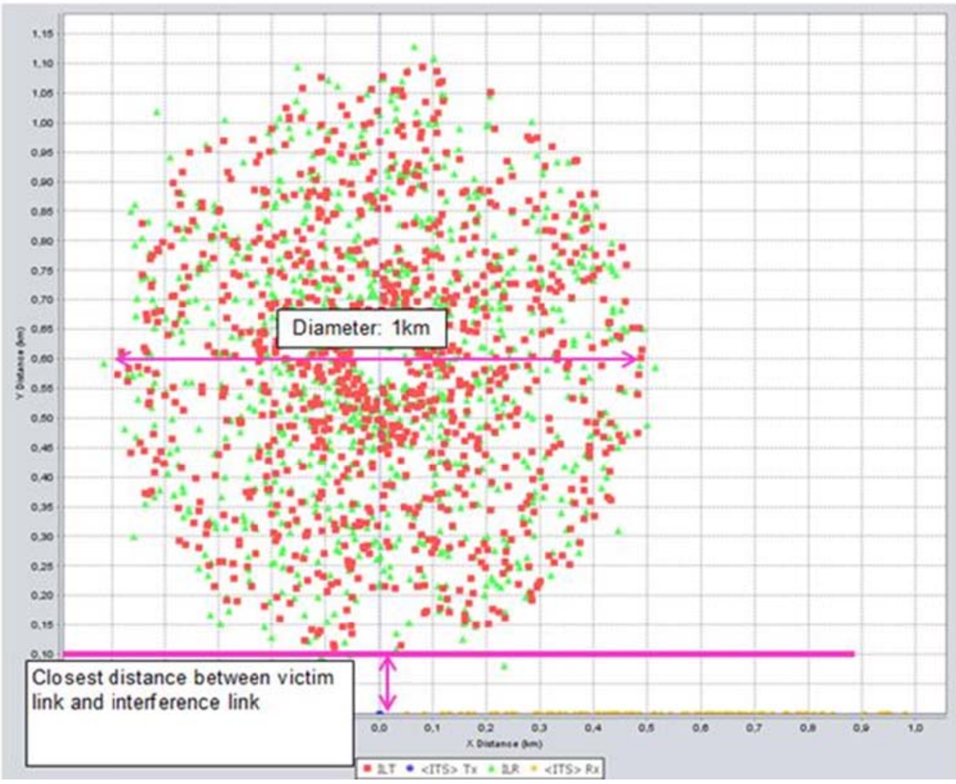


Figure 20: SEAMCAT scenario outline RTTT vs WIA

4.2.2.2 Interference Transmitter WIA with 25 mW e.i.r.p.

The first SEAMCAT simulations are provided with interference transmit power e.i.r.p. of 25 mW in order to show the influence of WIA with 25 mW according to the existing regulations. This can be used as a reference scenario (existing situation).

The devices (OBU and RSU) of RTTT have different parameters. Therefor the simulation carried out for VLR RSU and VLR OBU. Table 31 provides the simulation results for VLR OBU and

Table 32 provide the result for VLR RSU.

Table 31: Simulation results, ILT with e.i.r.p. of 25 mW, Victim Link Receiver (VLR): OBU

Parameter	Scenario 01	Scenario 02	Scenario 03
Tx power conducted WIA	9 dBm		
ILT->VLR path	IEEE 802.11 plugin : ▪ Log-Normal before BP: 3		

Parameter	Scenario 01	Scenario 02	Scenario 03
	▪ Log-Normal after BP: 4		
	BP distance: 500 m (Rural)	BP distance: 50 m (Suburban)	BP distance: 5 m (Urban)
Closest distance between VLR and ILT	5 m	5 m	5 m
dRSS(Mean ; StdDev)	-62 dBm ; 10 dB	-62 dBm ; 10 dB	-62 dBm 9 dB
$iRSS_{unwantend}$ (Mean ; StdDev)	-76.1 dBm 3.0 dB	-86 dBm 5 dB	-101 dBm 7 dB
$iRSS_{blocking}$ (Mean ; StdDev)	-79.1 dBm 3.0 dB	-89 dBm 5 dB	-104 dBm 7 dB
Prob that dRSS/iRSS < C/I	0.9 %	0.3 %	0 %

Table 32: Simulation results, ILT with e.i.r.p.=25 mW, VLR: RSU

Parameter	Scenario 04	Scenario 05	Scenario 06
Tx power conducted WIA	9 dBm		
ILT->VLR path	IEEE 802.11 plugin : ▪ Log-Normal before BP: 3 ▪ Log-Normal after BP: 4		
	BP distance: 500 m (Rural)	BP distance: 50 m (Suburban)	BP distance: 5 m (Urban)
Closest distance between VLR and ILT	5 m	5 m	5 m
dRSS(Mean ; StdDev)	-94.5 dBm ; 6,0 dB	-95,0 dBm ; 6,0 dB	-94.9 dBm 5.9 dB
$iRSS_{unwantend}$ (Mean ; StdDev)	-102.9 dBm 4.7 dB	-112.9 dBm 7.5 dB	-131.4 dBm 7.5 dB
$iRSS_{blocking}$ (Mean ; StdDev)	-119.3 dBm 28.6 dB	-127.2 dBm 27.5 dB	-145.0 dBm 26.8 dB
Prob that dRSS/iRSS < C/I	72.8 %	29.1 %	1.5 %

4.2.2.3 Interference Transmitter WIA with 400 mW e.i.r.p. and TPC

4.2.2.3.1 Scenario Outline for VLR OBU and VLR RSU

The following figures depict the scenario outline, which are valid for Victim Link Receiver (VLR) RSU and OBU. Extra scenario outlines are depicted, if this simulation case varies from the following scenario outline.

An offset between victim link (RTTT) and interfering link (WIA) is used, because a WIA device on the road is unrealistic.

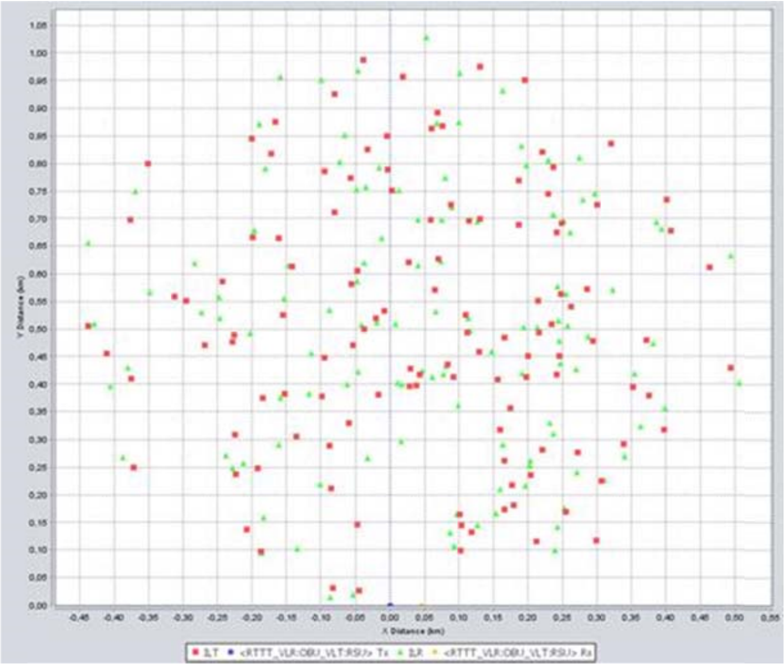


Figure 21: Scenario outline for 1 simulation event

The WIA are spread in an area of 1000 m diameter. The RSU is assumed to be located outside of the factory where the WIA are deployed.

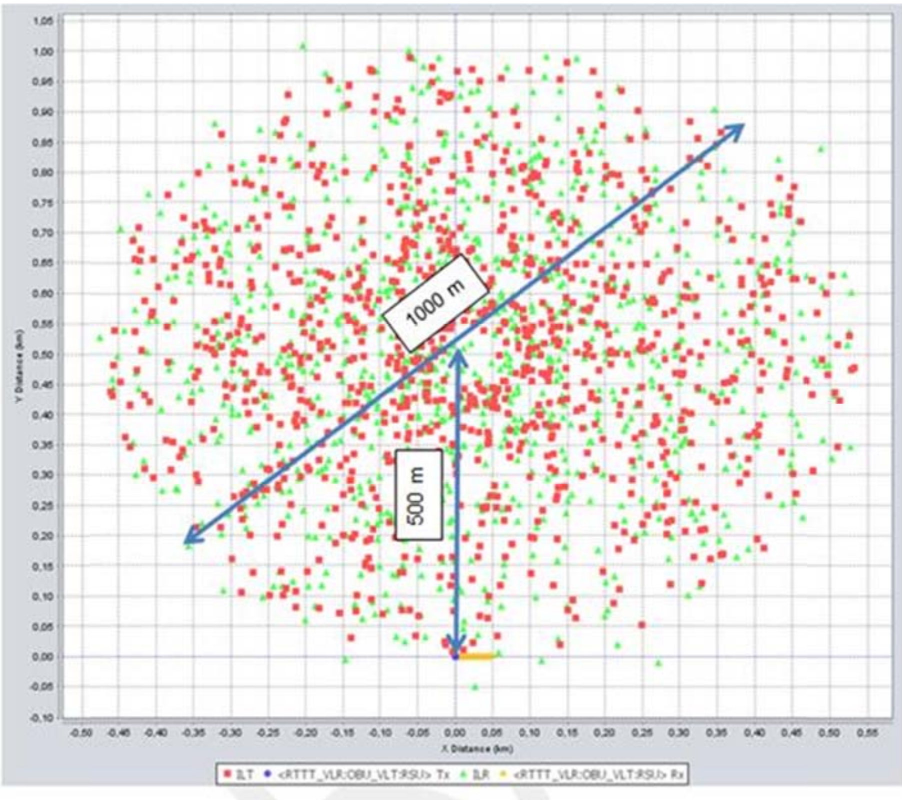


Figure 22: Scenario outline for 1000 simulation events

The length of the link between the RTTT RSU and the RTTT OBU is assumed to be 50 m maximum, in order to ensure that the received power is above the susceptibility of the receivers.

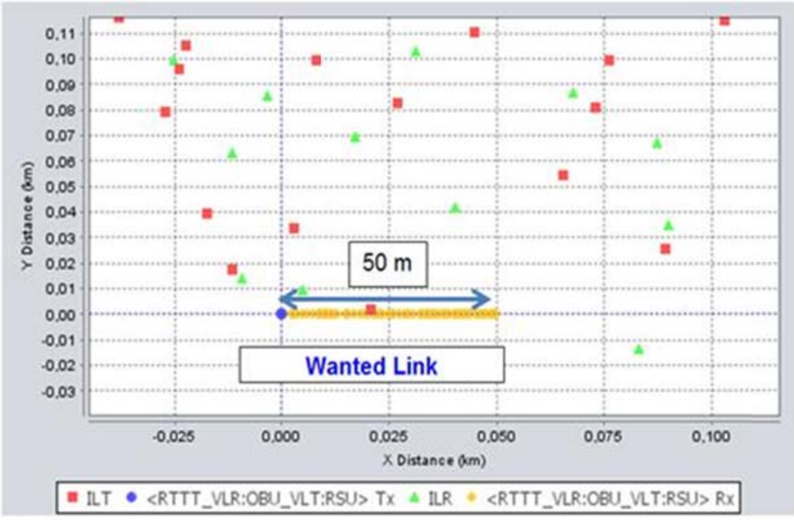


Figure 23: RSU – OBU link

4.2.2.3.2 Victim receiver: OBU

The following table present the simulation results for ILT with e.i.r.p.=400 mW, with adaptive Transmit Power Control (TPC) for the different environment Rural, Suburban and Urban between ILT and VLR. The VLR is the OBU of RTTT.

Table 33: VLR: OBU; ILT WIA with TPC, Separation distance between ILT and VLR 0 m

Parameter	Scenario 07	Scenario 08	Scenario 09
Victim link transmitter	RSU		
Frequency	5835 MHz Note		
Victim link receiver	OBU		
Reception bandwidth	200.000 kHz		
ILT Tx power conducted	21 dBm (antenna gain 5 dBi)		
Power Control	Power control step size: 6 dB Min threshold: Outdoor: -4 dBm; Indoor -24 Dynamic range: 30 dB		
ILT->VLR path	IEEE 802.11 plugin : ▪ Log-Normal before BP: 3 ▪ Log-Normal after BP: 4		
	BP distance: 500 m (Rural)	BP distance: 50 m (Suburban)	BP distance: 5 m (Urban)
Closest distance between VLR and ILT	0 m	0 m	0 m
dRSS (Mean ; StdDev)	-61 dBm 10 dB	-61 dBm 10 dB	-61 dBm 10 dB
$iRSS_{unwantend}$ (Mean ; StdDev)	-71 dBm 3 dB	-77 dBm 5 dB	-89 dBm 8 dB

Parameter	Scenario 07	Scenario 08	Scenario 09
$iRSS_{blocking}$ (Mean ; StdDev)	-74 dBm 3 dB	-80 dBm 5 dB	-92 dBm 8 dB
Prob that dRSS/iRSS < C/I	6,1 %	3.5 %	0.9 %

Note: The frequency was set virtually to the middle of the band used for the WIA.

4.2.2.3.3 *Victim receiver: RSU - separation distance 0 m*

The following table present the simulation results for ILT with e.i.r.p.=400 mW, with adaptive transmit power control (TPC) for the different environment Rural, Suburban and Urban between ILT and VLR. The VLR is the RSU of RTTT.

Table 34: VLR: RSU; ILT WIA with TPC, Separation distance 0 m

Parameter	Scenario 10	Scenario 11	Scenario 12
Victim link transmitter	OBU		
Frequency	Uniform distributed min.: 5797 MHz max.: 5872 MHz Note		
Victim link receiver	RSU		
ILT Tx power conducted	21 dBm (antenna gain 5 dBi)		
Power Control	Power control step size: 6 dB Min threshold: Outdoor: -4 dBm; Indoor -24 Dynamic range: 30 dB		
ILT->VLR path	IEEE 802.11 plugin : ▪ Log-Normal before BP: 3 ▪ Log-Normal after BP: 4		
	BP distance: 500 m (Rural)	BP distance: 50 m (Suburban)	BP distance: 5 m (Urban)
Closest distance between VLR and ILT	0 m	0 m	0 m
dRSS (Mean ; StdDev)	-93.7 dBm; 6.6 dB	-93.3 dBm; 6.5 dB	-93.4 dBm 6.6 dB
$iRSS_{unwantend}$ (Mean ; StdDev)	-91.6 dBm; 4.8 dB	-104.6 dBm, 7.4 dB	-119.3 dBm 8.7 dB
$iRSS_{blocking}$ (Mean ; StdDev)	-108.4 dBm ; 28.1 dB	-117.7 dBm, 27.7 dB	-132.0 dBm 27.0 dB
Prob that dRSS/iRSS < C/I	94.4 %	64.6 %	12.6 %

Note: The frequency of the victim was virtually randomly distributed through the whole WIA band to achieve an average result.

4.2.2.3.4 *Separation distance 100 m*

The scenarios 13 up to 15 simulate the case, that the minimum distance between the road with RTTT and the industrial plant is 100 m (offset in y axis is 600 m). This is illustrated in the following figure.

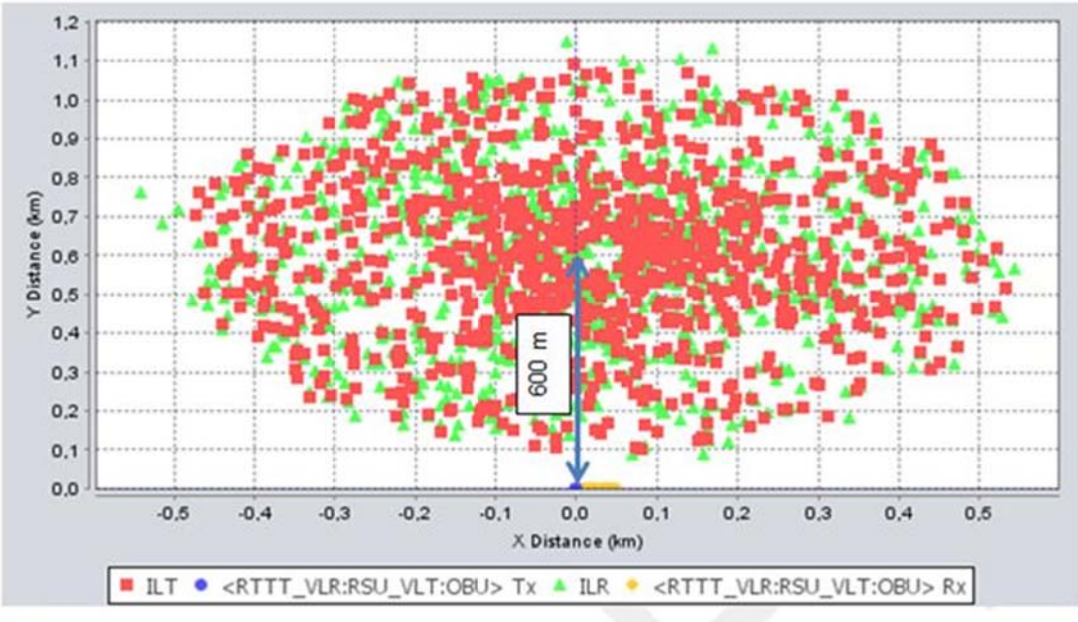


Figure 24: Separation distance 100 m

The simulation results for VLR RSU with a separation distance of 100 m between VLR and ILT are provided in Table 35.

Table 35: VLR: RSU; ILT WIA with TPC, Separation distance 100 m

Parameter	Scenario 13	Scenario 14	Scenario 15
Victim link transmitter	OBU		
Frequency	Uniform distributed min.: 5797 MHz max. : 5872 MHz		
Victim link receiver	RSU		
ILT Tx power conducted	21 dBm (antenna gain 5 dBi)		
Power Control	Power control step size: 6 dB Min threshold: Outdoor: -4 dBm; Indoor -24 Dynamic range: 30 dB		
ILT->VLR path	IEEE 802.11 plugin : ▪ Log-Normal before BP: 3 ▪ Log-Normal after BP: 4		
	BP distance: 500 m (Rural)	BP distance: 50 m (Suburban)	BP distance: 5 m (Urban)
Closest distance between VLR and ILT	100 m	100 m	100 m
dRSS (Mean ; StdDev)	-93.3 dBm 6.7 dB	-93.2 dBm 6.9 dB	-93.4 dBm 6.6 dB
$iRSS_{unwantend}$ (Mean ; StdDev)	-96.7 dBm 4.3 dB	-108.4 dBm 6.1 dB	-126.8 dBm 6.1 dB
$iRSS_{blocking}$ (Mean ; StdDev)	-111.5 dBm 28.6 dB	-121.5 dBm 28.2 dB	-140.7 dBm 27.9 dB

Parameter	Scenario 13	Scenario 14	Scenario 15
Prob that dRSS/iRSS < C/I	87.6 %	47.3 %	1.3 %

Victim receiver: RSU - Separation distance 500 m, 1000 m and 2500 mThe scenarios 16 up to 18 (see Figure 25: Separation distance between 500 m and 2500 m

) simulate the case, that the minimum distance between the road with RTTT and the industrial plant is 500 m (offset in y axis is 1000 m), 1000 m (offset in y axis is 1500 m) and 2500 m (offset in y axis is 3000 m). The scenario 19 and 20 simulate the case, that the environment is suburban and the minimum distance between road with RTTT and industrial plant is 500 m and 1000 m.

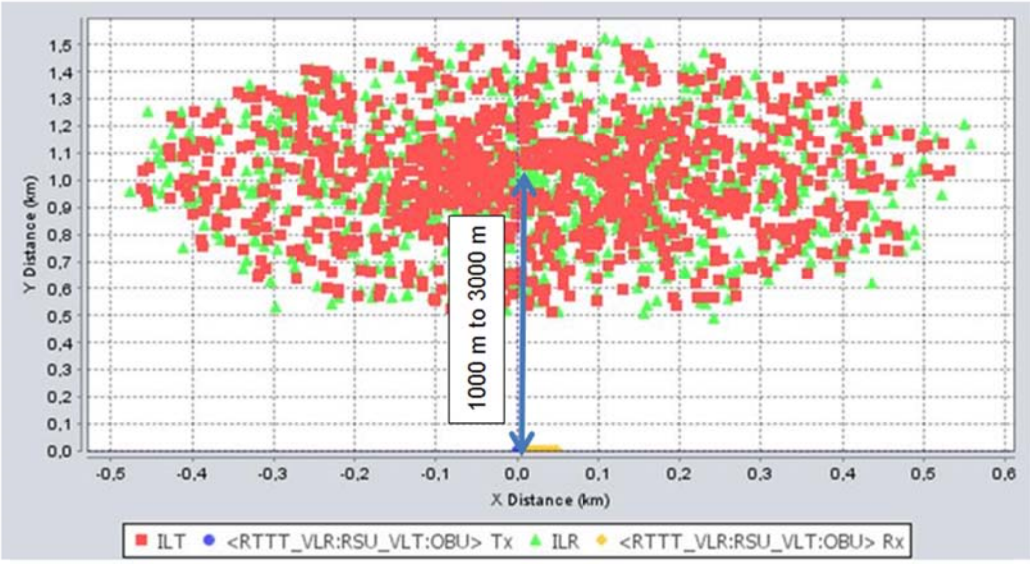


Figure 25: Separation distance between 500 m and 2500 m

The simulation results for VLR RSU with a separation distance of 500 m, 1000 m and 2500 m between VLR and ILT provided Table 36.

Table 36: VLR: RSU; ILT WIA with TPC, Separations distance 500 m to 2500 m

Parameter	Scenario 16	Scenario 17	Scenario 18	Scenario 19	Scenario 20
Victim link transmitter	OBU				
Frequency	Uniform distributed min.: 5797 MHz max. : 5872 MHz				
Victim link receiver	RSU				
ILT Tx power conducted	21 dBm (antenna gain 5 dBi)				
Power Control	Power control step size: 6 dB Min threshold: Outdoor: -4 dBm; Indoor -24 Dynamic range: 30 dB				
ILT->VLR path	IEEE 802.11 plugin : ▪ Log-Normal before BP: 3 and Log-Normal after BP: 4				
	BP distance: 500 m			BP distance: 50 m	

Parameter	Scenario 16	Scenario 17	Scenario 18	Scenario 19	Scenario 20
	(Rural)			(Suburban)	
Closest distance between VLR and ILT	500 m	1000 m	2500 m	500 m	1000 m
dRSS (Mean ; StdDev)	-93.6 dBm ; 6.6 dB	-93.2 dBm; 6.8 dB	-93.7 dBm 6.5 dB	-93.5 dBm ; 6.8 dB	-92.8 dBm; 6.8 dB
$iRSS_{unwantend}$ (Mean ; StdDev)	-103.5 dBm 4.1 dB	-109.8 dBm 3.9 dB	-120.3 dBm 4.0 dB	-118,1 dBm 4.7 dB	-124.7 dBm; 4.3 dB
$iRSS_{blocking}$ (Mean ; StdDev)	-119.2 dBm 29.0 dB	-124.4 dBm 28.5 dB	-135.4 dBm 28.6 dB	-133.1 dBm 28.8 dB	-137.3 dBm 27.9 dB
Prob that dRSS/iRSS < C/I	70.7 %	40.6 %	3.6 %	8,8 %	0,8 %

4.2.3 Conclusions

The results for the OBU as victim are summarised in Table 39.

Table 37: Summary table of C/I interference probability for VLR OBU

Scenario	Rural	Suburban	Urban
ILT: e.i.r.p.=25 mW reference without TPC Closest distance between ILT and VLR: 5 m in y axis	0.9 %	0.3 %	0.0 %
ILT: e.i.r.p.=400 mW reference with TPC Closest distance between ILT and VLR: 0 m in y axis	6.1 %	3.5 %	0.9 %

For the VLR OBU and ILT with 25 mW e.i.r.p. no interference is expected. For the VLR OBU and ILT with 400 mW e.i.r.p. the C/I interference probability is acceptable in Urban environment. But in Suburban and Rural environment the interference probability goes up to 3.5 % in Suburban and up to 6.0 % in Rural environments.

The results for the RSU as victim are summarised in Table 40.Table 38: Summary table of C/I interference probability for VLR RSU

Scenario	Rural	Suburban	Urban
ILT: e.i.r.p.=25 mW reference without TPC Closest distance between ILT and VLR: 5 m in y axis	72.8 %	29.1 %	1.5 %
ILT: e.i.r.p.=400 mW reference without TPC Closest distance between ILT and VLR: 0 m in y axis	94.4 %	64.6 %	12.6 %
ILT: e.i.r.p.=400 mW reference with TPC Closest distance between ILT and VLR: 0 m in y axis	-	-	8 %
ILT: e.i.r.p.=400 mW reference with TPC Closest distance between ILT and VLR: 100 m in y axis	87.6 %	47,3 %	1,3 %

Scenario	Rural	Suburban	Urban
ILT: e.i.r.p.=400 mW reference with TPC Closest distance between ILT and VLR: 500 m in y axis	70,7 %	8,8 %	-
ILT: e.i.r.p.=400 mW reference with TPC Closest distance between ILT and VLR: 1000 m in y axis	40,6 %	0,8 %	-
ILT: e.i.r.p.=400 mW reference with TPC Closest distance between ILT and VLR: 2500 m in y axis	3,6 %	-	-

For the VLR RSU and ILT with 25 mW e.i.r.p. harmful interference is only expected in the rural and suburban environment (the interference probability goes up to 29.1 % in suburban and up to 72.8 % in rural environments). The C/I interference probability is acceptable in Urban environment.

For the RSU and the ILT with 400 mW e.i.r.p. separation distances are required: Urban 100m, Suburban 1000 m and Rural environment 2500 m. However, a coordination procedure between WIA and RTTT may be possible, if the position of the RTTT RSU is known.

DAA mitigation techniques were not considered, but the use of DAA mitigation techniques according ETSI TS 102 792 Annex D are recommended.

4.3 BROADBAND FIXED WIRELESS ACCESS (BFWA)

The BFWA characteristics and parameters are provided in section 3.3.2.

Section 4.3.1 contains MCL calculations, and section 4.3.2 SEAMCAT simulations.

4.3.1 MCL calculations - BFWA

The following table provides the required separation distances calculated assuming the propagation conditions specified in Note 1.

Table 39: MCL calculations – SIR

Input	Case 1	Case 2	Case 3	Case 4
f/GHz	5.75	5.75	5.75	5.75
Interferer: WIA				
Tx power mW	400	400	25	25
Tx power dBm/BWi	26.02	26.02	13.98	13.98
Receiver Bandwidth BWi kHz	1000	1000	1000	1000
Tx power dBm/BWv	26	26	14	14
Victim definition: BFWA CS				
sensitivity dBm/BWv	-68	-68	-68	-68
BWv kHz	20000	20000	20000	20000
signal level above Sens dB	10	10	10	10
SIR dB	27	27	27	27
Feeder loss dB	0	0	0	0
max permissible interf dBm/BWv	-85	-85	-85	-85

Input	Case 1	Case 2	Case 3	Case 4
Reception antenna gain dBi	16	16	16	16
Interference assessment				
Propagation exponent n (Note 1)	2	3.5	2	3.5
Additional wall loss aw dB (Note 1)	0	10	0	10
Protection distance r, m (Note 1)	9255	96	2314	43
Note 1: propagation model PL=32.5dB+20log(f/GHz)+n*10*log(r/m)+ aw				

Table 40: MCL calculations – I/N objective

Input	Case 1	Case 2	Case 3	Case 4
f/GHz	5.75	5.75	5.75	5.75
Interferer: WIA				
Tx power mW	400	400	25	25
Tx power dBm/BWi	26.02	26.02	13.98	13.98
Receiver Bandwidth BWi kHz	1000	1000	1000	1000
Tx power dBm/BWv	26	26	14	14
Victim definition: BFWA CS				
BWv kHz	20000	20000	20000	20000
max permissible interf dBm/BWv	-95	-95	-95	-95
Reception antenna gain dBi	16	16	16	16
Interference assessment				
Propagation exponent n (Note 1)	2	3.5	2	3.5
Additional wall loss aw dB (Note 1)	0	10	0	10
Protection distance r, m (Note 1)	29266	185	7316	84
Note 1: propagation model PL=32.5dB+20log(f/GHz)+n*10*log(r/m)+ aw				

Under worst case conditions (Free Space loss), the BFWA link can be affected by 400mW WIA within a radius around the WIA between 10 and 30 km. This situation is much less critical in urban environments with distances between 100m and 200m. These scenarios will be further analysed in the following sections.

4.3.2 SEAMCAT simulations

In this section a probabilistic analysis is provided using the SEAMCAT tool (www.seamcat.org).

The IEEE plugin was used in SEAMCAT in order to be able to consider also an urban-like propagation model (Model_C_IEEE_802_11_rev2, Date 17/10/2012), see also ANNEX 3:).

The following configuration was used in the simulations:

- Breakpoint distance 5m for urban environments
- Breakpoint distance 50m for suburban environments
- Breakpoint distance 500m for rural environments

4.3.2.1 WIA with 25 mW e.i.r.p.

The SEAMCAT simulations were carried out with interference transmit power e.i.r.p. of 25 mW in order to show the influence of the existing regulation on BFWA (reference scenario).

The Terminal Station (Tx) is assumed to be at the center of the factory and the distance between the Terminal Station and the Based Station (Rx) is **1** km (as shown in the following figure).

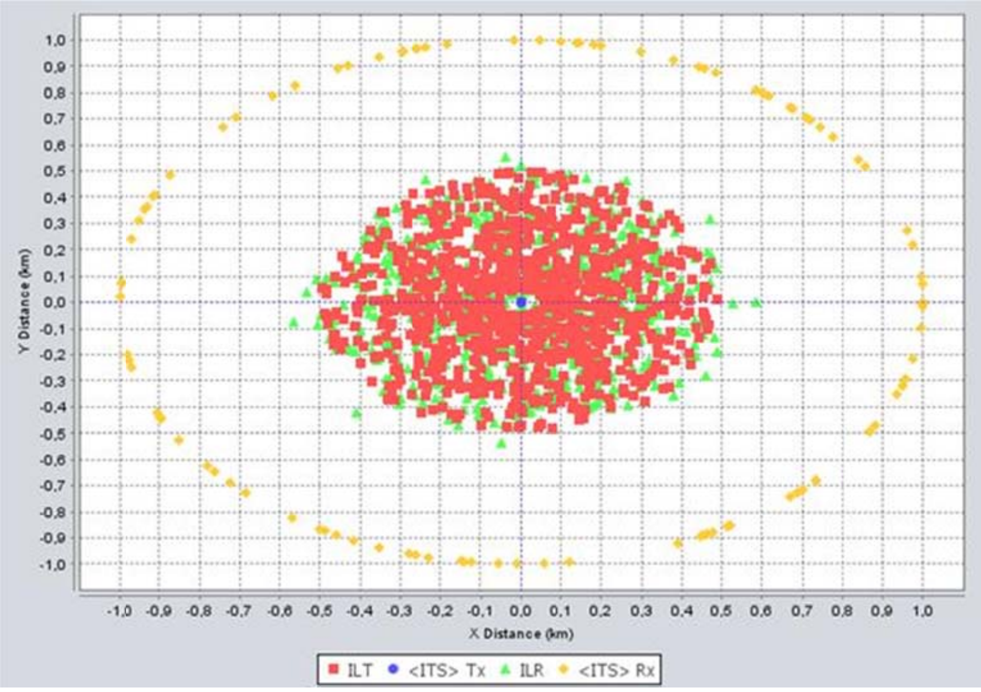


Figure 26: Scenario outline for WIA with 25 mW e.i.r.p.

The following table summarises the assumptions of the SEAMCAT simulations. Scenario 1, 2 and 3 consider different propagation conditions for the interfering path (Interfering Link Transmitter to Victim Link Receiver):

- Scenario 1: Rural propagation
- Scenario 2: Suburban propagation
- Scenario 3: Urban propagation

Table 41: VLR: BFWA; ILT WIA with TPC

Parameter	Scenario 1	Scenario 2	Scenario 3
Victim link Receiver	BFWA CS		
Frequency	Uniform distributed min.: 5807 MHz max.: 5865 MHz Note		
Reception bandwidth	20.000 kHz		
Propagation model on the victim link	Spherical diffraction outdoor- outdoor (see ANNEX 3:)		
C/(I+N)	24 dB		
Coverage radius	1000 m		
ILT->ILR path	IEEE 802.11 plugin : BP distance: Indoor 5 m; Outdoor 500 m (Rural)		

Parameter	Scenario 1	Scenario 2	Scenario 3
ILT->VLR path	IEEE 802.11 plugin : ▪ Log-Normal before BP: 3 ▪ Log-Normal after BP: 4		
	BP distance: 500 m (Rural)	BP distance: 50 m (Suburban)	BP distance: 5 m (Urban)
	None, Interfering link distributed around the VLR ▪ Distance between VLR and ILT from 500m to 1000m		
dRSS	-56 dBm	-56 dBm	-56 dBm
$iRSS_{unwantend}$ (Mean ; StdDev)	-72 dBm 1.5dB	-87 dBm 2.0 dB	-115 dBm 2.1 dB
$iRSS_{blocking}$ (Mean ; StdDev)	-93.2 dBm 0.8 dB	-108.1 dBm 1.4 dB	-136.9 dBm 1.3 dB
Prob that dRSS/iRSS<C/(I+N)	100 %	0.7 %	0 %
Prob I>N (I/N=0dB)	100 %	100 %	0 %

Note: The frequency of the victim was virtually randomly distributed through the whole WIA band to achieve an average result

These results are confirming that, in urban environments (breakpoint distance 5m in the path loss model), no problems are expected. In suburban environments (break point distance 50 m) there is only a problem with I/N criteria. In rural (break point distance 500m) there is a high risk of harmful interference. These results are valid for 25 mW e.i.r.p. system with 5 dBi antenna gain.

Devices operating with 25 mW (Annex 1 to ERC/REC 70-03 [2]) would produce an interference probability (C/I+N) between 0% and 100%. It should be noted that in this scenario the BFWA antenna main beam is assumed to be always pointing to the WIA installation and thus the simulations shows a worst case.

4.3.2.2 WIA with 400 mW e.i.r.p.

SEAMCAT simulations were conducted with WIA operating at 400 mW, without any consideration of mitigation techniques. Scenario 4, 5 and 6 considered different propagation conditions in the interfering path (Interfering Link Transmitter to Victim Link Receiver):

- Scenario 4: Rural propagation conditions
- Scenario 5: Suburban propagation conditions
- Scenario 6: Urban propagation conditions

The scenario is identical to the previous simulation with 25 mW.

Table 42: SEAMCAT results WIA with 400 mW e.i.r.p. without mitigations

Parameter	Scenario 4	Scenario 5	Scenario 6
Victim link Receiver	BFWA CS		
Frequency	Uniform distributed min.: 5807 MHz max.: 5865 MHz		
Reception bandwidth	20.000 kHz		
Propagation model on the victim link	Spherical diffraction outdoor- outdoor		
C/(I+N)	24 dB		
Coverage radius	1000 m		
Interfering Transmitter	WIA 400 mW – 5 dBi antenna gain		

Parameter	Scenario 4	Scenario 5	Scenario 6
ILT->VLR path	IEEE 802.11 plugin : ▪ Log-Normal before BP: 3 ▪ Log-Normal after BP: 4		
	BP distance: 500 m (Rural)	BP distance: 50 m (Suburban)	BP distance: 5 m (Urban)
	None, Interfering link distributed around the VLR ▪ Distance between VLR and ILT from 500m to 1000m		
dRSS (Mean ; StdDev)	-56 dBm	-56 dBm	-56 dBm
$iRSS_{unwantend}$ (Mean ; StdDev)	-60 dBm 1.5 dB	-75 dBm 2.0 dB	-103dBm 2 dB
$iRSS_{blocking}$ (Mean ; StdDev)	-81.2 dBm 0.8 dB	-102 dBm 2.8 dB	-130.8 dBm 2.7 dB
Prob that dRSS/iRSS<C/(I+N)	100 %	100 %	0 %
Prob I>N (I/N=0dB)	100 %	100 %	0,1 %

These results are confirming the MCL calculations in section 4.3.1, that in urban environments (breakpoint distance 5m in the path loss model) no problems are expected. In suburban (break point distance 50 m) and rural (break point distance 500m) environments there is a high risk of harmful interference.

It should be noted that in this scenario the BFWA antenna main beam is assumed to be always pointing to the WIA installation and thus the simulations shows a worst case.

Based on the propagation path loss from the worst case scenario 5 the effect of the mitigation techniques APC and LBT are analysed in the next sections.

4.3.2.3 WIA 400 mW -with Transmit Power Control (TPC)

The impact of the Transmit Power Control (TPC) is considered in this section. TPC as described in ANNEX 1: is implemented in the simulations.

Three scenarios are considered, where the Terminal Station (TS) of the BFWA is deployed outside from the factory and were the distance between the TS and the center of the factory is increased.

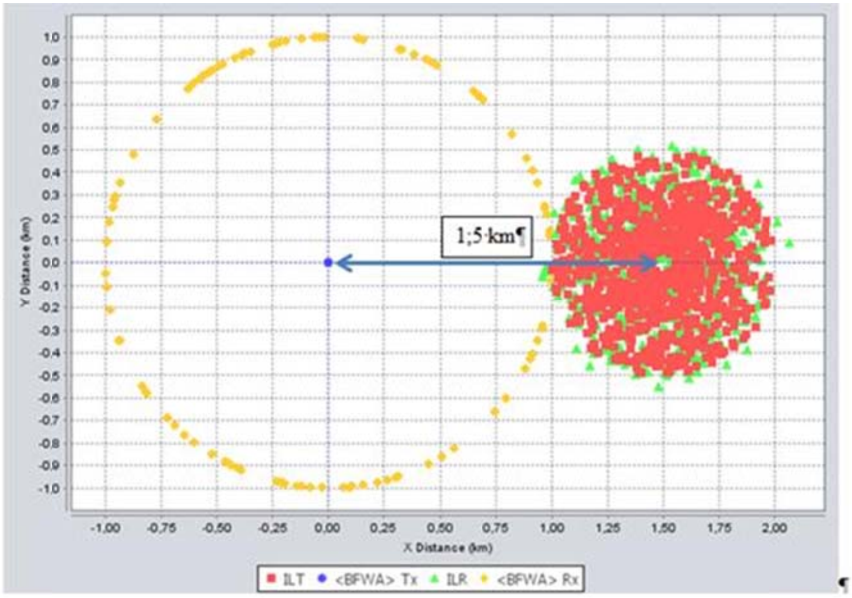


Figure 27: Scenario outline for WIA for scenario 7- Suburban

The following table provides the results for suburban environment.

Table 43: SEAMCAT results WIA with 400 mW e.i.r.p. with TPC in Suburban environment

Parameter	Scenario 7	Scenario 8	Scenario 9
Victim link Receiver	BFWA CS		
Frequency	Uniform distributed min.: 5807 MHz max.: 5865 MHz		
Reception bandwidth	20.000 kHz		
Propagation model on the victim link	Spherical diffraction outdoor- outdoor (see ANNEX 3:)		
C/(I+N)	24 dB		
Coverage radius	1000 m		
Interfering Transmitter	WIA 400 mW – 5 dBi antenna gain		
ILT->ILR path	IEEE 802.11 plugin : BP distance: Indoor 5 m; Outdoor 500 m (Rural)		
ILT->VLR path	IEEE 802.11 plugin : ▪ Log-Normal before BP: 3 ▪ Log-Normal after BP: 4		
	BP distance: 50 m (Suburban)		
	None, Interfering link distributed around the VLR		
Offset distance between ILT (center of the factory) and VLR (TS)	1.5 km	2 km	3 km
dRSS	-56 dBm	-56 dBm	-56 dBm
$iRSS_{unwantend}$ (Mean ; StdDev)	-75 dBm 2.0 dB	-89.5 dBm 2.9 dB	-109 dBm 8 dB
$iRSS_{blocking}$ (Mean ; StdDev)	-102.1 dBm 2.7 dB	-116.5 dBm 3.3 dB	-136 dBm 8 dB

Parameter	Scenario 7	Scenario 8	Scenario 9
Prob that dRSS/iRSS<C/(I+N)	99.9 %	1.6 %	0 %
Prob I>N (I/N=0dB)	100 %	99.4 %	0 %

In the rural environment, the considered distances between the BS and the centre of the factory are larger.

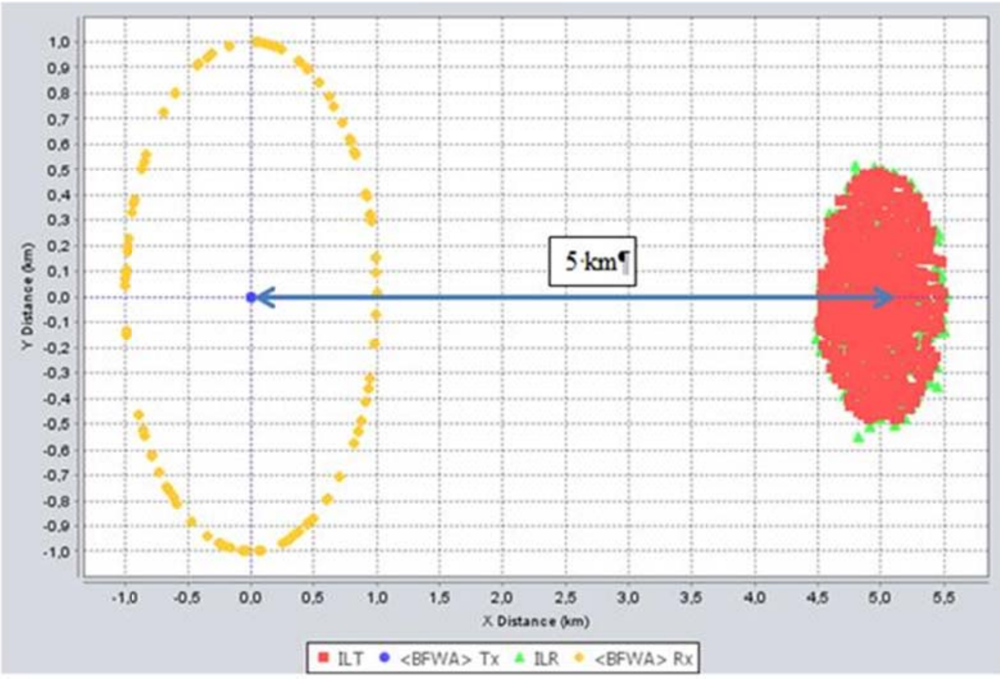


Figure 28: Scenario outline for WIA for scenario 10 – Rural

Table 44: SEAMCAT results WIA with 400 mW e.i.r.p. with TPC in Rural environment

Parameter	Scenario 10	Scenario 11	Scenario 12
Victim link Receiver	BFWA CS		
Frequency	Uniform distributed min.: 5807 MHz max.: 5865 MHz		
Reception bandwidth	20.000 kHz		
Propagation model on the victim link	Spherical diffraction outdoor- outdoor (ANNEX 3:)		
C/(I+N)	24 dB		
Coverage radius	1000 m		
Interfering Transmitter	WIA 400 mW – 5 dBi antenna gain		
ILT->ILR path	IEEE 802.11 plugin : BP distance: Indoor 5 m; Outdoor 500 m (Rural)		
ILT->VLR path	IEEE 802.11 plugin : ▪ Log-Normal before BP: 3 ▪ Log-Normal after BP: 4		
	BP distance: 500 m (Rural)		

Parameter	Scenario 10	Scenario 11	Scenario 12
	None, Interfering link distributed around the VLR		
Offset distance between ILT (center of the factory) and VLR (TS)	3 km	7 km	10 km
dRSS	-56 dBm	-56 dBm	-56
$iRSS_{unwantend}$ (Mean ; StdDev)	-93 dBm 8 dB	-107 dBm 11 dB	-109 dBm 11 dB
$iRSS_{blocking}$ (Mean ; StdDev)	-114 dBm 8 dB	-134 dBm 11 dB	-137 dBm 11 dB
Prob that dRSS/iRSS<C/(I+N)	0.6 %	0 %	0 %
Prob I>N (I/N=0dB)	66 %	7.4 %	0.1 %

The simulation above showed that TPC only is not sufficient to protect BFWA in all scenarios.

For the suburban environment a separation distance offset of 2 km is required to fulfil the interference criteria C/(I+N) of 24 dB and separation distance offset of 3 km is required to fulfil the interference criteria I/N of 0 dB.

For the rural environment a separation distance offset of 3 km is required to fulfil the interference criteria C/(I+N) of 24 dB and separation distance offset of 10 km is required to fulfil the interference criteria I/N of 0 dB.

4.3.2.4 WIA 400 mW -with Transmit Power Control (TPC) and Detect and Avoid (DAA)

4.3.2.4.1 Sensing on BFWA TS

The additional mitigation technique detect and avoid (DAA) is considered in this section. The same methodology as for the Radiolocation Service in used in order to determine the thresholds (see Annex 5). The WIA are sensing for the power transmitted by the TS.

The following table provides the threshold depending on the WIA system.

Table 45: DAA Thresholds for BFWA

Characteristics of the BFWA	WIA I	WIA II	WIA III
Tx power into antenna peak (dBm)	14,00	14.00	14.00
BFWA bandwidth (MHz)	20	20	20
Characteristics of a WIA device			
WIA e.i.r.p (dBm) outdoor	26	26	26
Bandwith (MHz)	1	20	3
Antenna gain (dBi)	5	5	5
WIA spectral density power (dBm/MHz) at the antenna connector	21	8	16
Characteristics of the DAA			
Receiver sensitivity (dBm)	-68	-68	-68
Interference level (dBm/MHz)	-105	-105	-105
DAA Detection threshold (dBm)	-112	-99	-107

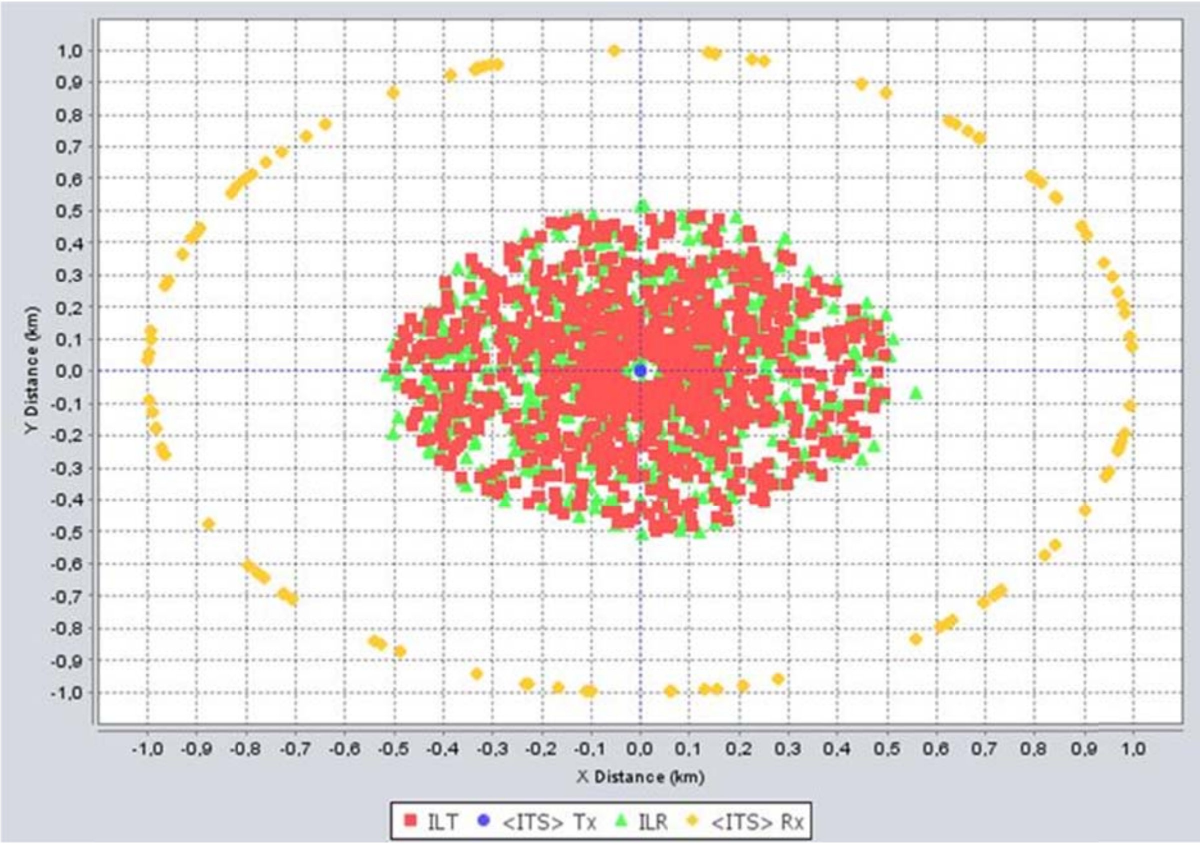


Figure 29: Simulation outline for SEAMCAT simulations with DAA

The following table provides the results for simulations were different thresholds are considered for WIA.

Scenarios 14 and 15 correspond to the case where a central station is sensing (see ANNEX 5:). Scenario 13 considers the case where the sensing is implemented on each of the devices.

Table 46: SEAMCAT results WIA with 400 mW e.i.r.p. with TPC and DAA

Parameter	Scenario 13	Scenario 14	Scenario 15
Victim link Receiver	BFWA CS		
Frequency	Uniform distributed min.: 5807 MHz max.: 5865 MHz		
Reception bandwidth	20.000 kHz		
Propagation model on the victim link	Spherical diffraction outdoor- outdoor		
C/(I+N)	24 dB		
Coverage radius	1000 m		
Interfering Transmitter	WIA 400 mW – 5 dBi antenna gain		
ILT->ILR path	IEEE 802.11 plugin Breakpoint distance Indoor: 5m; Outdoor: 500 m (see ANNEX 3:)		
DAA Threshold	-112 dBm/1 MHz -107 dBm/3 MHz	-112 dBm/1 MHz -107 dBm/3 MHz	-99 dBm/1 MHz -99 dBm/3 MHz

	-99 dBm/20 MHz	-99 dBm/20 MHz	-99 dBm/20 MHz
Sensing path VLT-ILT	IEEE 802.11 plugin, Breakpoint distance 500m		
ILT->VLR path	IEEE 802.11 plugin Breakpoint distance (500 m)	IEEE 802.11 plugin Breakpoint distance (50 m)	IEEE 802.11 plugin Breakpoint distance (50 m)
dRSS	-56 dBm	-56 dBm	-56 dBm
$iRSS_{unwantend}$ (Mean ; StdDev)	-97 dBm 9dB	-111 dBm 9 dB	-102 8.5 dB
$iRSS_{blocking}$ (Mean ; StdDev)	-110.1 dBm 3 dB	-125 dBm 3 dB	-122 dBm 3 dB
Prob that dRSS/iRSS<C/(I+N)	4 %	0 %	0 %
Prob I>N (I/N=0dB)	43 %	3 %	19.5 %

The following table provides the results for simulations were a single threshold is considered for all WIA. Scenario 17 correspond to the case where a central station is sensing (see ANNEX 5:). Scenarios 16 and 18 considers the case where the sensing is implemented on each of the devices

Table 47: SEAMCAT results WIA with 400 mW e.i.r.p. with TPC and DAA

Parameter	Scenario 16	Scenario 17	Scenario 18
Victim link Receiver	BFWA CS		
Frequency	Uniform distributed min.: 5807 MHz max.: 5865 MHz		
Reception bandwidth	20.000 kHz		
Propagation model on the victim link	Spherical diffraction outdoor- outdoor		
C/(I+N)	24 dB		
Coverage radius	1000 m		
Interfering Transmitter	WIA 400 mW – 5 dBi antenna gain		
ILT->ILR path	IEEE 802.11 plugin Breakpoint distance Indoor: 5m; Outdoor: 500 m (see ANNEX 3:)		
DAA Threshold	-99 dBm/20 MHz		
Sensing path VLT-ILT	IEEE 802.11 plugin, Breakpoint distance 500m		IEEE 802.11 plugin, Breakpoint distance 50m
ILT->VLR path	IEEE 802.11 plugin Breakpoint distance (500 m)	IEEE 802.11 plugin Breakpoint distance (50 m)	IEEE 802.11 plugin Breakpoint distance (50 m)
dRSS	-56 dBm	-56 dBm	-56 dBm
$iRSS_{unwantend}$ (Mean ; StdDev)	-104 dBm 6 dB	-119 dBm 6 dB	-92 6 dB
$iRSS_{blocking}$ (Mean ; StdDev)	-113 dBm 5 dB	-129 dBm 5 dB	-118 dBm 5 dB
Prob that dRSS/iRSS<C/(I+N)	0.3 %	0 %	3.4 %
Prob I>N (I/N=0dB)	8.5 %	0.5 %	69.6 %

Detection on BWFA TS seems sufficient to meet the BFWA C/I protection criteria; to fulfil the I/N objective a centralised sensing could help.

A sensing antenna to be installed on top of the industrial plant would improve the detection process since there will be a better propagation conditions on the sensing path to detect the possible victim link. In addition, this will allow having the possibility to implement a higher gain antenna for the sensing purpose.

It should be noted that the directional antenna of BFWA TS is directed with 4° elevation angle pointing in the direction of the sky and making difficult the detection by the WIA. Therefore, the detection of the BFWA CS is considered.

4.3.2.4.2 Sensing on BFWA CS

In this section, a centralized detector is assumed to implement DAA in order to detect the BFWA CS. Therefore, addition simulations were conducted with VLR BFWA TS and VLT BFWA CS.

In the case of BFWA CS, the elevation angle of the direction antenna is -4°, which means that they can be directed toward or nearby for the WIA devices.

Simulation outline

The CS is transmitting in the direction of a TS which is located in the area of the factory. In the following figure the TS is located at the centre of the factory.

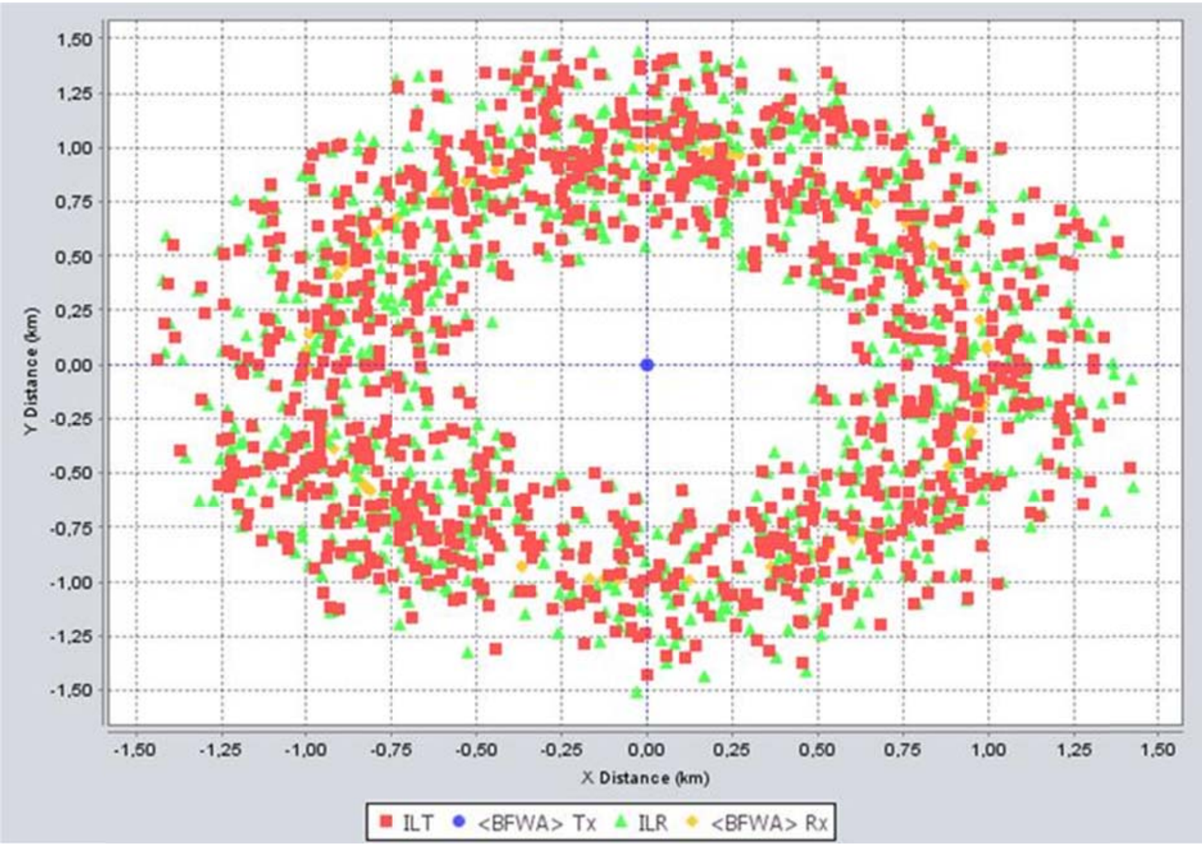
- 

Figure 30: Simulation outline for VLT: BFWA TS at the center of the factory

The following table provides the results of simulations assuming that the TS is located at the center of the factory.

Table 48: SEAMCAT results WIA with 400 mW e.i.r.p. with TPC and DAA on the CS

Parameter	Scenario 22	Scenario 23
Victim link Receiver	BFWA CS	
Frequency	Uniform distributed min.: 5807 MHz max.: 5865 MHz	
Reception bandwidth	20.000 kHz	
Propagation model on the victim link	Spherical diffraction outdoor- outdoor	
C/(I+N)	24 dB	
Coverage radius	1000 m	
Interfering Transmitter	WIA 400 mW – 5 dBi antenna gain	
ILT->ILR path	IEEE 802.11 plugin Breakpoint distance Indoor: 5m; Outdoor: 500 m (see ANNEX 3:)	
DAA Threshold	-90 dBm for 20 MHz	
Sensing path VLT-ILT	IEEE 802.11 plug in BP=500 m	Spherical diffraction
ILT->VLR path	IEEE 802.11 plugin Breakpoint distance 50 m (Suburban)	
dRSS	-50 dBm	-50 dBm
$iRSS_{unwantend}$ (Mean ; StdDev)	-98 dBm 7 dB	-104 dBm 6 dB
$iRSS_{blocking}$ (Mean ; StdDev)	-109 dBm 8 dB	-111 dBm 7 dB
Prob that dRSS/iRSS<C/(I+N)	0.2 %	0 %
Prob I>N (I/N=0dB)	37 %	7.9 %

Also here the C/I objective is fulfilled. But also in this configuration, there is still a risk of interference to the BFWA that the I/N objective is exceeded.

In general, there should be no deployment of BFWA CS within the factory except if so agreed between the factory manager and the BFWA manager.

Additional scenarios are considered as follows:

The following figure shows a sample where the TS is located at the edge of the factory.

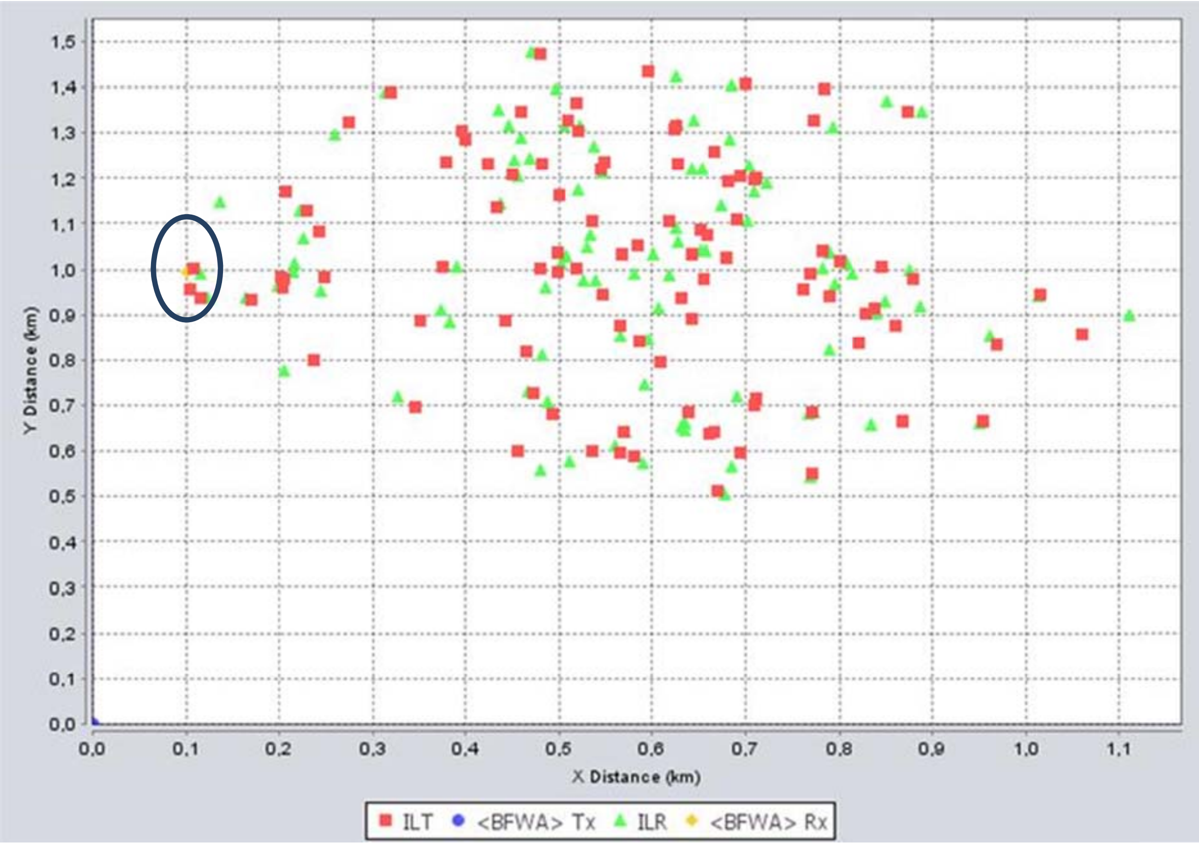


Figure 31: Scenario outline for Scenario 24

Two scenarios considered the cases where the CS is located at one edge of the factory and the TS is located at the other edge.

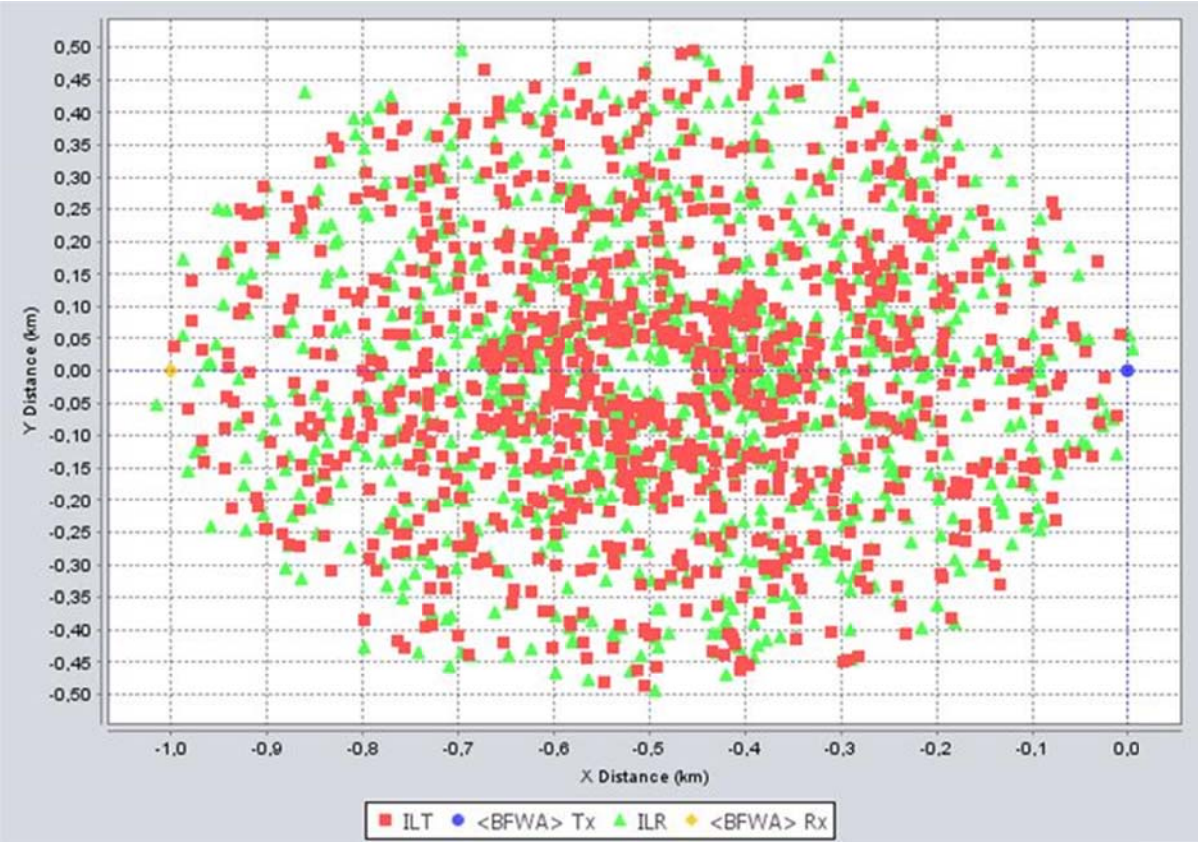


Figure 32: Scenario outline for Scenario 25 and 26

The following table provides the results for the three scenarios above. Two different DAA thresholds for the centralised detector are considered in two last scenarios.

Table 49: SEAMCAT results WIA with 400 mW e.i.r.p. with TPC and DAA

Parameter	Scenario 24	Scenario 25	Scenario 26
Frequency	Uniform distributed min.: 5807 MHz max.: 5865 MHz		
Reception bandwidth	20.000 kHz		
Interfering Transmitter	WIA 400 mW – 5 dBi antenna gain		
DAA Threshold	-85 dBm/20 MHz	-85 dBm/20MHz	-80 dBm/20MHz
Sensing path VLT-ILT	Spherical diffraction		
ILT->VLR path	IEEE 802.11 plugin Breakpoint distance (50 m) (Suburban)		
Offset X relative to VLR	500 m	Factory in the middle between VLT and VLR	
dRSS	-50 dBm	-50 dBm	-50 dBm
$iRSS_{unwantend}$ (Mean ; StdDev)	-114 dBm 11 dB	-104 dBm 6 dB	-103 dBm 6 dB
$iRSS_{blocking}$ (Mean ; StdDev)	-121 dBm 12 dB	-110 dBm 7 dB	-106 dBm 7 dB
Prob that dRSS/iRSS<C/(I+N)	0 %	0 %	0 %
Prob I>N (I/N=0dB)	5 %	9.3 %	27 %

4.3.3 Summary and Conclusions for BFWA

The use of TPC is not sufficient to meet the BFWA interference criteria.

For the suburban environment no harmful interference is expected, with or without mitigation techniques.

For the suburban environment a separation distance offset of 2 km is required to fulfil the interference criteria C/(I+N) of 24 dB and separation distance offset of 3 km is required to fulfil the interference criteria I/N of 0 dB.

For the rural environment a separation distance offset of 3 km is required to fulfil the interference criteria C/(I+N) of 24 dB and separation distance offset of 10 km is required to fulfil the interference criteria I/N of 0 dB. These results are valid for 400mW e.i.r.p. system with 5 dBi antennas and adaptive transmit power control (TPC).

The DAA mechanism within the WIA devices seems sufficient to meet the C/I BFWA interference criteria. To fulfil the I/N objective a centralised sensing could help; such a more efficient sensing procedure would be a centralized sensing device with an antenna to be installed on top of the industrial plant, with the advantage of better propagation conditions to the victim link and the possibility to choose a higher gain antenna for the sensing purpose.

It should be noted that devices according to the existing regulations with 25 mW having in the same SEMCAT scenario also a potential of interference in the rural and suburban environment.

Table 52 summarises the main SEAMCAT results.

Table 50: Summary of the results for BFWA

Simulation case	Interference criteria	Interference Path (ILT→ VLR)		
		Rural	Suburban	Urban
WIA with 25 mW e.i.r.p. without mitigation techniques → According existing regulations	C/(I+N)	100 %	0,7 %	0 %
	I/N	100 %	100 %	0 %
WIA with 400 mW e.i.r.p. without mitigation techniques	C/(I+N)	100 %	100 %	0 %
	I/N	100 %	100 %	0.1 %
WIA with 400 mW e.i.r.p. With TPC and closest distance between VLR and VLT (3 km)	C/(I+N)	0.6 %	0 %	-
	I/N	66 %	0 %	-
WIA with 400 mW e.i.r.p. With TPC and closest distance between VLR and VLT (10 km)	C/(I+N)	0 %	-	-
	I/N	0.1 %	-	-
WIA with 400 mW e.i.r.p. With TPC and DAA threshold -112 dBm/1MHz; -107dBm/3MHz; -99dBm/20MHz Sensing path (VLT→ILT) Rural environment	C/(I+N)	4 %	0 %	-
	I/N	43 %	3 %	-
WIA with 400 mW e.i.r.p. With TPC and DAA threshold -99 dBm for 1MHz; 3MHz; and 20MHz Sensing path (VLT→ILT) Rural environment	C/(I+N)	-	0 %	-
	I/N	-	19.5 %	-
WIA with 400 mW e.i.r.p. With TPC and DAA threshold -99 dBm / 20MHz Sensing path (VLT→ILT) Rural environment Centralize Sensing	C/(I+N)	0.3 %	0 %	-
	I/N	8.5 %	0.5 %	-
WIA with 400 mW e.i.r.p. With TPC and DAA threshold -99 dBm / 20MHz Sensing path (VLT→ILT) Suburban environment	C/(I+N)		3.4 %	-
	I/N		69.6 %	-
WIA with 400 mW e.i.r.p.	C/(I+N)		0.2 %	

Simulation case	Interference criteria	Interference Path (ILT→ VLR)		
		Rural	Suburban	Urban
With TPC and DAA threshold -90 dBm / 20MHz Sensing path (VLT→ILT) Suburban Centralize Sensing Position relative to BFWA Rx	I/N		37 %	
WIA with 400 mW e.i.r.p. With TPC and DAA threshold -90 dBm / 20MHz Sensing path (VLT→ILT) Spherical diffraction Centralize Sensing Position relative to BFWA Rx	C/(I+N)		0 %	
	I/N		7.9 %	

4.4 FIXED SATELLITE (E-S) SERVICE (FSS)

This section provides methods and results of sharing studies between different types of WIA systems and geostationary satellite networks of the Fixed Satellite Service (FSS) in the frequency band 5725-5875 MHz.

The study adopted the ΔT/T approach described in Appendix 8 of the ITU Radio Regulations [25] in order to assess the impact of interference from a large number of WIA devices in the field-of-view of a satellite antenna beam. Although not directly suitable for use in the case of inter-service sharing, it does provide a very simple method of analysing the impact without much knowledge of the characteristics of the carriers used on the satellite network requiring protection. In this technique, the interference from the WIA into the satellite receivers is treated as an increase in thermal noise in the wanted FSS network and hence is converted to a noise temperature (by considering the interference power per Hz) and compared with tolerable percentage increases in noise temperature. Moreover, as explained in Appendix 5 of the ITU RR for the band 5725-5875 MHz, this calculation has to be done separately for uplink and downlink. This approach has the advantage that very few satellite parameters are required to be known and a detailed link budget for every type of carrier (especially those most sensitive to interference) is not required for the satellite network requiring protection.

Recommendation ITU-R S.1432 [26] deals with the allowable error performance degradations to the FSS below 15 GHz. For a source of interference that is neither FSS systems, it recommends number 4:

“that error performance degradation due to interference at frequencies below 15 GHz should be allotted portions of the aggregate interference budget of 32% or 27% of the clear-sky satellite system noise in the following way:

- 6% for other systems having co-primary status;
- 1% for all other sources of interference.

Methods of calculating the interference from WIA devices into an FSS Satellite Receiver
In this sharing case of interference from WIA devices into an FSS satellite receiver, the study takes only into account the uplink case.

Consequently, the limitation of increase of equivalent noise temperature is expressed by the following relationship:

$$\frac{\Delta T_{sat}}{T_{sat}} < Y\,\% \qquad (1)$$

where,

ΔT_{sat} :	apparent increase in the receiving system noise temperature at the satellite, due to an interfering emission (K);
T_{sat}	the receiving system noise temperature at the satellite referred to the output of the receiving antenna of the satellite (K)
Y	noise increase allowed (e.g. 1%, 6%, etc.).

In the case under consideration here, ΔT_{sat} is the contribution of aggregate emissions from WIA devices at the input of satellite receiver. Assuming that WIA interference can be treated similarly to thermal noise, the following relationship can be assumed (linear scale, not dB):

$$\Delta T_{sat}[°K] = \frac{e.i.r.p._{WIA}\, g_{sat}}{kl} \qquad (2)$$

where,

$e.i.r.p._{WIA}$	the aggregate e.i.r.p. spectral density of the WIA transmitters in the satellite beam and in the direction of the satellite ($W*Hz^{-1}$);
g_{sat}	the gain of receiving antenna of the satellite in the direction of WIA interferer (linear ratio, relative to isotropic);
K	Boltzmann's constant ($1.38x10^{-23}$ J/K);
L	uplink Free Space path loss (linear power ratio). Note that this could also include gaseous attenuation due to absorption by water vapour and oxygen molecules

Combining the equations (1) and (2), we find:

$$e.i.r.p._{WIA}\left[\frac{W}{Hz}\right] = Y\left(\frac{g_{sat}}{T_{sat}}\right)^{-1} k \cdot l \qquad (3)$$

For a nominal range of 38 000 km (distance from Europe to a satellite at the same longitude) and a carrier frequency of 5.9 GHz, the propagation loss L=10Log(l) is about 200 dB.

The logarithmic form of equation (3) is then:

$$\begin{aligned} e.i.r.p._{WIA}[dB] &= 10Log(Y) - 29 - 10Log\left(\frac{g_{sat}}{T_{sat}}\right) \\ &= 10Log(Y) - 29 - G_{sat} + 10Log(T_{sat}) \end{aligned} \qquad (4)$$

where:

$e.i.r.p._{WIA}$	$e.i.r.p._{WIA}$=10Log($e.i.r.p._{WIA}$) dBW/Hz the expression of $e.i.r.p._{WIA}$ in dB,
Y	noise increase allowed (e.g. 1%),
G_{sat}	G_{sat}=10Log(g_{sat}) the value in dB of the linear satellite antenna gain
G_{sat}/T_{sat}	G_{sat}/T_{sat} is the figure of merit "G/T" at the satellite receiver input derived from the values of G_{sat} and T_{sat} given in Table 9

4.4.1 Method of calculating the interference from all WIA types into an FSS Satellite Receiver

The following steps describe the interference calculation from all WIA types into an FSS satellite receiver.

Step 1: Calculation of transmit power per WIA device:

$$P_{WIA\_Dev}[dBW] = P_{WIA}[dBW] + G_{WIA}[dBi] - L_{Wall}[dB] - L_{TPC}[dB]$$

The calculations include the consideration of the TPC (see ANNEX 1:). A summary of the TPC average values are given below. In order to show the benefit of TPC, a table provides an overview of the impact of WIA if TPC is not implemented.

Table 51: Average TPC Value

WIA	Average reduction of transmit power for indoor WIA [dB]	Average reduction of transmit power for outdoor WIA [dB]
1 MHz	.0	-
3 MHz	1.5	21.8
20 MHz	.94	19.9

For the 25mW devices, no TPC is considered.

Step 2: Calculation of total aggregated transmit power per WIA type in consideration of number of WIA devices in Europe, number of channel used by WIA devices and the activation factor (Average Tx ratio (%))

- WIA 1 MHz (25 mW): NCh=150
- WIA 1 MHz (400 mW): NCh=140
- WIA 3 MHz (400 mW): NCh= 28
- WIA 20 MHz (400 mW): NCh= 7

$$P_{Total}\left[\frac{dBW}{Hz}\right] = P_{Total}[dBW] - 10 * log(B_{WIA}[Hz])$$

The following assumptions were used for the deployment of WIA (details can be found under ANNEX 1:).

Table 52: Assumptions about the number of active wireless devices per application environment

	Application Environment					
	Manufacturing cell (Indoor)	Factory hall (Indoor)			Plant level (Outdoor)	
Bandwidth [MHz]	1	1	3	20	3	20
Number of simultaneously active WIA devices per EU at 5.8 GHz (25% of total amount)	273 162	136 581	546	16 390	1 639	5 463

It is assumed that the number of simultaneously active WIA devices per EU at 5.8 GHz is representative of the number of WIA devices which would be seen in the main beam of the satellite or nearby. These numbers were derived assuming worst case assumptions (see ANNEX 2:).

Step 3: Calculation of total aggregated transmit power per WIA type with regard to the WIA bandwidth

$$P_{Total}\left[\frac{dBW}{Hz}\right] = P_{Total}[dBW] - 10 * log(B_{WIA}[Hz])$$

Step 4: Calculation of e.i.r.p. WIA with the total aggregated transmit power per WIA type with regard to bandwidth and the gain of satellite

$$P_{Total}\left[\frac{dBW}{Hz}\right] = P_{Total}[dBW] - 10 * log(B_{WIA}[Hz])$$

Step 5: Calculation of increase space station receiving system noise temperature per WIA type

$$\Delta T_{Sat\_j}[K] = \frac{eirp_{WIA}\left[\frac{W}{Hz}\right]}{k\left[\frac{Ws}{K}\right] * l}; l = 10^{\frac{L_{FS}[dB]}{10}}$$

Step 6: Calculation of total increase space station receiving system noise temperature due to all WIA types

$$\Delta T_{Sat}[K] = \sum_{j \in WIA} \Delta T_{Sat\_j}[K]$$

Step 7: Noise increase in percentage depending on space station receiving system noise temperature

$$Y\ [\%] = \frac{\Delta T_{Sat}[K]}{T_{Sat}[K]}$$

The procedure is illustrated by the example of WIA type “Manufacturing cell” with e.i.r.p.=25 mW in the following Table.

Table 53: Noise Example for WIA type "Manufacturing cell" with e.i.r.p.=25 mW – on Satellite A

Step	Parameter	Symbol	Manufacturing cell	
			Value	Unit
1	Number of WIA devices in Europe (Table 102)	N_{WIA}	273162	
2	Transmit power e.i.r.p. of WIA device	P_{WIA}	25	mW
			-16	dBW
3	WIA Tx antenna gain in direction of satellite	G_{WIA}	-5	dBi
4	Wall Attenuation	L_{Wall}	15	dB
5	Attenuation of average Transmit power control	L_{TPC}	0	dB
6	Tx power per device	$P_{WIA\ Dev}$	-36	dBW
7	Average Tx ratio (%)	R_{Tx}	100%	
8	Bandwidth of WIA	B_{WIA}	1	MHz
9	Number of channels	N_{CH}	150	
10	Total (aggregated) WIA e.i.r.p. in direction of satellite	P_{total}	-3.4	dBW
			-63.4	dBW/Hz
11	Gain of satellite receiving antenna in the direction of WIA	G_{sat}	34	dBi
12	Free Space path loss	L_{FS}	199.8	dB
13	Step 10 + Step 11	e.i.r.p.$_{WIA}$	-29.4	dBW/Hz
14	ΔT_{sat} increase for contribution of WIA devices per WIA type	$\Delta T_{sat\ j}$	0.9	K

Step	Parameter	Symbol	Manufacturing cell	
			Value	Unit
15	Space Station Receiving System Noise Temperature	T_{sat}	773	K
16	ΔT_{sat} / T_{sat} increase from all WIA devices per WIA device type	Y_{WIA}	0.11 %	

The following table provides the noise increase at the FSS receivers if TPC is not implemented.

Table 54: Noise increase (%) in the satellite – TPC not activated

Satellite	Noise increase of Manu-facturing cell [%]	Factory hall			Plant level		Sum of Noise increase [%]
		Noise increase of 1 MHz [%]	Noise increase of 3 MHz [%]	Noise increase of 20 MHz [%]	Noise increase of 3 MHz [%]	Noise increase of 20 MHz [%]	
A	0.011	1.77	0.01	0.27	1.14	2.85	6.04
B	0.001	0.20	0.00	0.03	0.13	0.32	0.69
C	0.010	1.49	0,01	0.23	0.95	2.38	5.06
D	0.011	1.77	0.01	0.27	1.14	2.85	6.04
E	0.010	1.49	0.01	0.23	0.95	2.38	5.06
F	0.001	0.20	0.00	0.03	0.13	0.32	0.69
G	0.007	1.14	0.01	0.17	0.73	1.83	3.89
H	0.015	2.30	0.02	0.35	1.47	3.68	7.84
I	0.010	1.49	0.01	0.23	0.95	2.38	5.06

The following table provides the noise increase at the FSS receivers if TPC is implemented as described in Annex A1.4.

Table 55: Noise increase (%) in the satellite – TPC activated

Satellite	Noise increase of Manu-facturing cell [%]	Factory hall			Plant level		Sum of Noise increase [%]
		Noise increase of 1 MHz [%]	Noise increase of 3 MHz [%]	Noise increase of 20 MHz [%]	Noise increase of 3 MHz [%]	Noise increase of 20 MHz [%]	
A	0.11	0.30	0.001	0.015	0.006	0.01	0.45
B	0.01	0.04	0.000	0.002	0.001	0.00	0.05
C	0.09	0.26	0.000	0.012	0.005	0.01	0.38
D	0.11	0.30	0.001	0.015	0.006	0.01	0.45
E	0.09	0.26	0.000	0.012	0.005	0.01	0.38
F	0.01	0.04	0.000	0.002	0.001	0.00	0.05
G	0.07	0.20	0,000	0.009	0.004	0.01	0.29
H	0.15	0.40	0.000	0.019	0.008	0.02	0.58
I	0.09	0.26	0,000	0.012	0.005	0.01	0.38

4.4.2 Conclusions

The results provided in this section indicated that the deployment of WIA will comply with the FSS interference thresholds (1%) if TPC with 30 dB dynamic range (see A1.4) is implemented. Therefore, it is concluded that the deployment of WIA is compatible with FSS in this frequency range. If the numbers given in Table 55 for the WIA deployment are exceeded, compatibility may no longer be ensured.

Remarks:

- The 3 MHz systems will be deployed using a 5 MHz channel arrangement; this means that only 3 MHz over each 5 MHz will be used by the WIA.
- Calculations assumed that all WIA deployed in the 5.8 GHz range in the EU are used in the bandwidth of the satellites and are seen by the satellites.

4.5 AMATEUR SERVICE

4.5.1 Compatibility between WIA interferer and the Amateur Service victim

4.5.1.1 MCL calculations

As a first step, the determination of the maximum tolerable interference level from emissions of a single WIA device at the Amateur Service (AS) receiver is based on ECC Report 172 [18], where it is said that this level should be lower than N + (I/N) where N is the Amateur Station receiver inherent noise level and I/N the interference to noise ratio. The interference to noise ratio can be taken as –10 dB as given in ECC Report 172 [11].

The propagation model from ANNEX 4: is used for the calculation of separation distance. But only the worst case environment/models “Rural” and “ETSI” are considered. A 20 dB rejection in the side lobe is considered.

Table 56: Separation distances (km) for Amateur Service Victim –WIA I (1 MHz – indoor) Interferer

	Units	CW-Morse	SBB Voice	FM Voice	Digital
Emission part: WIA-I - 1 MHz					
Bandwidth	MHz	1	1	1	1
Tx out, e.i.r.p.	dBm	26	26	26	26
Average reduction of transmit power by TPC (dB)	dB	0	0	0	0
Wall loss	dB	15	15	15	15
Antenna Gain	dBi	0	0	0	0
Maximum transmit power of interferer	**dBm**	**11**	**11**	**11**	**11**
Reception part: Amateur Service					
Receiver bandwidth	MHz	0.0004	0.0027	0.009	0.0027
Receiver noise	dBm	-147	-139	-132	-138
Antenna gain	dBi	33	33	33	27
N min per MHz at antenna input	**dBm**	**-180**	**-172**	**-165**	**-165**
Bandwidth correction factor	**dB**	**-34**	**-26**	**-20**	**-26**
Protection criterion					
Criterion I/N	**dB**	10	10	10	10
MAIN LOBE WIA - MAIN LOBE Amateur Service					
Required Attenuation	**dB**	**167.0**	**167.3**	**166.5**	**160.3**
Separation distance WIA → Amateur Service	**km**	**45.4**	**46.4**	**41.0**	**28.4**

	Units	CW-Morse	SBB Voice	FM Voice	Digital
(Rural)					
Separation distance WIA → Amateur Service (ETSI)	**km**	**53.2**	**54.6**	**46.9**	**30**
MAIN LOBE WIA - SIDE LOBE Amateur Service					
Side lobe attenuation (dB)	**dB**	20	20	20	20
Required Attenuation	**dB**	**147.0**	**147.3**	**146.5**	**140**
Separation distance WIA → Amateur Service (Rural)	**km**	**11.2**	**11.5**	**10.1**	**7.0**
Separation distance WIA → Amateur Service (ETSI)	**km**	**9.7**	**9.9**	**8.5**	**5.5**

The following table provides an overview of the calculated separation distances for AS victim – WIA interferer. Separations distances were also calculated considering the implementation of TPC as described in Annex A1.4.

Table 57: Separation distances (km) for Amateur Service Victim – WIA Interferer

WIA type	Antenna gain	CW-Morse		SBB Voice		FM Voice		Digital	
		Rural	ETSI TR 102-492	Rural	ETSI TR 102-492	Rural	ETSI TR 102- 492	Rural	ETSI TR 102- 492
WIA I – 1 MHz indoor	Main lobe	45.4	53.2	46.4	54.6	41.0	46.9	28.4	30.0
	Side lobe	11.2	9.7	11.5	9.9	10.1	8.5	7.0	5.5
WIA I – 1 MHz indoor with TPC	Main lobe	32.0	34.7	32.7	35.6	28.9	30.6	20.1	19.6
	Side lobe	7.9	6.3	8.1	6.5	7.2	5.6	5.0	3.6
WIA II – 20 MHz indoor	Main lobe	18.3	17.5	18.7	18.0	16.5	15.5	11.5	9.9
	Side lobe	4.5	3.2	4.6	3.3	4.1	2.8	2.8	1.8
WIA II – 20 MHz indoor with TPC	Main lobe	9.8	8.2	10.0	8.4	8.9	7.2	6.2	4.6
	Side lobe	2.4	1.5	2.5	1.5	2.2	1.3	1.5	0.8
WIA III – 3 MHz outdoor	Main lobe	92.7	127.3	94.6	130.5	83.6	112.2	58.1	71.9
	Side lobe	23.0	23.1	23.4	23.7	20.7	20.4	14.4	13.1
WIA III – 3 MHz outdoor with TPC	Main lobe	20.3	19.8	20.7	20.5	18.3	17.5	12.7	11.1
	Side lobe	5.0	3.6	5.1	3.7	4.5	3.2	3.1	2.0
WIA IV – 20 MHz outdoor	Main lobe	52.2	63.1	53.3	64.7	47.1	55.6	32.7	35.6
	Side lobe	12.9	11.5	13.2	11.7	11.7	10.1	8.1	6.5
WIA IV – 20 MHz outdoor with TPC	Main lobe	13.0	11.6	13.3	11.8	11.7	10.1	8.2	6.5
	Side lobe	3.2	2.1	3.3	2.2	2.9	1.8	2.0	1.2

As a second step, calculations are done assuming:

- 30 dB rejection in the side lobe as given in Recommendation ITU-R F.699 [35].
- that the Radio Amateur station is receiving a power above the sensitivity allowing for a relaxed interference criterion I/N of 0 dB, considering that the station of the Amateur Service will receive a power 3dB higher than the sensitivity.

The following table provides the results of calculations considering the revised assumptions.

Table 58: Separation distances (km) for Amateur Service Victim – WIA Interferer

WIA type	Antenna gain	CW-Morse		SBB Voice		FM Voice		Digital	
		Rural	ETSI TR 102-492	Rural	ETSI TR 102- 492	Rural	ETSI TR 102- 492	Rural	ETSI TR 102- 492
WIA I – 1 MHz indoor	Main lobe	22.6	22.7	23.1	23.3	20.4	20.0	14.2	12.8
	Side lobe	2.8	1.8	2.8	1.8	2.5	1.5	1.7	1.0
WIA I – 1 MHz indoor with TPC	Main lobe	15.9	14.8	16.3	15.2	14.4	13.1	10.0	8.4
	Side lobe	2.0	1.1	2.0	1.2	1.8	1.0	1.2	0.6
WIA II – 20 MHz indoor	Main lobe	9.1	7.5	9.3	7.7	8.2	6.6	5.7	4.2
	Side lobe	1.1	0.6	1.1	0.6	1.0	0.5	0.7	0.3
WIA II – 20 MHz indoor with TPC	Main lobe	4.9	3.5	5.0	3.6	4.4	3.1	3.1	2
	Side lobe	0.5	0.3	0.6	0.3	0.5	0.2	0.3	0.2
WIA III – 3 MHz outdoor	Main lobe	46.1	54.3	47.1	55.6	41.6	47.8	28.9	30.6
	Side lobe	5.7	4.2	5.8	4.3	5.1	3.7	3.6	5.6
WIA III – 3 MHz outdoor with TPC	Main lobe	10.1	8.5	10.3	8.7	9.1	7.5	6.3	4.8
	Side lobe	1.2	0.7	1.3	0.7	1.1	0.6	0.7	0.4
WIA IV – 20 MHz outdoor	Main lobe	26.0	26.9	26.5	27.6	23.4	23.7	16.3	15.2
	Side lobe	3.2	4.9	3.3	2.1	2.9	1.8	2.0	1.2
WIA IV – 20 MHz outdoor with TPC	Main lobe	6.5	4.9	6.6	5	5.8	4.3	4.1	2.8
	Side lobe	0.5	0.4	0.8	0.4	0.7	0.3	0.4	0.2

4.5.2 Compatibility between Amateur Service interferer and WIA victim

4.5.2.1 MCL calculations

The propagation model from ECC Report 101, Section 5.2 [5] is used for the calculation of separation distance. But only the worst case environment/models “Rural” and “ETSI” are considered.

The results of calculations of separation distances between the interferer Amateur Service (AS) and the victim WIA (indoor) with 1 MHz bandwidth are listed in Table 59.The rejection in the side lobe of the Radio Amateur transmitter is assumed to be 20 dB.

Table 59: Amateur Service Interferer and WIA I (bandwidth 1 MHz – indoor) Victim

	Units	CW-Morse	SBB Voice	FM Voice	Digital
Emission part: Amateur Service					
Bandwidth	MHz	0.0004	0.0027	0.009	0.0027
Tx out, e.i.r.p.	dBm	45	45	42	32
Average reduction of transmit power by TPC (dB)	dB	0	0	0	0
Wall loss	dB	15	15	15	15
Antenna Gain	dBi	33	33	33	27
Transmitter feeder loss	dB	1	1	1	1
Maximum transmit power of interferer	**dBm**	**-4**	**-4**	**-7**	**-11**

	Units	CW-Morse	SBB Voice	FM Voice	Digital
Reception part: WIA (1 MHz indoor)					
Receiver bandwidth	MHz	1	1	1	1
Receiver sensitivity	dBm	-84	-84	-84	-84
Antenna gain	dBi	0	0	0	0
C min per MHz at antenna input	**dBm**	**-84**	**-84**	**-84**	**-84**
Bandwidth correction factor	**dB**	**0**	**0**	**0**	**0**
Protection criterion					
Criterion C/I	**dB**	6	6	6	6
MAIN LOBE WIA - MAIN LOBE Amateur Service					
Required Attenuation	**dB**	**119**	**119**	**116**	**106**
Separation distance WIA → AS (Rural)	m	1592	1592	1292	592
Separation distance WIA → AS (ETSI)	m	886	886	686	292
MAIN LOBE WIA - SIDE LOBE Amateur Service					
Side lobe attenuation (dB)	dB	20	20	20	20
Required Attenuation	**dB**	**99**	**99**	**96**	**86**
Separation distance WIA → AS (Rural)	m	333	333	260	83
Separation distance WIA → AS (ETSI)	m	161	161	125	53

The following table provides an overview of the calculated separation distances for WIA victim – AS interferer.

Table 60: Separation distances (m) for WIA Victim – Amateur Service Interferer

Interferer type	Antenna gain	WIA – I (1 MHz indoor)		WIA – II (20 MHz indoor)		WIA – III (3 MHz outdoor)		WIA – IV (20 MHz outdoor)	
		Rural	ETSI TR 102-492	Rural	ETSI TR 102-492	Rural	ETSI TR 102- 492	Rural	ETSI TR 102- 492
CW-Morse/SBB Voice	Main lobe	1592	886	2105	1246	6893	5312	5995	4479
	Side lobe	333	161	462	226	1707	965	1485	814
FM Voice	Main lobe	1292	686	1707	965	1963	1144	4863	3468
	Side lobe	260	125	361	175	426	208	1205	630
Digital	Main lobe	592	292	1831	1051	969	488	5214	3777
	Side lobe	83	53	392	191	165	89	1292	686

Considering a side lobe rejection of 30 dB instead of 20 dB, the distances calculated for the side lobe case will be further reduced by a factor of 2.

4.5.3 Conclusions

In co-channel case where the antenna main lobes are pointing at each other, the required MCL between outdoor WIA using TPC and stations in the Amateur Service can be significant. A more realistic scenario would be an indoor used WIA with TPC in the side lobe of the amateur service; this scenario requires separation distances up to 2 km. All this results were derived based on rural propagation conditions (very close to free space loss), which maybe applicable for amateur stations but not for WIA installations, which are normally deployed in urban environments with many obstacles and buildings. With more realistic propagation conditions (e.g. urban/suburban environment) separation distance well below 1 km are expected. In addition, the study is based on an I/N protection criterion, which ignores that the victim link works mostly with a margin above its sensitivity.

It should be noted that the most sensitive amateur service operations are globally harmonised at 5760-5762 MHz (CW, SSB etc), where long distance reception occurs close to the noise floor. Administrations may wish avoiding this most sensitive channels for the high power WIA outdoor devices 3 MHz (prohibit the use of channel 152 centred at 5760 MHz).

It should be noted that devices according to the existing regulations with 25 mW also have a potential of interference.WIA as a victim the WIA would require separation distances of about 2.5 km. under worst case conditions.

4.6 AMATEUR-SATELLITE (s-E) SERVICE

4.6.1 MCL - Amateur Service victim

The same approach as for the Radio Amateur is considered. It is expected that the Radio Amateur receiving station will be pointing at the sky and therefore only the side lobe calculations are considered in this section and the results can be directly extracted from section 4.5.

In the following, separation distances are determined assuming an I/N of -10 dB, 20 dB rejection in the side lobe.

Separations distances were also calculated considering the implementation of TPC as described in Annex A1.4.

Table 61: Separation distances (km) for Amateur Satellite Service Victim – WIA Interferer

WIA type	CW-Morse	
	Rural	ETSI TR 102- 492
WIA I – 1 MHz indoor	11.2	9.7
WIA I – 1 MHz indoor with TPC	7.9	6.3
WIA II – 20 MHz indoor	4.5	3.2
WIA II – 20 MHz indoor with TPC	2.4	1.5
WIA III – 3 MHz outdoor	23.0	23.1
WIA III – 3 MHz outdoor with TPC	5.0	3.6
WIA IV – 20 MHz outdoor	12.9	11.5
WIA IV – 20 MHz outdoor with TPC	3.2	2.1

The following table provides calculations considering a side lobe rejection of 30 dB and I/N of 0 dB.

Table 62: Separation distances (km) for Amateur Satellite Service Victim – WIA Interferer

WIA type	CW-Morse	
	Rural	ETSI 102- 492
WIA I – 1 MHz indoor	2.8	1.8
WIA I – 1 MHz indoor with TPC	2.0	1.1
WIA II – 20 MHz indoor	1.1	0.6
WIA II – 20 MHz indoor with TPC	0.5	0.3
WIA III – 3 MHz outdoor	5.7	4.2
WIA III – 3 MHz outdoor with TPC	1.2	0.7

WIA type	CW-Morse	
	Rural	ETSI 102- 492
WIA IV – 20 MHz outdoor	3.2	2.1
WIA IV – 20 MHz outdoor with TPC	0.5	0.4

4.6.2 Compatibility between Amateur Service interferer and WIA victim

The same approach as for the Radio Amateur is considered. It is expected that the Radio Amateur receiving station will be pointing at the sky and therefore only the side lobe calculations are considered in this section and the results can be directly extracted from section 4.5.

Table 63: Separation distances (m) for WIA Victim – Amateur Service Interferer

Interferer type	WIA – I (1 MHz indoor)		WIA – II (20 MHz indoor)		WIA – III (3 MHz outdoor)		WIA – IV (20 MHz outdoor)	
	Rural	ETSI TR 102- 492	Rural	ETSI TR 102- 492	Rural	ETSI TR 102- 492	Rural	ETSI TR 102- 492
CW-Morse/SBB Voice	333	161	462	226	1707	965	1485	814
FM Voice	260	125	361	175	426	208	1205	630
Digital	83	53	392	191	165	89	1292	686

Considering a side lobe rejection of 30 dB instead of 20 dB, the distances calculated for the side lobe case will be further reduced by a factor of 2.

4.6.3 Conclusions

It should be noted that the most sensitive Amateur-Satellite Service operations are globally harmonised at 5840-5842 MHz (CW), where long distance reception occurs close to the noise floor.

For the reception of Radio Amateur Satellites (which are Space-to-Earth only in the 5830-5850 MHz allocation), the realistic situation is that the WIA will be not be directly seen by the Radio Amateur stations, since their main beams will be pointing in the direction of sky. The calculations have assumed a 20 dB rejection in the receive antenna side-lobes. An optimised antenna can provide an even higher rejection (about 30dB, based on Recommendation ITU-R F.699), facilitating the compatibility between WIA and receive stations for Amateur Satellites.

4.7 INTELLIGENT TRANSPORT SYSTEMS (ITS)

The characteristics of ITS are given in section 3.6 (see also SRdoc ETSI TR 102 492-1 [19]).

WIA and ITS systems can operate on the same channel, therefore coexistence problems can be expected at both sites.

Regarding coexistence studies, two main types of potential problems have been identified:

- interference from WIA (indoor / outdoor) on the ITS On-Board Unit (OBU) and vice versa,
- interference from WIA (indoor/outdoor) on the ITS Road Side Unit (RSU) and vice versa.

Section 4.7.1 contains MCL calculations, and section 4.7.2 SEAMCAT simulations.

4.7.1 MCL calculations

4.7.1.1 MCL - OBU

4.7.1.1.1 *Separation distances between WIA interferer and ITS OBU victim*

The results of calculations of separation distances between the interferer WIA (indoor) with 1 MHz bandwidth and the victim ITS OBU are provided in Table 64.

Table 64: Interferer WIA I (1 MHz – indoor) - Victim ITS OBU

	Units	Propagation model			
		Urban	Suburban	Rural	ETSI TR 102- 492
Emission part: WIA I (1 MHz indoor)					
Bandwidth	MHz	1	1	1	1
Tx out, e.i.r.p.	dBm	26	26	26	26
Effect of TPC (dB)	dB	0	0	0	0
Wall loss	dB	15	15	15	15
Antenna Gain	dBi	0	0	0	0
Net Tx power	**dBm**	**11**	**11**	**11**	**11**
Reception part: ITS - OBU					
Receiver bandwidth	MHz	10	10	10	10
Receiver sensitivity	dBm	-82	-82	-82	-82
Antenna gain	dBi	8	8	8	8
C min at antenna input	**dBm**	**-90**	**-90**	**-90**	**-90**
Protection criterion					
Criterion C/I	**dB**	6	6	6	6
Allowable Interfering power level 'I' at receiver antenna input	**dBm**	**-96**	**-96**	**-96**	**-96**
Acceptable interference power level at receiver	dBm	**-88**	**-88**	**-88**	**-88**
MAIN LOBE WIA - MAIN LOBE ITS					
Required Attenuation	**dB**	**107**	**107**	**107**	**107**
Separation distance WIA → ITS	**m**	**239**	**395**	**635**	**315**
MAIN LOBE WIA - SIDE LOBE ITS					
Sidelobe attenuation (dB)	**dB**	12	12	12	12
Required Attenuation	**dB**	**95**	**95**	**95**	**95**
Separation distance WIA → ITS	**m**	**125**	**182**	**229**	**113**

The following table provides an overview of the calculated separation distances for ITS OBU victim – WIA interferer.

Table 65: Separation distances (m) for ITS OBU Victim – WIA Interferer

WIA type	Antenna gain	Propagation model			
		Urban	Suburban	Rural	ETSI TR 102- 492
WIA I – 1 MHz indoor	Main lobe	239	395	635	315
	Side lobe	125	182	229	113
WIA II – 20 MHz indoor	Main lobe	203	329	496	244
	Side lobe	104	148	162	88
WIA III – 3 MHz outdoor	Main lobe	533	979	1945	1131
	Side lobe	281	473	813	407
WIA IV – 20 MHz outdoor	Main lobe	454	816	1576	875
	Side lobe	239	394	635	315

4.7.1.1.2 Separation distances between ITS OBU interferer and WIA victim

The following table provides an overview of the calculated separation distances for ITS OBU interferer – WIA victim.

Table 66: Separation distances (m) for ITS OBU Interferer –WIA Victim

WIA type	Antenna gain	Propagation model			
		Urban	Suburban	Rural	ETSI TR 102- 492
WIA I – 1 MHz indoor	Main lobe	93	129	129	74
	Side lobe	32	32	32	27
WIA II – 20 MHz indoor	Main lobe	203	329	496	244
	Side lobe	104	148	162	88
WIA III – 3 MHz outdoor	Main lobe	425	758	1448	789
	Side lobe	224	366	574	284
WIA IV – 20 MHz outdoor	Main lobe	454	816	1577	876
	Side lobe	239	395	635	315

4.7.1.2 MCL - RSU

4.7.1.2.1 Separation distances between WIA interferer and ITS RSU victim

The results of calculations of separation distances between the interferer WIA (indoor) with 1 MHz bandwidth and the victim ITS RSU are provided in Table 67.

Table 67: Interferer WIA I (bandwidth 1 MHz – indoor) - Victim ITS RSU

	Units	Propagation model			
		Urban	Suburban	Rural	ETSI
Emission part: WIA-I - 1 MHz					
Bandwidth	MHz	1	1	1	1
Tx out, e.i.r.p.	dBm	26	26	26	26

	Units	Propagation model			
		Urban	Suburban	Rural	ETSI
Effect of TPC (dB)	dB	0	0	0	0
Wall loss	dB	15	15	15	15
Antenna Gain	dBi	0	0	0	0
Net Tx power density	**dBm/MHz**	**11**	**11**	**11**	**11**
Reception part: ITS - RSU					
Receiver bandwidth	MHz	10	10	10	10
Receiver sensitivity	dBm	-82	-82	-82	-82
Antenna gain	dBi	10	10	10	10
C min per MHz at antenna input	**dBm/MHz**	**-102**	**-102**	**-102**	**-102**
Protection criterion					
Criterion C/I	**dB**	6	6	6	6
Allowable Interfering power level 'I' at receiver antenna input	**dBm/MHz**	**-108**	**-108**	**-108**	**-108**
Acceptable interference power at receiver	**dBm/MHz**	-98	-98	-98	-98
MAIN LOBE WIA - MAIN LOBE ITS					
Required Attenuation	**dB**	**109**	**109**	**109**	**109**
Separation distance WIA → ITS	**m**	266	445	749	373
MAIN LOBE WIA - SIDE LOBE ITS					
Sidelobe attenuation (dB)	**dB**	12	12	12	12
Required Attenuation	**dB**	**97**	**97**	**97**	**97**
Separation distance WIA → ITS	**m**	140	210	279	134

The following table provides an overview of the calculated separation distances for ITS RSU victim – WIA interferer.

Table 68: Separation distances (m) for ITS RSU Victim – WIA Interferer

WIA type	Antenna gain	Propagation model			
		Urban	Suburban	Rural	ETSI TR 102- 492
WIA I – 1 MHz indoor	Main lobe	266	445	749	373
	Side lobe	140	210	279	134
WIA II – 20 MHz indoor	Main lobe	226	371	585	289
	Side lobe	118	170	204	104
WIA III – 3 MHz outdoor	Main lobe	594	1105	2236	1342
	Side lobe	312	534	958	482
WIA IV – 20 MHz outdoor	Main lobe	505	921	1812	1038
	Side lobe	266	445	748	373

4.7.1.2.2 Separation distances between ITS RSU interferer and victim WIA

The following table provides an overview of the calculated separation distances for ITS RSU interferer – WIA victim.

Table 69: Separation distances (m) for WIA Victim – ITS RSU Interferer

WIA type	Antenna gain	Propagation model			
		Urban	Suburban	Rural	ETSI TR 102- 492
WIA I – 1 MHz indoor	Main lobe	93	129	129	74
	Side lobe	32	32	32	27
WIA II – 20 MHz indoor	Main lobe	118	170	205	104
	Side lobe	51	51	51	37
WIA III – 3 MHz outdoor	Main lobe	425	758	1448	789
	Side lobe	224	366	574	284
WIA IV – 20 MHz outdoor	Main lobe	454	816	1577	876
	Side lobe	239	395	635	315

4.7.2 SEAMCAT simulations ITS

4.7.2.1 Scenario outline

The following figure depicts the scenario outline, which are valid for victim link receiver (VLR) RSU. Extra scenario outlines are depicted, if the simulation case varies from the following scenario outline.

The offset between victim link (ITS on a road) and interfering link (WIA) is used as a variable in the simulations to show the required separation distance. Mostly the distance between road and closest WIA is shown.

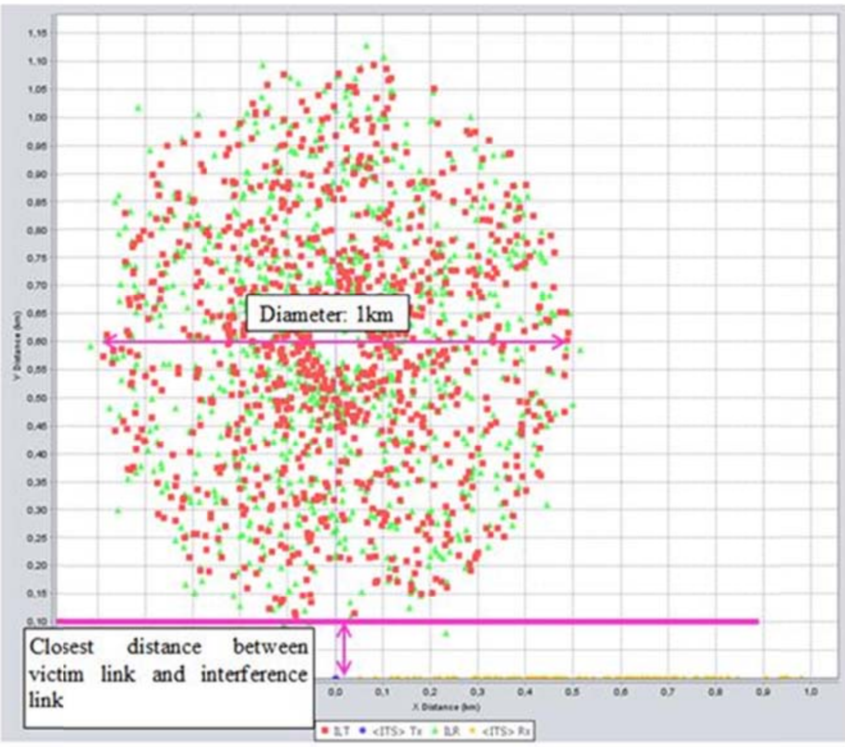


Figure 33: SEAMCAT scenario outline

4.7.2.2 Interference Transmitter WIA with 25 mW e.i.r.p.

The first SEAMCAT simulations are provided with interference transmit power e.i.r.p. of 25 mW in order to show the influence of WIA with 25 mW according to the existing regulations. This can be used as a reference scenario (existing situation).

Table 70: Simulation results, ILT with e.i.r.p.=25 mW; Separation between VLR and VLT: 5 m

Parameter	Scenario 04	Scenario 05	Scenario 06
Tx power conducted WIA	9 dBm		
ILT->VLR path	IEEE 802.11 plugin : ▪ Log-Normal before BP: 3 ▪ Log-Normal after BP: 4		
	BP distance: 500 m (Rural)	BP distance: 50 m (Suburban)	BP distance: 5 m (Urban)
Closest distance between VLR and ILT	5 m	5 m	5 m
dRSS(Mean ; StdDev)	-73.6 dBm 11.1 dB	-74.3 dBm 11.1 dB	-74.0 dBm 10.5 dB
$iRSS_{unwantend}$ (Mean ; StdDev)	-81.8 dBm 4.3 dB	-93.8 dBm 6.5 dB	-109.4 dBm 6.5 dB
$iRSS_{blocking}$ (Mean ; StdDev)	-92.7 dBm 6.6 dB	-104.4 dBm 7.9 dB	-120.3 dBm 8.3 dB
Prob that dRSS/iRSS < C/I	53.7 %	1.2 %	0.0 %

The result of the simulation with 25mW and only 5m separation distance shows only coexistence problems in the rural environment.

Table 71: Simulation results, ILT with e.i.r.p.=25 mW, Separation between VLR and VLT

Parameter	Scenario 01	Scenario 02	Scenario 03
Tx power conducted WIA	9 dBm		
ILT->VLR path	IEEE 802.11 plugin : ▪ Log-Normal before BP: 3 ▪ Log-Normal after BP: 4		
	BP distance: 500 m (Rural)	BP distance: 500 m (Rural)	BP distance: 50 m (Suburban)
Closest distance between VLR and ILT	100 m	1000 m	100 m
dRSS(Mean ; StdDev)	-73.8 dBm ; 11.4 dB	-74.3 dBm ; 11.0 dB	-73.8 dBm 10.6 dB
$iRSS_{unwantend}$ (Mean ; StdDev)	-83.4 dBm 3.6 dB	-93.7 dBm 2.1 dB	-96.1 dBm 5.0 dB
$iRSS_{blocking}$ (Mean ; StdDev)	-94.6 dBm 6.1 dB	-104.7 dBm 5.5 dB	-107.1 dBm 6.9 dB
Prob that dRSS/iRSS < C/I	40.8 %	0.4 %	0.1 %

The coexistence problem with 25 mW in the rural environment can be solved with 1km separation distance.

4.7.2.3 Interference Transmitter WIA with 400 mW e.i.r.p. and TPC

The following table present the simulation results for ILT with e.i.r.p.=400 mW, with adaptive transmit power control (TPC) for the different environment Rural, Suburban and Urban between ILT and VLR.

Table 72: Simulation results, ILT with e.i.r.p.=400 mW and with TPC – Separation distance of 100 m

Parameter	Scenario 07	Scenario 08	Scenario 09
Tx power conducted WIA	21 dBm (antenna gain 5 dBi)		
Power Control	Power control step size: 6 dB Min threshold: Outdoor: -4 dBm; Indoor -24 Dynamic range: 30 dB		
ILT->VLR path	IEEE 802.11 plugin : ▪ Log-Normal before BP: 3 ▪ Log-Normal after BP: 4		
	BP distance: 500 m (Rural)	BP distance: 50 m (Suburban)	BP distance: 5 m (Urban)
Closest distance between VLR and ILT	100 m	100 m	100 m
dRSS(Mean ; StdDev)	-74.1 dBm ; 10.8 dB	-74.2 dBm 10.8 dB	-75.5 dBm 10.8 dB
$iRSS_{unwantend}$ (Mean ; StdDev)	-85.6 dBm 2.0 dB	-88.7 dBm 2.0 dB	-99.7 dBm 5.3 dB
$iRSS_{blocking}$ (Mean ; StdDev)	-96.8 dBm 5.5 dB	-99.8 dBm 5.6 dB	-110.6 dBm 7.1 dB
Prob that dRSS/iRSS < C/I	29.3 %	14.8 %	0.3 %

Note: The frequency of the victim was virtually randomly distributed through the whole WIA band to achieve an average result

Table 73: Simulation results, ILT with e.i.r.p.=400 mW and with TPC –various separation distances

Parameter	Scenario 10	Scenario 11	Scenario 12
Tx power conducted WIA	21 dBm (antenna gain 5 dBi)		
Power Control	Power control step size: 6 dB Min threshold: Outdoor: -4 dBm; Indoor -24 Dynamic range: 30 dB		
ILT->VLR path	IEEE 802.11 plugin : ▪ Log-Normal before BP: 3 ▪ Log-Normal after BP: 4		
	BP distance: 500 m (Rural)	BP distance: 500 m (Rural)	BP distance: 500 m (Rural)
Closest distance between VLR and ILT	1500 m	2000 m	2500 m
dRSS(Mean ; StdDev)	-74 dBm ; 11 dB	-74 dBm 11 dB	-74 dBm 10.8 dB
$iRSS_{unwantend}$	-89 dBm	-92 dBm	-95 dBm

Parameter	Scenario 10	Scenario 11	Scenario 12
(Mean ; StdDev)	2 dB	2 dB	2 dB
iRSS$_{blocking}$ (Mean ; StdDev)	99 dBm 5 dB	103 dBm 5 dB	106 dBm 5 dB
Prob that dRSS/iRSS < C/I	13.1 %	.4 %	.4 %

With a separation distance of 100 m the protection criterion can be fulfilled only for the urban environment (see Table 74). For rural environments (see Table 75) a separation distance of 2 500 m would be needed.

4.7.2.4 Interference Transmitter WIA with TPC and with DAA

The previous section showed that TPC only is not sufficient for the protection of ITS in suburban and rural environments. Therefore an additional mitigation technique like detect and avoid (DAA) is considered. The same methodology as for the Radiolocation Service in used in order to determine the thresholds (see ANNEX 5:).

The following table provides the threshold depending on the WIA system.

Table 74: DAA Thresholds for ITS RSU

Characteristics of the ITS Road Side Unit	WIA I	WIA II	WIA III
Tx power into antenna peak (dBm)	23.00	23.00	23.00
ITS bandwidth (MHz)	10	10	10
Characteristics of a WIA device			
WIA e.i.r.p (dBm) outdoor	26	26	26
Bandwith (MHz)	1	20	3
Antenna gain (dBi)	5	5	5
WIA spectral density power (dBm/MHz) at the antenna connector	21	8	16
Characteristics of the DFS			
Receiver sensitivity (dBm)	-82	-82	-82
Interference level (dBm/MHz)	-98.00	-98.00	-98.00
DFS Detection threshold Th (dBm)	-96,00	-82.99	-91.23

Table 75 provides the simulation results for the DAA procedure with different detection threshold levels for each WIA device type for the worst cas rural scenario.

Table 75: Simulation results, ILT with TPC and DAA (different detection thresholds), Separation distance 5 m

Parameter	Scenario 13
Tx power conducted WIA	21 dBm (antenna gain 5 dBi)
Power Control	Power control step size: 6 dB Min threshold: Outdoor: -4 dBm; Indoor -24 Dynamic range: 30 dB
Spectrum sensing characteristics	Sensing reception bandwidth and corresponding detection threshold : ▪ 1 MHz -96 dBm

Parameter	Scenario 13
	▪ 3 MHz: -91 dBm ▪ 20 MHz: -83 dBm Probability of failure: 0 %
ILT->VLR path	IEEE 802.11 plugin : ▪ Log-Normal before BP: 3 ▪ Log-Normal after BP: 4
	BP distance: 500 m (Rural)
Closest distance between VLR and ILT	5 m
dRSS(Mean ; StdDev)	-67.3 10.7 dB
$iRSS_{unwantend}$ (Mean ; StdDev)	-95.3 dBm 7.1 dB
$iRSS_{blocking}$ (Mean ; StdDev)	-103.9 dBm 6.8 dB
Prob that dRSS/iRSS < C/I	1 %

In addition, simulations were conducted in order to consider that all WIA systems implement DAA with the same detection threshold level of -85 dBm and The closest distance between VLR and ILT is 5 m.

Table 76: Simulation results, ILT with TPC and DAA, Separation distance 5 m

Parameter	Scenario 14	Scenario 15	Scenario 16
Tx power conducted WIA	21 dBm (antenna gain 5 dBi)		
Power Control	Power control step size: 6 dB Min threshold: Outdoor: -4 dBm; Indoor -24 Dynamic range: 30 dB		
Spectrum sensing characteristics	Detection threshold: Indoor/Outdoor: -85 dBm Probability of failure: 0 % Sensing reception bandwidth: 1 MHz, 3 MHz, 20 MHz		
ILT->VLR path	IEEE 802.11 plugin : ▪ Log-Normal before BP: 3 ▪ Log-Normal after BP: 4		
	BP distance: 500 m (Rural)	BP distance: 50 m (Suburban)	BP distance: 5 m (Urban)
Closest distance between VLR and ILT	5 m	5 m	5 m
dRSS(Mean ; StdDev)	-67 dBm 11 dB	-67 dBm 11 dB	-67 dBm 11 dB
$iRSS_{unwantend}$ (Mean ; StdDev)	-106 dBm 11 dB	-92 dBm 6 dB	-97 dBm 6 dB
$iRSS_{blocking}$ (Mean ; StdDev)	-100 dBm 4 dB	-101 dBm 6 dB	-106 dBm 6 dB
Prob that dRSS/iRSS < C/I	0.4 %	2.5 %	0.0 %

It is shown that even in rural environments the protection of ITS can be ensured by DAA mitigation techniques. The implementation of a single threshold for all types of WIA may be sufficient.

4.7.3 Summary and Conclusions

Table 79 summarises the main SEAMCAT results.

Table 77: Summary table

Scenario	Rural	Suburban	Urban
ILT: e.i.r.p.=25 mW reference without TPC Closest distance between ILT and VLR: 5 m	53.7 %	1.2 %	0.0 %
ILT: e.i.r.p.=25 mW reference without TPC Closest distance between ILT and VLR: 100 m	40.8 %	0.1 %	-
ILT: 25 mW reference without TPC Closest distance between ILT and VLR: 1000 m	0.4 %	-	-
ILT: e.i.r.p.=400 mW with TPC Closest distance between ILT and VLR: 100 m	29.3 %	14.8 %	0.3 %
ILT: e.i.r.p.=400 mW with TPC Closest distance between ILT and VLR: 1500 m	13.1 %	-	-
ILT: e.i.r.p.=400 mW with TPC Closest distance between ILT and VLR: 2000 m	3.4 %	-	-
ILT: e.i.r.p.=400 mW with TPC Closest distance between ILT and VLR: 2500 m	0.4 %	-	-
ILT: e.i.r.p.=400 mW with TPC and with DAA (Detection threshold 1 MHz: -96 dBm; 3 MHz: -91 dBm; 20 MHz:. -83 dBm) Closest distance between ILT and VLR: 5 m	-	1.0 %	-
ILT: e.i.r.p.=400 mW with TPC and with DAA (Detection threshold -85 dBm in the bandwidth of the WIA systems) Closest distance between ILT and VLR: 5 m	0.4 %	2.5 %	0.0 %

Coexistence issues with 25 mW are only expected in rural environments and could be solved with 1km separation distance.

The results for 400m W devices are:

- Without DAA, a separation distance should be implemented (100 m in Urban environments and 2500 m in Rural environments).
- Alternatively, the implementation of DAA would allow mitigating interference.

Note, if a centralised sensing is implemented (for example with a specific antenna on the roof of the factory), the DAA threshold may be increased since the gain of the antenna could be increased and the propagation conditions on the detection path would be improved (see ANNEX 5:).

4.8 COMPATIBILITY BETWEEN WIA AND SHORT RANGE DEVICES

The characteristics of SRD are given in section 3.7. Two systems are considered in this section (SRD type I – maximum antenna gain and SRD type III) in order to cover this case.

The same propagation model as given in ANNEX 4: is considered for the MCL calculations.

4.8.1 Compatibility between WIA interferer and SRD victim

4.8.1.1 SRD type I

The following table provides the results of the separation distances calculated for WIA I indoor and for SRD type I with maximum antenna gain (20 dBi). For this case a side lobe attenuation of 30 dB is assumed.

Table 78: Interferer WIA I (bandwidth 1 MHz – indoor) - Victim SRD type I with maximum antenna gain

	Units	Urban	Suburban	Rural	ETSI TR 102- 492
Emission part: WIA I - 1 MHz indoor					
Bandwidth	MHz	1	1	1	1
Tx out, e.i.r.p.	dBm	26	26	26	26
Effect of TPC (dB)	dB	0	0	0	0
Wall loss	dB	15	15	15	15
Antenna Gain	dBi	0	0	0	0
Net Tx power density	**dBm/MHz**	**11**	**11**	**11**	**11**
Reception part: SRD type I					
Receiver bandwidth	MHz	0.25	0.25	0.25	0.25
Receiver noise	dBm/MHz	-114	-114	-114	-114
Noise Figure F	dB	9	9	9	9
Antenna gain	dBi	20	20	20	20
N per MHz at antenna input (kTBF-gain)	**dBm/MHz**	**-125**	**-125**	**-125**	**-125**
Protection criterion					
Criterion I/N	**dB**	0	0	0	0
Allowable Interfering power level 'I' at receiver antenna input (kTBF-gain+I/N)	**dBm/MHz**	**-125**	**-125**	**-125**	**-125**
MAIN LOBE WIA - MAIN LOBE SRD					
Required Attenuation	**dB**	**136**	**136**	**136**	**136**
Separation distance WIA → SRD	**m**	1129	2287	5165	3734
MAIN LOBE WIA - SIDE LOBE SRD					
Sidelobe attenuation	dB	30	30	30	30
Required Attenuation	**dB**	**106**	**106**	**106**	**106**
Separation distance WIA -> SRD	**m**	226	371	585	289

The following table provides an overview of the calculated separation distances for SRD type I maximum antenna gain.

Table 79: Separation distances (m) for WIA Interferer - SRD type I maximum antenna gain Victim

WIA type	Antenna gain	Propagation model			
		Urban	Suburban	Rural	ETSI TR 102- 492
WIA I – 1 MHz indoor	Main lobe	1129	2287	5165	3734
	Side lobe	226	371	585	289
WIA II – 20 MHz indoor	Main lobe	562	1040	2084	1231
	Side lobe	111	158	182	95
WIA III – 3 MHz outdoor	Main lobe	1952	4250	10546	8933
	Side lobe	392	690	1300	692
WIA IV – 20 MHz outdoor	Main lobe	1256	2580	5935	4424
	Side lobe	252	419	689	343

It has to be noted that the SRD are expected to be deployed mostly indoor resulting in a reduction of the separation distances. The following table provides an overview of the calculated separation distances for SRD type I maximum antenna gain deployed indoor.

Table 80: Separation distances (m) for WIA Interferer - SRD type I maximum antenna gain indoor Victim

WIA type	Antenna gain	Propagation model			
		Urban	Suburban	Rural	ETSI TR 102- 492
WIA I – 1 MHz indoor	Main lobe	506	921	1814	1039
	Side lobe	98	138	145	80
WIA II – 20 MHz indoor	Main lobe	252	419	689	343
	Side lobe	32	32	32	27
WIA III – 3 MHz outdoor	Main lobe	874	1713	3703	2486
	Side lobe	175	278	395	192
WIA IV – 20 MHz outdoor	Main lobe	562	1040	2084	1231
	Side lobe	111	158	182	95

4.8.1.2 SRD type III

The following table provides an overview of the calculated separation distances for SRD type III Isotropic antenna).

Table 81: Separation distances (m) for WIA Interferer - SRD type III Victim

WIA type	Propagation model			
	Urban	Suburban	Rural	ETSI TR 102- 492
WIA I – 1 MHz indoor	662	1250	2576	1596
WIA II – 20 MHz indoor	330	568	1039	526
WIA III – 3 MHz outdoor	1145	2323	5260	3817
WIA IV – 20 MHz outdoor	736	1410	2960	1891

It has to be noted that the SRD are expected to be deployed mostly indoor resulting in a reduction of the separation distances. The following table provides an overview of the separation distances for SRD type III deployed indoor.

Table 82: Separation distances (m) for WIA Interferer - SRD type III indoor Victim

WIA type	Propogation model			
	Urban	Suburban	Rural	ETSI TR 102- 492
WIA I – 1 MHz indoor	296	504	885	444
WIA II – 20 MHz indoor	148	225	304	146
WIA III – 3 MHz outdoor	513	936	1847	1062
WIA IV – 20 MHz outdoor	330	568	1039	526

4.8.2 Compatibility between SRD interferer and WIA victim

4.8.2.1 SRD type I

The following table provides an overview of the calculated separation distances for SRD type I maximum antenna gain (20 dBi). In this case a side lobe attenuation of 30 dB is assumed.

Table 83: Separation distances (m) for SRD type I maximum antenna gain Interferer – WIA Victim

WIA type	Antenna gain	Propagation model			
		Urban	Suburban	Rural	ETSI TR 102- 492
WIA I – 1 MHz indoor	Main lobe	87	115	115	68
	Side lobe	4	4	4	4
WIA II – 20 MHz indoor	Main lobe	227	372	586	289
	Side lobe	26	26	26	22
WIA III – 3 MHz outdoor	Main lobe	403	713	1350	724
	Side lobe	76	89	89	56
WIA IV – 20 MHz outdoor	Main lobe	506	922	1815	1040
	Side lobe	98	138	145	81

It has to be noted that the SRD are expected to be deployed mostly indoor resulting in a reduction of the separation distances. The following table provides an overview of the calculated separation distances for SRD type I maximum antenna gain deployed indoor.

Table 84: Separation distances (m) for SRD type I maximum antenna gain indoor Interferer – WIA Victim

WIA type	Antenna gain	Propagation model			
		Urban	Suburban	Rural	ETSI TR 102- 492
WIA I – 1 MHz indoor	Main lobe	20	20	20	20
	Side lobe	1	1	1	1
WIA II – 20 MHz indoor	Main lobe	98	138	145	81
	Side lobe	5	5	5	5
WIA III – 3 MHz outdoor	Main lobe	181	287	413	202
	Side lobe	16	16	16	16

WIA type	Antenna gain	Propagation model			
		Urban	Suburban	Rural	ETSI TR 102- 492
WIA IV – 20 MHz outdoor	Main lobe	227	372	586	289
	Side lobe	26	26	26	22

4.8.2.2 SRD type III

The following table provides an overview of the calculated separation distances for SRD type III. In this case, calculations are not done for the side lobe, since the results will be similar as in the main lobe.

Table 85: Separation distances (m) for SRD type III Interferer – WIA Victim

WIA type	Propagation model			
	Urban	Suburban	Rural	ETSI TR 102- 492
WIA I – 1 MHz indoor	41	41	41	31
WIA II – 20 MHz indoor	140	209	279	134
WIA IV – 3 MHz outdoor	249	413	675	335
WIA IV – 20 MHz outdoor	312	533	957	481

It has to be noted that the SRD are expected to be deployed mostly indoor resulting in a reduction of the separation distances. The following table provides an overview of the separation distances for SRD type III deployed indoor.

Table 86: Separation distances (m) for SRD type III indoor Interferer – WIA Victim

WIA type	Propagation model			
	Urban	Suburban	Rural	ETSI TR 102- 492
WIA I – 1 MHz indoor	7	7	7	7
WIA II – 20 MHz indoor	51	51	51	37
WIA IV – 3 MHz outdoor	109	156	177	93
WIA IV – 20 MHz outdoor	140	209	279	134

4.8.3 Conclusion on WIA sharing with SRDs

The below Table summarises the calculated separation distances for expected urban environment for the protection criterion I/N 0dB.

Table 87: Separation distances (m) to protect SRD

	WIA indoor	WIA outdoor
SRD mainbeam, outdoor	1 km	2 km
SRD sidelobe, outdoor	0.2 km	0.4 km
SRD sidelobe, indoor	0.1 km	0.2 km

Those distances are expected to be reduced essentially if considering the real usage of SRDs with a margin above sensitivity.

It has also to be noted that:

- The number of SRD currently using this band is very low.

- SRD 25 mW may be part of WIA deployment and therefore their deployment will be managed by the "operator" of WIA.

4.9 ADJACENT BAND STUDIES

This section investigates the possible impact of WIA on systems operation in the adjacent bands. Only limited consideration has been given to this issue.

4.9.1 Radiolocation

For the case that a WIA installation is using bands above 5.725 GHz, the adjacent band impact needs to be assessed to possible radars below 5.725 GHz

Based on the worst radar X in relation to the DFS threshold (see ANNEX 5:) the required distances and threshold values were recalculated to account for the adjacent band case.

Table 88 shows the distances under worst case conditions and Table 89 for the more realistic indoor case and non line of sight conditions.

Table 88: Radar separation distances free space loss, WIA outdoor

	Unit	Co-channel	OOB	OOB	OOB
Frequency	GHz	5.75	5.75	5.75	5.75
Bandwidth (BW)	MHz	4	4	4	4
BW1	MHz	1	1	1	1
Tx power WIA	dBm/BW1	21	-20	-30	-40
Antenna gain radar	dBi	35	35	35	35
WIA antenna gain	dBi	5	5	5	5
Nise figure radar F	dB	4	4	4	4
Noise radar	dBm/BW	-104	-104	-104	-104
Wall attenuation	dB	0	0	0	0
I/N	dB	-6	-6	-6	-6
Imax	dBm/BW	-110	-110	-110	-110
Propagation exponent (2= LOS)	dB	2	2	2	2
Separation distances	km	2595	13	4.	1.3

Table 89: Radar separation distances free space loss, WIA indoor

	Unit	Co-channel	OOB	OOB	OOB
Frequency	GHz	5.75	5.75	5.75	5.75
Bandwidth (BW)	MHz	4	4	4	4
BW1	MHz	1	1	1	1
Tx power WIA	dBm/BW	-30	-30	-30	-30
Antenna gain radar	dBi	35	35	35	35
Antenna WIA	dBi	5	5	5	5
Noise figure radar F	dB	4	4	4	4
Noise floor radar	dBm/BW	-104	-104	-104	-104
Wall attenuation	dB	10	10	10	10

	Unit	Co-channel	OOB	OOB	OOB
I/N	dB	-6	-6	-6	-6
Imax	dBm/BW	-110	-110	-110	-110
Propagation exponent (2= LOS)	dB	2	2.5	3	3.5
Separation distances	m	1301.1	310.1	119.2	60.2

It may be concluded based on the above calculations that the coexistence between WIA above 5.725 and radars below 5.725 GHz is possible in real life.

4.9.2 BFWA

A similar exercise as in the previous section was conducted for BFWA.

Table 90: BFWA separation distances free space loss, WIA outdoor

	Unit	Co-channel	OOB	OOB	OOB
Frequency	GHz	5.75	5.75	5.75	5.75
Bandwidth (BW)	MHz	4	4	4	4
BW1	MHz	1	1	1	1
WIA Tx power	dBm/BW	21	-20	-30	-40
Antenna gain BFWA	dBi	16	16	16	16
Antenna gain WIA	dBi	5	5	5	5
Noise figure BFWA	dB	6	6	6	6
Noise floor BFWA	dBm/BW	-95	-95	-95	-95
Wall attenuation	dB	0	0	0	0
I/N	dB	27	27	27	27
Fade margin	dB	10	10	10	10
Smin	dBm/BW	-58	-58	-58	-58
SIR	dB	27	27	27	27
Imax	dBm/BW	-85	-85	-85	-85
Propagation exponent n 1 (interfering path)	dB	2	2	2	2
Separation distances	m	9221.8	82.2	26.0	8.2

It is also here expected that the OOB and spurious emissions of WIA is not producing harmful interference to BFWA.

For all other adjacent band scenarios (e.g. ITS above 5.875 GHz) it is assumed that the conclusions for radars and BFWA are also valid here.

4.9.3 Guard band in the WIA channel plan

It should be noted that a guard band of 2.5 MHz is planned in the WIA channel arrangement. This implies that the frequency range 5725 to 5727.5 MHz and 5872.5 to 5875 MHz will not be used providing additional protection to the Radiolocation operating below 5825 MHz and to the “safety” ITS operating above 5875 MHz.

5 CONCLUSIONS

Relating to the channel utilization, it was noted that the WIA system would need 76 MHz to operate on a given site, however since part of this 76 MHz may not be available for WIA usage due to other possible users (RTTT, BFWA…), there would be a need to identify more than 76 MHz for WIA systems in order to ensure that they can operate. For some of the compatibility studies, the WIA was assumed to have access to the whole spectrum 5725 to 5875 MHz.

It should be noted that WIA systems with a maximum e.i.r.p. of 400 mW limited to indoor deployment (assuming 15 dB attenuation for the wall loss and similar devices quantities) would have an impact on the others services/systems similar to the impact resulting from SRD devices deployed outdoor according to the existing regulations (25 mW) [2]. Therefore, an indoor restriction may be seen as equivalent to the existing regulations and thus sufficient for the protection of others services/systems.

Independent on the above consideration, the Table below provides an overview of the conducted study results.

Table 91: Summary of the compatibility studies

Service/Systems	Results	Comments
Radiolocation 5.725-5.850 GHz	Large separation distances are required under worst case assumptions without mitigation technique. Thus DFS is required with the following detection thresholds: ▪ -65 dBm in 1 MHz ▪ -60.5 dBm in 3 MHz ▪ -52 dBm in 20 MHz The adjacent band coexistence appears possible. Note 1, Note 4	A DAA mitigation technique that is fully in operation at all times is mandatory. This must be ensured by the manufacturers of the WIA devices. Moreover, as the frequency band in question is dedicated to military services in some European countries, thus further reaching restrictions may apply. DFS as developed for WLAN and BFWA does not allow detecting all types of radars (cf. e.g. ECC Report 192 [34]). Recommendation ITU-R M.1638 [6], which lists the radar characteristics for the 5 GHz range, is under revision in ITU WP 5B. Due to the ongoing process this report at hand does not encompass all types of radars. Part of the spectrum may be blocked by radars
RTTT 5.795-5.805 GHz, 5.805-5.815 GHz (used by some Administrations)	No interference is expected in the case of OBU RTTT. In the case of RTTT RSU the separation distances without DAA mitigation techniques are depending on the environment: ▪ Urban environment 100 m	

Service/Systems	Results	Comments
	▪ Suburban environment 1000 m ▪ Rural environment 2500 m DAA mitigation techniques were not studied but the same threshold as for ITS may be considered. Note 2, Note 4	
BFWA 5.725-5.875 GHz	The separation distances without DAA mitigation techniques are depending on the environment: ▪ Urban environment no separation distance required ▪ Suburban environment less than 3 km ▪ Rural environment between 3 km (C/I criterion) and 10 km (I/N criterion) Thus DAA with a threshold of -99 dBm on WIA device level is required in suburban and rural environments. Note 1, Note 2, Note 3, Note 4, Note 5	
FSS 5725-5875 MHz	The deployment of WIA is compatible with FSS if TPC (based on a minimum power strategy) is implemented and the assumptions on the number of devices are met (see Table 52).	
Radio Amateur Service 5725-5850 MHz	Under worst case assumptions, separation distances may be needed. Considering more realistic cases, the separation distances are significantly reduced. Note 2	It should be noted that the most sensitive amateur service operations are globally harmonised at 5760-5762 MHz
Radio Amateur Satellite Service 5830-5850 MHz	No interference is expected. Note 2.	
ITS 5855-5875 MHz	Required separation distances without DAA mitigation techniques are depending on the environment: ▪ Urban environment 100 m ▪ Rural environment 2500 m Thus DAA with a threshold of -85 dBm on WIA device level is required. Note 1, Note 2, Note 3, Note 4, Note 5	
Non Specific SRD 5725-5875 MHz	Under worst cases assumptions, separation distances may be needed. Considering a realistic case, no separation distance is needed	Limited information on the SRDs deployed in the band was provided

Note 1: DFS/DAA on device level may not be possible for all WIA applications. Further developments may show automated solutions so that a sensing procedure may be able to coordinate centralized the spectrum.

Note 2: Due to the fact that TPC was found necessary to meet the FSS protection criterion, TPC was assumed when conducting the compatibility studies.

Note 3: higher threshold would be possible with the use of centralized sensing.

Note 4: A registration/ notification / light licensing procedure for WIA could help in enforcing the required separation distances (e.g. to tolling bridges, RTTT).

Note 5: If both systems (interferer and victim) are based on IEEE 802.11, coexistence between those systems might be possible using an updated CSMA/CA protocol. However, this is still to be demonstrated.

Relating to Direct Air To Ground Communications, it should be noted that the work relating to the identification of spectrum was still on going at the time where this ECC Report was developed, therefore, those systems were not considered in the framework of this report.

In addition, in the framework of Agenda item 1.1 WRC-15, CPG is investigating the possibility to introduce RLAN in the frequencies under consideration for WIA. In addition, the EC has issued a Mandate calling for studies in the 5 GHz frequency range. Since those studies are still at an initial stage, this case was not considered in this report.

Those additional studies may result in the implementation of additional mitigation techniques.

ANNEX 1: INDUSTRIAL WIRELESS APPLICATIONS PARAMETERS AND DEPLOYMENT SCENARIOS

A1.1 TECHNICAL PARAMETERS

A1.1.1 Transmitter Parameters

A1.1.1.1 Transmitter output power

For the manufacturing cells, it is expected that the existing regulations (25 mW) is sufficient.

For the other applications which may operate at distances up to 100 m under non line of sight condition a e.i.r.p. up to 400 mW (26 dBm) is required[2] .

A1.1.1.2 Transmitter masks

The following table provides the steps of the 1 MHz mask.

Table 92: Transmit Spectrum mask for 1 MHz system

Frequency offset	Transmit Power	Reference Bandwidth
± 500 kHz	26 dBm	1 MHz
± 550 kHz	–20 dBc	1 MHz
± 2 MHz	–20 dBm	1 MHz
Larger than 3 MHz	–40 dBm	1 MHz

This is further illustrated in the following figure.

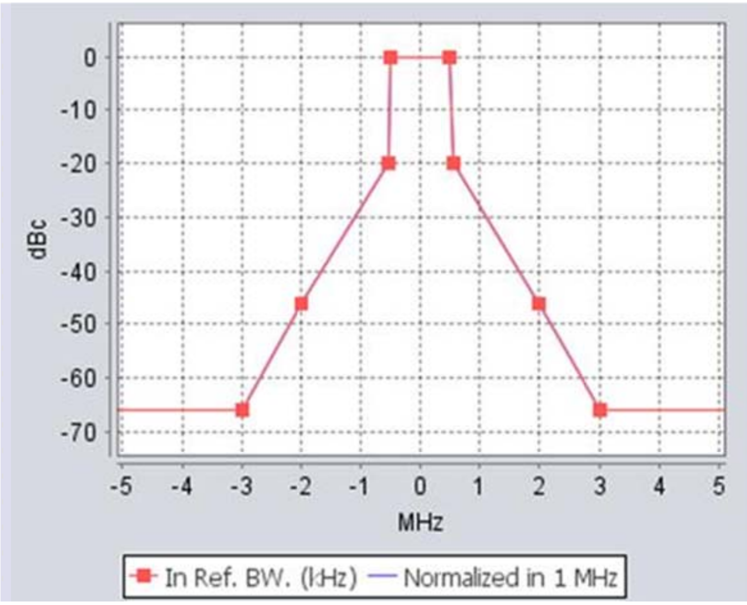


Figure 34: WIA - 1 MHz emission mask

The following table provides the steps of the 3 MHz mask.

[2] The value for the transmitter output power is higher than the specified value of 250 mW (24 dBm) in the technical report ETSI TR 102 889-2 V1.1.1 [1] since the specified transmitter output power in [1] refers to the 2.4 GHz frequency band. In the frequency band from 5.725 to 5.875 GHz, the electromagnetic wave propagation conditions are worse; therefore a higher level of transmitter output power is needed to meet the requirements of industrial wireless applications also within this frequency band.

Table 93: Transmit Spectrum mask for 3 MHz system

Frequency offset	Transmit Power	Reference Bandwidth
± 1,5	26 dBm	3 MHz
± 3,5	Relative: –20 dBc Absolut: -20 dBm	1 MHz
± 7,5	-30 dBm	1 MHz (ERC/REC 74-01) [27]

This is further illustrated in the following figure.

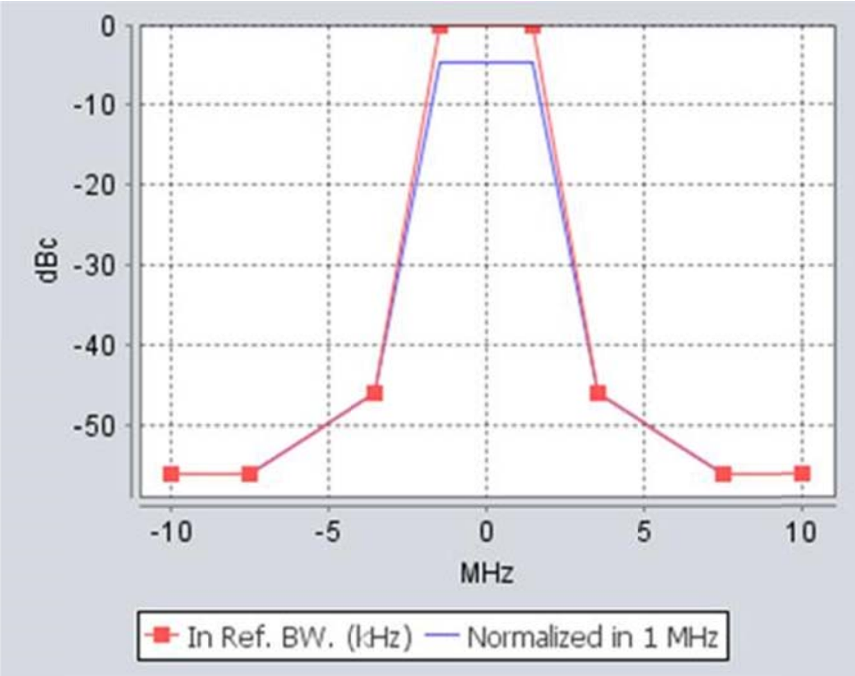


Figure 35: WIA - 3 MHz emission mask

The following table provides the steps of the 20 MHz mask.

Table 94: Transmit Spectrum mask for 20 MHz system

Frequency offset	Transmit Power	Reference Bandwidth
± 9	26 dBm	20 MHz
± 11	-20 dBr	1 MHz
± 20	-28 dBr	1 MHz
± 30	-43 dBr	1 MHz

This is further illustrated in the following figure.

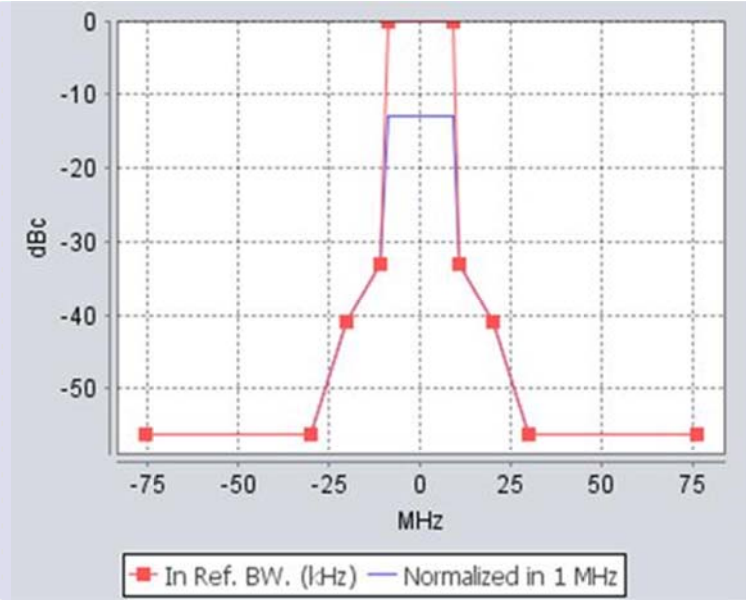


Figure 36: WIA - 20 MHz emission mask

A1.1.1.3 Antenna Characteristics

No restrictions on antenna characteristics, according to the description in section 6.3.2 of ETSI TR 102 889-2 V1.1.1 (2011-08) [1].

The default antenna type is omnidirectional (collinear dipole antenna). Therefore, Recommendation ITU-R F.1336-3 [28] should be used. Following section (1.a) in section formula (2.1) Recommendation ITU-R F.1336-3 [28] the expression of antenna gain in dBi at elevation angle Θ in degrees is given by:

$$G(\Theta) = \begin{cases} G_0 - 12 \cdot \left(\dfrac{\Theta_0}{\Theta_3}\right) & 0° \le |\Theta| \le \Theta_3 \\ G_0 - 12 + 10\log\left[\left(\dfrac{\Theta_0}{\Theta_3}\right)^{-1,5}\right] + k & \Theta_3 \le |\Theta| \le 90° \end{cases}$$

$$\Theta_3 \approx 107{,}6 \cdot 10^{-0{,}1 \cdot G_0} = 34°$$

where:

Θ: absolute value of the elevation angle relative to the angle of maximum gain (degrees)
Θ_3: the 3 dB beamwidth in the vertical plane (degrees)
k: sidelobe factor → for all antennas operating in the 3-70 GHz range, the parameter k should be 0.
G(Θ) : gain relative to an isotropic antenna (dBi)
G_0 : the maximum gain in the azimuth plane (dBi)

The WIA antenna is shown in the following figures. The hinge mounting allows various orientations. Therefore, in simulations, a random antenna tilt between 0º and 90º (for azimuths between 0º and 360º) is taken into account.

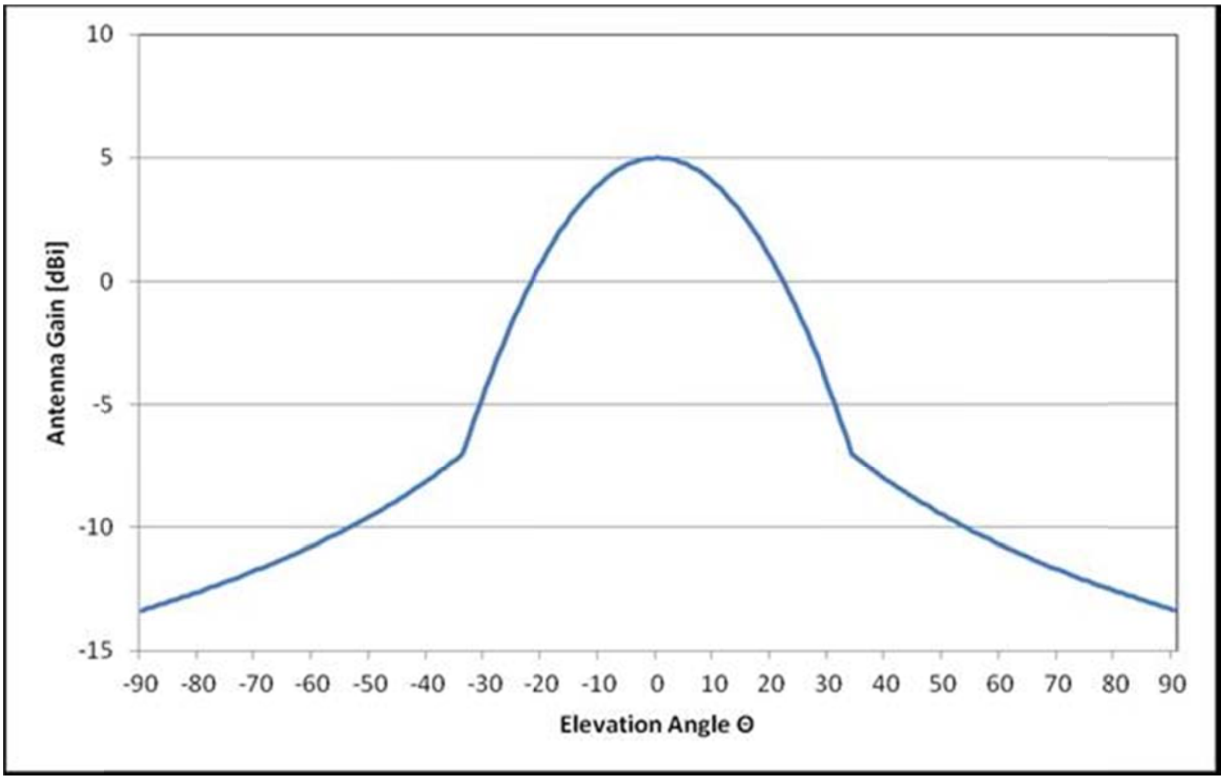


Figure 37: Antenna pattern according Recommendation ITU-R F.1336 [28]

The following material provides information on typical WIA antennas.

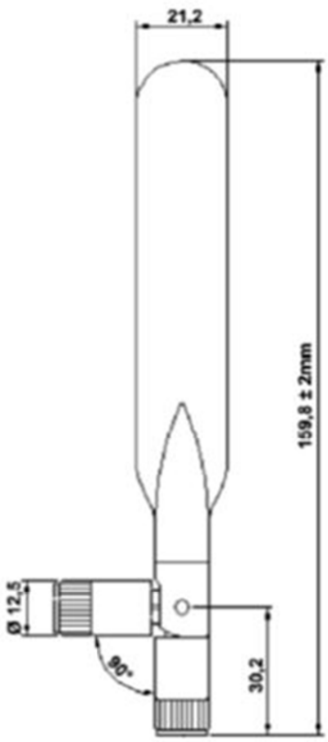


Figure 38: Example of dual band antenna (Siemens AG)

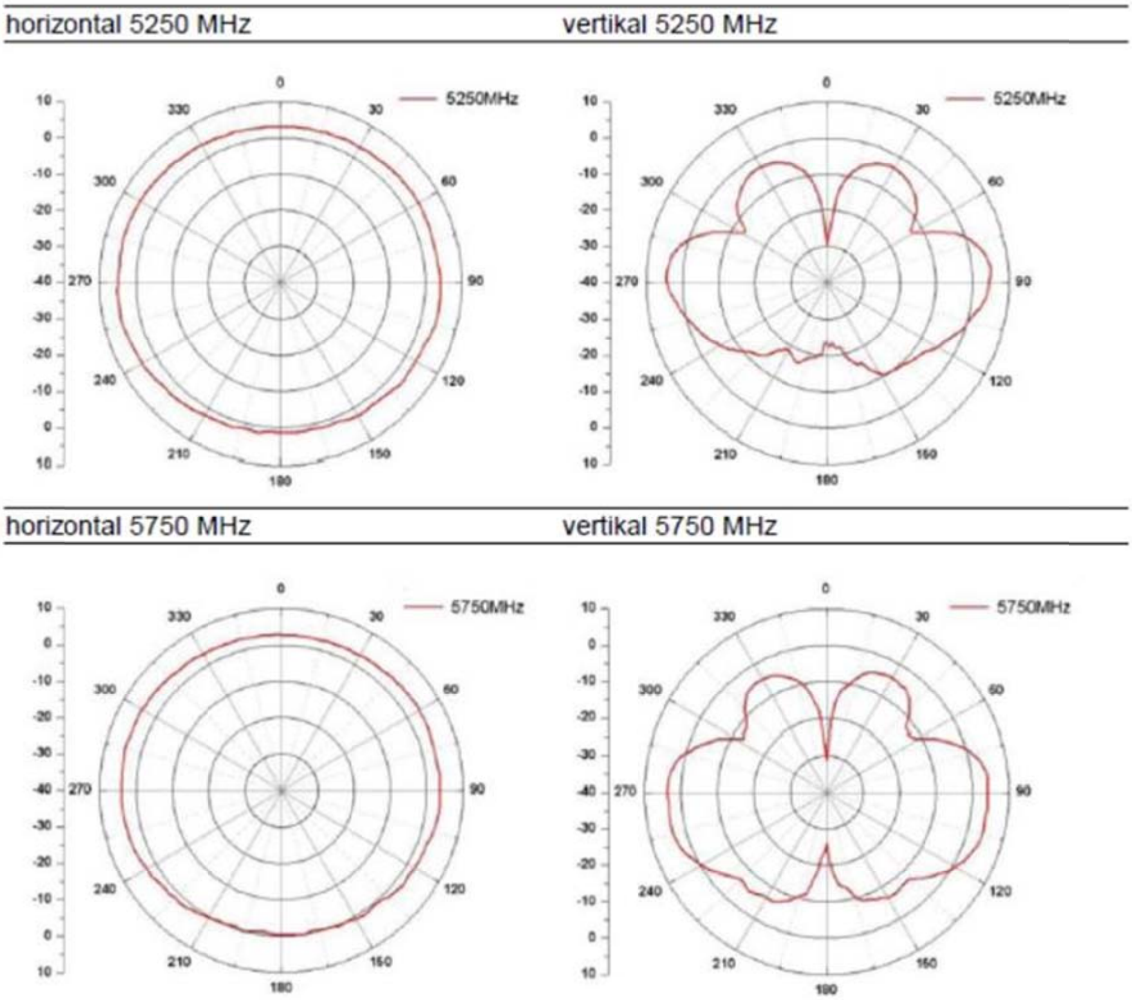


Figure 39: Antenna pattern of dual band antenna (Siemens AG)

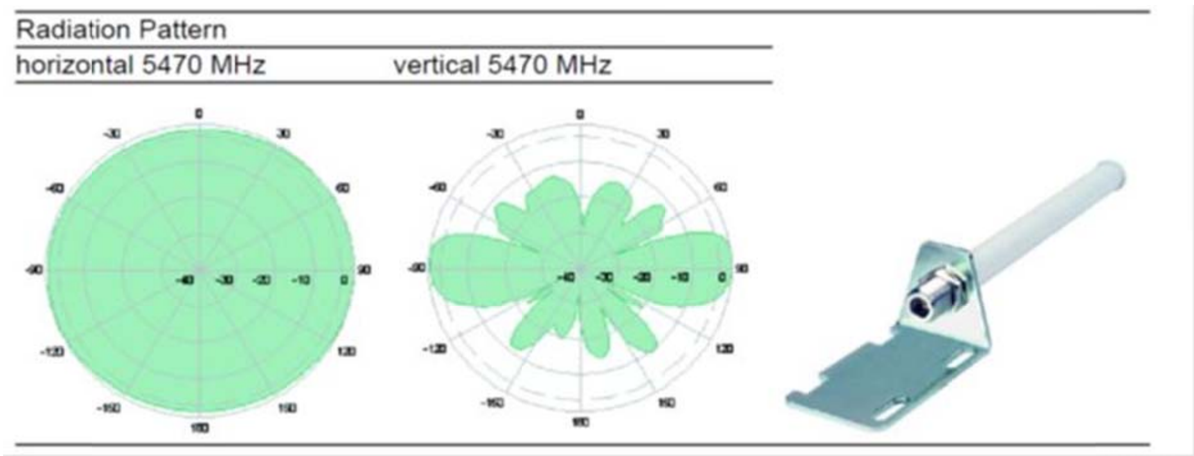


Figure 40: Antenna pattern of dual band antenna (Hirschmann Automation and Control GmbH)

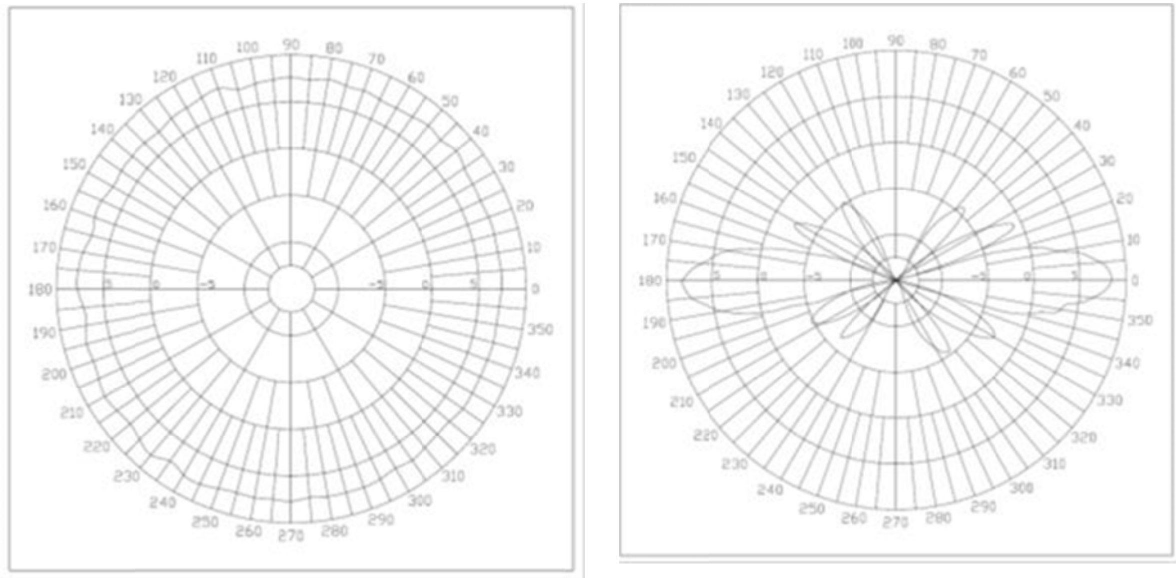


Figure 41: H-Plane field pattern (WIMo GmbH) (left) - E-plane field pattern (WIMo GmbH) (

A1.1.1.4 Bandwidth

As different technologies are used, the typical occupied bandwidth for a single device varies between 1 MHz and 20 MHz. Frequency Hopping as well as non-frequency hopping technologies is used. The parallel use of all tree classes requires a preferably continuous spectrum of 76 MHz..

A1.1.1.5 Receiver parameters

Most of the technologies used in the industrial applications are based on specifications such as IEEE 802.11 [20], IEEE 802.15.1 [29] and IEEE 802.15.4 [30]. The relevant receiver parameters including the receiver sensitivity and protection criteria (C/I) can be found in the following table.

Table 95: Receiver parameters

Characteristic	Unit	WIA 1 MHz	WIA 3 MHz	WIA 20 MHz
Bandwidth	MHz	1	3	20
Receiver sensitivity	dBm	-84	-90	-88
Protection criteria C/I	dB	6	6	6

A1.1.1.6 Channel access techniques

For maximised spectrum efficiency, including sharing among all wireless industrial applications present, a spectrum sharing mechanism appropriate for industrial applications is required. Various channel access techniques are under consideration: TDMA, CSMA and adaptive FHSS.

An example of that is also Frequency Agility. Frequency Agility is the ability of a system to operate according to frequency or channel assignments of a centralized or distributed control mechanism, which will define the configuration of all devices within an industrial site or subarea thereof. Configurations may change over time depending on the application requirements. If non-contiguous spectrum is assigned, then the Frequency Agility feature is supposed to operate across all assigned sub-bands.

Cognitive features for wireless industrial applications are under development and this may allow dynamically adapting the configuration of the WIA installation to the local requirements in terms of frequency regulations and other SRD users.

A1.1.2 Summary of technical parameters

The following table provide an overview of the characteristics of WIA operating with 1 MHz, 3 MHz or 20 MHz channel bandwidths.

Table 96: Technical parameters of WIA system

Parameter	System for Manufacturing Cell	System for Factory Hall	System for Plant
max e.i.r.p.	25 mW (14 dBm)	400 mW (26 dBm)	400 mW (26 dBm)
Receiver sensitivity	-84 dBm in 1 MHz	-84 dBm in 1 MHz - 90 dBm in 3 MHz -88 dBm @ 6 MBit/s in 20 MHz	- 90 dBm in 3 MHz -88 dBm in 20 MHz
Channel bandwidth (MHz)	1 MHz	1 MHz, 3 MHz and 20 MHz	3 MHz and 20 MHz
Channel spacing (MHz)	1 MHz	1 MHz, 5 MHz and 20 MHz	5 MHz and 20 MHz
Min. Number of hopping channels	no requirements	-	no requirements
Max. Number of hopping channels	BW_{Total}/1 MHz	-	BW_{Total}/5 MHz
Topology	Star	Star/Mesh	Mesh
Duty Cycle	20 %	20 %	20 %
Antenna	See Annex 1	See Annex 1	See Annex 1
Antenna height (m)	0.5 m to 3 m	0,5 m to 10 m	0.5 m to 50 m

The manufacturing cells can be deployed under the existing regulatory framework of ERC/REC 70-03 Annex 1 [2].

A1.2 DEPLOYMENT SCENARIOS

All of the three wireless classes (cell or sub-unit automation; factory hall or plant sub-unit automation and plant level automation) are operated in parallel. Parallel means that at most parts of the plant, the three "wireless" classes operate overlapping, preferably in the same frequency band for maximal flexibility of coexistence management reasons, to increase spectrum efficiency and to have the same needed spectrum properties like industrial-interference-free, power efficiency (range) and bending/damping by obstacles.

A1.2.1 Channelization

The establishment of coexistence is a combination of technical and/or organizational measures to ensure the interference-free operation of wireless industrial applications in their environments. Coexistence between wireless industrial automation communication systems can be achieved by uncoupling the dimensions frequency, time and space. Consequential the WIA with 1 MHz, 3 MHz and 20 MHz use separate frequency bands in a given cell.

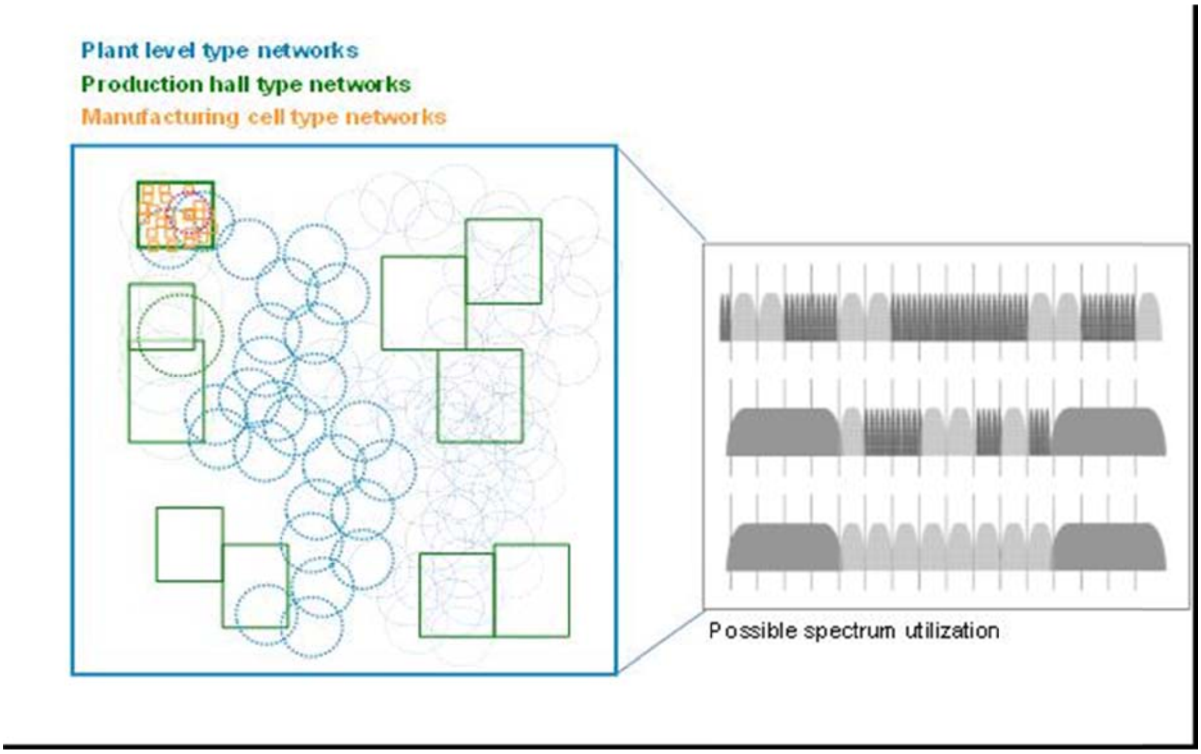


Figure 42: Possible channel pattern

The use of WIA systems with 1 MHz, 3 MHz and 20 MHz bandwith depends on the requirement of industrial application.

The WIA industry is considering a channel plan with 5 MHz grid for the deployment of WIA systems based on the channels given in the following table. The first 2.5 MHz at the edges of the band are not planned to be used.

Table 97: Possible channels

Channel No.	Channel centre frequency [MHz]	Channel No.	Channel centre frequency [MHz]	Channel No.	Channel centre frequency [MHz]
145	5725	156	5780	167	5835
146	5730	157	5785	168	5840
147	5735	158	5790	169	5845
148	5740	159	5795	170	5850
149	5745	160	5800	171	5855
150	5750	161	5805	172	5860
151	5755	162	5810	173	5865
152	5760	163	5815	174	5870
153	5765	164	5820	175	5875
154	5770	165	5825		
155	5775	166	5830		

The channel plans for 1 MHz, 3 MHz and 20 MHz are further described in the following sections.

A1.2.2 WIA with 1 MHz bandwidth

WIA with 1 MHz uses a frequency spread scheme. Instead of generating a wideband signal, the useful signal is divided into numerous narrowband signals, the carrier frequency of these signals changes during transmission based on a hopping scheme. The spread technique is a Frequency Hopping Spread Spectrum (FHSS) technique with a simple modulation technique such as Gaussian Frequency Shift Keying (GFSK). WIA with 1 MHz bandwidth divides the available band into single channels each with a channel width of 1 MHz.

It is possible to use the following channel by WIA systems with 1 MHz bandwidth:

$$f_{C_n} = f_{start} + n_{ch}^{1MHz}; \qquad n_{ch}^{1MHz} = 0,......,140$$

where:

f_{C_n} is the channel center frequency

f_{start} is the channel starting frequency, defined as 5730 MHz

n_{ch}^{1MHz} is the channel number 0 to 140

A1.2.3 WIA with 3 MHz bandwidth

WIA with 3 MHz bandwidth uses DSSS as spreading scheme. The available band is divided into single channels with a channel width of 5 MHz. These channels are non-overlapping channels, because the channel width is greater than the channel bandwidth.

The possible channel centre frequency for the WIA systems with 3 MHz bandwidth can be calculated with following equation:

$$f_{C_n}[MHz] = f_{start} + 5 \cdot (n_{ch}^{3MHz} - 147); \qquad n_{ch}^{3MHz} = 146,......,174$$

where:

f_{C_n} is the channel center frequency

f_{start} is the channel starting frequency, defined as 5725 MHz

n_{ch}^{3MHz} is the channel number 146 to 174

A1.2.4 WIA with 20 MHz bandwidth

The WIA with 20 MHz bandwidth offers a lot of data rates depending on the applied modulation schemes and multiplex mechanism. The modulation schemes supported are:

- Binary Phase Shift Keying (BPSK): 6 and 9 Mbit/s,
- Quaternary Phase Shift Keying (QPSK): 12 and 18 Mbit/s,
- 16-Quadrature Amplitude Modulation (16-QAM): 24 and 36 Mbit/s,
- 64-Quadrature Amplitude Modulation (64-QAM): 48 and 54 Mbit/s.

To implement undisturbed communication, e.g. for transmission of real-time fieldbus traffic, in various WIA systems with 20 MHz bandwidth within the same area of coverage, is recommended to use non-overlapping channel. WIA with 20 MHz bandwidth divides the available band into non-overlapping channels each of

20 MHz channel bandwidth with a minimum space of 20 MHz between the center frequencies of the channels.

The possible channel center frequency for the WIA systems with 20 MHz bandwidth can calculate with following equation:

$$f_{C_n}[MHz] = f_{start} + 5 \cdot (n_{ch}^{20MHz} - 147); \qquad n_{ch}^{20MHz} = 147,......,173$$

Where:

f_{C_n} is the channel center frequency

f_{start} is the channel starting frequency, defined as 5725 MHz

n_{ch}^{20MHz} is the channel number 147 to 173

$n_{ch_{NO}}^{20MHz}$ is an example of channel number of non-overlapping channels: 149, 153, 157, 161, 165, 169 to 173

A1.2.5 Channel utilisation in a factory

The use of WIA systems with 1 MHz, 3 MHz and 20 MHz bandwidth depends on the requirement of industrial application. Figure 43 depicts three different examples of WIA channelization (see also section A1.2.1 for additional details).

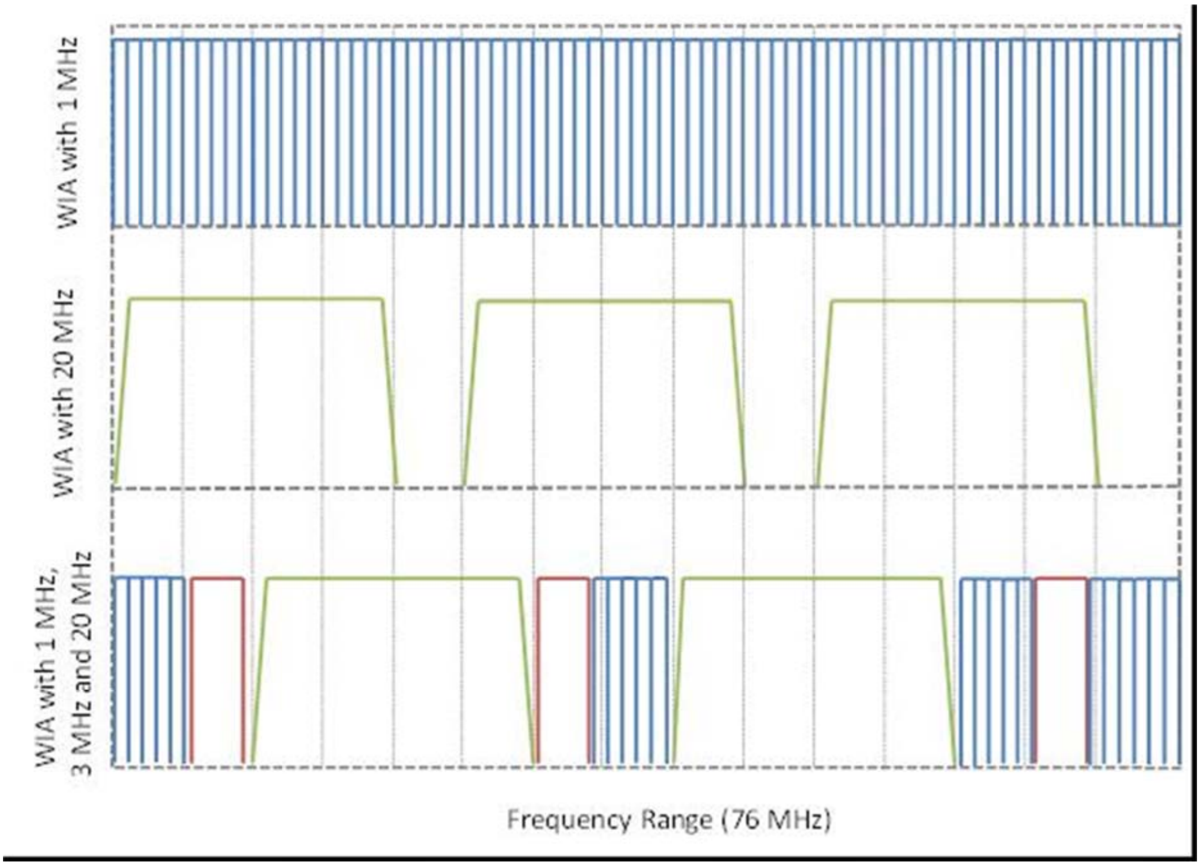


Figure 43: Example of channelization

Three deployment scenarios shall be considered.

A1.2.5.1 Case 1: Only indoor WIA systems with 1 MHz bandwidth and 400 mW e.i.r.p.

250 WIA systems with 1 MHz bandwidth use the required frequency range of 76 MHz within the industrial plant.
The following assumptions were made:

- The WIA system with 1 MHz bandwidth use a frequency hopping spread spectrum (FHSS) for signal spreading.
- The duty cycle per WIA system with a bandwidth of 1 MHz, which contains of 2 WIA devices is nearly 30 %. That mean, each WIA system with a bandwidth of 1 MHz use 30 % or each WIA device with a bandwidth of 1 MHz use 15% of available time.
- Per timeslot only 75 from 500 WIA devices with 1 MHz bandwidth are simultaneously active over the frequency range of 76 MHz.
- One WIA device with 1 MHz bandwidth is active in each of the 75 x 1 MHz channels

A1.2.5.2 Case 2: Only WIA systems with 20 MHz bandwidth and 400 mW e.i.r.p.

40 WIA systems with 20 MHz bandwidth use three non-overlapping channels over the required frequency range of 76 MHz.
The following assumptions were made:

- 30 WIA systems deploy indoor and 10 WIA Systems deploy outdoor
- The WIA system with 20 MHz bandwidth use OFDM for signal spreading.
- The system architecture of WIA systems with 20 MHz bandwidth allows only one active device per system and channel.
- The number of 20 MHz width channels is 3.
- The number of simultaneous active systems and active devices per 1 out of 3 channels is around 13, distributed over the whole industrial plant area.
- The number of simultaneous active indoor WIA devices is 10 per 20 MHz channel.
- The number of simultaneous active outdoor WIA devices is 3 per 20 MHz channel.

A1.2.5.3 Case 3: Mixed scenario of all WIA type and 400 mW e.i.r.p.:

The following devices are simultaneously active in the frequency range of 76 MHz:

- 250 WIA systems with 1 MHz bandwidth are deployed indoor,
- 4 systems with 3 MHz bandwidth: 3 are deployed outdoor and 1 is deployed indoor
- 40 systems with 20 MHz bandwidth: 10 are deployed outdoor and 30 are deployed indoor

The following assumptions are valid:

- Bullet point level 2
  - Bullet point level 3

- WIA systems with 20 MHz bandwidth
  - Two 20 MHz channels are available for the mixed scenario.
  - The number of simultaneously active devices with 20 MHz bandwidth per channel is 20.
  - Indoor 15 WIA device and outdoor 5 WIA devices simultaneously active per channel.
- WIA systems with 3 MHz bandwidth
  - Three channels with 3 MHz bandwidth are used by four WIA systems with 3 MHz bandwidth.
  - One outdoor WIA device is active on each 3 MHz channel.
  - In addition, on one out of these three available channels is one indoor WIA device active.
- WIA systems with 1 MHz bandwidth
  - The 250 WIA systems with 1 MHz bandwidth can use 27 channels with 1 MHz bandwidth.
  - The consequence of reduced available frequency range is that around 3 WIA devices with 1 MHz bandwidth operate simultaneously per channel over the whole industrial plant (indoor).

Table 98: Summary in case of mixed scenario

Parameter	20 MHz	3 MHz	1MHz
Indoor	15	1	3
Outdoor	5	1	None

A1.3 GEOGRAPHICAL DEPLOYMENT OF WIA

The following table provides an estimation of the number of wireless industrial automation devices other than UWB (WIA) over Germany. This estimation considers the deployment of WIA equipment in both large and small plants.

Table 99: Deployment of WIA in Germany

Parameters	Values
Population / Germany	80 000 000
Population / Frankfurt am Main	690 000
Plants / Frankfurt am Main	4
Plants / Germany	533
Wireless Devices / Germany	12 590 000
Area Germany km²	357 000
Wireless devices Germany/km²	34.3

The numbers given for Germany are further defined for each of the WIA system in the following table.

The information relating to Germany is then extended to the whole EU considering a ratio of 4,1 between Germany and the rest of Europe (additional information on the derivation of this ratio is given in ANNEX 2:).

Table 100: Deployment of WIA in EU

Parameters	Values
Automation ratio EU/Germany	4,1
Wireless Devices EU	51 496 000
Area EU km²	10 180 000
Device density EU/km²	5.06

WIA devices may be deployed at 2.4 GHz, at 5 GHz (5.15 - 5.35 / 5.47 - 5.725 GHz and at 5.8 GHz resulting in a decrease to about 25 % of the devices to be considered in the compatibility studies in the 5.8 GHz band. The following table provides an overview of the WIA deployment considering these three bands.

Table 101: Distribution of WIA devices via different frequency ranges

	Long term number of wireless industrial automation devices in EU
Anticipated number of WIA equipment	51 496 000
Percentage of WIA device deployed at 2.4 GHz	50%
Percentage of WIA device deployed at 5.15-5.725 GHz	25%

Percentage of WIA device deployed at 5.725-5.875 GHz (5.8 GHz)	25%
Number of WIA devices at 5,8 GHz	12 874 000
Percentage of WIA device with 25 mW e.i.r.p. percentage	75%
Number of WIA devices with e.i.r.p.>25 mW at 5.8 GHz in the EU	3 218 500

It should be noted that another study (see ANNEX 2:) anticipated a deployment of 14 300 000 equipment worldwide in 2015. Based on this information, it is expected that the numbers above may provide an overestimation of the number of WIA equipment to be deployed over the EU.

A1.3.1 Assumptions for a realistic deployment scenario

The following table depicts the assumption about the number of wireless devices per application environment.

Table 102: Assumption about the number of wireless devices per application environment

	Application Environment					
	Manufacturing cell	Factory hall			Plant level	
Bandwidth [MHz]	1	1	3	20	3	20
Transmit power e.i.r.p. [mW]	25	400	400	400	400	400
Spatial dimension [m]	10 x 10 x 3	100 x 100 x 10			1 000 x 1 000 x 50	
Network type	Star	Point-to-Point/Star/Mesh			Star/Mesh	
Location	Indoor	Indoor			Outdoor	
Number of devices per wireless system	30	2	500	100	500	150
Number of locally parallel systems/units (=cluster)	10	10	1	3	3	1
Number of such clusters / plant	50	25	1	10	1	10
Number of systems / plant	500	250	1	30	3	10
Number of devices / plant	15000	500	500	3000	1500	1500
Number of devices/Germany (533 plants)	7995000	266500	266500	1599000	799500	799500
Number of devices/Europe (ratio EU/Germany=4.1)	32 779 500	1 092 650	1 092 650	6 555 900	3 277 950	3 277 950
Number of simultaneously active devices per plant	500	250	1	30	3	10
Number of simultaneously active devices per Germany	266500	133250	533	15990	1599	5330
Total number of simultaneously active WIA devices per Europe (ratio EU/Germany=4.1)	1 092 650	546 325	2 185	65 559	6 556	21 853
Number of simultaneously active WIA devices per EU at 5.8 GHz (25% of total amount)	273 162	136 581	546	16 390	1 639	5 463

A1.4 TRANSMIT POWER CONTROL (TPC) MECHANISM

The implementation of TPC in WIA is under consideration in order to decrease the impact of their deployment on the other users of the frequency range 5725-5875 MHz.

The key parameters of WIA devices/systems are depicted in the following table.

Table 103: Characteristics of WIA devices

	WIA 1 MHz	WIA 3 MHz	WIA 20 MHz
Transmit power e.i.r.p.	26 dBm	26 dBm	26 dBm
Receiver sensitivity	-70 dBm	- 90 dBm	-88 dBm
Path loss capability	96 dB	116 dB	114 dB
Max Distance	48 m	179 m	157 m
Number of Devices per plant	500	500	3000

The transmit power reduction is dependent on received power (Transmit power [dBm]-Path Loss [dB]) and the receiver sensitivity. There is a direct relationship between TPC Value (Transmit power reduction) and fade margin. The calculation of fade margin is done as follows:

Fade Margin [dB] = Transmit Power [dBm] - Path Loss [dB] - (Receiver Sensitivity + 3 dB)

The relationship between TPC value and fade margin is depicted in the following table.

Table 104: Relationship between TPC Value and Fade Margin

TPC Value [dB]	Fade Margin [dB]
30	>30
27	<30
24	<27
21	<24
18	<21
15	<18
12	<15
9	<12
6	<9
3	<6
0	<3

A1.4.1 TPC Indoor

The probability of transmit power reduction of WIA devices depending on distance between transmitter and receiver is listed in the following for each WIA type. The following assumptions will form the basis of further considerations.

- The distance between WIA devices is uniform distributed between 1 and maximum transmission distance for WIA-I:1 MHz and between 1 m and 100 m for WIA-II: 3 MHz and WIA-III: 20 MHz
- The distances are calculated with SEAMCAT path loss Model_C_IEEE_802_11_rev2 (Break point: 5m, Log-normal distribution before break point: 3 dB and after BP: 4dB) and fading margin (see ANNEX 3:).

Table 105: Probability of Transmit Power Reduction

Transmit power Reduction [dB]	WIA 1 MHz		WIA 3 MHz		WIA 20 MHz	
	Distance [m]	Probability	Distance [m]	Probability	Distance [m]	Probability
0	40	0.20	150	0.00	128	0.00
3	32	0.14	121	0.01	106	0.13
6	27	0.15	99	0.19	88	0.17
9	22	0.10	81	0.15	72	0.14
12	18	0.07	67	0.09	59	0.10
15	15	0.08	56	0.09	48	0.09
18	12	0.05	46	0.10	39	0.07
21	10	0.04	37	0.08	32	0.05
24	8	0.03	30	0.03	27	0.05
27	7	0.04	25	0.04	22	0.04
30	5	0.13	20	0.22	18	0.17

The cumulative distribution function of TPC value is depicted in the following figure.

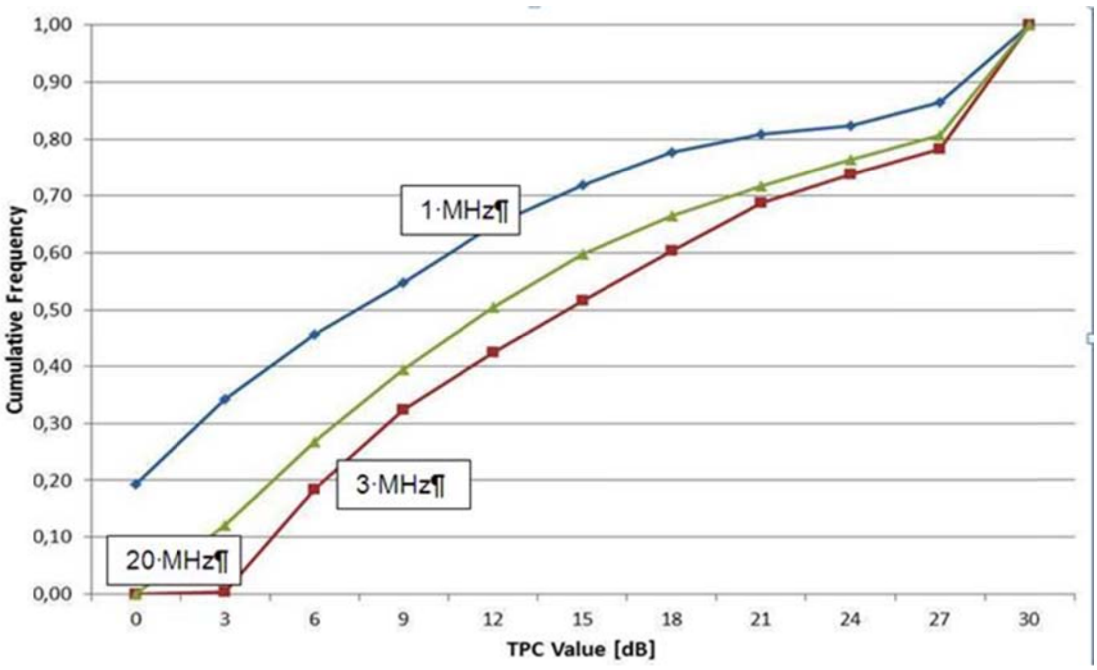


Figure 44: Cumulative distribution function of transmit power control value (WIA-indoor)

The result of transmit power reduction by the use of TPC is listed in the following table.

Table 106: Average reduction of transmit power (Indoor)

WIA	No. of Device	Aggregate e.i.r.p. [dBm]		Average reduction of transmit power (dB)
		without TPC	with TPC	
1 MHz	500	53.01	47.97	5.04
MHz	500	53.01	41.53	11.48
0 MHz	3000	60.79	51.85	8.94

A1.4.2 TPC Outdoor

The probability of transmit power reduction of WIA devices depending on distance between transmitter and receiver is listed in the following table for each WIA type. The following assumptions will form the basis of further considerations.

- The distance between WIA devices is uniform distributed between 1 m and 100 m
- The distances are calculated with SEAMCAT path loss Model_C_IEEE_802_11_rev2 (Break point: 500 m, Log-normal distribution before BP: 3 dB and after BP: 4 dB) and fading margin.

Table 107: Probability of Transmit Power Reduction

Transmit power Reduction [dB]	WIA 1 MHz		WIA 3 MHz		WIA 20 MHz	
	Distance [m]	Probability	Distance [m]	Probability	Distance [m]	Probability
0	177	0.00	1000	0.00	923	0.00
3	119	0.12	852	0.00	736	0.00
6	87	0.32	685	0.00	606	0.00
9	66	0.48	557	0.00	499	0.00
12	51	0.61	435	0.00	358	0.00
15	38	0.69	322	0.00	260	0.12
18	29	0.78	229	0.24	177	0.28
21	22	0.86	151	0.22	119	0.16
24	14	0.89	107	0.15	87	0.11
27	11	0.95	78	0.12	66	0.08
30	5	1.00	59	0.28	51	0.25

The cumulative distribution function of TPC value is depicted in the following Figure.

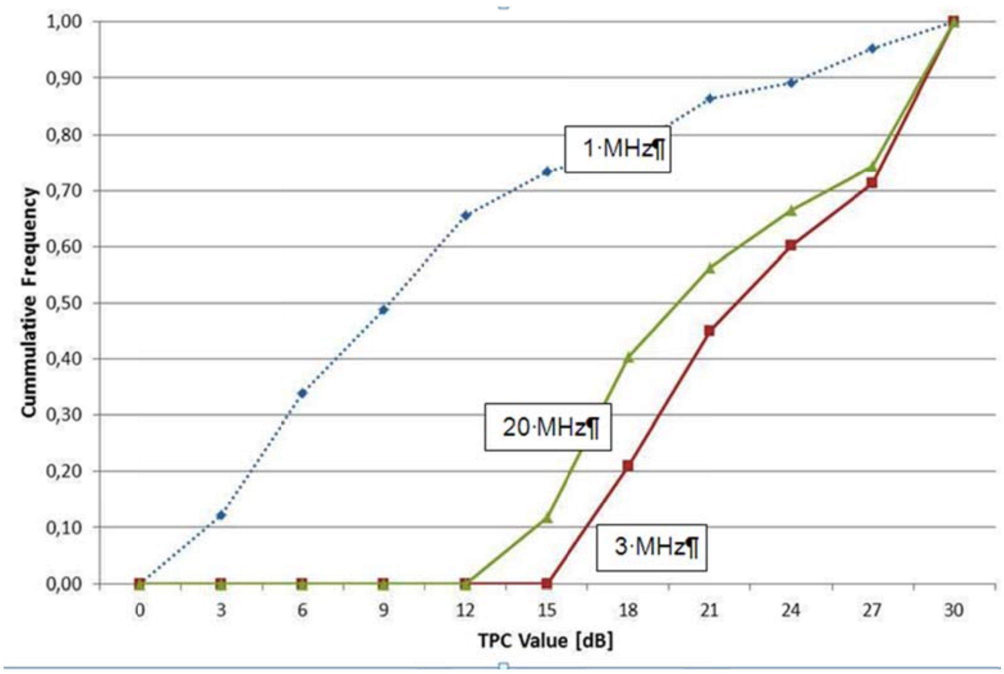


Figure 45: Cumulative distribution function of transmit power control value (WIA-Outdoor)

A1.4.3 Overview of the TPC values

The results of average reduction of transmit power achieved by implementing TPC are listed in the following table.

Table 108: Average reduction of transmit power (Outdoor)

WIA	No. of Device	Aggregate e.i.r.p. [dBm]		Average reduction of transmit power (dB)
		Without TPC	With TPC	
1 MHz (*)	500.00	53.01	44.53	8.48
3 MHz	500.00	53.01	31.18	21.83
20 MHz	3000.00	60.79	40.89	19.90

(*) calculations are provided for WIA I (1 MHz) outdoor for information only since WIA I are not expected to be deployed outdoor.

ANNEX 2: ESTIMATIONS OF THE NUMBER OF WIRELESS INDUSTRIAL AUTOMATION DEVICES OTHER THAN UWB (WIA)

A study from from IMSResearch (see [31]) indicated that worldwide around 15 million wireless automation devices would be deployed in year 2015.

Information made available in ETSI while developing the SRdoc [1]are as follows:

The number of plants per Germany is focused primarily on large industrial plants. But the total number of wireless devices is not affected by other micro, small or medium plants or factories. The following table provides an overview of the deployment anticipated in Germany.

Table 109: Deployment of WIA in Germany

Parameters	Values
Population / Germany	80 000 000
Population / Frankfurt am Main	690 000
Plants / Frankfurt am Main	4
Plants / Germany	533
Wireless Devices / Germany	12 590 000
Area Germany km²	357 000
Wireless devices Germany/km²	34.3

The value added by enterprise size class is in European countries [32] is further depicted in the following table.

Table 110: Enterprise size in Europe

Country	Value added by enterprise size class, mining and quarrying and manufacturing, 2008 (% share of size class in total sectoral value added)			
	Micro (0-9)	Small (10-49)	Medium (50 - 249)	Large (+250)
EU (27 Countries)	7		23.5	
Belgium	6.30	13.5	21.4	53.8
Bulgaria	5.90	17.6	34.3	58.7
Czech Republic	9.10	11.3	24.4	42.1
Denmark	5.90	15.2	24.5	55.1
Germany	3.30	10.3	21.5	64.9
Estonia	6.60	20.3	42.7	30.4
Ireland	2.30	7.3	24.2	66.3
Greece				
Spain	11.30	25.5	23.6	39.6
France	10.30	15.7	20.6	53.1
Italy	13.00	27.8	26.5	32.6
Cyprus	23.40	36.2	23.5	16.9
Latvia	5.70	20.8	42	31.4
Lithuania	3.40	15.8	37.7	43.2
Luxembourg	1.60			
Hungary	4.40	9.4	17.8	68.4

Country	Value added by enterprise size class, mining and quarrying and manufacturing, 2008 (% share of size class in total sectoral value added)			
	Micro (0-9)	Small (10-49)	Medium (50 - 249)	Large (+250)
Malta				
Netherlands	7.90	18.9	26.4	46.8
Austria	4.60	12	24.1	59.3
Poland	7.30	10	25.3	57.3
Portugal	9.40	23.6	32.2	34.8
Rumania	4.30	12.7	24.1	58.9
Slovenia	10.20	14.4	25.6	49.7
Slovakia	3.20	12.7	24	60.1
Finland	5.80	12.1	17.8	64.2
Sweden	6.30	12.5	19.4	61.6
United Kingdom	7.60	14.8	22.4	55.2

The automation ratio EU/Germany is also an acceptance of the industry and based on economic estimates The number of persons employed in manufacturing is around 7 million in Germany. That's around 24 % of all persons employed in manufacturing in Europe. Another fact is that in Germany more automation technology is in use. For this reason the automation ratio EU/Germany was set to 3.

The number of residents can't be used for an assessment of the industrial wireless devices in Europe. The number of inhabitants (see column 3, Table 111) isn't equal to the number of persons employed in manufacturing (see column 6, Table 111).

Table 111: Statistical data from Eurostat yearbook 2012 '

Country	GDP (€ 1000 million) 2010	Population Demographic balance, 2010		Population age structure by major age groups, 1990 and 2010 (% of the total population)	Number of persons employed in Manufacturing, 2008		Value added, 2008
		Million	%	15 -64 years old	Million	%	Manufacturing
EU (27 Countries)	9191	501.0	100	67.0	29	100	1652.60
Belgium	353	10.8	2.2	65.9	0.59	2.0	49.20
Bulgaria	36	7.6	1.5	68.9	0.64	2.2	4.30
Czech Republic	145	10.5	2.1	70.6	1.37	4.7	31.70
Denmark	234	5.5	1.1	65.6	0.39	1.3	28.70
Germany	2499	81.8	16.3	65.9	7.10	24.3	453.8
Estonia	15	1.3	0.3	67.8	0.12	0.4	2.2
Ireland	156	4.5	0.9	67.3	0.20	0.7	30.5
Greece	230	11.3	2.3	66.7			
Spain	1063	46.0	9.2	68.2	2.41	8.3	126.7
France	1933	64.7	12.9	64.8			203.3
Italy	1549	60.3	12.0	65.7	4.41	15.1	211.7

Country	GDP (€ 1000 million) 2010	Population Demographic balance, 2010		Population age structure by major age groups, 1990 and 2010 (% of the total population)	Number of persons employed in Manufacturing, 2008		Value added, 2008
		Million	%	15 -64 years old	Million	%	Manufacturing
Cyprus	17	0.8	0.2	70.1	0.04	0.1	1.2
Latvia	18	2.2	0.5	68.9	0.14	0.5	1.9
Lithuania	27	3.3	0.7	68.9	0.23	0.8	2.7
Luxembourg	42	0.5	0.1	68.3	0.04	0.1	5.4
Hungary	98	10.0	2.0	68.6	0.76	2.6	19.3
Malta	6	0.4	0.1	69.6			
Netherlands	591	16.6	3.3	67.1	0.75	2.6	59.3
Austria	284	8.4	1.7	67.5	0.63	2.2	46.7
Poland	354	38.2	7.6	71.3	2.56	8.8	57.2
Portugal	173	10.6	2.1	66.9	0.77	2.6	19.0
Rumania	122	21.5	4.3	69.9	1.40	4.8	15.5
Slovenia	36	2.0	0.4	69.4	0.23	0.8	6.7
Slovakia	66	5.4	1.1	72.4	0.44	1.5	8.0
Finland	180	5.4	1.1	66.4	0.42	1.4	32.1
Sweden	347	9.3	1.9	65.3	0.75	2.6	50.3
United Kingdom	1697	62.0	12.4	66.1	2.80	9.6	185.2

The ratio of gross domestic product (GDP) between Germany (2.499 billion €) and Europe (12.27 billion €) is 4.1.

The number of employee in manufacturing is 7.103 million for Germany and 29 million for Europe. The ratio of employee in manufacturing between Europe and Germany is 4.1.

The ratio of value added between Europe (16.695 billion €) and Germany (4.538 billion €) is 3.6.

The mean value of ratio of GDP, ratio of number of employees in manufacturing and ratio of value added is 3.8.

In order to assess the deployment of WIA over the whole EU based on the data from Germany, the value of 4,1 is considered as a ratio between Germany and the EU as a worst case assumption (the same ratio could be considered for the whole CEPT).

Table 112: Deployment of WIA in EU

Parameters	Values
Automation ratio EU/Germany	4,1
Wireless Devices EU	51 496 000
Area EU km²	10 180 000
Device density EU/km²	5.06

ANNEX 3: PATH LOSS MODELS USED IN SEAMCAT SIMULATIONS

This annex provides information on the propagation model which was used in the SEAMCAT simulations.

The models are based on:

- Spherical diffraction as defined in SEAMCAT;
- Line Of Sight (Free space loss);
- Free space loss with 3,5 exponent;
- IEEE model as defined in the SEAMCAT library.

The following figure shows a comparison of the IEEE model depending on the breakpoints with other models.

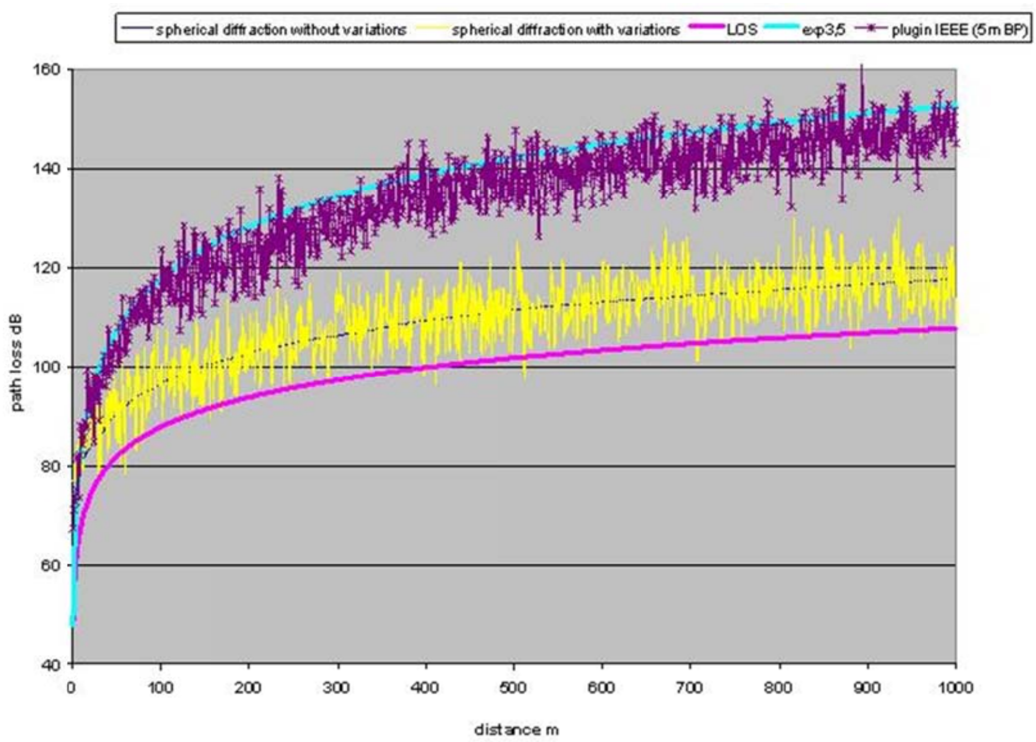


Figure 46: comparison IEEE model with 5m breakpoint distance with spherical diffraction and LOS/exp3.5

The IEEE plugin was used in SEAMCAT in order to be able to consider also an urban-like propagation model (Model_C_IEEE_802_11_rev2, Date 17/10/2012).

The following configuration was used in the simulations:

- Breakpoint distance 5m for urban environments
- Breakpoint distance 50m for suburban environments
- Breakpoint distance 500m for rural environments

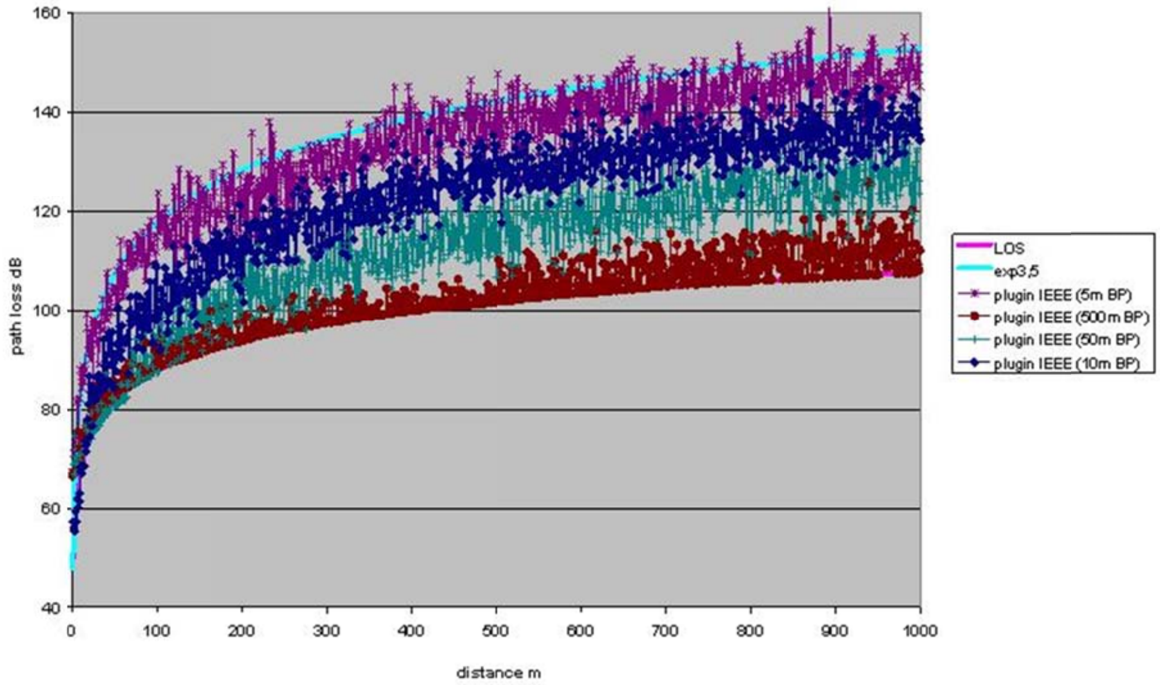


Figure 47: in SEAMCAT used IEEE model compared to LOS and exponent 3.5

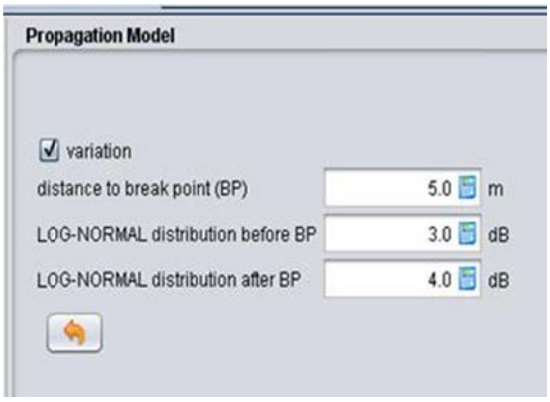


Figure 48: IEEE 802.11 plugin for SEAMCAT

The following figure provides a comparison of additional path loss models (for example including the model used for the MCL calculations (see ANNEX 4:).

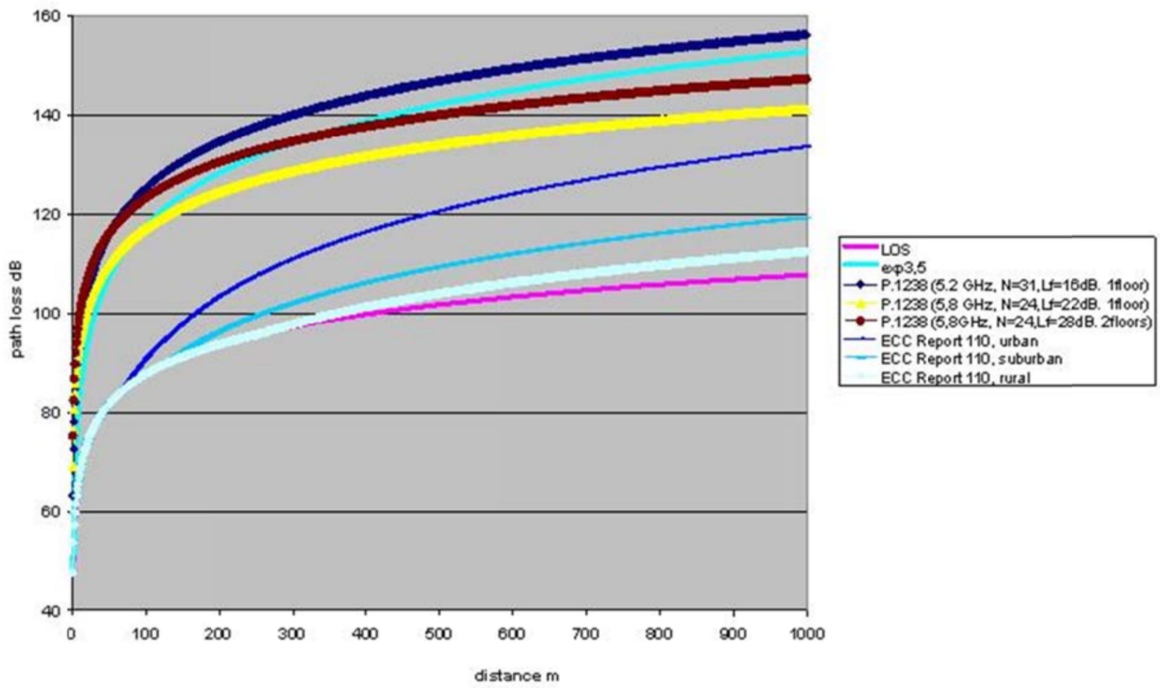


Figure 49: comparison of other indoor path loss models

ANNEX 4: PROPAGATION MODELS USED IN MCL CALCULATIONS

The calculations developed in the MCL sections in this report used the same propagation model as in ECC Report 101 [5].

The propagation model has two breakpoints and is as follows:

$$\begin{cases} 20\log\left(\frac{\lambda}{4\pi d}\right) & d \le d_0 \\ 20\log\left(\frac{\lambda}{4\pi d_0}\right) - 10n_0 log\left(\frac{d}{d_0}\right) & d_0 \le d \le d_1 \\ 20\log\left(\frac{\lambda}{4\pi d_0}\right) - 10n_0 log\left(\frac{d_1}{d_0}\right) - 10n_1 log\left(\frac{d}{d_1}\right) & d > d_1 \end{cases}$$

The used values of the breakpoints and pathloss factors depend on the environment and are given in the following table.

Table 113: Parameters for propagation models

	Urban	Suburban	Rural	ETSI TR 102- 492
Breakpoint distance d_0 (m)	64	128	256	15
Pathloss factor n_0 beyond the first break point	3.8	3.3	2.8	2.7
Breakpoint distance d_1 (m)	128	256	1024	1024
Pathloss factor n_1 beyond the first break point	4.3	3.8	3.3	2.7

The first three columns are according to ECC Report 101 and the last column the ITS SRdoc ETSI TR 102 492-1 [19].

ANNEX 5: SENSING PROCEDURE

A5.1 GENERAL CONSIDERATIONS

This section provides the methodology based on link budget analysis; that is used for the determination of the DFS detection threshold to protect radars.

The threshold is determined from two link budget analyses, (1) and (2) whose description is provided below. This is based on the assumption of a symmetrical propagation path between the interfering system with DFS (this system is quoted as *Int*) and the radar (RL) and also that the transmitter and receiver bandwidths of the radar are the same:

> (1): The link budget gives the propagation losses *PL* to limit the interference level coming from the interfering system *Int* towards the radar receiver below the noise level minus 6dB (I/N=-6dB). Let *d* be the separation distance.
> (2): The link budget gives the propagation losses *PL* to allow the interferer *Int* to detect at the distance *d* the presence of a radar. Therefore, the interference level coming from the radar towards the receiver of the *Int* system will be used as the detection threshold at the antenna connector (*Th*).

Note that:

- P^0_{Int} : spectral density of the interferer (dBm/MHz)
- G_{Int}: Antenna gain of the interferer
- B_{Int}: Bandwidth of the interferer
- $P_{Int} = P^0_{Int} + 10\,Log\,(B_{Int})$: power of the interferer (dBm)
- $N^0 = 10\,Log\,(kTB_0) + F$: Ambient noise (dBm/MHz) with noise temperature of T=290°K, a reference bandwidth B_o=1 MHz and *F* the noise figure in dB
- $I^O = N^0 - 6$ the maximum allowable level of interference on the RL
- P^0_{Radar} : spectral desity of the radar (dBm/MHz)
- G_{radar} : Antenna gain of the radar
- B_{radar} : Bandwidth of the radar
- $P_{radar} = P^0_{radar} + 10\,Log\,(B_{radar})$: power of the radar (dBm)
- Th^0: Detection threshold at the antenna connector (dBm/MHz)
- $Th = Th^0 + 10\,Log\,(B_{Int})$: Detection threshold at the antenna connector (dBm) in the bandwidth of the interferer
- PL: Propagation losses

If $B_{Int} > B_{radar}$

(1) $P^0_{Int} + G_{Int} + PL + G_{radar} = I^O = N^0 - 6$

(2) $P_{radar} + G_{radar} + PL + G_{Int} = Th$

$$PL = N^0 - 6 - G_{radar} - G_{Int} - P^0_{Int} = Th - G_{Int} - G_{radar} - P_{radar}$$

=> $\Rightarrow N^0 - 6 - P^0_{Int} = Th - P_{radar}$

$$\Rightarrow Th = \left(N^0 - 6 + P_{radar}\right) - P^0_{Int}$$

If $B_{Int} < B_{radar}$

(1) $P_{Int} + G_{Int} + PL + G_{radar} = I = N - 6$

(2) $P^0_{radar} + G_{radar} + PL + G_{\text{int}} = Th^0$

$$PL = N - 6 - G_{radar} - G_{Int} - P_{Int} = Th^0 - G_{Int} - G_{radar} - P^0_{radar}$$
$$\Rightarrow N - 6 - P_{Int} = Th^0 - P^0_{radar}$$
=> $$\Rightarrow Th = Th^0 + 10Log(B_{Int}) = (N - 6 + P^0_{radar}) - (P_{Int} - 10Log(B_{Int}))$$
$$\Rightarrow Th = (N^0 - 6 + P_{radar}) - P^0_{Int}$$

Finally, these calculations lead to the same formula:

$$Th = \underbrace{(N^0 - 6 + P_{radar})}_{\lambda} - P^0_{Int}$$ in dBm over the bandwidth of the interferer

Note: The ECC Report 68 indicated that an appropriate detection threshold Th_{FWA} should be -69dBm (close to -67.18dBm which can be calculated using this method) over the BFWA bandwidth.

Calculations for WIA, applying the equation above give the following results.

Table 114: DFS threshold WIA – 1 MHz

Characteristics of the Radars	**Radar L**	**Radar M**	**Radar N**	**Radar O**	**Radar Q**	**Radar X & Y**	**Radar Z**
Tx power into antenna peak (kW)	2800	1200	1000	165	285	12	70
Tx power into antenna peak (dBm)	94.47	90.79	90.00	82.17	84.55	70.79	78.45
Radar bandwidth (MHz)	4.8	4	8	8	10	4	1
Noise figure (dB)	7	4	2.3	3	3	5	13
Characteristics of a WIA device							
WIA e.i.r.p (dBm) outdoor	26	26	26	26	26	26	26
Bandwith (MHz)	1	1	1	1	1	1	1
Antenna gain (dBi)	5	5	5	5	5	5	5
WIA spectral density power (dBm/MHz) at the antenna connector	21	21	21	21	21	21	21
Characteristics of the DFS	Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X & Y	Radar Z
Noise level (dBm/MHz)	-106.98	-109.98	-111.68	-110.98	-110.98	-108.98	-100.98
DFS Detection threshold Th (dBm)	-39.51	-46.19	-48.68	-55.80	-53.43	**-65.19**	-49.53

Table 115: DFS threshold WIA – 3 MHz

Characteristics of the Radars	Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X & Y	Radar Z
Tx power into antenna peak (kW)	2800	1200	1000	165	285	12	70
Tx power into antenna peak (dBm)	94.47	90.79	90.00	82.17	84.55	70.79	78.45
Radar bandwidth (MHz)	4.8	4	8	8	10	4	1
Noise figure (dB)	7	4	2.3	3	3	5	13
Characteristics of a WIA device							
WIA e.i.r.p (dBm) outdoor	26	26	26	26	26	26	26
Bandwith (MHz)	3	3	3	3	3	3	3
Antenna gain (dBi)	5	5	5	5	5	5	5
WIA spectral density power (dBm/MHz) at the antenna connector	16	16	16	16	16	16	16
Characteristics of the DFS	Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X & Y	Radar Z
Noise level (dBm/MHz)	-106.98	-109.98	-111.68	-110.98	-110.98	-108.98	-100.98
DFS Detection threshold Th (dBm)	-34.73	-41.41	-43.91	-51.03	-48.66	**-60.41**	-44.76

Table 116: DFS threshold WIA – 20 MHz

Characteristics of the Radars	Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X & Y	Radar Z
Tx power into antenna peak (kW)	2800	1200	1000	165	285	12	70
Tx power into antenna peak (dBm)	94.47	90.79	90.00	82.17	84.55	70.79	78.45
Radar bandwidth (MHz)	4.8	4	8	8	10	4	1
Noise figure (dB)	7	4	2.3	3	3	5	13
Characteristics of a WIA device							
WIA e.i.r.p (dBm) outdoor	26	26	26	26	26	26	26
Bandwith (MHz)	20	20	20	20	20	20	20
Antenna gain (dBi)	5	5	5	5	5	5	5
WIA spectral density power (dBm/MHz) at the antenna connector	8	8	8	8	8	8	8
Characteristics of the DFS	Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X & Y	Radar Z

Characteristics of the Radars	Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X & Y	Radar Z
Noise level (dBm/MHz)	-106.98	-109.98	-111.68	-110.98	-110.98	-108.98	-100.98
DFS Detection threshold Th (dBm)	-21.50	-28.18	-30.67	-37.79	-35.42	**-52.18**	-36.52

In the above calculations, the same level for the DFS threshold for indoor case and outdoor case since the wall attenuation is compensated on the two paths.

A5.2 CONSIDERATIONS ON CENTRAL SENSING

In this section the requirements for WIA systems (Interfering transmitter IT, transmitting to its wanted receiver WR) to detect BFWA systems (Wanted transmitter WT transmitting to the victim receiver VR) is analysed. IT is able to monitor the WT, which is the basis for the sensing mechanism which is called LBT in this section.

The following abbreviations and definitions are valid in this annex:

- Dimensions: r/m, P/dBm, S/dBm, SIR/dB, f/GHz, All antennas 0dBi
- VR Victim receiver (BFWA)
    - N: Noise floor kTBF of VR (-95 dBm/20MHz)
    - F: Noise figure of VR, (BFWA 6 dB)
    - S: Signal strength received at the VR from WT (Pwt)
    - SNR: signal to noise ratio, or C/N at VR
    - SIRmin: Signal to interference ratio, or C/I at VR (27 dB)
    - WT Wanted transmitter (victim link, BFWA)
    - Pwt Transmit power of WT (CS) (BFWA 14 dBm)
    - Gs Antenna gain WT (22 dBi)
- IT Interfering Transmitter (WIA)
    - Pit Transmit power of IT (SRD 21 dBm)
    - Antenna gain IT 5dBi
    - WR Wanted receiver (Interfering Link)
    - Plbt: LBT power received at WR from WT (Pwt)
    - Pthr: power threshold for the LBT mechanism at IT
- I: Interfering power at VR,
- n: Path loss exponent n (e.g. n=2 free space loss)
- Rint: radius around VR; inside interference can occur (S-I<SIRmin)
- Rsig: radius around VR; inside the victim link works wit S-N<SNRmin
- Rdet: radius around WT; inside the IT can detect the WT
- Wall: wall attenuation dB

The following figure explains the investigated scenario. Within a radius of Rint around the VR the IT can exceed the protection objective of the VR (e.g. C/I). Within a radius of Rdet around the WT the IT can detect the WT (Threshold is exceeded).
In the light blue area in the following figure 7 LBT is working effectively. The red area is the so called “hidden node”, where the IT is not able to detect the WT.

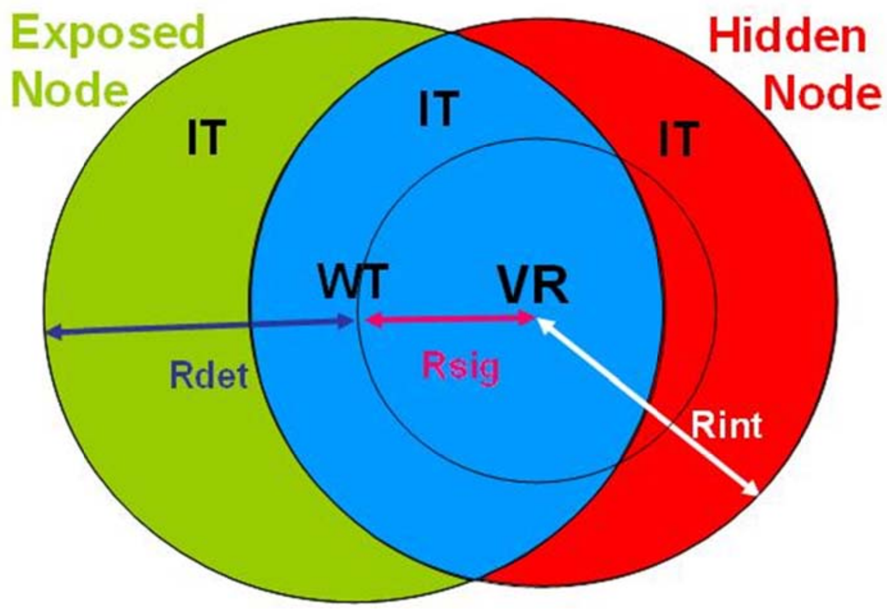


Figure 50: Hidden node and Exposed node

The situation is simplified because each BFWA station is assumed to transmit and receive simultaneously (TDD).

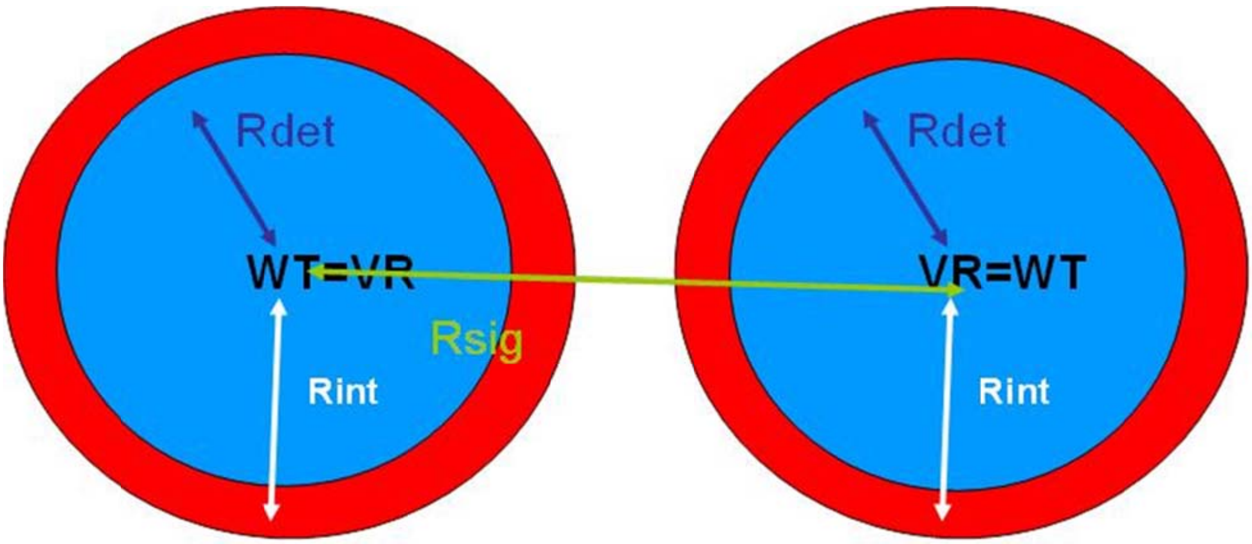


Figure 51: Illustration of the scenario

The formulas given hereafter are the basis for the analysis.

Signal strength at the BFWA receiver:
S (at VR)= N + SNR = Pwt (BFWA)+ Gsbfwa+Gebfwa- PL(Rsig) (1)

The interference power at the BFWA receiver:
I (at VR)= S - SIRmin = Pit (SRD)+Gswia(p)+Gebfwa(p)-Wall- PL(Rint) (2)

The threshold power at the SRD:
Pthr (at SRD) = Pwt (BFWA)+Gsbfwa(p)+Gewia(p)-Wall- PL(Rdet) (3)

Path loss model:
PL = 32.5+10*n*log(R/m)+20*log(f/GHz) (4)

(1)+(4) -> 10n*log(Rsig) = Pwt+ Gsbfwa+Gebfwa -N-SNR-32.5-20logf (5)
(2)+(4) -> 10n*log(Rint) = Pit+ Gswia(p)+Gebfwa(p)-Wall-N-SNR+SIRmin-32.5-20logf (6)
(3)+(4) -> 10n*log(Rdet) = Pwt+ Gsbfwa(p)+Gewia(p)-Wall-Pthr-32.5-20logf (7)

Relation Rdet/Rint: (7)-(6) -> 10n*log(Rdet/Rint)=Pwt-Pit-Pthr+N+SNR-SIRmin (8)

Under the assumption Rdet=Rint the WI system should be perfectly able to detect the BFWA system and thus with formula (8) it follows:

. Pthr=Pwt-Pit+N+SNR-SIRmin (9)

Table 119 shows the required LBT threshold values using formula above with variable WIA bandwidth (1MHz, 3 MHz, 20 MHz) and 3 different SNR values (27dB, 37 dB, 47 dB).

Table 117: LBT thresholds for different SNR

	WIA I	WIA III	WIA II	WIA I	WIA III	WIA II	WIA I	WIA III	WIA II
BW1/MHz WIA	1	3	20	1	3	20	1	3	20
BW2/MHz BFWA	20	20	20	20	20	20	20	20	20
Pit dBm/BW1 e.i.r.p.	21	21	21	21	21	21	21	21	21
Pit dBm/BW2 e.i.r.p.	21	21	21	21	21	21	21	21	21
Pwt dBm/BW2	14	14	14	14	14	14	14	14	14
NF dB	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
N dBm/BW2	-94.99	-94.99	-94.99	-94.99	-94.99	-94.99	-94.99	-94.99	-94.99
SNR dB	27.00	27.00	27.00	37.00	37.00	37.00	47.00	47.00	47.00
Smin dBm/BW	-67.99	-67.99	-67.99	-57.99	-57.99	-57.99	-47.99	-47.99	-47.99
SIRmin dB	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00
Pthr dBm/BW2	-101.99	-101.99	-101.99	-91.99	-91.99	-91.99	-81.99	-81.99	-81.99
Pthr dBm/BW1	-115	-110.23	-101.99	-105	-100.23	-91.99	-95	-90.23	-81.99

In the above calculation it is assumed that all links having the same path loss model. For the case of a specific sensing antenna on top of the WIA plant, with better propagation conditions for the detection path (propagation exponent n2) the situation is more complicated and cannot be reduced to a simple formula, but the situation can be improved.

10n1*log(Rint) = Pit+ Gswia(p)+Gebfwa(p)-Wall-N-SNR+SIRmin-32.5-20logf (10)
10n2*log(Rdet) = Pwt+ Gsbfwa(p)+Gesensing- Pthr-32.5-20logf (11)

Table 118 shows the interference and detection ranges using the above formulas (10) and (11).

Table 118: Interference and detection ranges comparison

	Case 1	Case 2	Case 3	Case 4
BW1/MHz WIA	1	3	20	1
BW2/MHz BFWA	20.	20	20	20
Pit dBm/BW1 e.i.r.p.	21	21	21	21
f/GHz	5,75	5.75	5,75	5.75
BW/MHz	20	20	20	20
Pit dBm/BW	**21**	**21**	**21**	**21**
Pwt dBm/BW	**14**	**14**	**14**	**14**
Gsbfwa dBi	**22**	**22**	**22**	**22**
Ge bfwa dBi	**16**	**16**	**16**	**16**
Gs sensing dBi	**10**	**10**	**10**	**10**
Gs_wia dBi	**5**	**5**	**5**	**5**
NF dB	6.00	6.00	6.00	6.00
N dBm/BW	-94.99	-94.99	-94.99	-94.99
Pthr dBm/BW	**-87.00**	**-87.00**	**-87.00**	**-87.00**
wall dB	**0.00**	**15.00**	**0.00**	**15.00**
SNR dB	**27.00**	**27.00**	**27.00**	**27.00**
fade margin dB	**10.00**	**10.00**	**10.00**	**10.00**
Smin dBm/BW	-57.99	-57.99	-57.99	-57.99
SIR dB	27.00	27.00	27.00	27.00
Imax dBm/BW	-84.99	-84.99	-84.99	-84.99
propagation exp n1 (interfering path)	2.00	2.00	2.50	2.50
propagation exp n2 (sensing path)	2.00	2.00	2.00	2.00
Rsig m	**1302.6**	**1302.6**	**1302.6**	**1302.6**
Rint/m	**9221.8**	**1639.9**	**1485.4**	**373.1**
Rdet/m	**9232.8**	**9232.8**	**9232,8**	**9232,8**

The calculations in Table 118 shows that a specific sensing antenna improves the situation because the detection distance is always higher as the interference distance; only for unrealistic combination of a outdoor WIA usage (0 dB wall loss) and the same propagation conditions in the sensing and interfering path the advantages of a sensing antenna are disappearing.

ANNEX 6: LIST OF REFERENCES

[1] ETSI TR 102 889-2 V1.1.1: Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference Document; Short Range Devices (SRD); Part 2: Technical characteristics for SRD equipment for wireless industrial applications using technologies different from Ultra-Wide Band (UWB)
[2] ERC/REC 70-03: Short Range Devices (SRD)
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