ECC Report 343

New coexistence studies between various Short range device (SRD) applications and SRDs in data networks in the frequency band 915-919.4 MHz

approved 7 October 2022

0 EXECUTIVE SUMMARY

This Electronic Communications Committee (ECC) Report considers the coexistence studies between various Short Range Devices (SRDs) applications including SRDs in data networks in the range 915-919.4 MHz. New opportunities for high-power SRDs in data networks are in 916.5-917.3 MHz (range A) and 917.7-918.5 MHz (range B). For the compatibility of SRD and RFID applications with other services and applications, the conclusions of ECC Report 200 [1] and its addendum apply in the band 915-921 MHz.

This Report studied the impact of high-power SRD in data networks (current 500 mW entries and new opportunities) on the following systems: the Radio Frequency Identification (RFID) interrogators, the 25 mW Wideband SRDs, the 25 mW Generic SRDs and the 25 mW SRD in data networks.

The baseline has been established where the Duty Cycle (DC) is set to its maximum allowed value for high-power SRDs in the two RFID channels in the middle of the band centered at 917.5 MHz and 918.7 MHz. The DC for SRDs operating in between RFID channels has been reduced.

Figure 1 illustrates the current/baseline use that is allowed in the band and labels the sub-bands considered in this Report for the new opportunities, Range A and Range B, for high power devices.

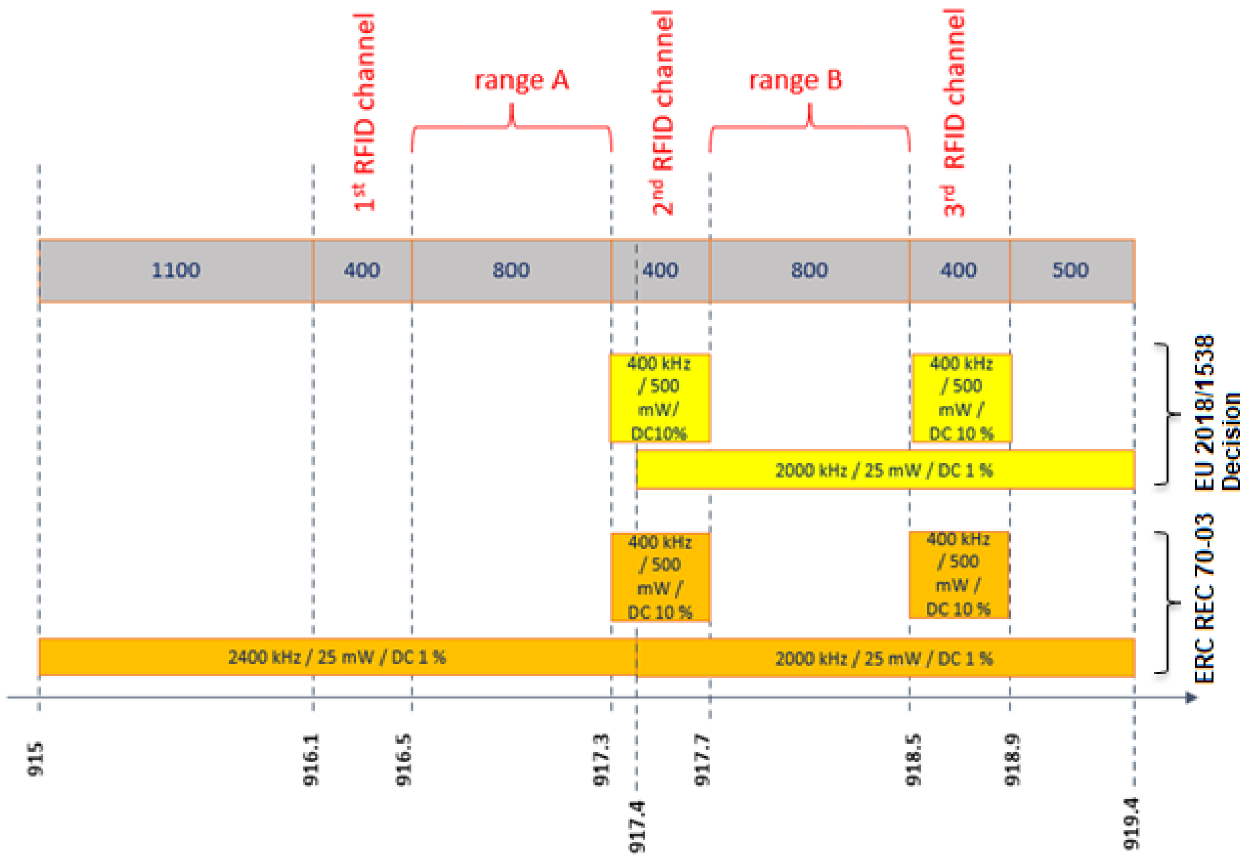


Figure 1: 915-919.4 MHz band

Three Networked SRD technologies are considered in this Report:

- Narrow band Networks (NBN): a mesh technology used primarily to connect smart electric meters;
- Low-Power Wide-Area Network (LPWAN) - Ultra-Narrow Band (UNB): a long-range technology with a star topology used primarily to connect IoT devices;
- LPWAN - Chirp Spread Spectrum (CSS): a long-range technology with a star topology also used primarily to connect IoT devices.

All three systems comprise a Network Access Point (NAP) used for backhauling data via a fixed network, and Terminal Nodes (TN) that act as data collectors. The NBN system also comprises an intermediate Network Node (NN) for relaying data between the NAPs and TNs.

Five studies/scenario sets have been executed in the compilation of this Report, each examining a slightly different aspect of sharing. The studies are summarised in Table 1.

Table 1: The five studies executed in this Report

Scenario set	Interfering systems in new ranges	Victim systems	Workspace	Notes
A	NBN (TN & NN only)	RFID, CSS (NAP), UNB (NAP), 25 mW Generic SRD and Wideband SRD	SEAMCAT workspace available	Presents Baseline. Investigates TN and NN in range A and B. Examines impact of Adaptive Power Control (APC) parameters. SEAMCAT
B	NBN, UNB, CSS (all TN and NN only)	RFID, CSS, NBN and UNB	SEAMCAT workspace available	Presents Baseline. Investigates TN and NN Tx in range A and B, as well as segmentation of the spectrum (high power / low power). SEAMCAT
C	NBN, UNB, CSS (all NAP only)	RFID, CSS, NBN, UNB and 25 mW Generic SRD, Wideband SRD	SEAMCAT workspace available	Investigates NAP in range B, as well as segmentation of the spectrum (high power / low power) SEAMCAT
D	NBN (TN and NN only)	RFID	-	Excel
E	NBN (TN and NN only)	CSS (TN and NAP), 25 mW Generic SRD (outdoor only) and Wideband SRD (indoor/outdoor)	-	Uses propagation model Recommendation ITU-R P.452-16 [1] MATLAB

The first study (Scenario set A) investigated the impact of new opportunities for operating NBN devices, other than relatively high DC NAPs, in between the RFID interrogator by determining the appropriate power and duty cycle levels to ensure compatibility with existing SRDs in the band in each of the two frequency ranges 916.5 to 917.3 MHz and 917.7 to 918.5 MHz. This study considered a part of the full density corresponding to the ratio between the band studied and the total assigned spectrum (min release / full release).

Table 2 summarises the first study results and shows the DC applicable to TN and NN between the RFID channels to achieve an interference probability below 5% on the SRDs victim (if such a value exists, otherwise “Baseline exceeded”). The DC is expressed in per cent of the maximum DC already allowed in the second and third RFID channels (i.e. 2.5% and 1% respectively for the NN and TN).

Table 2: NBNs (TN and NN) DC allowing for a probability interference below 5% on the SRD victim

Interfering Tx power		50 mW		500mW	
Density		Average	Maximum (min release / full release)	Average	Maximum (min release / full release)
Victim	RFID	100% of max DC	50% / 100% of max DC	100% of max DC	20% / 70 % of max DC
	25 mW/(350 kHz) Generic SRD system (indoor)	100% of max DC	70% / 100% of max DC	100% of max DC	50% / 100% of max DC
	25 mW/(350 kHz) Generic SRD system (outdoor)	100% of max DC	100% of max DC	100% of max DC	50% / 100% of max DC
	25 mW Wide band SRD system (indoor)	0% of max DC	Baseline exceeded	0% of max DC	Baseline exceeded
	25 mW Wide band SRD system (outdoor)	20% of max DC	Baseline exceeded	20% of max DC	Baseline exceeded
	LPWAN CSS NAP (Spreading Factor (SF) 7)	20% of max DC	0% / 10% of max DC	20% of max DC	0% of max DC
	LPWAN CSS NAP (SF12)	10% of max DC	Baseline exceeded / 0% of max DC	0% of max DC	Baseline exceeded / 0% of max DC
	LPWAN UNB NAP	50% of max DC	Baseline exceeded / 0% of max DC	20% of max DC	Baseline exceeded / 0% of max DC

For RFIDs, the results of the worst-case scenario correlates well with those calculated using the alternative spreadsheet-based analysis (Scenario set D) shown, and so long as activity levels are equivalent to TN = 0.05% (NN = 1.25%), the interference is acceptable.

It should be noted that the baseline interference levels are high for two such systems suggesting that they may either struggle to operate in these bands or are more robust than the modelling suggests. In particular, for wideband devices, even in the baseline scenarios, the victim bandwidth overlaps with the bandwidths operated by the possible interferer, resulting in high probably of interference. As expected, the interference level increases with the power, DC and density of interference. In many cases, it is above 5 %.

For RFID, results of the worst-case scenario correlate well with those calculated using an alternative spreadsheet-based analysis shown in section 7, and so long as activity levels equivalent to TN=0.05% (NN=2.5%), interference is acceptable.

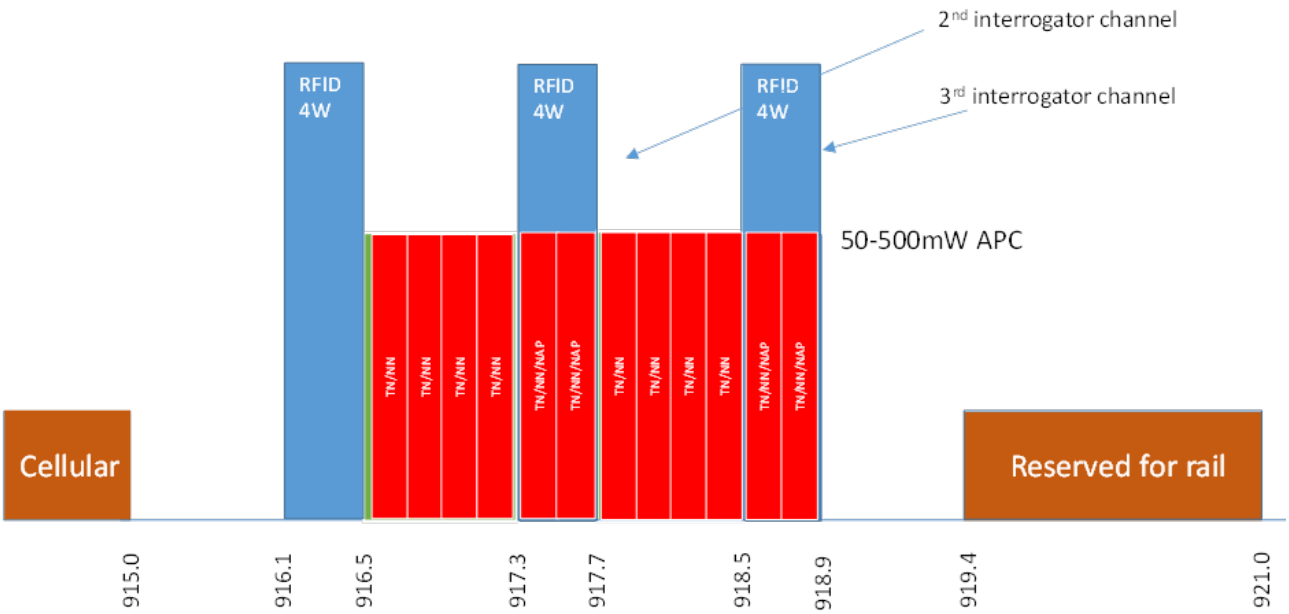


Figure 2: Assumed deployment of NBN technology

The second study (Scenario set B) considered the new opportunity of high-power devices by segmenting high-power and low-power devices: range A and the second RFID interrogator channel for high-power devices and range B and C for low-power devices. NAPs remain in the second and the third RFID interrogator channels. Figure 3 illustrates a possible split of the different SRD in data networks while considering the new opportunities.

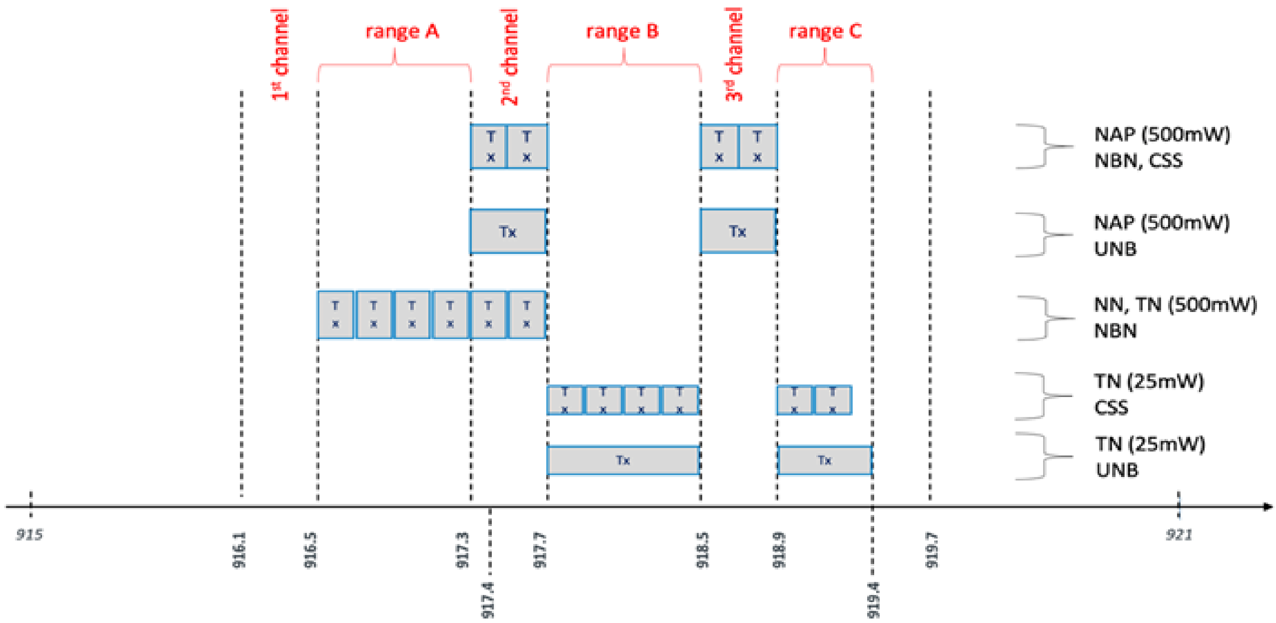


Figure 3: Frequency use of transmitters for NBN, LPWAN-UNB and LPWAN-CSS systems

The simulation results given by the set B scenario are summarised in Table 3.

Table 3: Interference ratios of Scenario set B

Scenario			Interferer					
			NBN			UNB	CSS7	CSS12
			NAP→NN	NN→NAP and NN→TN collocated	TN→NN	NAP→TN	NAP→TN	NAP→TN
Victim	NBN	NAP→NN				0.0%	0.0%	0.0%
		NN→TN				0.0%	0.0%	0.0%
		TN→NN				0.0%	0.1%	0.1%
		NN→NAP				0.0%	0.0%	0.0%
	UNB	NAP→TN	1.9%	3.5%	0.6%		1.0%	1.1%
		TN→NAP	6.1%	7.6%	1.7%		0.5%	0.5%
	CSS7	NAP→TN	0.2%	0.8%	0.3%	0.6%		
		TN→NAP	3.6%	10.4%	2.3%	2.1%		
	CSS12	NAP→TN	0.0%	0.2%	0.1%	0.0%		
		TN→NAP	1.0%	4.0%	0.0%	0.1%		
	RFID	TAG→INT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

The third study (Scenario set C) considered that high-power SRDs are deployed in range B where four channels of 200 kHz are possibly available.

For interferer UNB NAPs operated at 500 mW and a Duty Cycle of 10% as well as 50%, a low level of interference is found for the following victims: RFID, SRD indoor, SRD outdoor, wideband indoor, wideband outdoor.

For interferer NBN NAPs operated at 500 mW and a Duty Cycle of 10% as well as 50% in maximum density, the interference probability can exceed 5% for the following victims: SRD indoor, SRD outdoor, wideband indoor, wideband outdoor, RFID.

For interferer CSS NAPs operated at 25mW and 500 mW and a Duty Cycle of 50% in maximum density, the interference probability can exceed 5% for the following victims: SRD indoor, SRD outdoor, wideband indoor.

The main issue is the compatibility between NAP transmitting and NAP receiving from different technologies deployed in the same area where the corresponding TN transmitter operates at 25 mW. Current practical deployment guidance aims to avoid this situation by separating the 500 mW high power transmitters and receiver of 25 mW TN by frequency into two different band portions. Segmentation of the band into high power and low power ranges would reduce the receiver interferences.

Simulations were performed with the Power Control (PC) for the 500 mW and 100 mW NAP interferer cases and without PC for the 25 mW NAP interferer case, corresponding to the current regulations for comparison. The results given in Table 4 shows that APC reduces the interference resulting from NAP operated at power higher than 25 mW.

Table 4: Interference probability from NAP (NBN, LPWAN-UNB and LPWAN-CSS) (500 mW) – Scenario set C

Scenario	Interferer	LPWAN-CSS (NAP)		UNB (NAP)		NBN (NAP)		NBN (NAP)	
	Victim	UNB (NAP)		LPWAN-CSS (NAP – SF7)		UNB (NAP)		LPWAN-CSS (NAP – SF7)	
	e.r.p. (mW)	Duty Cycle (%)		Duty Cycle (%)		Duty Cycle (%)		Duty Cycle (%)	
		1	2.5	1	2.5	1	2.5	1	2.5
Typical density	500	22	24	9	11.2	8	15.6	5.3	8.5
	100	16	16.4	6.2	8.5	6.8	12.4	3	7.9
	25 (Note 1)	31.8		6.7		27.5		2.9	
Maximum density	500	24	30.4	9	11.9	8.8	14.2	5.6	9.4
	100	17.3	22.8	7.7	10.1	7.4	13.2	4.7	8
	25 (Note 1)	38.3		10.5		36.2		7.3	
Note 1: No power control									

The fourth study (Scenario set D) investigated the potential impact of NBN systems (TN and NN) in the band 916.5-918.9 MHz on RFID systems. This study used MCL (Minimum Coupling Loss) analysis methods based upon transmission and receive parameters and path loss and predicts the probability of interference to be between 2.6% and 11.2% (as summarised in Table 5). These levels are consistent with those predicted by Monte Carlo techniques in SEAMCAT.

Table 5: Interference probability (500 m impact range) from NBN SRDs

Scenario	Interference probability	
	300 m impact range	500 m impact range
Typical Density, 50 mW Interfering Link Transmitter (ILT)	2.6%	2.9%
Typical Density, 50-500 mW ILT	3.3%	5.6%
Maximum Density, 50 mW ILT	5.1%	5.9%
Maximum Density, 50-500 mW ILT	6.6%	11.2%

The fifth study (Scenario set E) presents a scenario taking into account a real city clutter and building data, where fixed SRD are deployed confirming to their topology to cover the studied geographic area. This study assessed the impact of the addition of the high-powers SRD, except NAP, in between the RFID channels together with the contribution of the already available RFID channels at the two RFID channels centred respectively at 917.5 MHz and 918.7 MHz. The result of the fifth study are summarised in Table 6.

Table 6: NBNs (TN and NN) DC allowing for a probability interference below 5% on the SRD victim – Scenario set E

Interfering Tx power		500 mW
Density		Average
Victim	25 mW/ (200 kHz) Generic SRD system	70% of max DC
	25 mw Wide band SRD system (indoor)	Baseline exceeded
	25 mw Wide band SRD system (outdoor)	Baseline exceeded
	LPWAN-CSS, SF7 NAP	Baseline exceeded
	LPWAN-CSS, SF7 TN	50% of max DC

From those results, it can be observed that:

- A DC (studies set A and E) or maximum transmit power (study set A) reduction promotes the sharing of new high-power SRD opportunities between RFID channels and some existing SRD systems. However, for other SRD systems, sharing is not apparently feasible despite this effort of reducing the DC or maximum transmit power. In particular, for wideband devices, even in the baseline scenario, the victim bandwidth is overlapping with the interferer's bandwidths resulting in a high level of probability of interference;
- The segmentation of high-power devices and low-power devices (studies set B and C) would suggest better coexistence compared to their aggregation, attributing one of the frequencies ranges 916.5-917.3 MHz or 917.7-918.5 MHz as a new opportunity for high power SRDs and the other to the 25 mW data network SRDs. The beneficial effect of segmentation on interference into RFID is not evident.

The impact of 500 mW SRDs on the incumbent SRDs depends on various parameter settings in the interfering system transmitters and receivers. It is shown that the receiver parameters have a significant impact and, in some cases, an even more important impact on the interference probability than the interfering transmitter signal e.i.r.p. As an example, the reduction of the maximum interfering transmitter e.i.r.p. from 27 dBm to 17 dBm reduces the interference probability by less than 10% for one of the scenarios. For the same scenario, the reduction of the APC threshold value from -80 dBm (a conservative value used in the studies) to -90 dBm reduces the interference probability by more than 50%.For some studies, an APC parameter value is considered to stabilise the interference system reception power to a level of 15 dB above the considered reference sensitivity level of -95 dBm. Conducting studies with an interference system receiver reference sensitivity of -88 dBm and configuring the APC for an interference system reception level of 18 dB above reference sensitivity, results in an interference probability increase from 14.9% to 24.2% when compared to the previous mentioned scenario (-95 dBm).

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Abbreviation	Explanation
APC	Adaptive Power Control
BER	Bit Error Rate
CDF	Cumulative Distribution Function
CR	Coverage Radius
CSS	Chirp Spread Spectrum
CEPT	European Conference of Postal and Telecommunications Administrations
DC	Duty Cycle
DL	Downlink
dRSS	Desire Received Signal Strength (term use in SEAMCAT)
ECC	Electronic Communications Committee
e.i.r.p.	Equivalent Isotopically Radiated Power
e.r.p.	Effective Radiated Power
ETSI	European Telecommunications Standards Institute
HA SRD	Home Automation Short Range Device
HH	Hand-held
IGN	Institut National de l'Information Géographique et Forestière
IL	Interferer Link
ILT	Interfering Link Transmitter
ITU-R	International Telecommunication Union - Radiocommunication Sector
LoS	Line-of-Sight
LPWAN	Low-Power Wide-Area Network
MCL	Minimum Coupling Loss
NF	Noise Floor
NAP	Network Access Point
NBN	Narrow Band Network
NLoS	Non-Line-of-Sight
NN	Network Node
NSRD	Networked SRD
OCW	Operating Channel Width
PC	Power Control
RBW	Resolution Bandwidth
RFID	Radio Frequency Identification
rSS	Received Signal Strength
RSSI	Received Signal Strength Indication
Rx	Receiver

Abbreviation	Explanation
SEAMCAT	Spectrum Engineering Advanced Monte Carlo Analysis Tool
SF	Spreading Factor
SRD	Short Range Device
SRdoc	System Reference document
STG	SEAMCAT Technical Group
TN	Terminal Nodes
TRR	Tactical Radio Relay
Tx	Transmitter
UL	Uplink
UNB	Ultra-Narrow Band
VL	Victim Link
VLR	Victim Link Receiver
VLT	Victim Link Transmitter

1 INTRODUCTION

1.1 SCOPE OF WORK

This Report considers spectrum in the range 915-919.4 MHz, as stated in the Commission Implementing Decision (EU) 2018/1538 of 11 October 2018 [3] and in the ERC Recommendation 70-03 [4]. This Report investigates new opportunities for higher power Networked SRDs in the frequency range 916.5 MHz to 917.3 MHz and 917.7 MHz to 918.5 MHz where the current regulations allow for an e.r.p. of 25 mW.

1.2 SPECTRUM AVAILABLE

Figure 4 illustrates the designations used in this Report for the new opportunities for high power Networked SRDs devices:

- Range A denotes the spectrum between first and second RFID interrogator channels, i.e. from 916.5 MHz to 917.3 MHz;
- Range B denotes the spectrum between second and third RFID interrogator channels, i.e. from 917.7 MHz to 918.5MHz.

The deployment of higher power Networked SRDs in the first RFID interrogator channel is not considered in this Report.

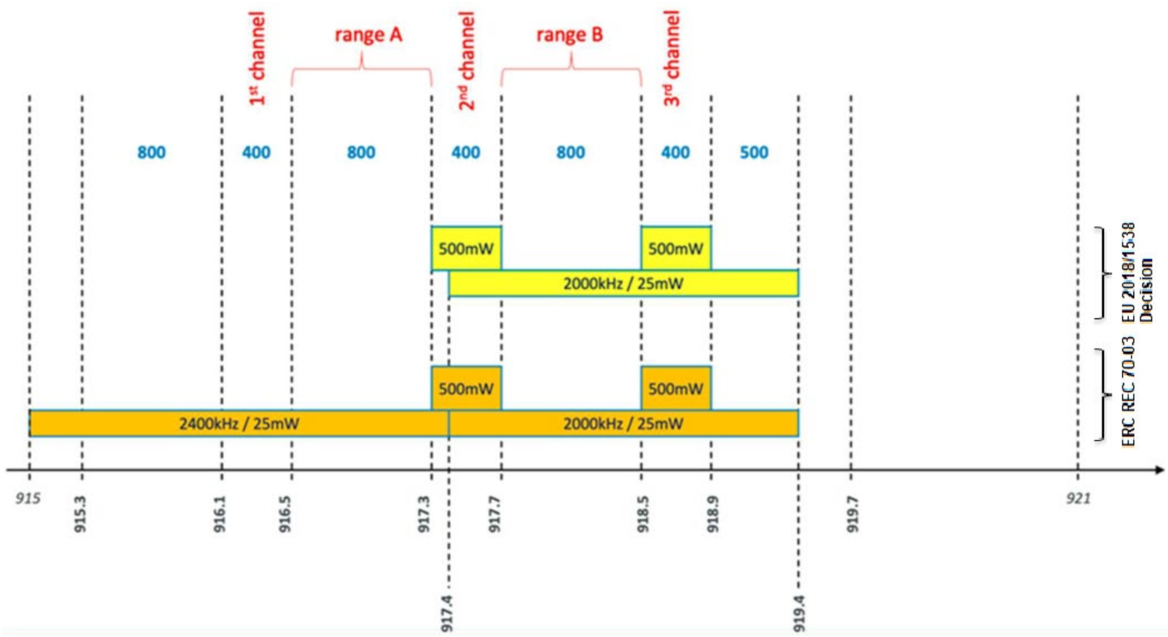


Figure 4: Radio spectrum deployment in accordance with EC 2018/1538 Decision and ERC Recommendation 70-03

1.3 DOCUMENT STRUCTURE

Section 2 provides a description of the technical characteristics of each system considered in this Report.

Section 3 provides simulation assumptions used in the SEAMCAT tool, when studying coexistence between various systems.

Section 4, 5, 6, 7 and 8 provide the results of coexistence studies for the different deployment scenarios, considered in this Report.

Section 9 documents the conclusions of this Report.

2 CHARACTERICTICS FOR SRD NETWORK SYSTEMS IN THE FREQUENCY BAND 915-919.4 MHZ

This section contains the characteristics that are specific to each SRD network.

2.1 NARROW BAND NETWORK (NBN) TECHNOLOGY AND SPECTRUM USE

Specific NBN-SRDs technical characteristics taken into account in the studies conducted in this Report are provided in this section.

2.1.1 NBN technical characteristics and typical deployment parameters

2.1.1.1 Transmitter parameters

Transmission parameters which were considered in ECC Report 261 [5] and summarised in Table 7 are used in the studies.

Table 7: Emission parameters of 500 mW NBN SRD (ECC Report 261)

Network Element	TN Tx (indoor/outdoor)	NN Tx (outdoor)	NAP Tx (outdoor)
Transmitter power	27 dBm/(200 kHz)	27 dBm/(200 kHz)	27 dBm/(200 kHz)
Bandwidth	200 kHz	200 kHz	200 kHz

Table 8 contains the parameters for NBN.

Table 8: NBN as interferer parameters

Parameter	Values
Interferer Link (IL) 1.A: Smart Metering – terminal nodes (to network nodes)	
Frequency	916.5 to 918.9 MHz, 0.2 MHz steps
ILT power e.i.r.p.	≤ 27 dBm/(200 kHz)
APC threshold and range/step	-80 dBm/(200 kHz); range 20 dB, step 2 dB
ILT probability of transmission	0.01% to 0.1%
Operational range	100 m
ILT → VLR interfering path	See section 3.1
ILT → VLR minimum distance	0 m
ILT → VLR positioning mode	None (simulation radius 1 km)
Antenna height	1.5 m
Interferer Link (IL) 1.B: Smart Metering – network nodes (to NAPs)	
Frequency	916.5 to 918.9 MHz, 0.2 MHz steps
ILT power e.i.r.p.	≤ 27 dBm/(200 kHz)
APC threshold and range/step	-80 dBm/(200 kHz); range 20 dB, step 2 dB
ILT probability of transmission	0.25% to 2.5%
Operational range	300 m

Parameter	Values
ILT → VLR interfering path	See section 3.1
Antenna height	3 m
Interferer Link (IL) 1.C: Smart Metering – NAPs (to network nodes)	
Frequency	Centred on 917.4, 917.6, 918.6 and 918.8 MHz
ILT power e.i.r.p.	≤ 27 dBm/(200 kHz)
APC threshold and range/step	-80 dBm/(200 kHz); range 20 dB, step 2 dB
ILT probability of transmission	1% to 10%
ILT → VLR interfering path	See section 3.1
Operational range	300 m
Antenna height	7 m

The mix of devices assumed to be operating across all available bands is set out as follows in Table 9.

Table 9: Densities of device classes

Device class	Maximum Density (/km^2)	Average density (/km^2)
NAP	10/1 (NBN/LPWAN)	5/1 (NBN/LPWAN)
NN	90 (NBN only)	45 (NBN only)
TN	1900/1990 (NBN/LPWAN)	950/995 (NBN/LPWAN)

The emission mask shape to be considered is depicted in Figure 5.

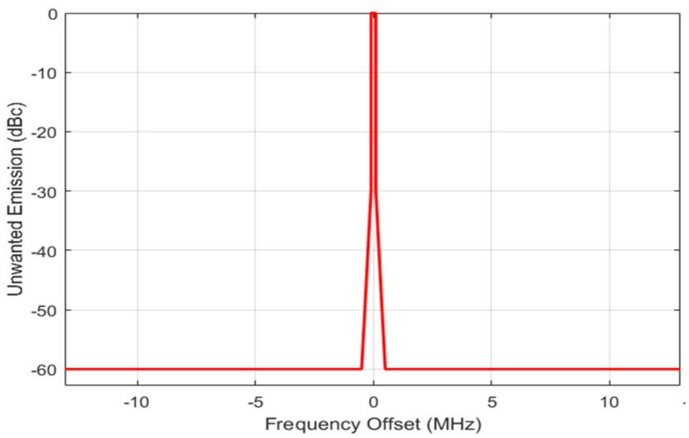


Figure 5: Spectrum emission mask with a 200 kHz measurement bandwidth for NBN SRDs 500 mW

The mask coefficients are given in Table 10.

Table 10: The coordinates of the points of Figure 5

Frequency Offset (MHz)	±20	±0.5	±0.35	±0.101	±0.1
Worst-case mask (dBc)	-60	-60	-49	-30	0

Adaptive Power Control (APC) parameters from ECC Report 261 are given in Table 11.

Table 11: APC parameters from ECC Report 261

Parameter	Value
Receive bandwidth (kHz)	200
APC dynamic range (dB)	20
Step size (dB)	2
APC Threshold (dBm)	-80

2.1.1.2 Antenna

The NBN-SRD uses an omnidirectional antenna whose gain is set to 2.15 dBi for the end-devices (TN and NN) and the NAP.

2.1.1.3 Deployment

According to the ECC Report 261, the 500 mW e.r.p. SRD network devices may operate with conditions summarised in the Table 12.

Table 12: Deployment assumptions for NBN SRDs in dense urban environment

Network Element	Max DC %	Average DC%	Max Density /km^2	Average Density /km^2	Antenna height (m)
NAP	10	2.5	10	5	7
NN	2.5	0.7	90	45	3
TN	0.1	0.1	1900	950	1.5

2.1.1.4 Receiver parameters

The parameters of the receiver are given in Table 13.

Table 13: Receiver parameters

Parameter	Value
Sensitivity (dBm)	-95
Receive bandwidth (kHz)	200
APC dynamic range (dB)	20

2.2 LPWAN-UNB TECHNOLOGY AND SPECTRUM USE

LPWAN-UNB specific technical characteristics and deployment scenario considered in the studies are summarised in this section.

2.2.1 UNB technical characteristics and typical deployment parameters

2.2.1.1 Transmitter parameters

Table 14 provides the main radio parameters for the transmitters as described in ETSI TR 103 435 [6].

Table 14: Main transmitter radio parameters (ETSI TR 103 435)

Parameter	Uplink	Downlink
Tx power per transmitter	Up to 25 mW e.r.p.	Up to 500 mW e.r.p.
Antenna type	omni-directional antenna	omni-directional antenna
Typical signal bandwidth (single carrier)	250 Hz	1 kHz

The Uplink (UL) and Downlink (DL) signals of LPWAN-UNB have ultra-narrow bandwidth within Operating Channel Width (OCW) of 200 kHz allowed by regulation, where the transmission frequency is chosen in this predefined range as shown below in Figure 6 (same for DL, but the carrier is 1 kHz).

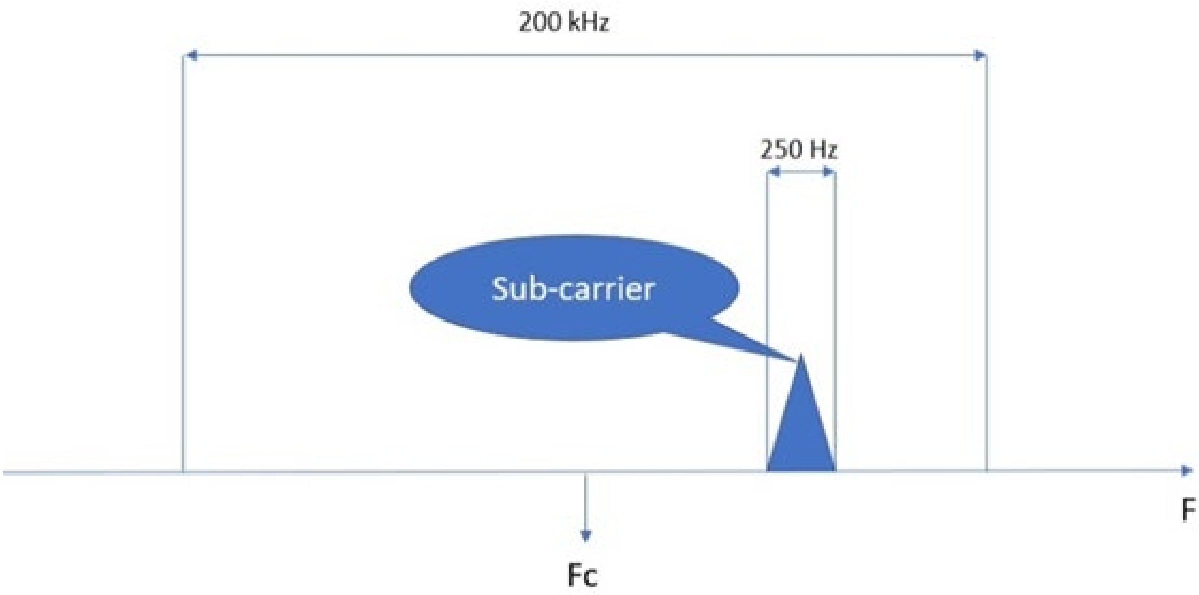


Figure 6: Demonstration of OCW and sub-carrier for UL

a) UL emission masks used in the study

The UL emission mask used for this study is compliant with ETSI EN 300 220-1 [7], and is illustrated in Figure 7.

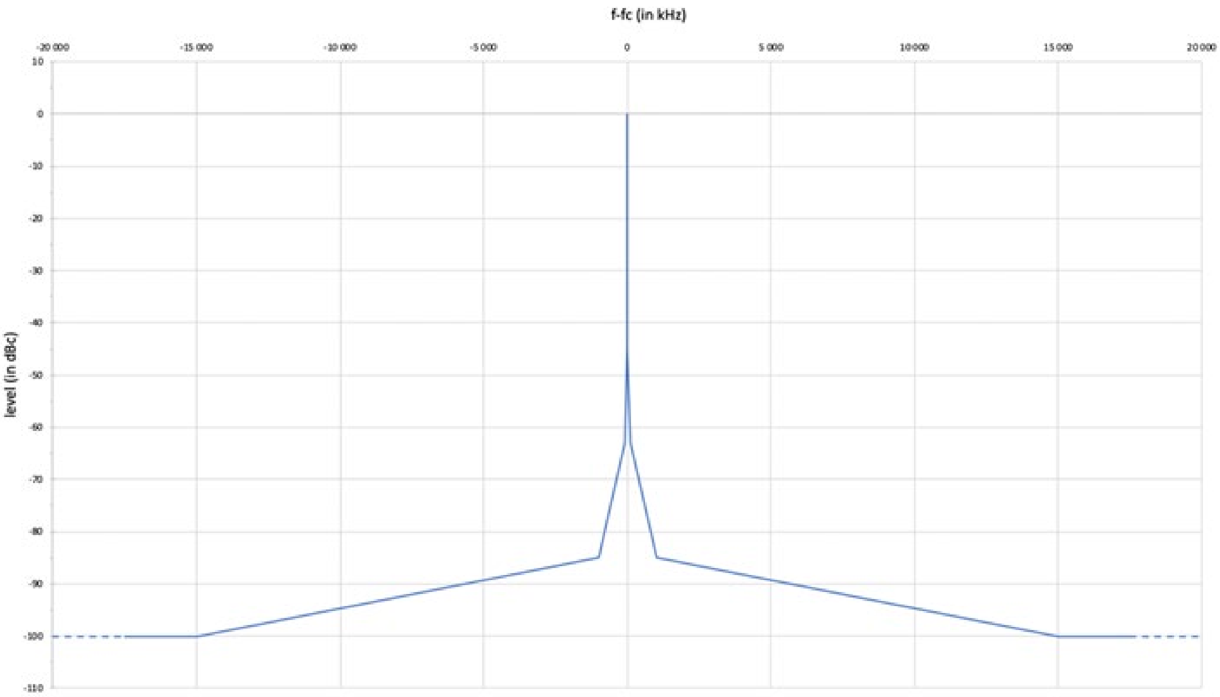


Figure 7: LPWAN-UNB TN emission mask

The transmission mask values provided in Table 15 from ETSI TR 103 435 [6] are considered for a Resolution Bandwidth (RBW) of 250 Hz.

Table 15: UL transmission mask values for LPWAN-UNB

f-fc (kHz)	Level (dBc, Note 1)
below -15000	-100
-15000	-100
-1000	-85
-100	-63
-1	-45
-0.125	0
+0.125	0
+1	-45
+100	-63
+1000	-85
+15000	-100
above +15000	-100
Note 1: Reference level is +14 dBm, normalised with a bandwidth of 250 Hz.	

b) DL emission mask used in the study

DL emission mask provided in ETSI TR 103 435 [6] has been used for this study and is illustrated in Figure 8.

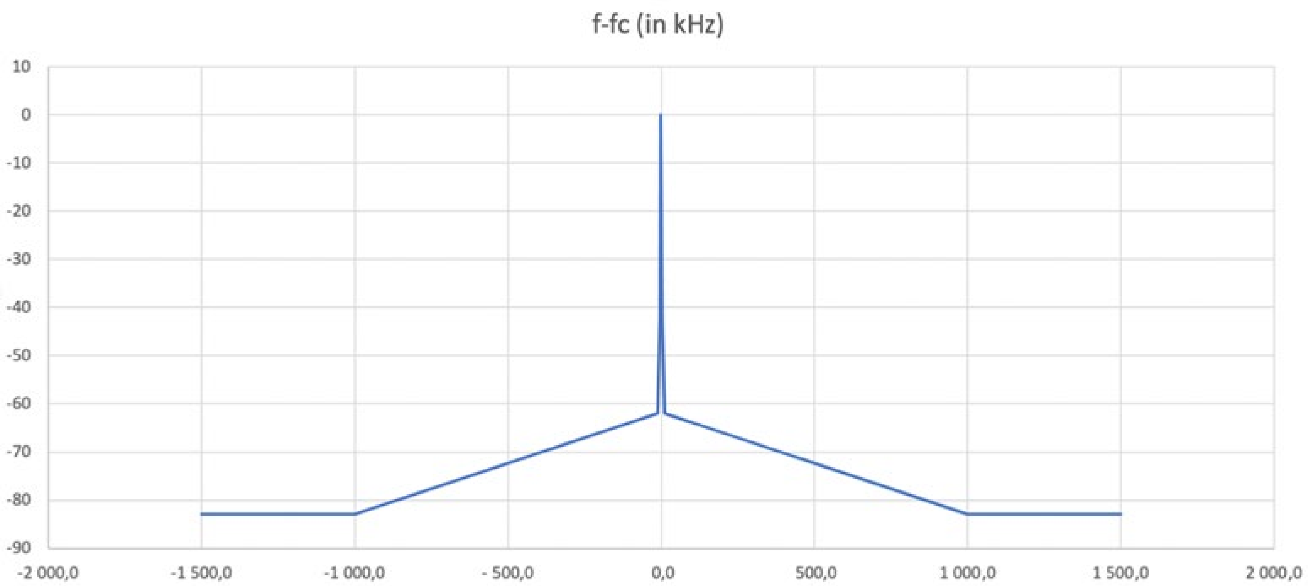


Figure 8: DL emission mask for LPWAN-UNB NAP

The transmission mask values provided in Table 16 are considered for a RBW of 1 kHz.

Table 16: LPWAN-UNB NAP emission mask values

f-fc (kHz)	1500.0	1000.0	12.0	4.0	0.5
Level (dBc)	-83	-83	-62	-42	0

c) APC parameters

For APC configuration in SEAMCAT, the reception parameters mentioned in ECC Report 252, annex 14 [8] are required. Among these parameters, the reception mask does not appear, therefore, it is not needed for this study.

Table 17 gives the values of the required reception parameters.

Table 17: Transceiver parameters

Parameter	Value	
	TN	NAP
Sensitivity (dBm)	-126	-136
Receive bandwidth (kHz)	1.5	0.25
Power control step size (dB)	-	1
APC dynamic range (dB)	-	30
APC Threshold (dBm)	-	-122

2.2.1.2 *Antenna*

As precised in ETSI TR 103 435 [6], the end-devices use an omnidirectional antenna with a gain of 0 dBi. The base station also uses an omnidirectional antenna with gain of 5 dBi.

2.2.1.3 Deployment

LPWAN-UNB systems have a star topology which consists of TNs and NAPs. The network itself is made of NAPs and a service centre, which connects the LPWAN-UNB system to the internet and/or application servers (see ETSI TR 103 435 [6]).

The duty cycles considered for LPWAN-UNB shown in Table 18 correspond to the maximum allowed by regulation and to an assumed realistic deployment average.

Table 18: LPWAN -UNB duty cycle

Network Element	Max DC%	Average DC%	Antenna Height (m)
NAPs	10	0.7	25
Terminals	1	0.07 (Note 1)	1.5
Note 1: Average DC from ECC Report 326, table 16 [9]			

2.2.1.4 Receiver parameters

Uplink receiver parameters are summarised in Table 19.

Table 19: LPWAN UNB Uplink receiver parameters

Parameter	Value
Typical Receiver (Rx) sensitivity	-136 dBm in 250 Hz
Bit error rate (BER) for sensitivity measurements	10^{-3}
Typical antenna gain	+5.15 dBi (omnidirectional base-station antenna)
Typical interference criteria	C/I = 9 dB
Operating range	1.962 km

The blocking mask is depicted in Figure 9.

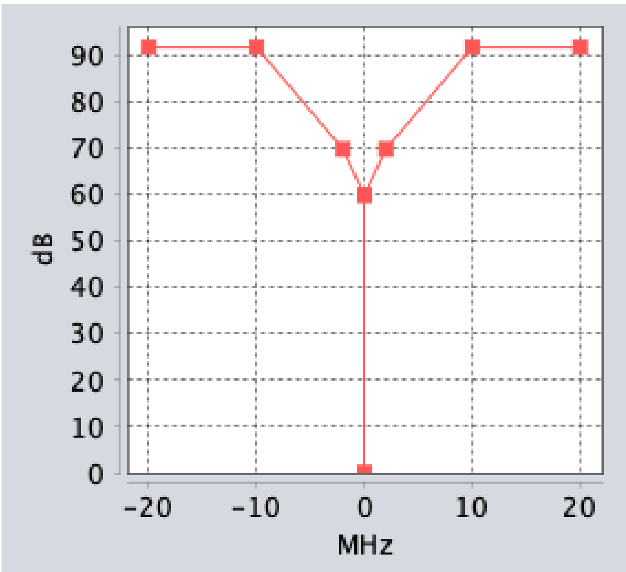


Figure 9: Uplink Rx blocking mask

Uplink receiver blocking mask coefficients are given in Table 20.

Table 20: Uplink blocking mask parameters

Frequency (MHz)	±20	±10	±2	±0.0001500	±0.0001250
Mask (dB)	92	92	70	60	0

Downlink receiver parameters are summarised in Table 21.

Table 21: Downlink receiver parameters

Parameter	Value
Typical Rx sensitivity	-126 dBm in 1 kHz
BER for sensitivity measurements	10^{-3}
Typical antenna gain	0 dBi (omnidirectional base-station antenna)
Typical interference criteria	C/I = 8 dB

The blocking mask is depicted in Figure 10.

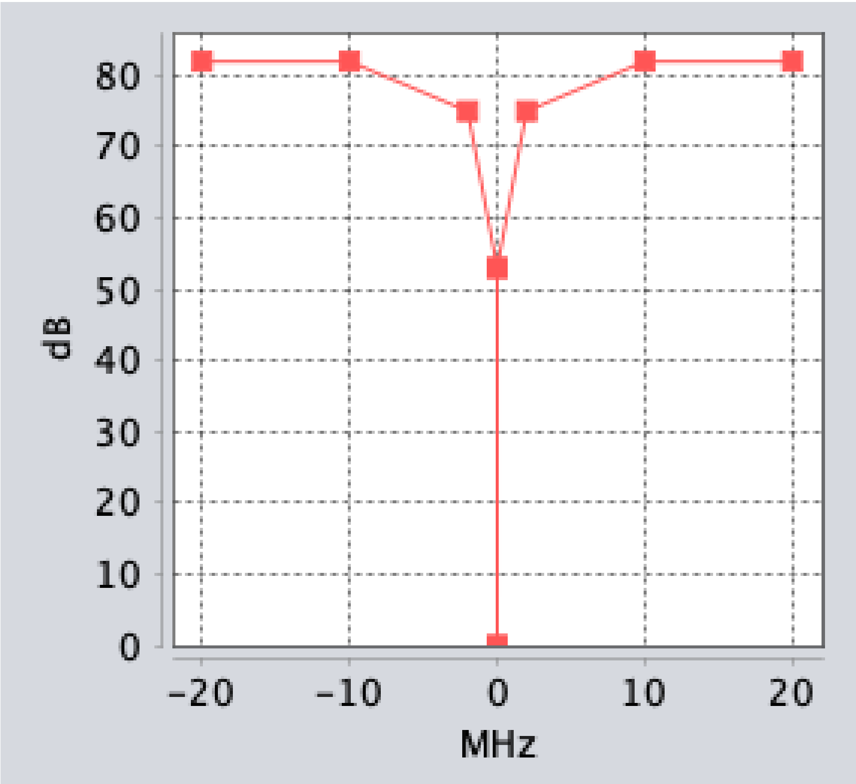


Figure 10: Downlink Rx blocking mask

Downlink receiver mask coefficients are given in Table 22.

Table 22: Downlink blocking mask parameters

Frequency (MHz)	±20	±10	±2	±0.001500	±0.000700
Mask (dB)	82	82	75	53	0

2.3 LPWAN-CSS TECHNOLOGY AND SPECTRUM USE

This section deals with LPWAN-CSS, it details their characteristics and deployment scheme as considered in the studies.

2.3.1 CSS technical characteristics and typical deployment parameters

2.3.1.1 Transmitter parameters

Table 23 presents the transmission power of the terminals and the NAPs.

Table 23: Transmission power for TNs and NAPs

Network Element	TN Tx (indoor)	NAP Tx (outdoor)
ILT transmitter output power (e.r.p.)	Up to 25 mW	Up to 500 mW
Typical signal bandwidth (single carrier)	125 kHz	125 kHz

a) Unwanted emission mask

For a transmission, devices powered at 25 mW (TN or NAP) and 500 mW (NAP), the emission mask is described in Figure 11.

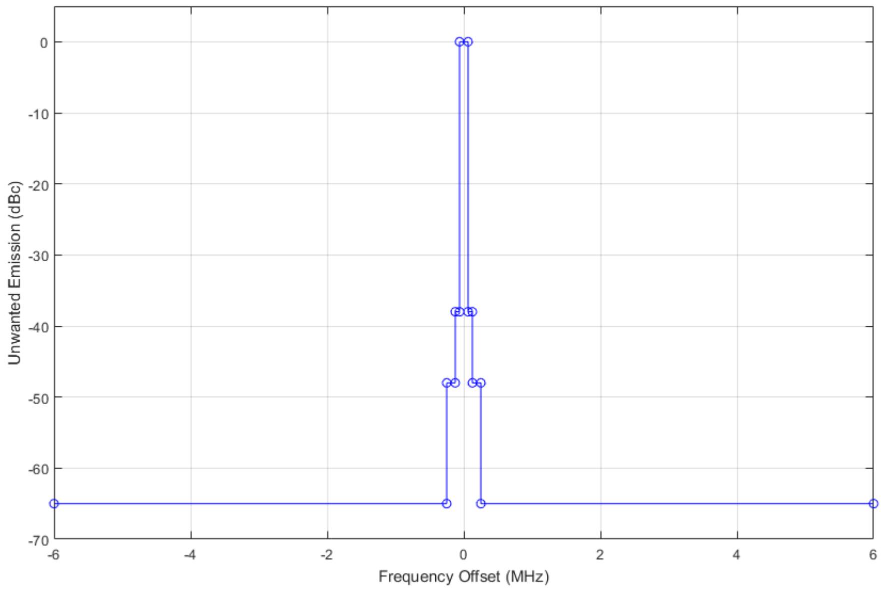


Figure 11: Spectrum emission mask with a 125 kHz measurement bandwidth for LPWAN-CSS NAP (500 mW) and TN (25 mW)

The corresponding attenuation values for NAP (500 mW) are given in Table 24 (see ETSI TR 103 526 [10]).

Table 24: Mask for NAP - 500 mW

Offset (kHz)	Level (dBm)	Bandwidth (kHz)	Level (dBm)	Bandwidth (kHz)	Attenuation in 125 kHz (dB)
0	27	125	27	125	0
125	-32	1	-11.03	125	38
249	-32	1	-11.03	125	38
250	-42	1	-21.03	125	48
499	-42	1	-21.03	125	48
500	-39	100	-38.03	125	65
6000	-39	100	-38.03	125	65

For NAP with an e.r.p. of 250 mW and 100 mW, the masks are based on Table 25 and Table 26.

Table 25: Mask NAP - 250 mW

Offset (kHz)	Level (dBm)	Bandwidth (kHz)	Level (dBm)	Bandwidth (kHz)	Attenuation in 125 kHz (dB)
0	24	125	27	125	0
125	-32	1	-11.03	125	35
249	-32	1	-11.03	125	35
250	-42	1	-21.03	125	45
499	-42	1	-34.03	125	45
500	-39	100	-38.03	125	62
6000	-39	100	-38.03	125	62

Table 26: Mask NAP - 100 mW

Offset (kHz)	Level (dBm)	Bandwidth (kHz)	Level (dBm)	Bandwidth (kHz)	Attenuation in 125 kHz (dB)
0	20	125	20	125	0
125	-32	1	-11.03	125	31
249	-32	1	-11.03	125	31
250	-42	1	-21.03	125	41
499	-42	1	-21.03	125	41
500	-39	100	-38.03	125	58
6000	-39	100	-38.03	125	58

For TN with an e.r.p. of 25 mW, the mask is based on Table 27 (see ETSI TR 103 526 [10]).

Table 27: Mask for TN - 25 mW

Offset (kHz)	Level (dBm)	Bandwidth (kHz)	Level (dBm)	Bandwidth (kHz)	Attenuation in 125 kHz (dB)
0	14	125	14	125	0
125	-45	1	-24.03	125	38
249	-45	1	-24.03	125	38
250	-55	1	-34.03	125	48
499	-55	1	-34.03	125	48
500	-52	100	-51.03	125	65
6000	-52	100	-51.03	125	65

b) APC parameters

APC parameters are given in Table 28.

Table 28: APC parameters

Parameter	Value	
	TN	NAP
Receive bandwidth (kHz)	125	125
APC dynamic range (dB)	14	24
APC Threshold (dBm)	-118	-118

2.3.1.2 Antenna

The TN uses an omnidirectional antenna whose gain is set to 0 dBi. The NAP uses an omnidirectional antenna with a maximum gain up to 5 dBi.

2.3.1.3 Deployment

The LPWAN-CSS system is deployed in a star-of-stars network architecture, whereby TNs are not associated with a specific NAP but transmit data to multiple gateways within their range with a reception bandwidth of 125 kHz.

Table 29 provides the density and the duty cycle of both the NAPs and the terminals.

Table 29: Deployment assumptions for LPWAN-CSS

Equipment	Typical Density	Max Density	Typical Duty Cycle	Max Duty Cycle	Antenna height (m)
TN	360 /km²	3000 /km²	0.007 %	0.02 %	1.5
NAP	0.5 /km²	3.5 /km²	0.5 %	0.7 %	25

According to ETSI TR 103 526, figure 7, section 7.2 [10], the DC of LPWAN-CSS TNs depends on the NAP density as shown in Table 30 and Figure 12.

Table 30: TN DC as a function of NAP density

NAP density	0	0.5	1	1.5	2	2.5	3	3.5	4
Average time on air (s)	0.24	0.19	0.14	0.1	0.08	0.065	0.06	0.055	0.05
TN DC (%)	0.02	0.0158	0.0117	0.0083	0.0067	0.0054	0.005	0.0046	0.0042

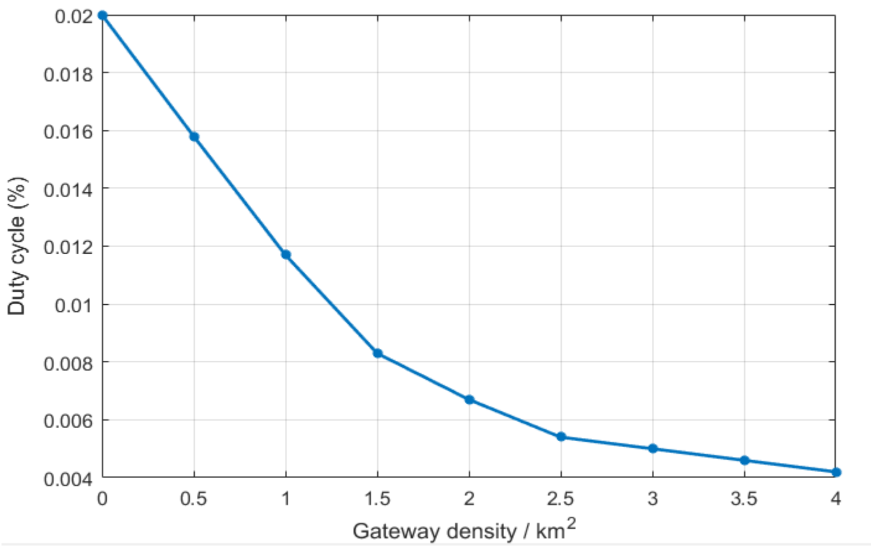


Figure 12: TN DC as a function of NAP density

2.3.2 LPWAN-CSS NAP

LPWAN-CSS system receiver parameters are summarised in Table 31.

Table 31: LPWAN-CSS system receiver parameters

Parameter	TN	NAP
Sensitivity (dBm)	-140 dBm (SF12)/-126 (SF7)	-139.9 (SF12) / -126 (SF7)
Receive bandwidth (kHz)	125	125
C/I (dB)	-17.57 (SF12)/ -3.67 (SF7)	-18.89 (SF12) / -4.99 (SF7)
Operating range	900m (SF7) / 3.7km (SF12)	

Blocking mask for LPWAN-CSS NAP, in accordance with ETSI TR 103 526 [10], is described in Figure 13.

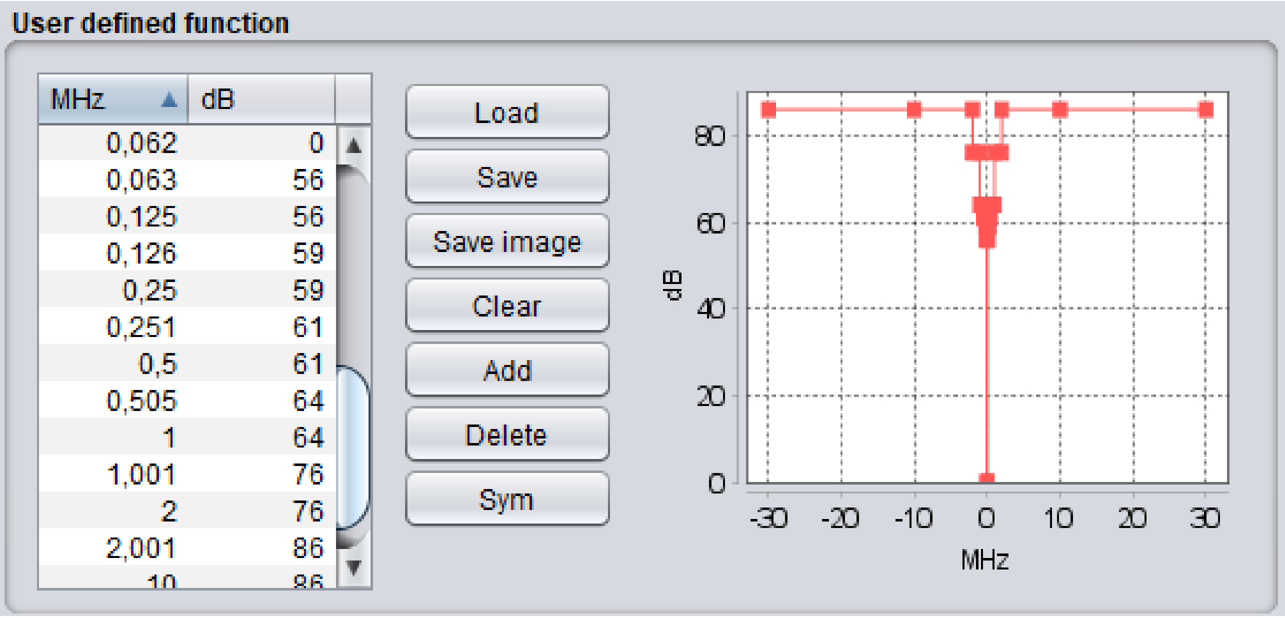


Figure 13: Blocking mask of LPWAN-CSS NAP from ETSI TR 103 526

NAP receiver blocking values are summarised in Table 32.

Table 32: NAP receiver blocking values

Offset (kHz)	Attenuation (dB)
62.5	0
62.6	56
125	56
125.5	59
250	59
251	61
500	61
505	64
1000	64
1001	76
2000	76
2001	86
5000	86
5999	86
6000	86

Blocking mask for LPWAN-CSS Terminal Node, in accordance with ETSI TR 103 526 [10], is described in Figure 14.

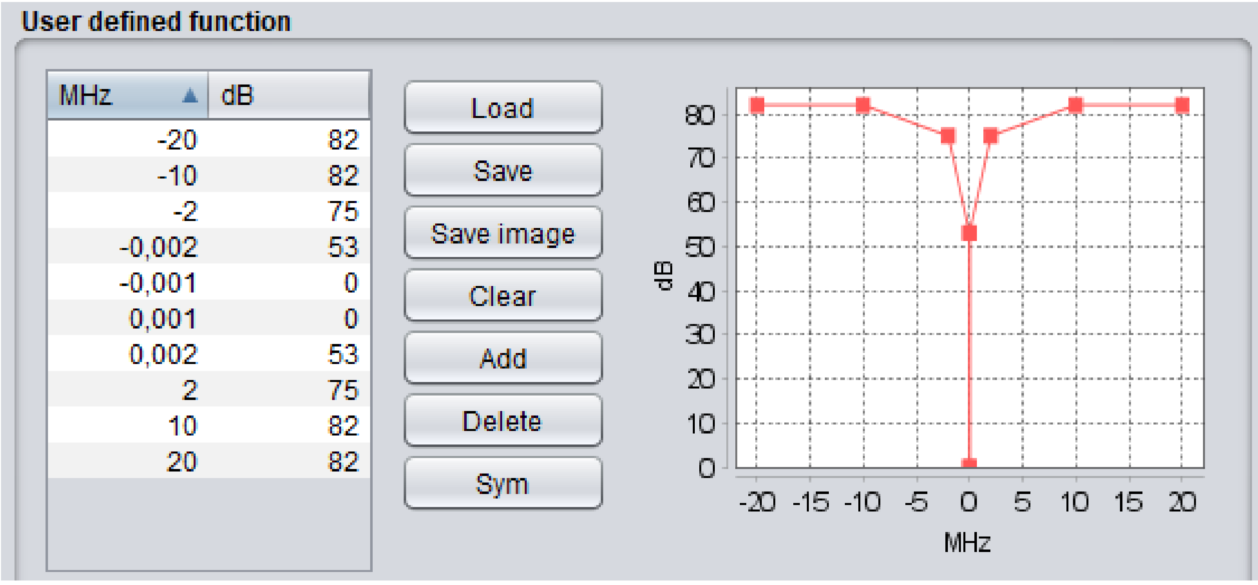


Figure 14: Blocking mask of LPWAN-CSS TN from ETSI TR 103 526

The values for the end devices receiver blocking mask are given in Table 33.

Table 33: End devices receiver blocking values

Offset (kHz)	Attenuation (dB)
62.5	0
62.6	42
125	42
125.5	47
250	47
251	57
500	57
501	67
1000	67
1001	72
2000	72
2001	82
5000	82
5999	82
6000	82

2.4 RFID SYSTEM TECHNICAL CHARACTERISTICS AND TYPICAL DEPLOYMENT PARAMETERS

Radio-frequency identification uses electromagnetic fields to automatically identify, and track tags attached to the objects. RFID systems consist of two components: an RFID interrogator (reader) and RFID tag.

Most of the tags are passive devices using the energy generated by the interrogator's antenna for responding. In passive backscatter RFID systems, the interrogator continuously transmits at a constant power level. Unlike the active mode where the tags can emit with their own energy and so the interrogators emit with a duty cycle.

Table 34 summarises the parameters used in this study for the RFID (victim) devices. Transmitter parameters are not shown since the study focuses only on RFID as a victim.

Table 34: RFID (Victim) parameters and deployment

Parameter	RFID interrogator
Frequency range (MHz)	915-919.4 MHz
Rx antenna gain	6 dBi
Maximum receiver sensitivity	-85 dBm
C/I objective	8 dB
Deployment scenario	Indoors
Antenna height	1.5 m
Building penetration loss	10 dB

2.4.1 Antenna

The antenna pattern considered in the study is shown in Figure 15 and is taken from atypical product available on the market [11]

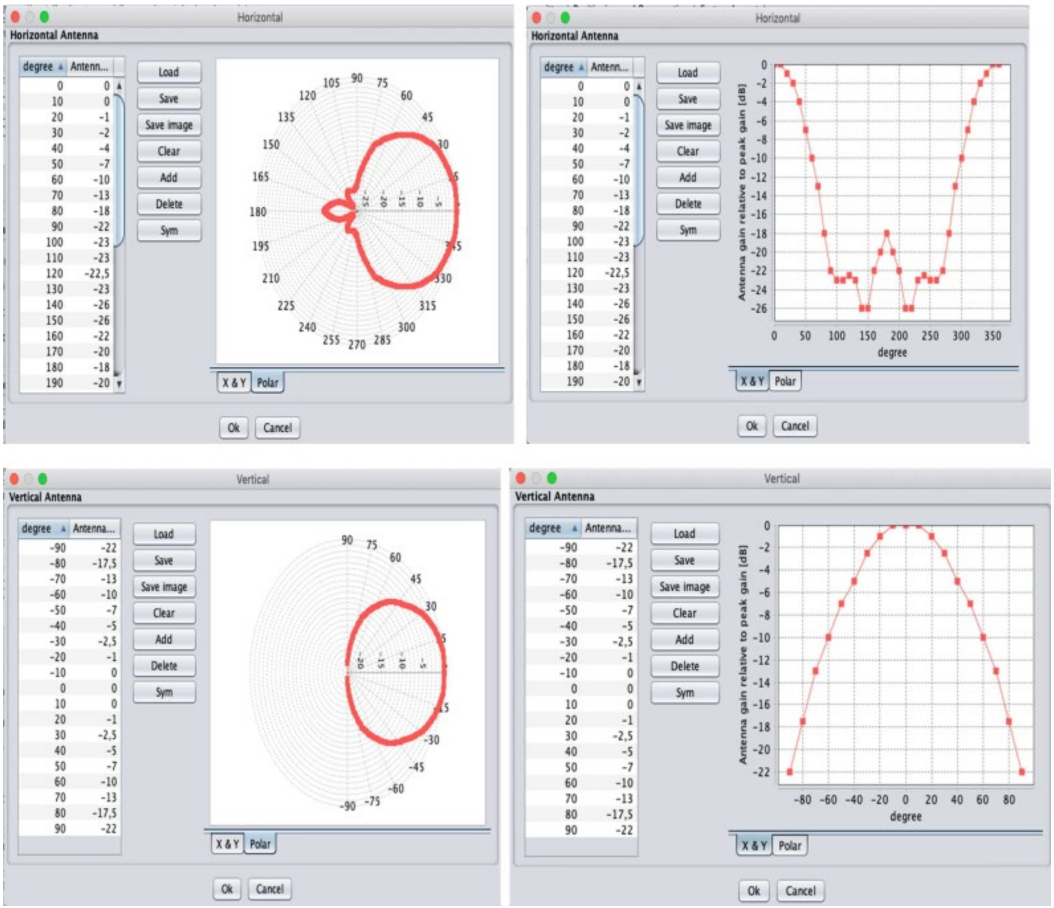


Figure 15: Antenna pattern considered in the study for RFID

2.4.2 Deployment

According to the ETSI TR 102 649-2 [12], the duty cycle of the interrogators depends mainly on the operating mode of tags, whether active or passive: with active tags, a DC of interrogators of 2.5% is assumed for the hot-spot scenario. In less dense scenarios higher DCs are possible. With passive tags, it is up to 100%.

However, the DC of tags is less than 1%.

2.4.3 Receiver parameters

The way in which RFID operates in this band is shown in Figure 16. Note that the interrogator transmits at high power in the central channel (centred on 916.3 MHz, 917.5 MHz and 918.7 MHz), and the RFID tags absorb that power and retransmit in sub-bands on both side of the high power channel:

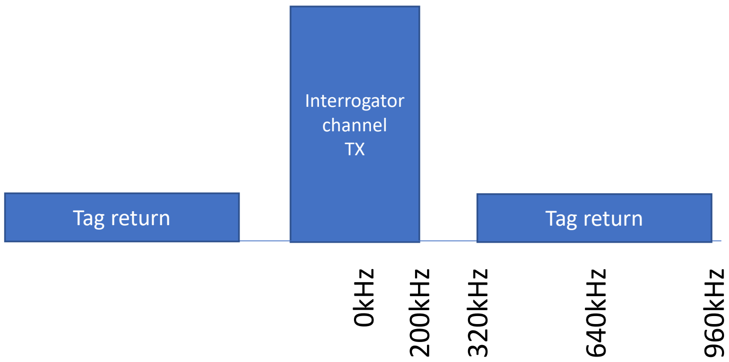


Figure 16: RFID operation

The emissions from the tags are received by the RFID interrogator receiver on both sides of the RFID interrogator channel.

They can be modelled by two 600 kHz wide emissions, +640 kHz and -640 kHz away from the interrogator channel, resulting in a 680 kHz gap (see Figure 17).

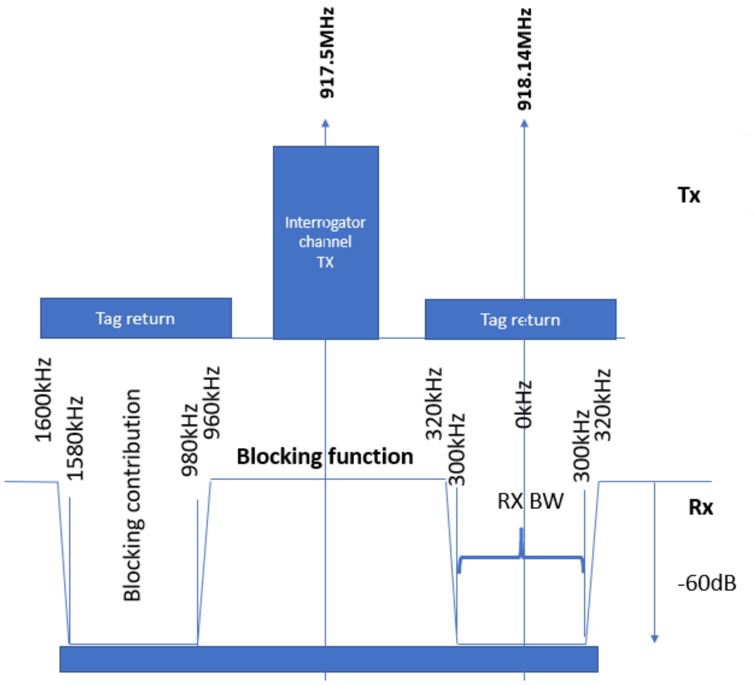


Figure 17: The corresponding SEAMCAT model for the blocking function

The corresponding SEAMCAT model for the blocking function of the RFID interrogator receiver is given in Table 35 and illustrated in Figure 17.

Table 35: Blocking model of RFID interrogator receiver

Frequency offset (MHz)	-3.000	-1.600	-1.580	-0.980	-0.960	-0.320	-0.300	0	0.300	0.320	3.000
Blocking level (dB)	60	60	0	0	60	60	0	0	0	60	60

Further parameters of the RFID receive system are shown in Table 36.

Table 36: RFID Rx parameters

Parameter	Value
Rx BW (upper and lower)	2 x 600 kHz
Sensitivity	-85 dBm
C/I objective	8 dB

The RFID system has had its tag returns and receiver modelled with probability of wanted Received Signal Strength (dRSS), a term used in SEAMCAT, as shown in Figure 18. Calculations are made only for fixed deployments.

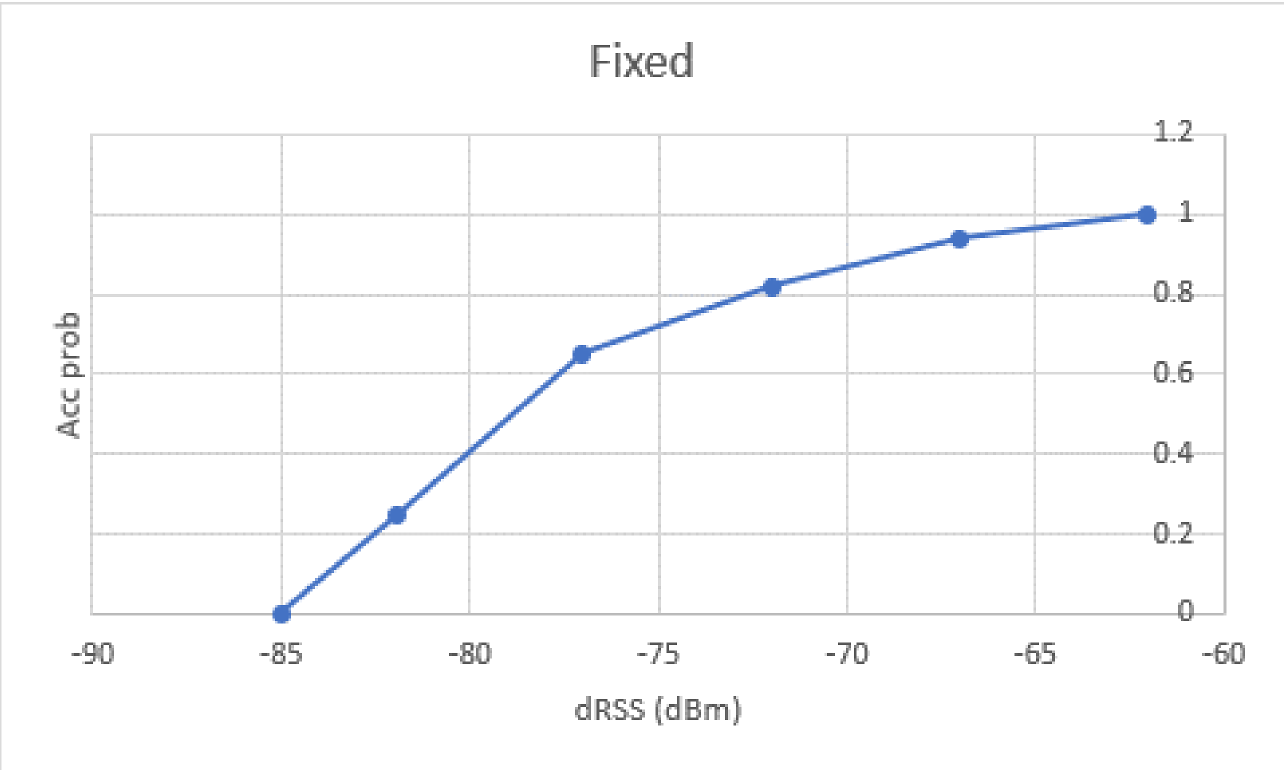


Figure 18: Assumed RFID dRSS

The parameter values to be used in these SEAMCAT studies for RFID systems (in Ranges A and B) as victims are taken from ECC Report 261 [5], updated for the 900 MHz band, as shown in Table 37.

Table 37: RFID parameters

Parameter	RFID Application			
	Fixed Infrastructure		Hand-held devices	
Frequency range, MHz	865-868	915-919	865-868	915-919
Transmitter power, dBm	29.2	30.7	27.0	27.0
Tx antenna gain, dBi	6	7.5	2.2	2.2
Tx radiated power (e.r.p.), dBm	33	36	27	27
Rx antenna gain, dBi	6	7.5	2.2	2.2
Receiver bandwidth, kHz	300	600	300	600
Declared receiver sensitivity, dBm	-85	-82	-80	-77
C/I objective, dB	8	8	8	8

2.5 GENERIC SRDS (25 MW/(350 KHZ))TECHNOLOGY AND SPECTRUM USE

2.5.1 Technical characteristics and typical deployment parameters

25 mW SRD considerations are as per ERC Recommendation 70-03, annex 1 [4].

2.5.2 Radio system parameters

Parameters for 25 mW SRD radio as victim are shown in Table 38 and illustrated in Figure 19.

Table 38: 25 mW SRD radio as victim parameters

SRD receiver bandwidth (kHz)	Sensitivity (dBm)	Min C/I (dB)	Selectivity (dB)	Operating range (m)
350	-103	8	50	40 (indoors) (Note 1) 100 (outdoors)
Note 1: With a room size assumed to be 4 m, this leads to some links that need to operate through 9 walls.				

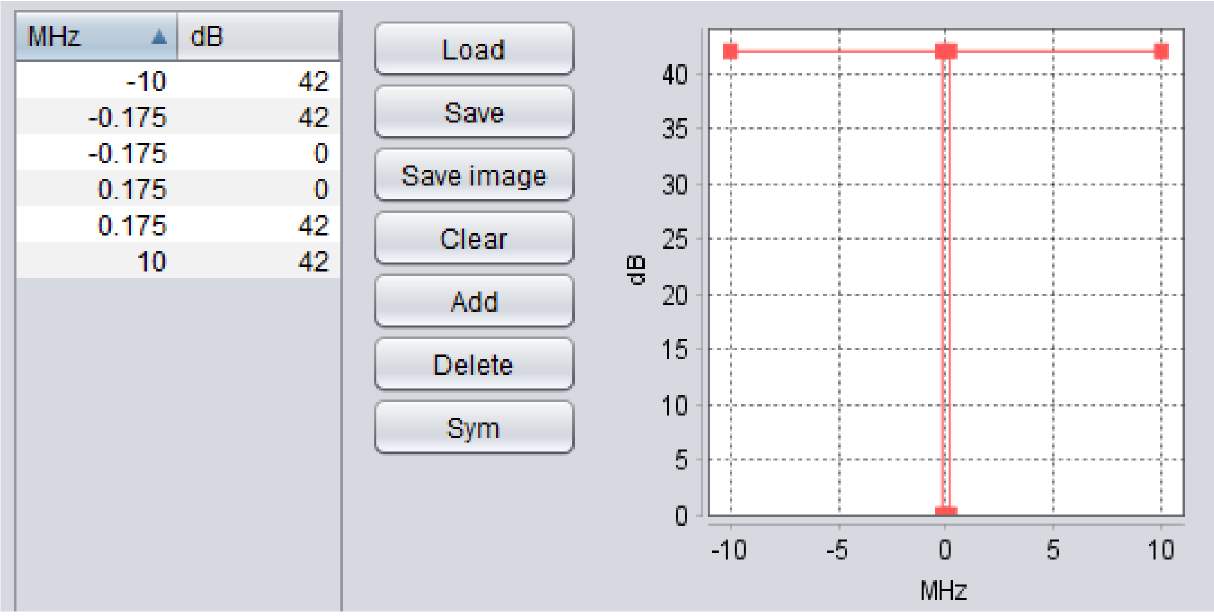


Figure 19: 25 mW SRD blocking mask

Parameters of home automation (HA) SRD / non-specific SRD according to ECC Report 261 [5] are shown in Table 39.

Table 39: Parameters of HA SRD / non-specific SRD according to ECC Report 261

Simulation input parameters	Settings
Frequency	917.9 MHz
VLR sensitivity	-103 dBm/(350 kHz)
VLR selectivity	Realistic Cat. 2 compliant masks, 350 kHz channel bandwidth
VLR C/I threshold	8 dB
VLR/Tx antenna	0 dBi, non-directional
VLR/Tx antenna height	1.5 m
VL Tx power	14 dBm/(350 kHz)
VL Tx → Rx path	Hata-SRD, urban, indoor-indoor/below roof
Coverage range	4m - 40 m
Deployment	Both indoor and outdoor simulations are considered

2.6 WIDE BAND SRDS

2.6.1 Wide band technology and spectrum use

25 mW SRD considerations are as per ERC Recommendation 70-03, annex 3 [4].

2.6.2 Wide band system technical characteristics and typical deployment parameters

Parameters for wideband system receiver are shown in Table 40 and illustrated in Figure 20.

Table 40: Wideband system receiver parameters

SRD receiver bandwidth (kHz)	Sensitivity (dBm)	Min C/I (dB)	Selectivity (dB)	Operating range (m)
1000	-98	12	42	40 (indoors) (Note 1) 100 (outdoors)
Note 1: With a room size assumed to be 4 m, this leads to some links that need to operate through 9 walls.				

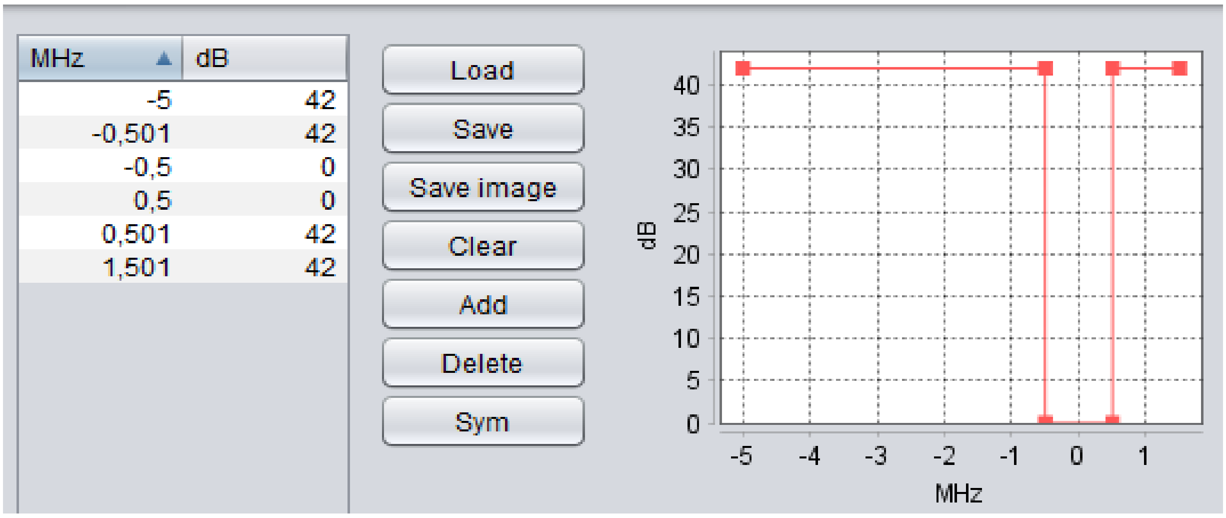


Figure 20: Wideband blocking mask

Parameters of wideband data transmission systems according ECC Report 261 [5] are shown in Table 41.

Table 41: Parameters of wide band data transmission systems according ECC Report 261

Simulation input/output parameters	Settings/Results
VL: WBN SRD Terminal Node Rx	
Frequency	915.8-919.4 MHz /(1000 kHz) channels
VLR sensitivity	-98 dBm/(1000 kHz)
VLR selectivity	Realistic Cat. 2, 42 dB @ dF=2 MHz
VLR C/I threshold	12 dB
VLR/Tx antenna	0 dBi, non-directional
VLR/Tx antenna height	1.5 m
VL Tx power	14 dBm/(1000 kHz)
VL Tx → Rx path	Hata-SRD, urban, indoor-indoor/below roof, R=0.02/0.04 km
Coverage range	20 m - 40 m
Deployment	Both indoor and outdoor simulations are conducted

2.7 GOVERNMENTAL APPLICATIONS

This section recalls the conclusions of the ECC Report 200 [1] on the sharing with the military systems. The ECC Report 200 concluded that for the coexistence with the military systems, if the Tactical Radio Relay (TRR) was deployed in the same areas as the SRD systems, the simulation results indicate clearly high interference levels, unless some additional coexistence arrangements and interference mitigation techniques are implemented. The impact could only be reduced if the TRR usage could be restricted to dedicated military exercise areas. Moreover, for the band 915-919.4 MHz, the results of simulations indicate that similarly as in the band 870-876 MHz, if the TRR use was restricted to separate military areas, then the interference risk would be moderate based on the C/I criterion, although the TRR receivers noise level would increase significantly. However, if SRD/RFIDs were to be deployed in the same areas as TRR, the simulation results across all criteria indicate clearly the high interference potential.

3 METHODOLOGY AND ASSUMPTIONS FOR SIMULATIONS

3.1 PROPAGATION MODELS

The most appropriate, available propagation model is selected for each of the paths, both inter-system and intra-system is shown in the figures below. A module has been developed by the SEAMCAT Technical Group (STG) which combines Recommendation ITU-R P.1411 [13] and the Line of sight (LoS) probability calculations from Report ITU-R M.2135-1 [14]. Furthermore, building loss entry are calculated using Recommendation ITU-R P.2109 [15] and assumes that 70% of buildings are traditional buildings with 30% thermal efficient. Details about propagation models can be found in Annex 3.

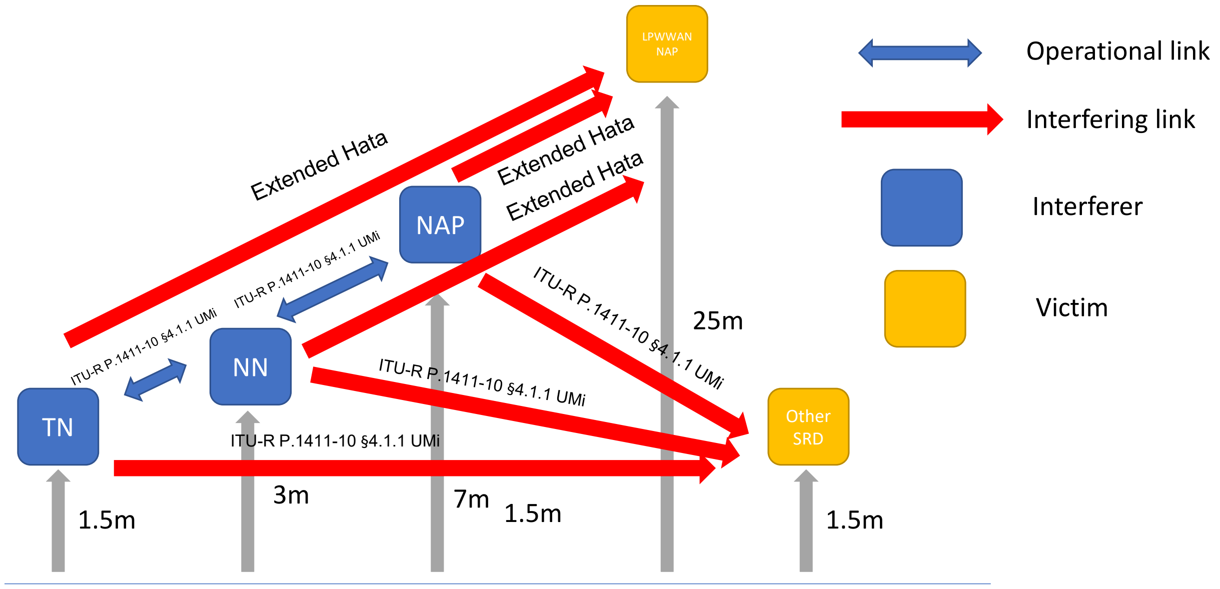


Figure 21: Propagation models for NBN as interferer

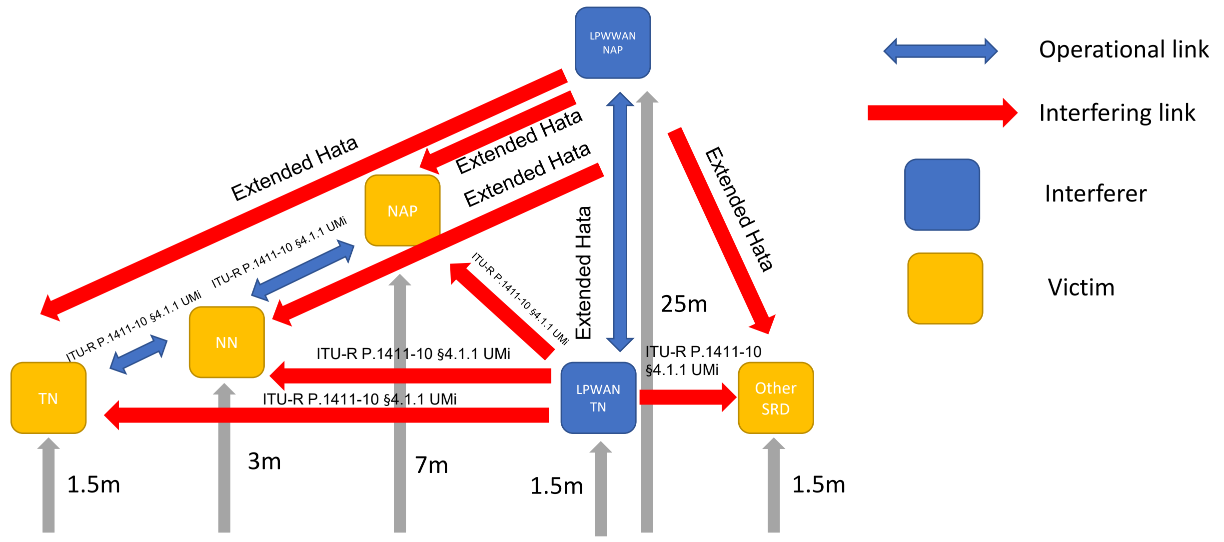
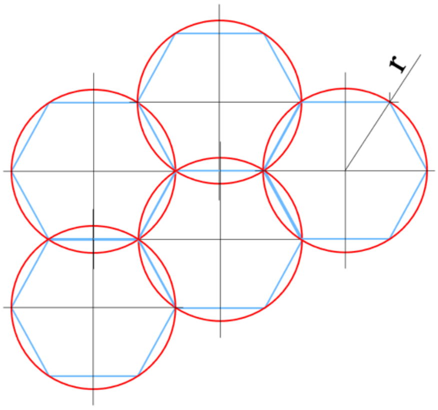


Figure 22: Propagation models for LPWAN as interferer

For the simulations involving NAP LPWAN-CSS and NAP LPWAN-UNB the free space model is considered.

3.2 COVERAGE AND SIMULATION RADIUS

The coverage radius, used for networked SRDs (i.e. NBN, LPWAN-UNB and LPWAN-CSS systems) in SEAMCAT, is derived from the node density, that each system uses for its deployment parameters. Figure 23 gives the formula used for coverage radius evaluation with node density.



coverage radius: $r = \sqrt{\frac{2}{3\sqrt{3}\eta}}$

where η is the node density

Figure 23: Node density formula

SEAMCAT offers several options for evaluating the simulation radius, i.e. the disk where interferer transmitters are put around each victim receiver. This Report uses the “uniform distribution” option, where SEAMCAT automatically evaluates the simulation radius from the node densities and the number of interferers, that are reasonably needed to simulate interference for the considered technologies.

3.3 INTERFERENCE RATIO CALCULATION

SEAMCAT evaluates the interference ratio of a scenario over many events, where victim link is interfered by interfering systems. Once the victim transmitter and victim links are randomly placed, it may appear that the random nature of propagation models creates victim links that are not operational, i.e. carrier level is lower than the sensitivity threshold of the victim receiver. In the field, this case is not an issue since network SRDs are networked systems where each node is served by more than one counter-part node.

For this reason, interference ratios are all evaluated over interfered links with carrier greater than sensitivity.

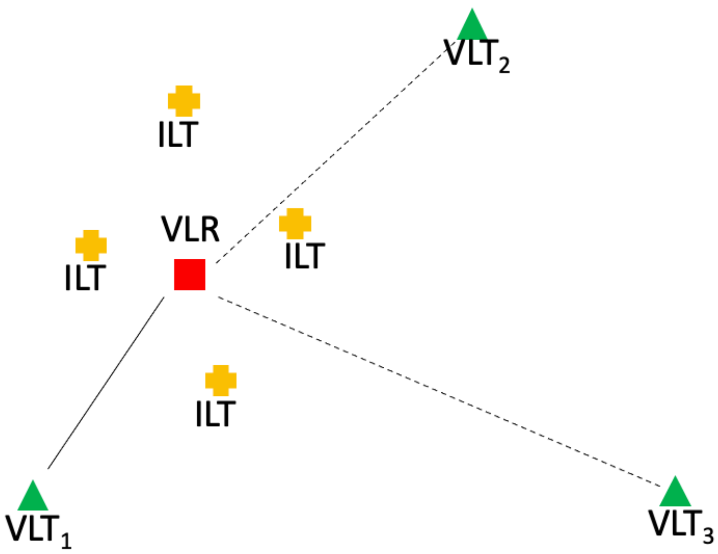


Figure 24: VLR serving other nodes than the VLT in a SEAMCAT simulated event

4 SCENARIO SET A

4.1 DESCRIPTION

This scenario set examines opportunities for operating NBN devices, other than relatively high DC NAPs, in the spectrum between the first and third RFID interrogator channels. The technical parameters of the assumed NBN systems and those of the victims are found in section 2.1, and the assumed propagation models are shown in section3. Further details of this set of simulations are described below.

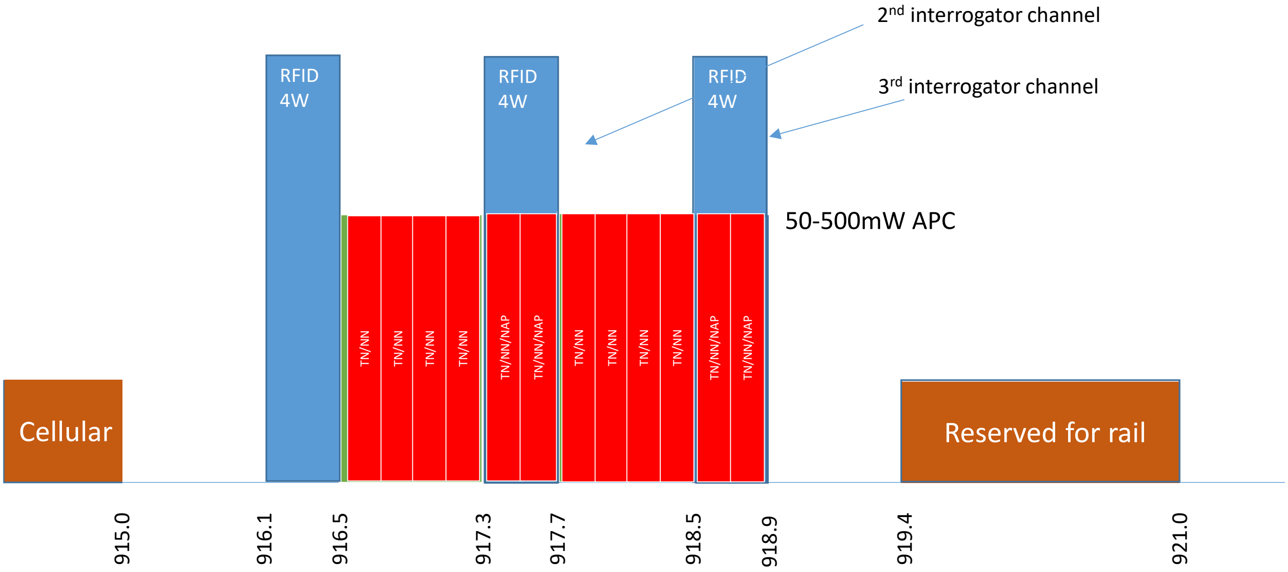


Figure 25: Assumed deployment of NBN technology

Initially, a set of baseline interference scenarios (assuming full allowed DC) has been considered, deployed as illustrated in Figure 25 and Figure 26.

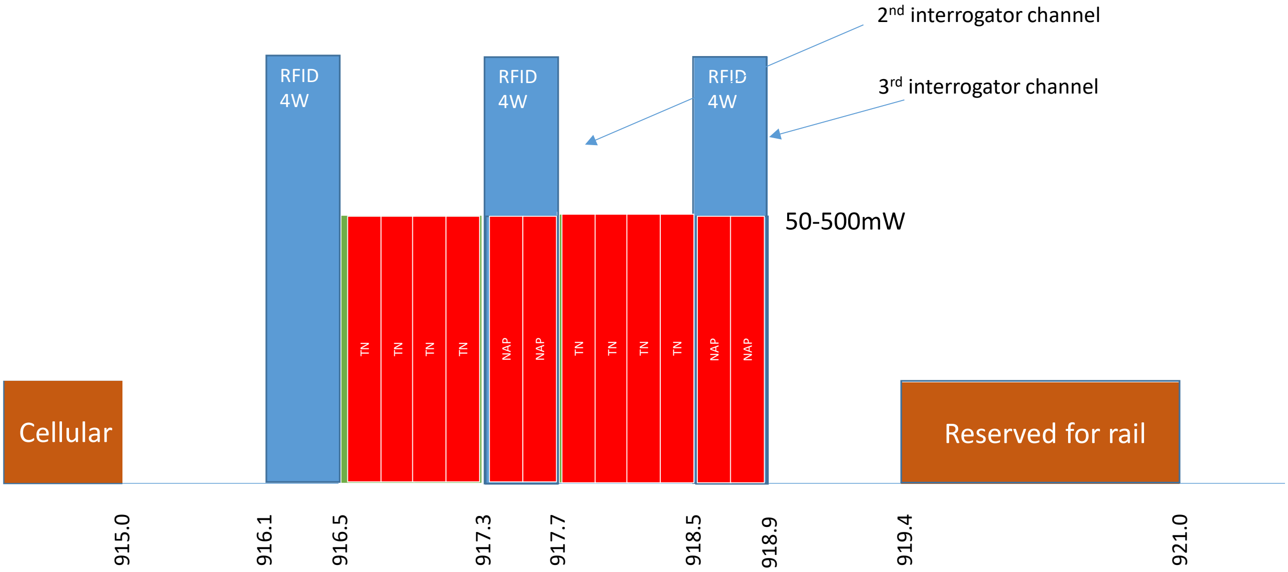


Figure 26: Assumed deployment of LPWAN-CSS and LPWAN-UNB technology

Victim systems considered, illustrated in Figure 27 and Figure 28 are:

- RFID operating using three interrogator channels in the 915-919.4 MHz band;
- Wideband SRD operating in the 917.7 to 918.5 MHz band (operating both indoors and outdoors);
- Generic 25 mW SRD operating in the 917.7 to 918.5 MHz band (operating both indoors and outdoors);
- LPWAN-CSS and LPWAN-UNB.

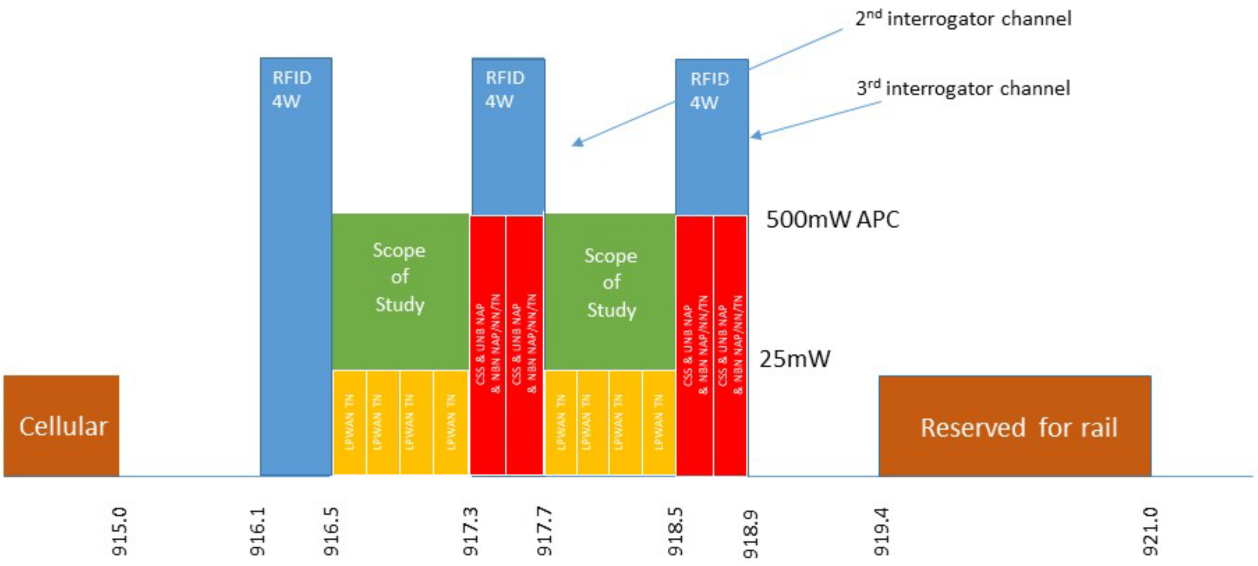


Figure 27: Assumed baseline deployments

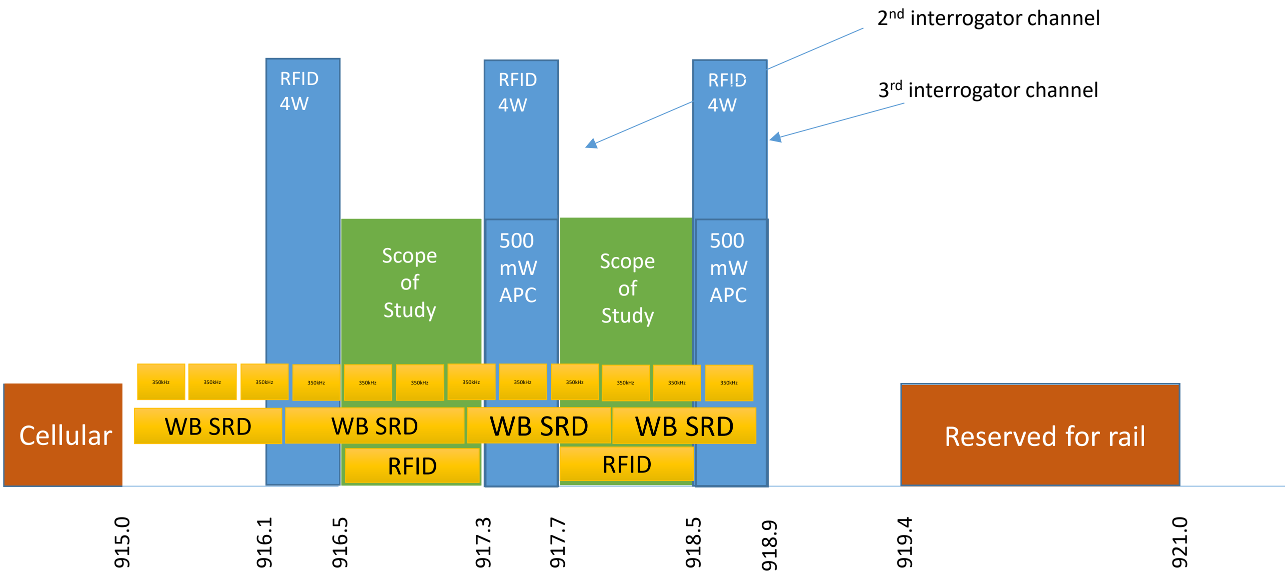


Figure 28: Victim system deployments

Interference between these systems has not been considered, as it has been the topic of previous studies, notably leading to ECC Report 200 [1], ECC Report 246 [16] and ECC Report 261 [5]. Furthermore, interference to services operating in these bands across national borders have not been considered; that scenario having been recently considered in an addendum to ECC Report 200.

The power of the Networked SRD (NSRD) group is increased in steps (50 mW, 100 mW, 250 mW and 500 mW) and the DC varied, and the predicted probability of interference noted.

4.2 TECHNICAL DETAILS

4.2.1 Input parameters

4.2.1.1 Baseline scenario and Relative DC

All scenarios are preceded by a baseline scenario which calculates the impact of NSRDs operating in the second and third RFID channels at full DC as is currently allowed by European regulation. Thereafter, additional traffic associated with a second set of NNs and TNs (NAPs remain in the RFID interrogator channels) introduced into the ranges A and B is considered.

The ratios of the activities of NN to TN and NAP (for the interrogator channels) devices is modelled to reflect typical operation for these systems (and as done in previous ECC Reports) and is TN:NN:NAP of 0.1:2.5:10. The values used are summarised in the Table 42.

Table 42: Device activities for each scenario

Scenario	TN		NN		NAP	
	In RFID interrogator channels	In ranges A and B	In RFID interrogator channels	In ranges A and B	In RFID interrogator channels	In ranges A and B
Baseline	0.1%	-	2.5%	-	10%	-
TN= 0.01%	0.1%	0.01%	2.5%	0.25%	10%	-
TN= 0.02%	0.1%	0.02%	2.5%	0.5%	10%	-
TN= 0.05%	0.1%	0.05%	2.5%	1.25%	10%	-
TN= 0.07%	0.1%	0.07%	2.5%	1.75%	10%	-
TN= 0.1%	0.1%	0.1%	2.5%	2.5%	10%	-

4.2.1.2 Band loading dilution

Networked SRDs are designed to work using a range of spectrum. This study has assumed that the band 865-868 MHz is available along with the two RFID interrogator channels in the 915 MHz band and considered two sub-scenarios:

- Minimal EC Decision: where only an additional 400 kHz has been released, starting at 874 MHz (see Figure 29);
- Full ERC Recommendation 70-03 [4]: where an additional 3 MHz has been released, starting at 870 MHz (see Figure 30);

Therefore, these devices are forced to operate in whatever spectrum is available. Some are able to operate in a wide range of frequencies, others will be restricted to smaller bands. For example, one device (red configuration in Figure 29 and Figure 30) might be able to operate across the entire 800-900 MHz bands (being able to reject interference from interspersed cellular systems), whereas others (blue or green configurations) will limit their operation to specific bands e.g. the 870 MHz band or the 915 MHz band.

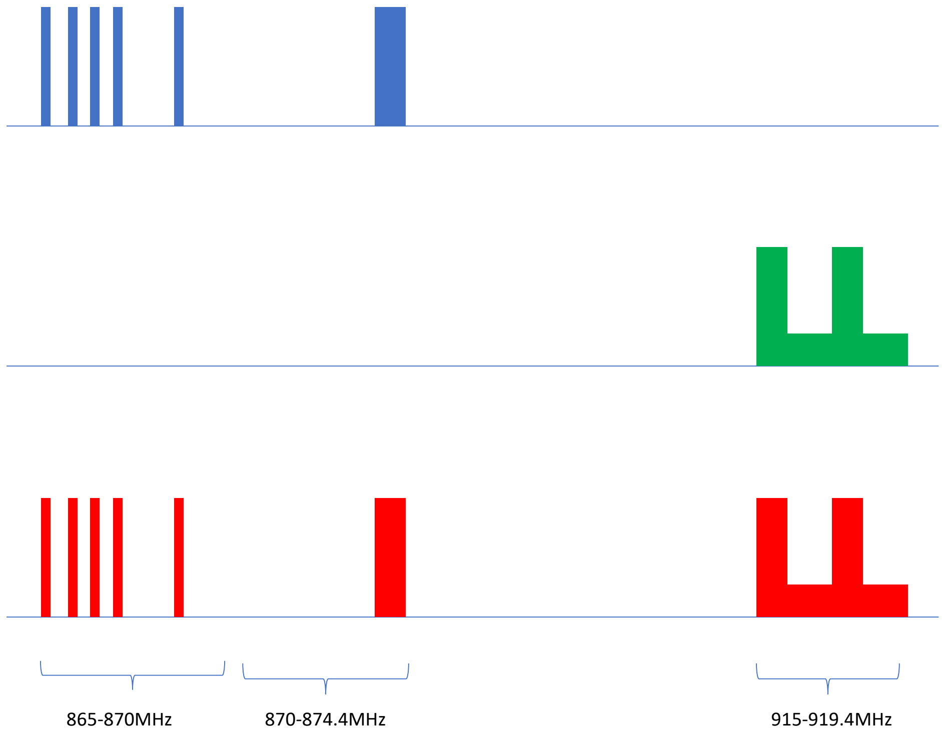


Figure 29: Potential spectrum occupancy of individual systems for Minimal EC Decision

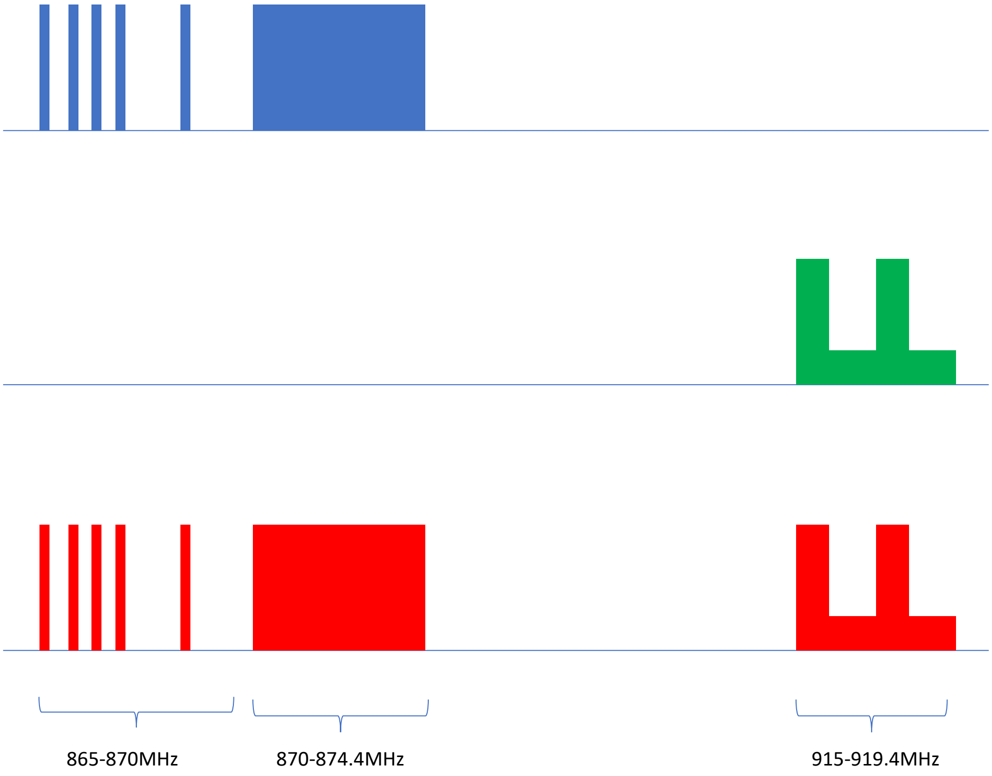


Figure 30: Potential spectrum occupancy of individual systems for full ERC Recommendation 70-03

On average, however, no band becomes particularly crowded and so it is a reasonable assumption that the traffic offered will be evenly distributed across all available bands. The number of devices from Table 12 are diluted in the bands of interest (916.5-917.3 MHz and 917.7-918.5 MHz) except for NAPs. This dilution effect is shown in the Table 43 and Table 44.

Table 43: Band loading dilution figures – BASELINE (FULL DC)

Deployment type	Existing spectrum available outside Ranges A and B (MHz)			Proportion of non-NAP devices in RFID interrogator channels (800 kHz)	NAPs in RFID interrogator channels (800 kHz)
	Band (MHz)	Spectrum (MHz)	Total (MHz)	= 800 kHz/ TOTAL spectrum	= 800 kHz/ TOTAL spectrum
Minimal EC Decision	865-870	1.0	2.2	=0.8/(2.2+1.6) =21%	=0.8/2.2 = 36%
	874-874.4	0.4			
	915-919.4 (Note 1)	0.8			
Full ERC Recommendation 70-03 [4]	865-870	1.0	6.2	=0.8/(6.2+1.6) =10%	=0.8/6.2 =13%
	870-874.4	4.4			
	915-919.4 (Note 1)	0.8			
Note 1: As the first interrogator channel is treated in ECC Report 326 [9], it is assumed that it lies outside the scope of available spectrum					

Table 44: Band loading dilution figures – VARIABLE DC

Deployment type	Available spectrum outside Ranges A and B (MHz)			Proportion of non-NAP devices in RFID interrogator channels (800 kHz)	Proportion of non-NAP devices in Ranges A and B (1.6 MHz)	NAPs in RFID interrogator channels (800 kHz)
	Band (MHz)	= 800 kHz/ TOTAL spectrum (Note 1)	=1.6 MHz/TOTAL spectrum	= 800 kHz/ TOTAL spectrum	=1.6 MHz/TOTAL spectrum	= 800 kHz/ TOTAL spectrum
Minimal EC Decision	865-870	1.0	2.2	=0.8/(2.2+1.6) =21%	=1.6/(2.2+1.6) =42%	=0.8/2.2 = 36%
	874-874.4	0.4				
	915-919.4	0.8				
Full ERC Recommendation 70-03 [4]	865-870	1.0	6.2	=0.8/(6.2+1.6) =21%	=1.6/(6.2+1.6) =21%	=0.8/6.2 =13%
	870-874.4	4.4				
	915-919.4	0.8				
Note 1: The density of devices in the interrogator channels associated with the Baseline case is maintained in the subsequent scenarios, in effect increasing the overall density of devices when compared to Table 43						

The density of each type of device in each band for each scenario is summarised in Table 45 and Table 46 and represents the distribution of the devices listed in Table 42 across the bands.

Table 45: Band (RFID interrogator channels only) loading dilution figures – BASELINE (full DC)

Scenario	TN density per km^2 in RFID channel	NN density per km^2 in RFID channel	NAP density per km^2 in RFID channel
Full release / AVE dens	95	4.5	0.65
Full release / MAX dens	190	9	1.3
Min release / MAX dens	399	18.9	3.6

Table 46: Band (900 MHz channels) loading dilution figures – Variable DC

Scenario	NN density per km2 in RFID channel	NN density per km2 in A + B channel	TN density per km2 in RFID channel	TN density per km2 in A+B channel	NN density per km2 in TOTAL	TN density per km2 in TOTAL
Full release / AVE dens	4.5	9.45	95	199.5	13.9	294
Full release / MAX dens	9	18.9	190	399	27.9	589
Min release / MAX dens	18.9	37.8	399	798	56.7	1197

4.2.1.3 Simulation methodology

The simulations have all been run in uniform density mode, where the simulation radius for any particular combination of interferer and victim is calculated by SEAMCAT.

4.3 NEW OPPORTUNITY RESULTS

This section sets out the results of interference calculations to victim systems from NBN technology. For each combination (interferer/victim) of technologies, a range of calculations have been carried out including investigations of the probability of interference to a victim receiver and, by way of reference, the time-averaged interference noise received by the victim devices. The full set of calculations is shown in Annex 3.Summary graphs of interference/interfering power vs overall DC are plotted below – for a combination of spectrum availability and device density assumptions - with interfering devices operating at up to (using APC) 50 mW and 500 mW with the DC of each component adjusted relative to the TN DC as set out in the methodology. Also, graphs of plotted of interference/interfering power vs interferer maximum transmit power for a combination of spectrum availability, device density assumptions and high (TN=0.1%) and low (TN=0.01%) DC. The Baseline calculations for each scenario correspond to a DC of zero (leftmost set on each graph).

Each interfering power summary graph also has the calculated interference/interfering power that would be expected for each baseline scenario: where all NBN devices are assumed to operate in the narrow high-power RFID interrogator channels (generally allowed by legislation now) at full power and full allowed DC.

The 0% duty cycle corresponds to the BASELINE scenario where operation according to the current regulatory limit alone is assumed.

RFID vs DC: 50mW

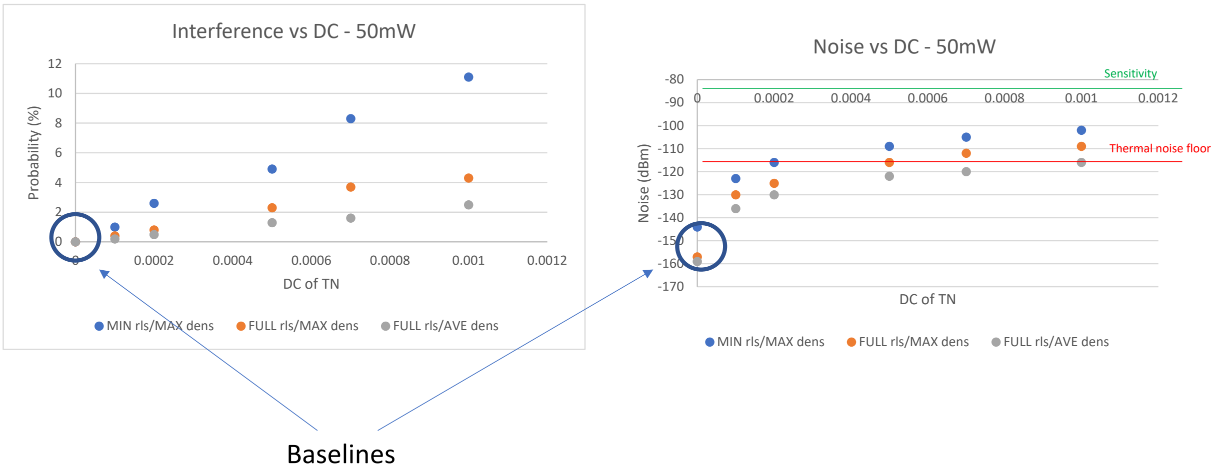


Figure 31: Sample graphs showing baselines, thermal noise floor and victim sensitivity

Finally, each interfering power graph has plotted on it the thermal noise floor (not including noise figure) for the victim device and the sensitivity of the victim device for context.

4.3.1 Victim RFID

RFID vs DC: 50mW

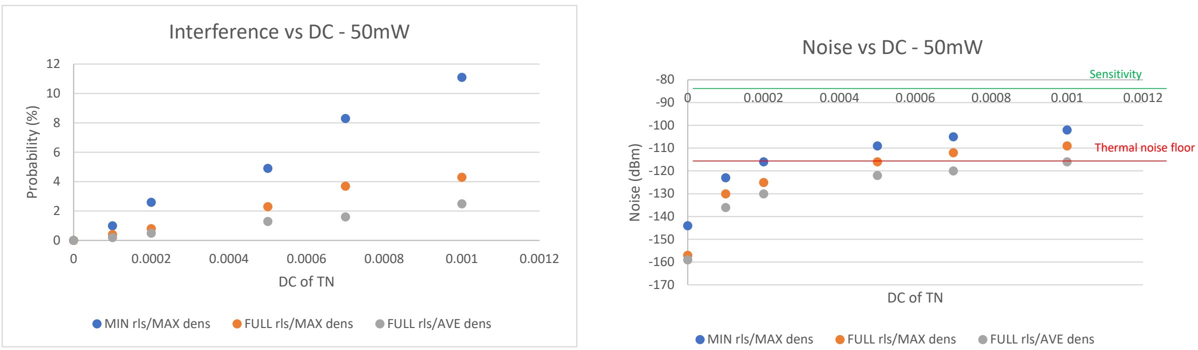


Figure 32: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from 50 mW NBN system versus TN DC into RFID

RFID vs DC: 500mW

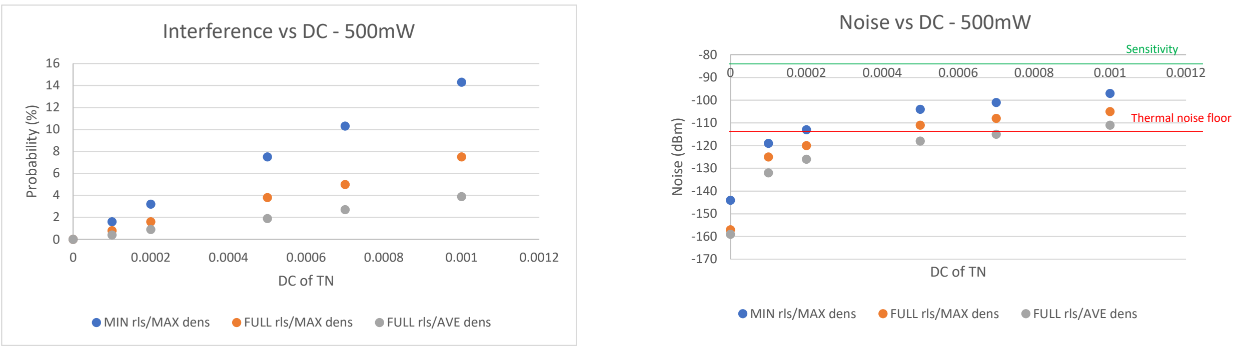


Figure 33: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from 500 mW NBN system versus TN DC into RFID

RFID vs power

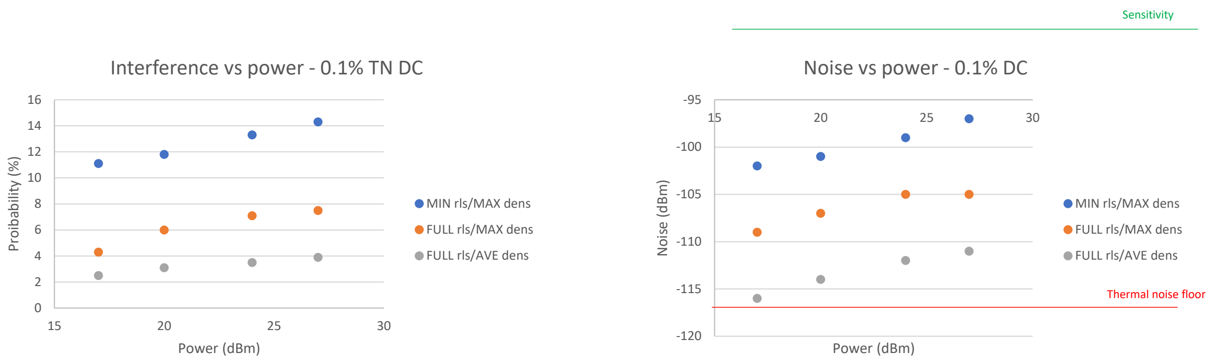


Figure 34: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from NBN system operating with TN DC of 0.1% versus Interfering power (mW) into RFID

4.3.1.1 Discussion

Interference into the RFID system sees levels of interference below 5% in all cases except the worst case (MINIMAL spectrum release, maximum interfering device density and 500 mW operation), and even then only for interfering device activity levels greater than 20% of the maximum (TN=0.02%; NN= 0.5%). It should be noted that in the scenario full release case, the three RFID channels will be impacted while in the min release scenario one of the channels is free of interference.

The results of the worst-case scenario correlate well with those calculated using an alternative spreadsheet-based analysis shown in section 7.

Analysis of the average noise floor rise associated with the interfering systems shows that a significant rise above thermal is only observed for the higher activity levels of the worst-case scenario.

4.3.2 Victim 25 mW system

4.3.2.1 Indoors

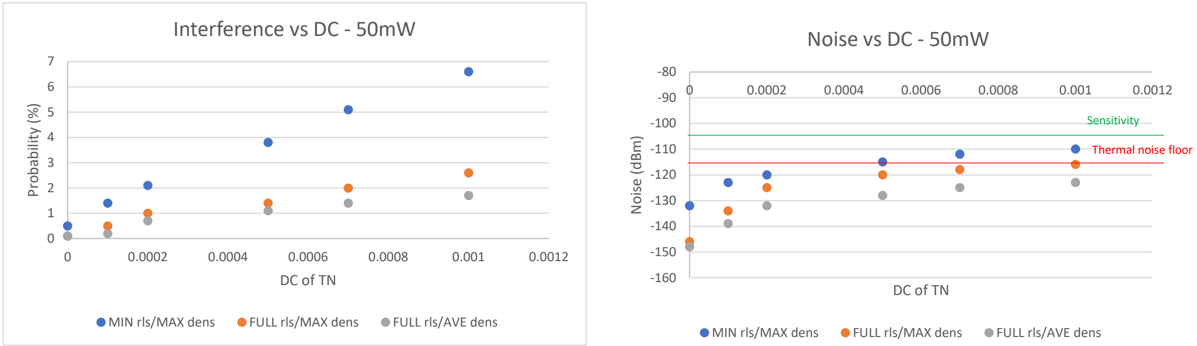


Figure 35: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from 50 mW NBN system versus TN DC into 25 mW/(350 kHz) system indoors

Non-specific indoors vs DC: 500mW

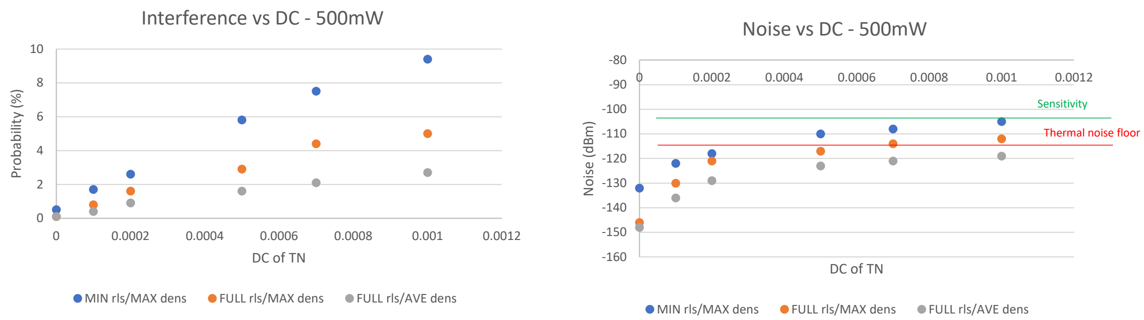


Figure 36: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from 500 mW NBN system versus TN DC into 25 mW/(350 kHz system indoors

Non-specific indoors vs power

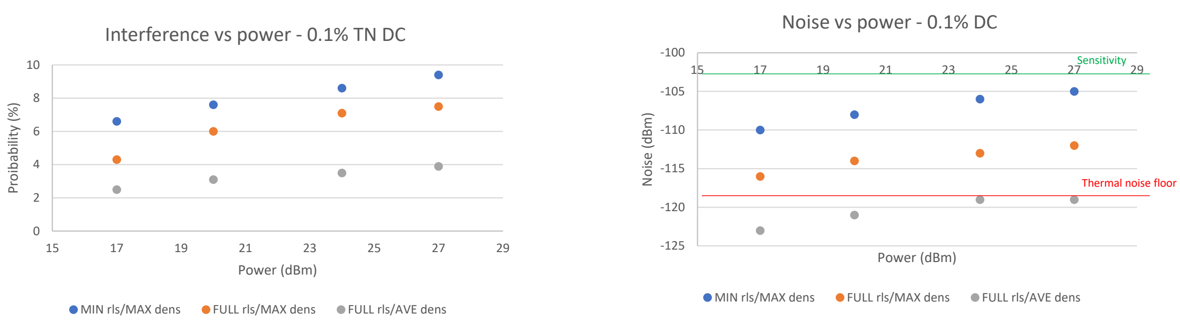


Figure 37: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from NBN system operating with TN DC of 0.1% versus Interfering power (mW) into 25 mW/(350 kHz) system indoors

4.3.2.2 Outdoors

Non-specific outdoors vs DC: 50mW

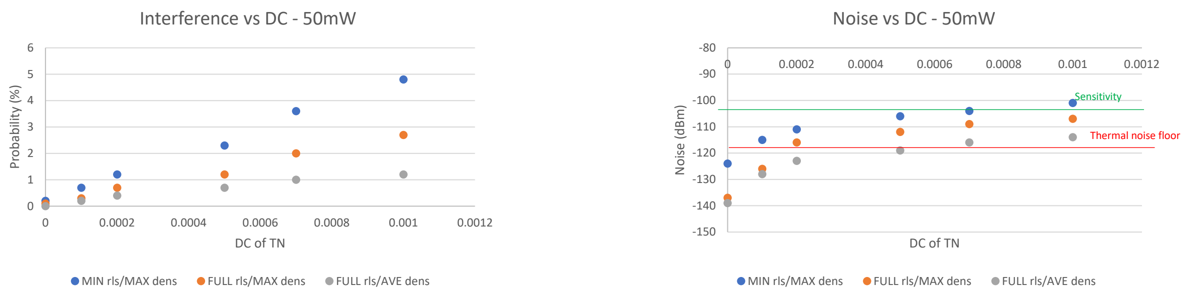


Figure 38: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from 50 mW NBN system versus TN DC into 25 mW/(350 kHz) system outdoors

Non-specific outdoors vs DC: 500mW

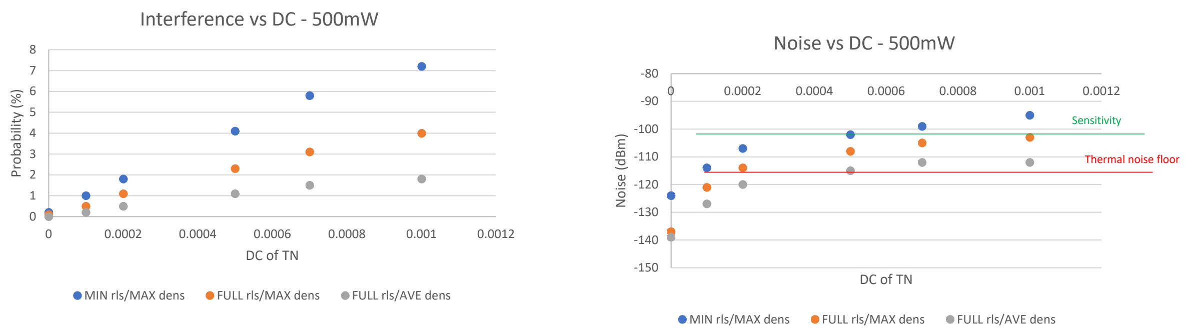


Figure 39: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from 500 mW NBN system versus TN DC into 25 mW/(350 kHz) system outdoors

Non-specific outdoors vs power

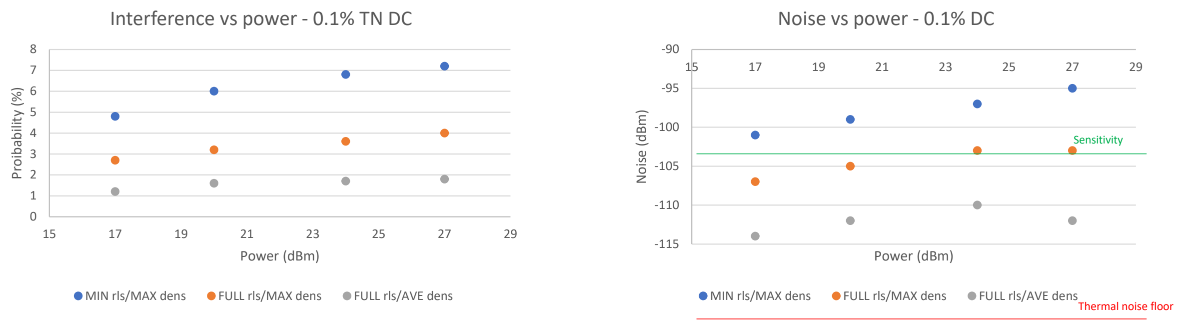


Figure 40: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from NBN system operating with TN DC of 0.1% versus Interfering power (mW) into 25 mW/(350 kHz) system outdoors

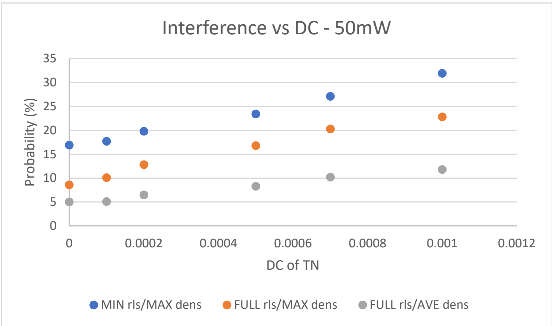
4.3.2.3 Discussion

Interference into the generic 25 mW system sees levels of interference - both indoors and outdoors - below 5% in all cases except the worst case of MINIMAL spectrum release MAXIMUM density for TN DC above 0.05% and power above 100 mW.

Analysis of the average noise floor rise associated with the interfering systems shows that a rise above thermal is only observed for the higher activity levels of the worst case scenario.

4.3.3 Victim Wideband networked SRD system

4.3.3.1 Indoors



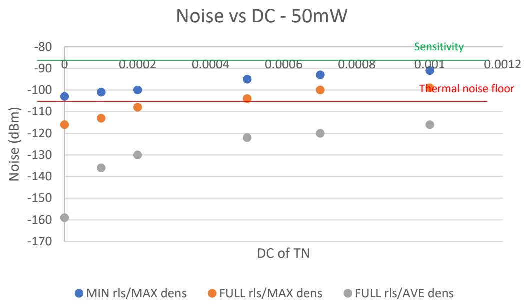
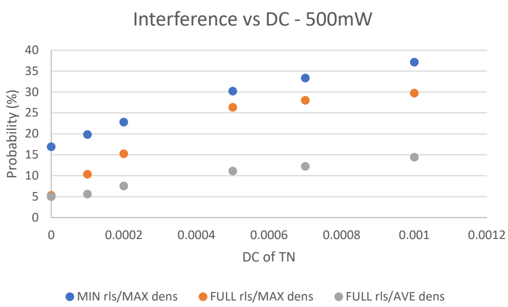


Figure 41: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from 50 mW NBN system versus TN DC into Wideband networked SRD system indoors

Wideband indoors vs DC: 500mW



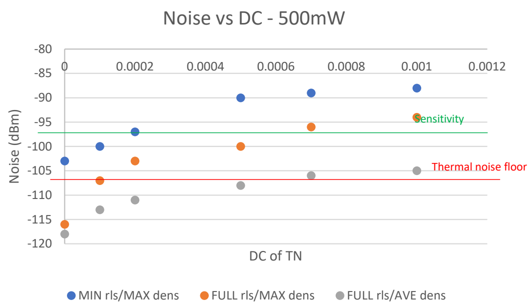


Figure 42: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from 500 mW NBN system versus TN DC into Wideband networked SRD system indoors

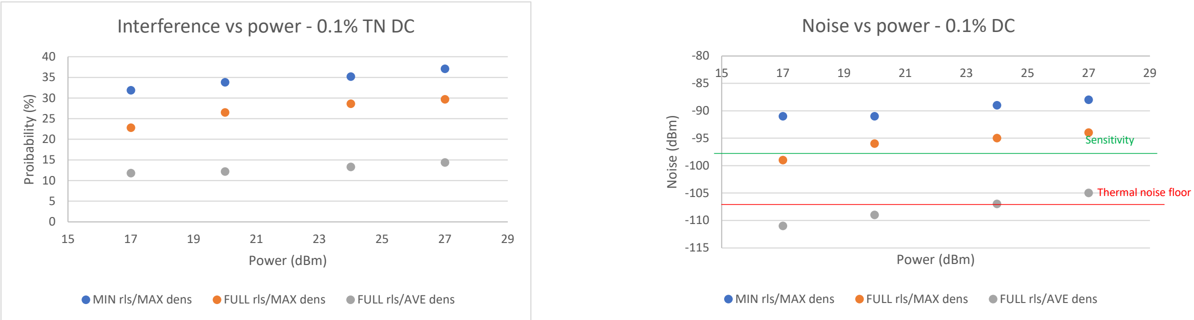


Figure 43: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from NBN system operating with TN DC of 0.1% versus Interfering power (mW) into Wideband networked SRD system indoors

4.3.3.2 Outdoors

Wideband outdoors vs DC: 50mW

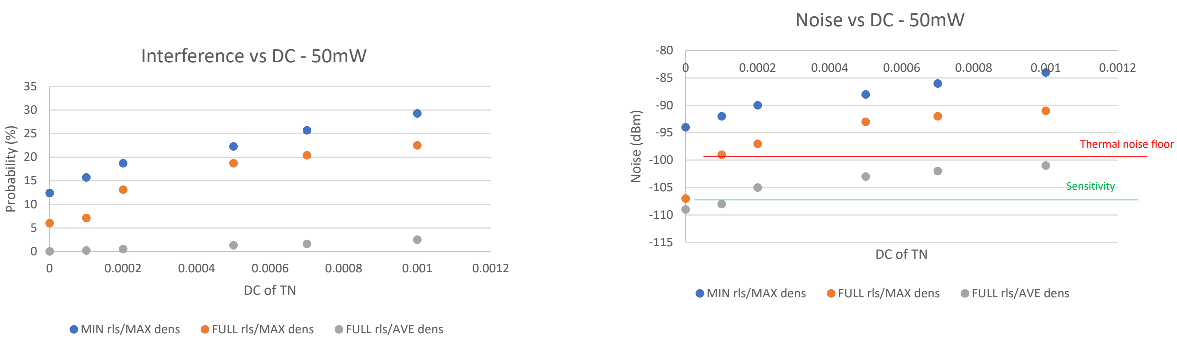


Figure 44: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from 50 mW NBN system versus TN DC into Wideband networked SRD system outdoors

Wideband outdoors vs DC: 500mW

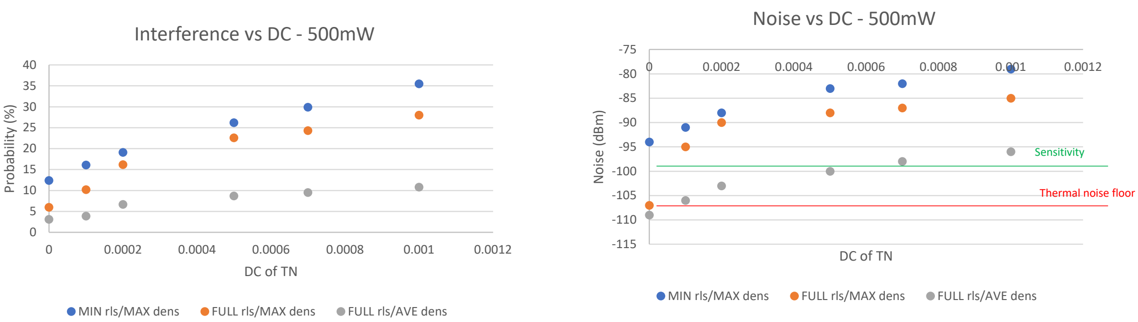


Figure 45: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from 500 mW NBN system versus TN DC into Wideband networked SRD system outdoors

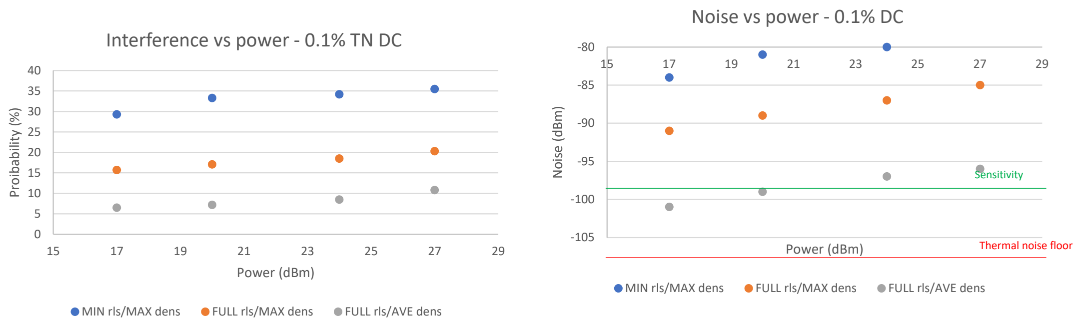


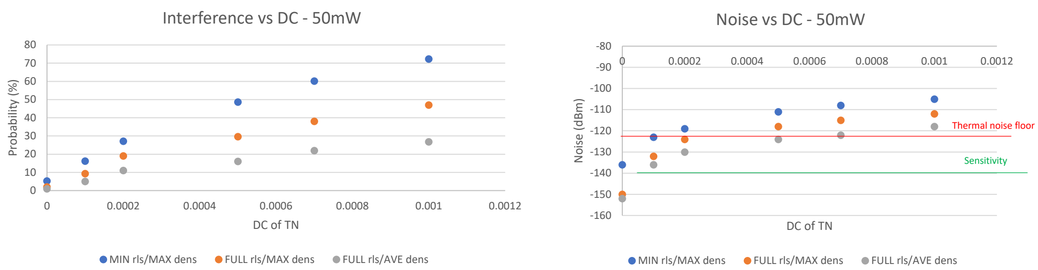
Figure 46: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from NBN system operating with TN DC of 0.1% versus Interfering power (mW) into Wideband networked SRD system outdoors

4.3.3.3 Discussion

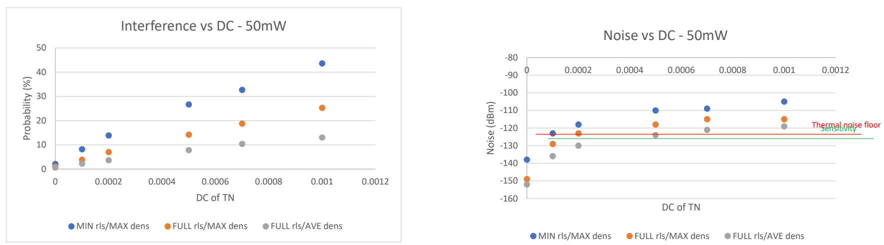
Interference into the Wideband networked system sees levels of interference above 5% in many cases – both indoors and outdoors. However, it can be observed that the reason for such apparently high numbers is the high baseline interference values i.e. even with current regulations these devices are likely to see high interference from other SRDs in the band, presumably because they have a large bandwidth (1 MHz) overlapping with the 500 mW systems operated in the interrogator channels. It should be noted that ECC Report 246 [16] did not consider interference into these devices when considering the feasibility of their operation in this band.

Proportionally, the interference rises for the very worst case by 33% and 36% for indoors and outdoors operation, respectively.

4.3.4 Victim LPWAN CSS NAP



SF12



SF7

Figure 47: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from 50 mW NBN system versus TN DC into LPWAN CSS SF12 and SF7

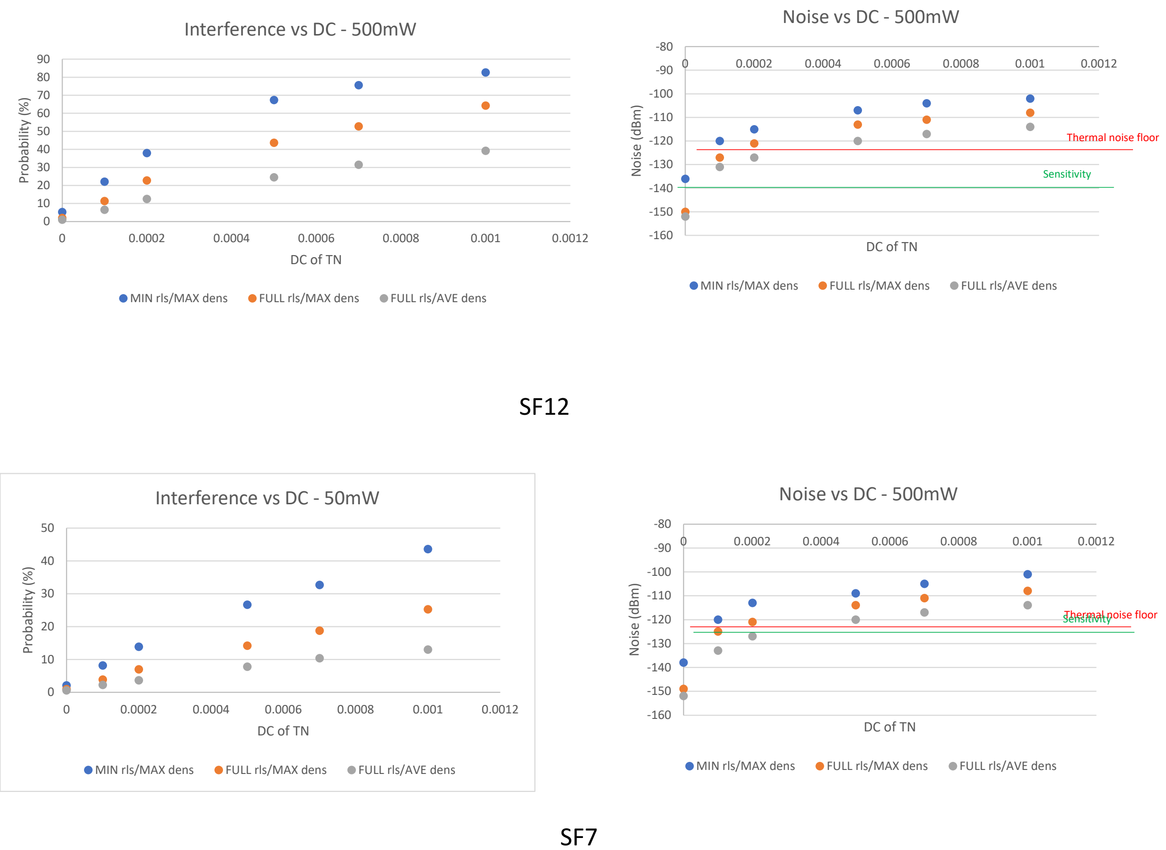
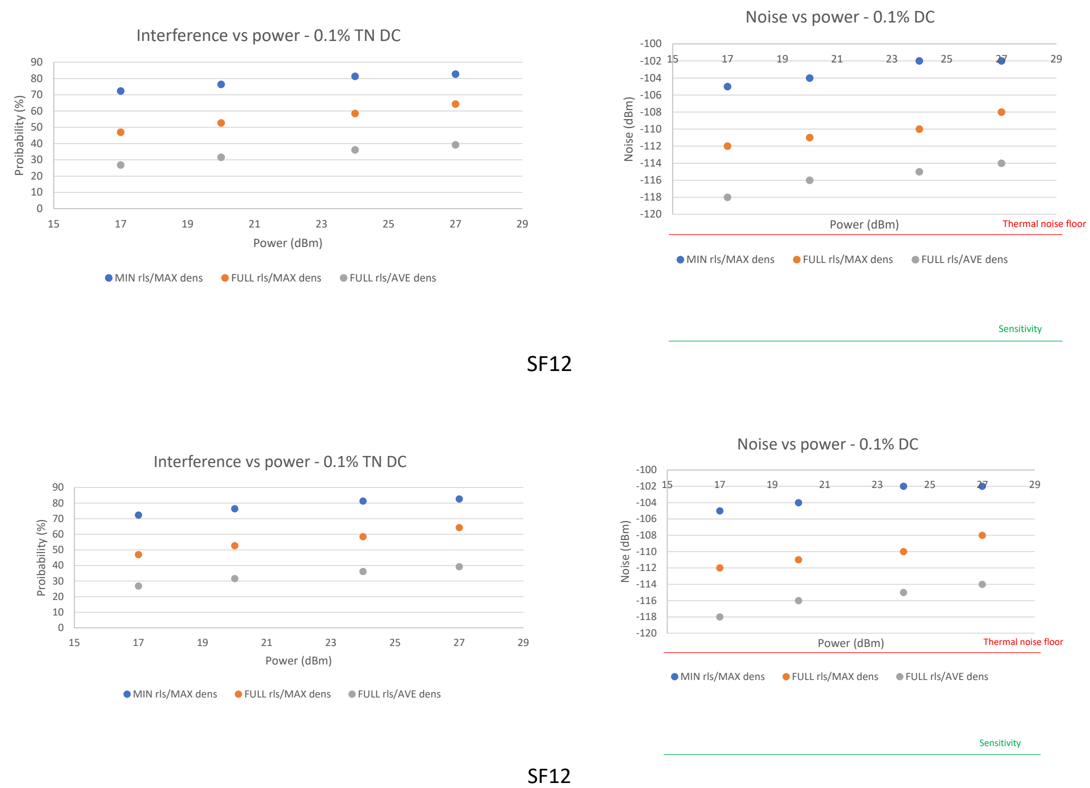
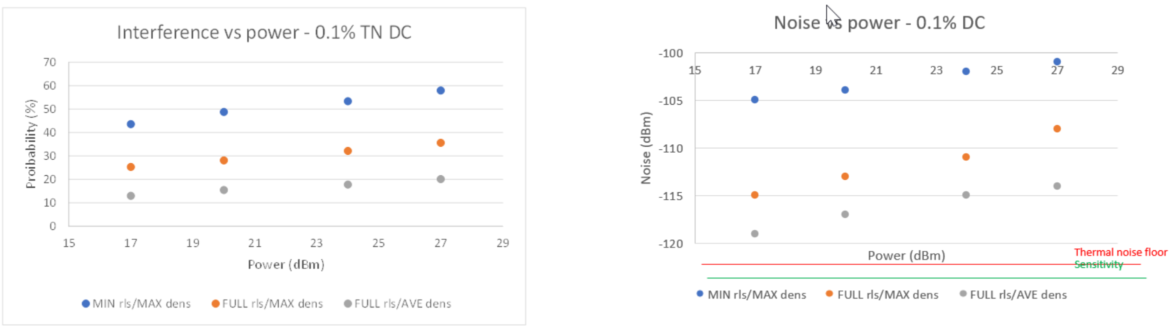


Figure 48: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from 500 mW NBN system versus TN DC into LPWAN CSS SF12 and SF7





SF7

Figure 49: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from NBN system operating with TN DC of 0.1% versus Interfering power (mW) into LPWAN CSS SF12 and SF7

4.3.4.1 Discussion

Interference into the LPWAN CSS system sees significant levels of interference above 5% in many cases – both for the SF7 and SF12 modes. It should be noted that the baseline scenario slightly exceeds the 5 % for SF = 12 configuration in the worse case scenario (5.5%). When new interferers above 25 mW are added co-frequency with LPWAN-CSS, the threshold is exceeded.

4.3.5 Victim LPWAN UNB NAP

UNB vs DC: 50mW

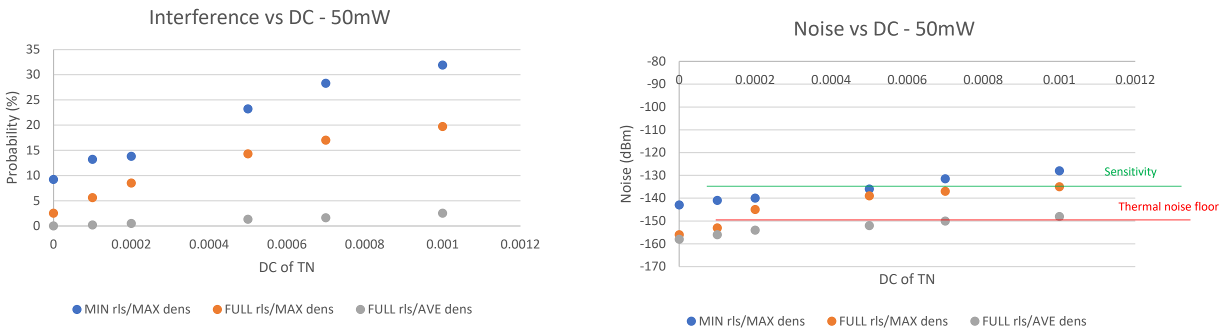


Figure 50: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from 50 mW NBN system versus TN DC into LPWAN UNB

UNB vs DC: 500mW

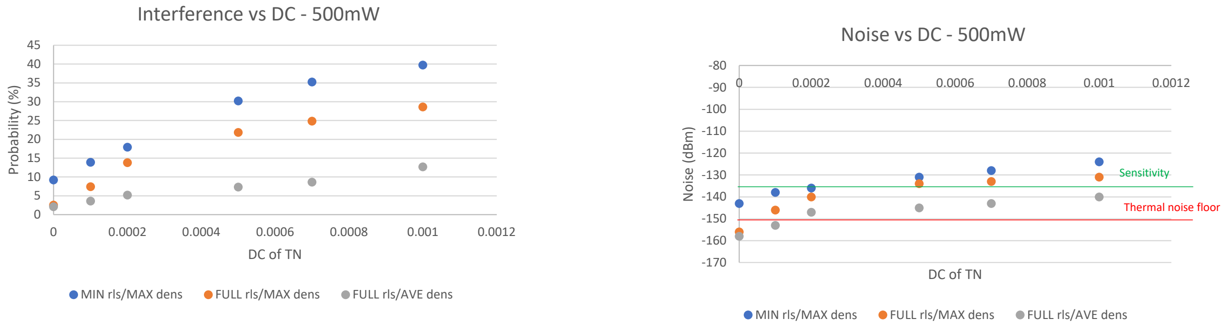


Figure 51: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from 500 mW NBN system versus TN DC into LPWAN UNB

UNB vs power

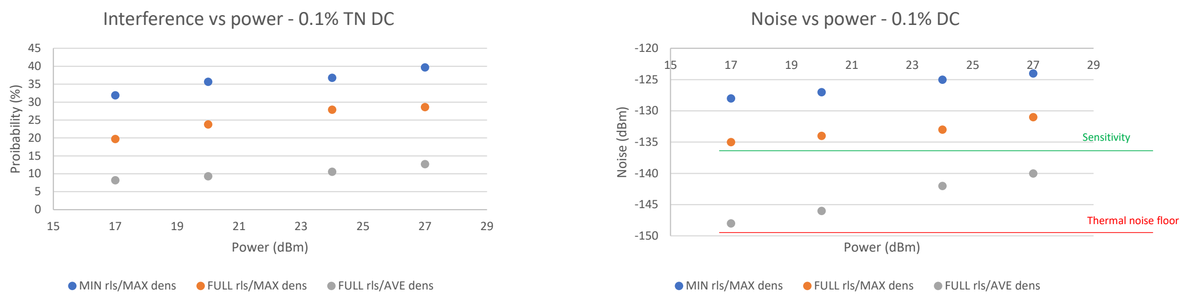


Figure 52: Interference probability and interference power (also showing thermal noise floor and victim sensitivity) from NBN system operating with TN DC of 0.1% versus Interfering power (mW) into LPWAN UNB

4.3.5.1 Discussion

Interference into the generic LPWAN UNB system sees significant levels of interference above 5% in most cases including several baseline scenarios.

The simulations suggest that the links are vulnerable because the attempted links lengths – up to 2 km – is overly ambitious for the system represented by the model.

4.4 SENSITIVITY ANALYSIS

4.4.1 APC parameters

The APC parameters assumed for the simulations have been set conservatively, with the central case Minimum Threshold of Received Signal Strength Indication (RSSI) being set to -80 dBm for a 200 kHz device, compared to typical sensitivities of -95 dBm and a (conservative) reference sensitivity in the relevant harmonised standard, ETSI EN 303 204 [17], of -88 dBm[1].

Using a reference calculation of worst-case interference into RFID assuming maximum devices density, minimum spectrum release and TN DC = 0.1%, the impact of altering the Minimum Threshold RSSI is shown in Table 47.

Table 47: The impact of altering the Minimum Threshold RSSI on interference probability (maximum devices density)

Minimum threshold RSSI (relative to sensitivity)	Interference probability
-75 dBm (+20 dB)	19.3%
-80 dBm (+15 dB)	14.9%
-85 dBm (+10 dB)	9.8%
-90 dBm (+5 dB)	6.4%

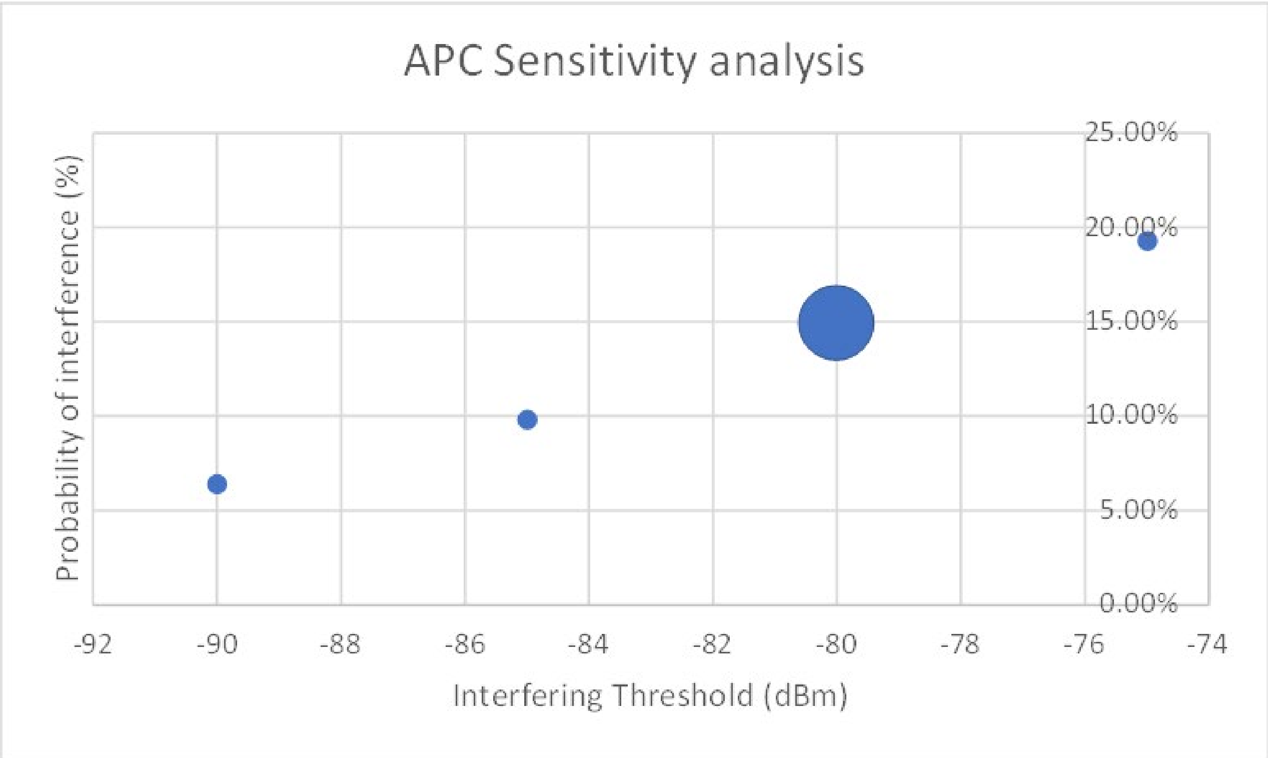


Figure 53: APC sensitivity analysis

Examination of the distribution of interfering transmit power induced by the APC mechanism shows a good distribution of powers.

[1] Assuming a data rate of 100 kbps

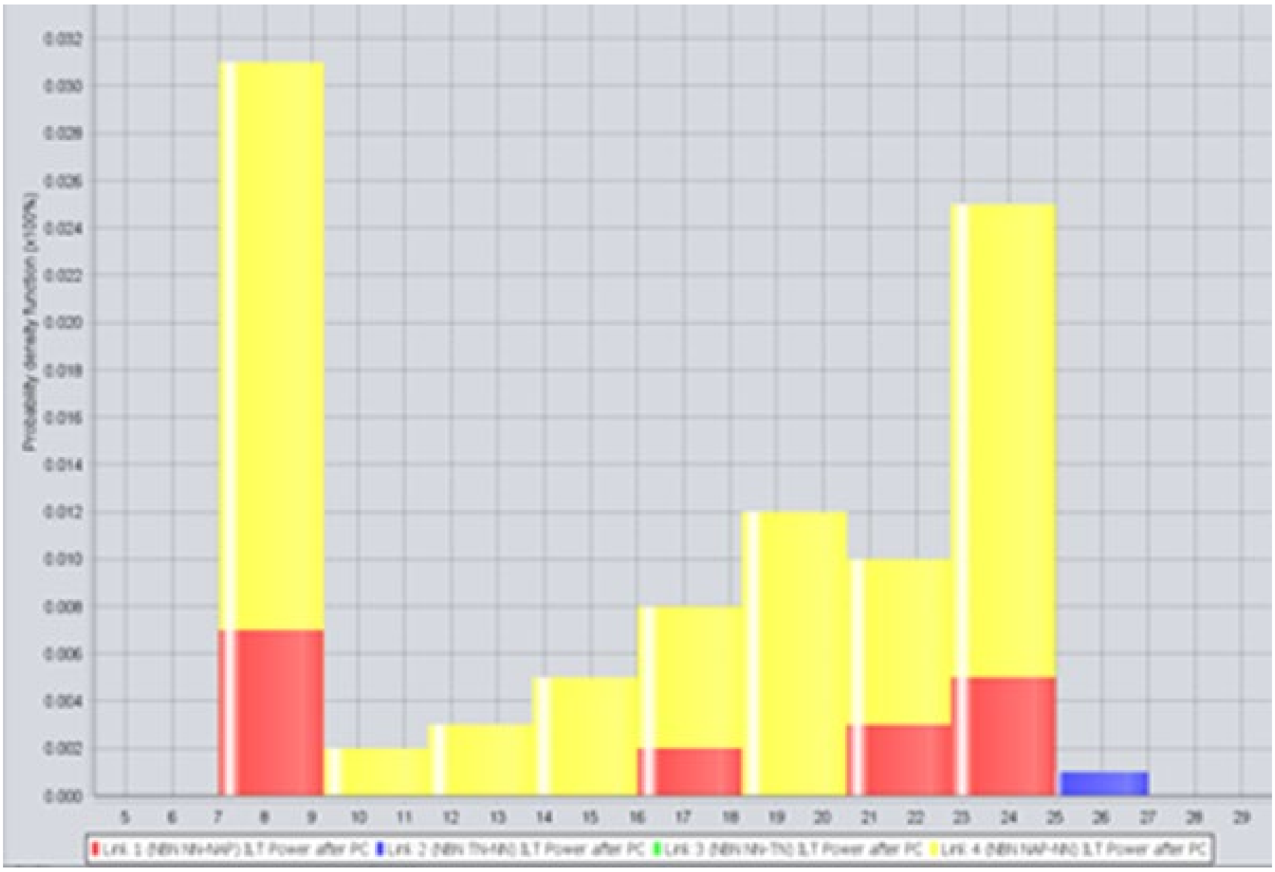


Figure 54: Typical NBN transmit power distribution to the different links

Finally, by altering the assumed sensitivity to be the worst-case allowed by the equivalent standard (EN 303 204): -88 dBm [2], the equivalent values are shown in Table 48.

Table 48: The impact of altering the Minimum Threshold RSSI on interference probability (worst-case)

Minimum threshold RSSI (relative to sensitivity)	Interference probability
-70 dBm (+15 dB)	24.2%
-75 dBm (+10 dB)	19.5%
-80 dBm (+5 dB)	14.7%

[2] assumes an RFID receive bandwidth of 1200 kHz

5 SCENARIO SET B

5.1 DESCRIPTION

This scenario set addresses the new opportunities for high power devices within a so-called baseline scenario approach. It focuses on coexistence studies between four networked SRD systems: RFID, NBN, LPWAN-UNB and LPWAN-CSS. When running SEAMCAT simulations, CSS technology is split into two subsystems: LPWAN-CSS SF7 where spreading factor is set to 7, and LPWAN-CSS SF12 where spreading factor is set to 12.

Scenario B implements RFID, NBN, UNB and CSS system parameters (e.g. Tx power, antenna height, Rx sensitivity, node density) as they are listed in previous section 2. If minimum, average and maximum cases for all the parameters of all technologies are considered, this would give more than one thousand different cases to study. To overcome this amount of work, the baseline scenario approach considers only typical values (i.e. average values as defined in ECC Report 326 [9] for the coexistence studies), and evaluates the impact of new opportunities of high-power devices in the baseline scenario only.

The results are enough to give a hint on how the interference ratios will be increased by new deployments of high-power devices.

5.2 TECHNICAL DETAILS

5.2.1 Spectrum use

The baseline scenario uses typical values for duty cycle and node densities, as defined in ECC Report 326 [9]. The spectrum use for the three networked SRD technologies is assumed as illustrated in Figure 55, Figure 56 and Figure 57. RFID is deployed in the three RFID channels, with equal probability.

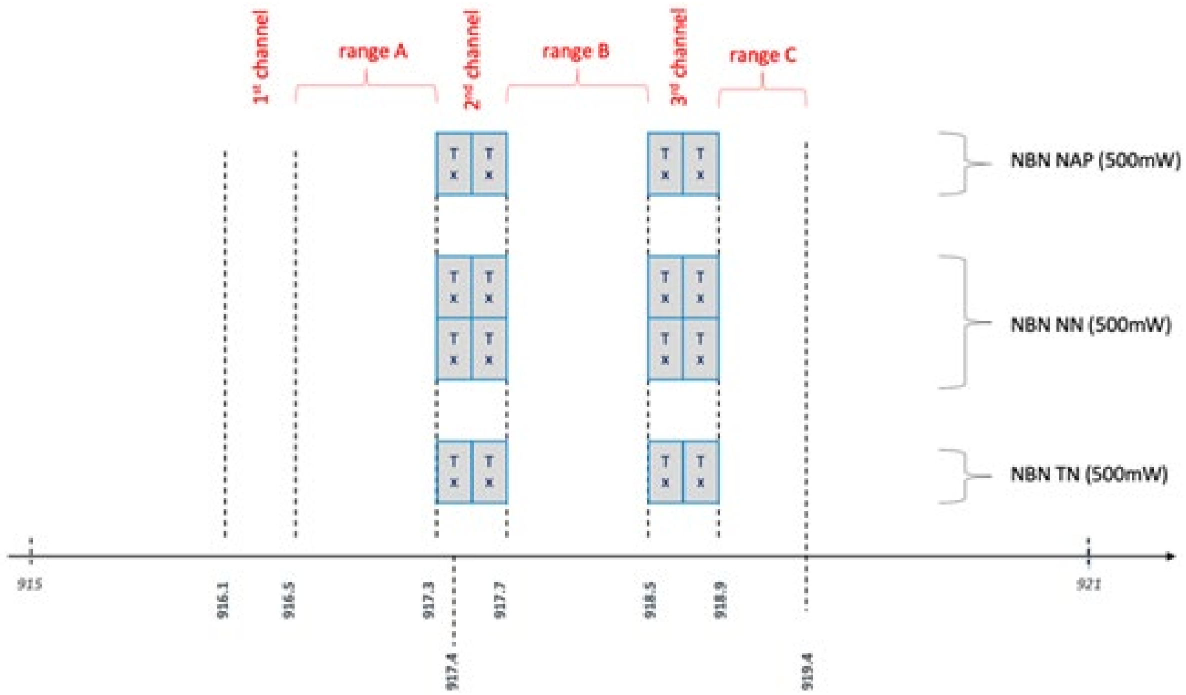


Figure 55: Spectrum use for NBN system in baseline scenario

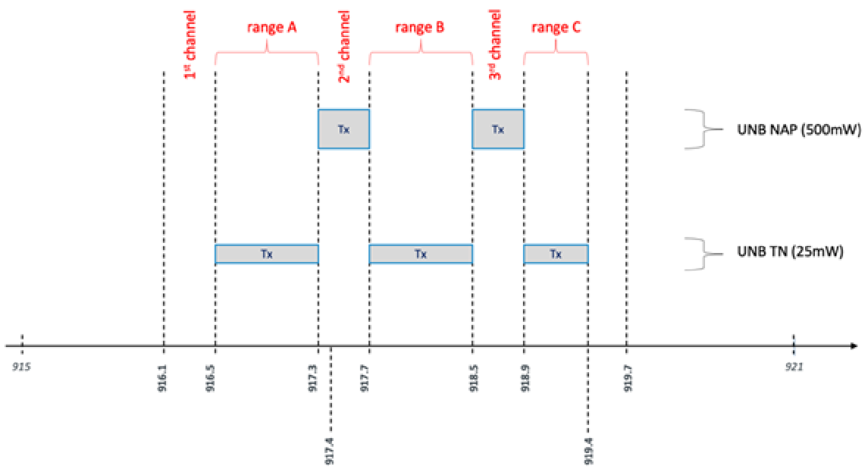


Figure 56: Spectrum use for LPWAN-UNB system in baseline scenario

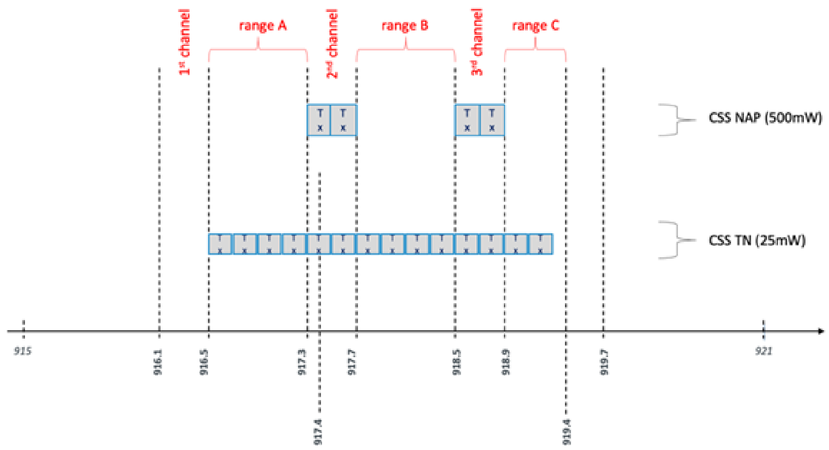


Figure 57: Spectrum use for LPWAN-CSS SF7 and LPWAN-CSS SF12 system in baseline scenario

5.2.2 SEAMCAT configuration parameters

The baseline scenario approach uses SEAMCAT 5.4.2 with two simulation assumptions, as follows.

First assumption is the way interference calculation is made. As NBN, LPWAN-UNB and LPWAN-CSS systems are networks of nodes, the coverage of an area is done by a set of base stations. If a node is simulated out of reach in a SEAMCAT event, there is a very high probability that this node is in touch with another nearby node in a real deployment. Therefore, this 'non-connected' event has not to be included in the interference ratio calculation. This assumption is implemented by checking the tick-box "only victim links with C>sensitivity" in the interference calculation pane of SEAMCAT.

Second assumption is the way NBN NNs are simulated in SEAMCAT. NBN NNs serve as relay between NBN NAPs and NBN TNs. As an NBN system is a structured network, signalling messages (e.g. acknowledgement, frequency allocation, time slot allocation, shutdown command, configuration) are exchanged between nodes, along with application messages. For NBN NNs, it means that part of the Duty cycle is for uplink communications (i.e. from NBN NNs to NBN NAPs) and part is for downlink communications (i.e. from the NBN NNs to NBN TNs). The offered load for downlink communication in a typical NBN deployment is evaluated as follows:

$$number\ of\ TNs\ in\ a\ NN\ coverage\ area\ \ n = \frac{typical\ density\ of\ TNs}{typical\ density\ of\ NNs} = \frac{950}{45} \approx 21.1 \tag{1}$$

$$offered\ load\ in\ uplink\ seen\ by\ a\ single\ NN\ \ L = n \times\ TN\ typical\ Duty\ Cycle = 21.1 \times 0.05\% \approx 1.05\% \quad (2)$$

Assuming that the downlink load of signalling messages is only 10% of the uplink offered load, the split of NN typical duty cycle (i.e. 0.7%) is as follows:

$$NN\ Duty\ Cycle\ for\ donwlink\ communication\ \ DC_{DL} = 10\% \times L \approx 0.1\% \quad (3)$$

$$NN\ Duty\ Cycle\ for\ uplink\ communication\ DC_{UL} = typical\ Duty\ Cycle -\ DC_{DL} = 0.7\% - 0.1\% = 0.6\% \quad (4)$$

In SEAMCAT, this split between uplink and downlink transmission is simulated with the ‘colocation’ function: for each NN node with a 0.6 uplink transmission, an NN with 0.1 downlink transmission is located at the same place.

The NBN receiver blocking mask considered in the simulation is depicted in Figure 58.

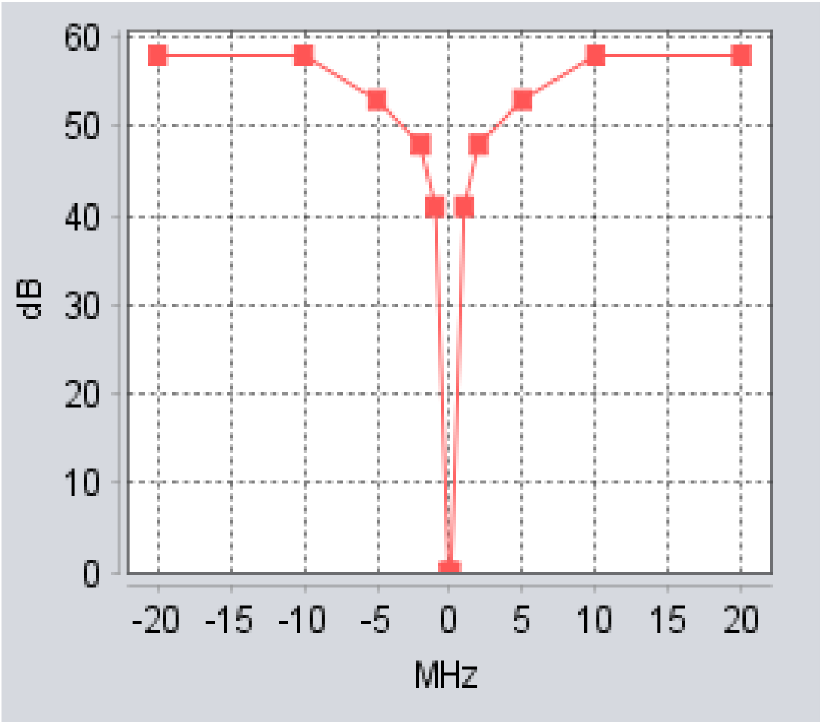


Figure 58: NBN Blocking mask

The blocking mask coefficients are given in Table 49.

Table 49: The coordinates of the points of Figure 58

Frequency Offset (MHz)	±20	±10	±5	±2	±1	±0.1
Mask (dB)	+58	+58	53	48	41	0

5.2.3 Baseline scenario results

Based on the assumptions detailed in the previous section, the interference ratios evaluated with SEAMCAT are summarised in Table 50.

Table 50: Interference ratios of baseline scenario

Scenario			Interferer					
			NBN			UNB	CSS7	CSS12
			NAP→NN	NN→NAP and NN→TN colocated	TN→NN	NAP→TN	NAP→TN	NAP→TN
Victim	NBN	NAP→NN				0.0%	0.0%	0.0%
		NN→TN				0.0%	0.0%	0.0%
		TN→NN				0.0%	0.1%	0.1%
		NN→NAP				0.0%	0.0%	0.0%
	UNB	NAP→TN	1.9%	3.5%	0.6%		1.0%	1.1%
		TN→NAP	6.1%	7.6%	1.7%		0.5%	0.5%
	CSS7	NAP→TN	0.2%	0.8%	0.3%	0.6%		
		TN→NAP	3.6%	10.4%	2.3%	2.1%		
	CSS12	NAP→TN	0.0%	0.2%	0.1%	0.0%		
		TN→NAP	1.0%	4.0%	0.0%	0.1%		
	RFID	TAG→INT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

The interference ratios for the baseline scenario show all values under the 5% threshold, except two cases, that can be analysed as follows:

- UNB-NAPs as victim and NBN-NAPs and NBN-NNs as interferers: LPWAN-UNB-NAP receivers are 25 m height, very sensitive, and with a low deployment density, that gives a low signal to noise ratio for communication from LPWAN-UNB-TNs. That's why LPWAN-UNB-NAPs are interfered by NBN-NAPs and NBN-NNs
- LPWAN-CSS SF7 NAPs as victim and NBN-NNs as interferers: LPWAN-CSS NAP receivers are 25 m height, very sensitive, and implement four of their twelve channels within the second and third RFID interrogators channels, where the NBN-NNs operate. That's why LPWAN-CSS SF7 NAPs are interfered by NBN-NNs.

5.3 NEW OPPORTUNITY RESULTS

5.3.1 New opportunity assumptions

The baseline scenario studies various cases, where interference can be in the same frequency range (i.e. from co-channel) or in different frequency ranges (i.e. from out-of-band and spurious).

To overcome this issue, the present scenario uses the new opportunity of high-power devices segmentation between high-power and low-power devices: range A (915-919.4 MHz). and the second RFID interrogator channel for high-power devices and range B (917.7-918.5 MHz) and C (918.9-919.4 MHz) for low-power devices. NAPs remaining in the second and the third RFID interrogator channels. Figure 59 illustrates how the NBN, LPWAN-UNB and LPWAN-CSS technologies may implement this segmentation new opportunity.

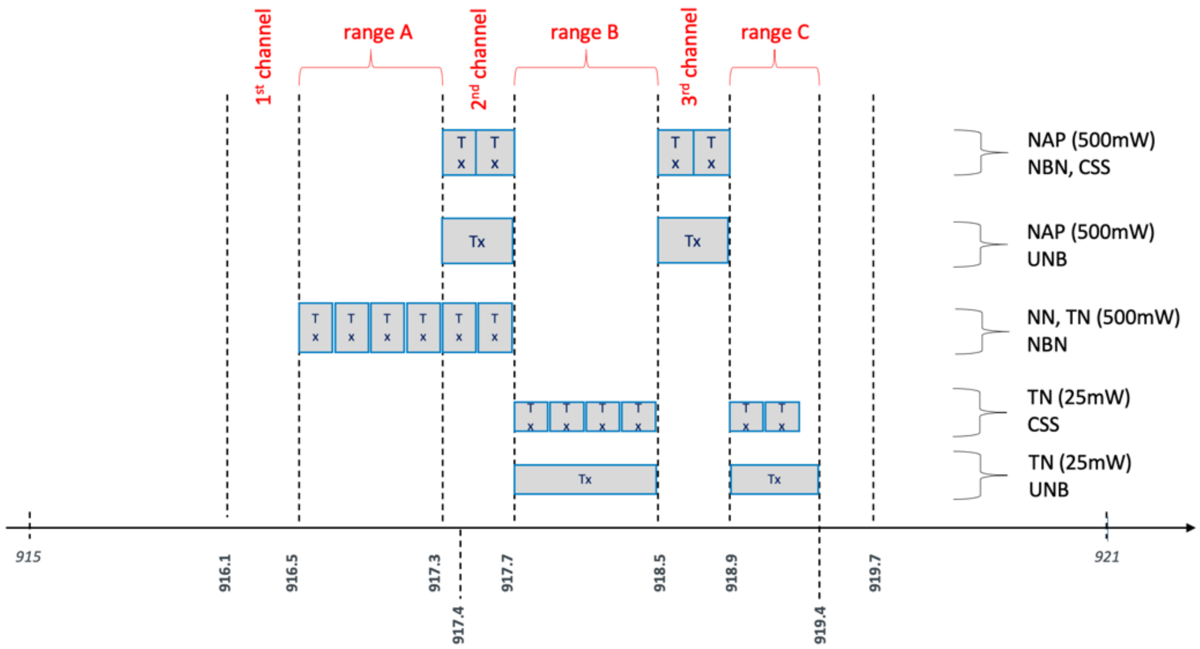


Figure 59: Frequency use of transmitters for NBN, LPWAN-UNB and LPWAN-CSS systems

5.3.2 New opportunity results

The new opportunity coexistence scenarios use the spectrum as detailed in section 5.3.1. New results are given in Table 51 only for cases where there is a change baseline interference ratios problematic. Other cases would exhibit lower interference ratios anyhow.

Table 51: Interference ratio for new opportunity scenario set B

Scenario			Interferer					
			NBN			UNB	CSS7	CSS12
			NAP→NN	NN→NAP and NN→TN collocated	TN→NN	NAP→TN	NAP→TN	NAP→TN
Victim	NBN	NAP→NN						
		NN→TN						
		TN→NN						
		NN→NAP						
	UNB	NAP→TN						
		TN→NAP	6.7%	6.0%				
	CSS7	NAP→TN				0.0%		
		TN→NAP		0.5%		0.4%		
	CSS12	NAP→TN						
		TN→NAP						
	RFID	TAG→INT	0.0%	3.2%	1.0%			

Compared to the baseline scenario, these new results demonstrate that the segmentation of high-power devices and low-power devices give lower interference probability for LPWAN-CSS SF7.

It is not enough to overcome the interference level generated by high-power devices on LPWAN-UNB NAPs. The LPWAN-UNB technology allows deployment with a low density of NAPs compared to the two other technologies considered in this study. But LPWAN-UNB networks can't fully benefit from this characteristic, since the only way forward is to increase the density of LPWAN-UNB NAPs. Table 52 shows the interference ratio for critical cases, where LPWAN-UNB NAP density is increased from the typical value of 0.01 NAP/km^2 to 0.05 NAP/km^2.

Results for RFID interrogator receivers show an increase in the interference ratio, which is due to in-band interferers that were not present in the baseline scenario.

Table 52: Interference ratio for new opportunity scenario set B with LPWAN-UNB NAP density increased

Scenario			Interferer					
			NBN			UNB	CSS7	CSS12
			NAP→NN	NN→NAP and NN→TN collocated	TN→NN	NAP→TN	NAP→TN	NAP→TN
Victim	NBN	NAP→NN				0.0%	0.0%	0.0%
		NN→TN				0.0%	0.0%	0.0%
		TN→NN				0.0%	0.1%	0.1%
		NN→NAP				0.0%	0.0%	0.0%
	UNB	NAP→TN	1.9%	3.5%	0.6%		1.0%	1.1%
		TN→NAP	3.7%	3.5%	1.7%		0.5%	0.5%
	CSS7	NAP→TN	0.2%	0.8%	0.3%	0.0%		
		TN→NAP	3.6%	0.5%	2.3%	0.4%		
	CSS12	NAP→TN	0.0%	0.2%	0.1%	0.0%		
		TN→NAP	1.0%	4.0%	0.0%	0.1%		
	RFID	TAG→INT	0.0%	3.2%	1.0%	0.0%	0.0%	0.0%

5.3.3 Discussion

Interference results show that the coexistence of NBN, LPWAN-CSS and LPWAN-UNB systems is difficult to achieve, even with typical values for node density and duty cycle. Segmentation of high-power devices and low-power devices in different frequency bands give better results (i.e. less interference ratio), but not for LPWAN-UNB systems that can operate at very low reception levels. LPWAN-UNB systems suffer less interference when LPWAN-UNB NAP density is significantly increased (from 0.01 to 0.05).

6 SCENARIO SET C

6.1 DESCRIPTION

This scenario considers the deployment of NAP in range B as described in Figure 60.

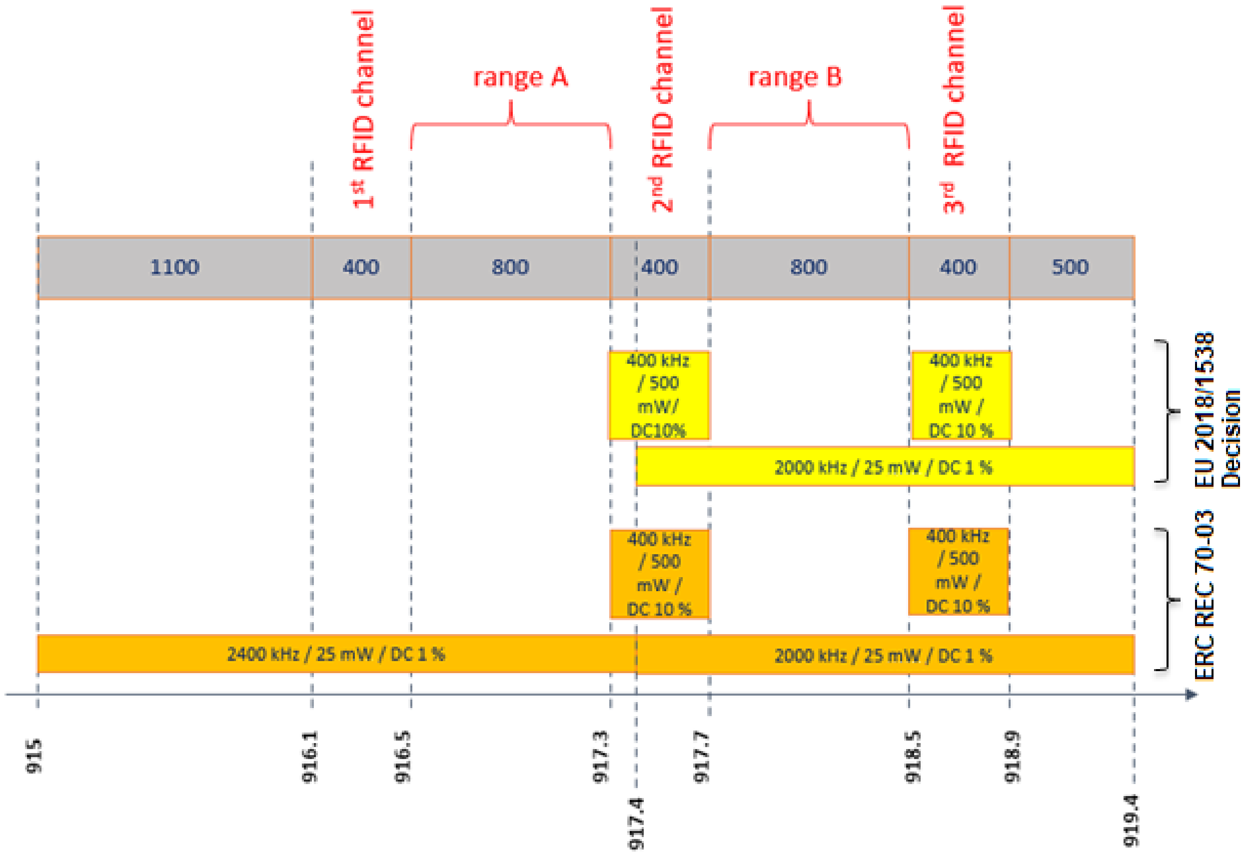


Figure 60: Overview of the scenario for NAP

The simulations assume that NAPs are deployed in range B where four channels of 200 kHz are possibly available.

The simulations consider the impact of NAP on the devices possibly deployed in ranges overlapping with range B. The scenarios considered in this study are presented in Table 53.

Table 53: The scenarios considered in scenario set C

Interferer	Victims	
NAP (NBN)	UNB NAP to TN (scenario C-6)	TN LPWAN-CSS NAP to TN (scenario C-6)
	UNB TN (25 mW) to NAP (scenario C-7)	LPWAN-CSS TN (25 mW) to NAP (scenario C-9)
NAP (LPWAN-UNB)	LPWAN-CSS NAP to TN (scenario C-6)	NBN NAP (500 mW) to NN (scenario C-8)
	LPWAN-CSS TN (25 m - 5 mW) to NAP (scenario C-9)	
NAP (LPWAN-CSS)	LPWAN-UNB NAP (500 mW) to TN (scenario C-7)	NBN NAP (500 mW) to NN (scenario C-8)
	LPWAN-UNB TN (25 mW) to NAP (scenario C-7)	
NAP (all technologies)	RFID receiver (scenario C-1)	
	25 mW Wide band indoor (scenario C-4)	25 mW Wide band outdoor (scenario C-5)
	25 mW SRD indoor (scenario C-2)	25 mW SRD outdoor (scenario C-3)

In some cases, when the probability of interference is above 5%, additional steps are considered in term of duty cycle (1%, 2.5%). Also some simulations were run with 25 mW e.r.p. and without the Power Control activated, which corresponds to the current regulations.

6.2 TECHNICAL DETAILS

6.2.1 LPWAN-CSS NAP characteristics

For LPWAN-CSS NAP, the considered distribution of frequencies is illustrated in Figure 61 and Figure 62.

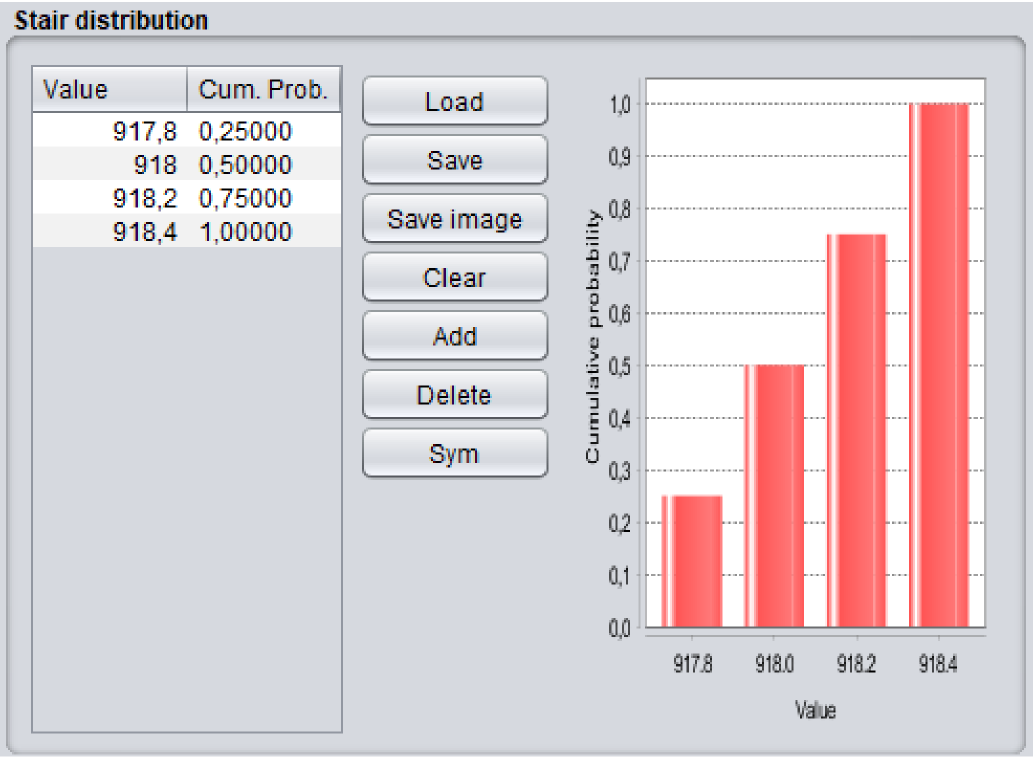


Figure 61: Frequency distribution for LPWAN-CSS NAP / NBN NAP

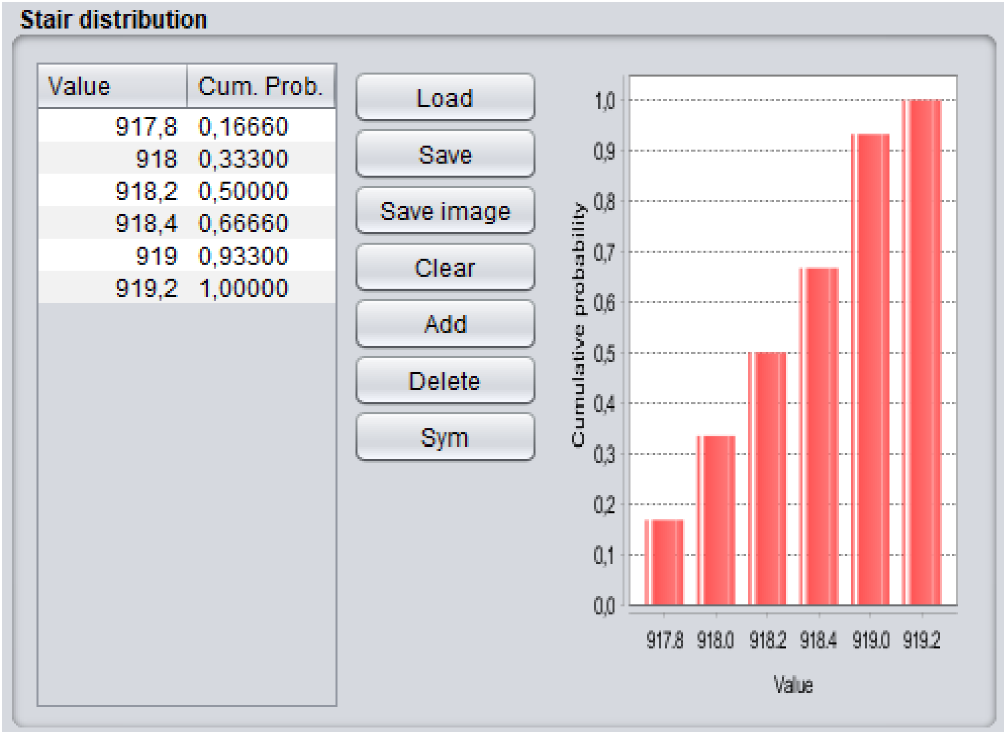


Figure 62: Frequency distribution for LPWAN-CSS NAP

6.2.2 UNB NAP characteristics

For LPWAN-UNB NAP, the considered distribution of frequencies is illustrated in Figure 63.

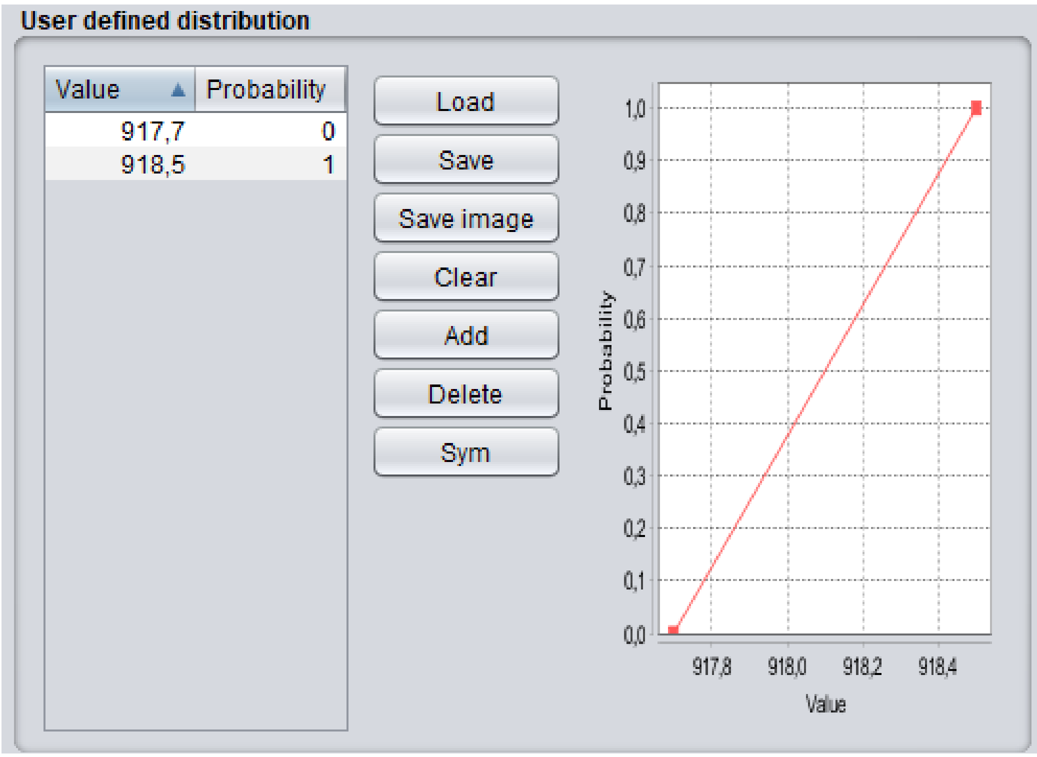


Figure 63: LPWAN-UNB NAP distribution of frequencies

6.2.3 UNB TN characteristics

For LPWAN-UNB TN, the considered distribution of frequencies is illustrated in Figure 64.

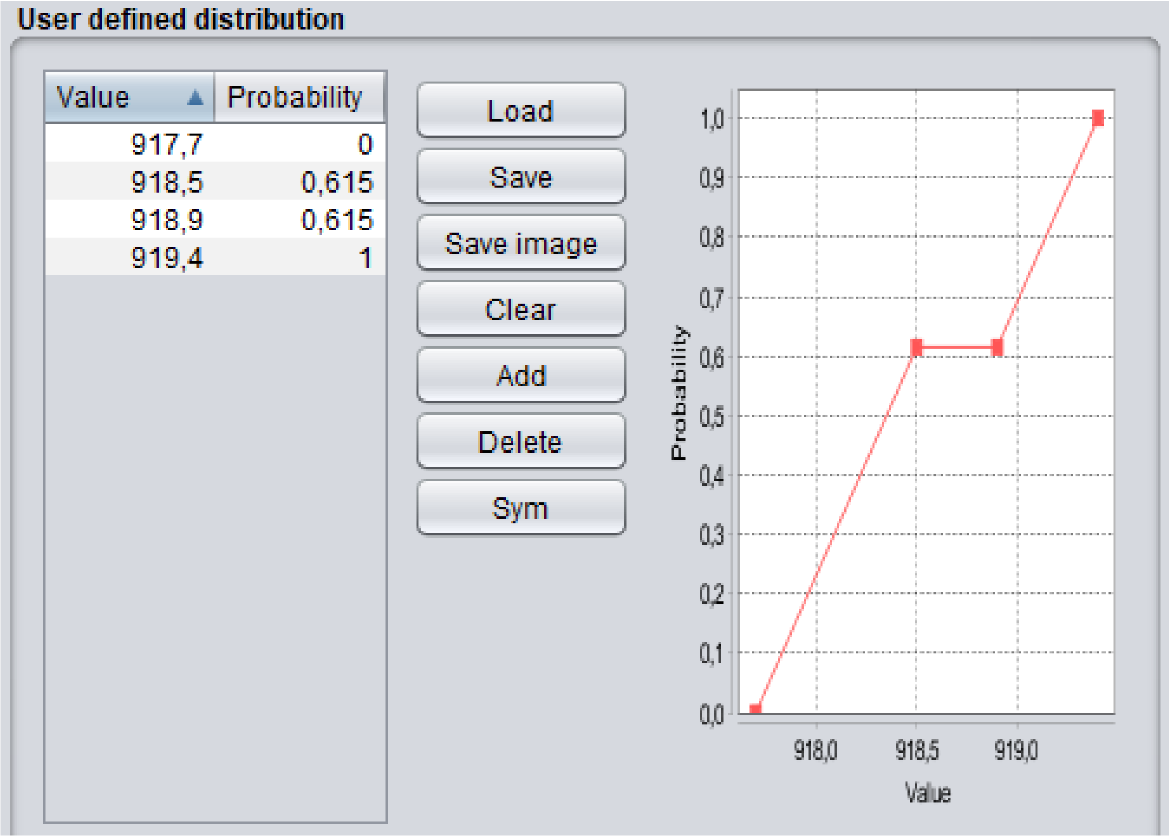


Figure 64: LPWAN-UNB TN distribution of frequencies

6.2.4 Victim links characteristics

- **25 mWGeneric SRDs indoor/outdoor**

The parameters for 25 mW SRDs used in this scenario can be found in Table 38. The frequency band considered in the simulations is 917.875 - 918.325 MHz. and the blocking mask is illustrated in Figure 19.

- **25 mW Wide Band SRDs indoor/outdoor**

The parameters for 25 mW Wide Band SRDs used in this scenario, can be found in Table 40. In the simulations three discrete channels centered at 916.6 MHz, 917.6 MHz and 918.6 MHz are considered and the blocking mask is illustrated in Figure 20.

- **NBN receiver blocking mask**

The NBN receiver blocking mask considered is depicted in Figure 65.

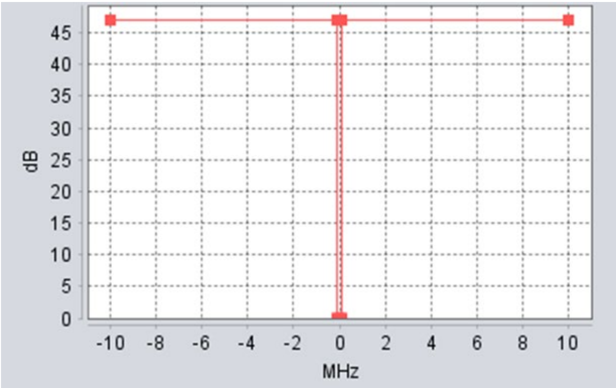


Figure 65: Blocking mask

The blocking mask coefficients are given in Table 54.

Table 54: The coordinates of the points of Figure 65

Frequency Offset (MHz)	±10	±0.101	±0.1	0
Mask (dB)	+47	+47	0	0

6.2.5 Simulations characteristics

In the simulations for the end devices, it is assumed that 75 % are deployed outdoor and 25% are deployed indoor for each of the Network SRDs technology.

Simulations are run using the uniform density mode.

As a first step, simulations are based on the typical densities given in ECC Report 326 [9] for NAP.

Table 55: Densities of NAP (see ECC Report 326)

Node	Typical density per km^2	Maximum density per km^2
UNB NAP	0.01	0.1
CSS NAP	0.5	3.5
NBN NAP	5	10

The approach given in 3.2 on coverage and simulation radius is considered for the star networks (LPWAN-CSS and LPWAN-UNB) to determine the coverage radius of the corresponding networks and presented in Table 56 for a typical density and in Table 57 for maximum density.

Table 56: Coverage radius for NAPs assuming the star network – typical density

Node	Typical density per km^2	Coverage radius (km)
UNB NAP	0.01	6.2
CSS NAP	0.5	0.877
NBN NAP	5	0.277

Table 57: Coverage radius for NAPs assuming the star network – maximum density

Node	Maximum density per km^2	Coverage radius (km)
UNB NAP	0.1	1.96
CSS NAP	3.5	0.33
NBN NAP	10	0.20

6.3 NEW OPPORTUNITY RESULTS

Results are provided in term of interference probability calculated using SEAMCAT.

6.3.1 Interferer LPWAN-CSS SF7 Noise Factor 7 dB

Table 58: Interference probability results for RFID (scenario C-1)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	0.5	0.7
	250	0.1	0.6
	100	0.1	0.6
Maximum	500	0.5	2.7
	250	0.4	2
	100	0.3	1.5

Table 59: Interference probability results for SRD indoor (scenario C-2)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	0.5	2.2
	250	0.5	2.1
	100	0.4	1.8
Maximum	500	1.7	6.9
	250	1.3	5.6
	100	1.1	4.4

Table 60: Interference probability results for SRD outdoor (scenario C-3)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	0.6	2.4
	250	0.5	2.1
	100	0.5	1.9
Maximum	500	2.3	7.7
	250	2	6.4
	100	1.5	5.3

Table 61: Interference probability results for Wideband SRD indoor (scenario C-4)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	0.3	1.4
	250	0.2	1.3
	100	0.2	1.0
Maximum	500	1	4.6
	250	0.8	3.7
	100	0.6	2.8

Table 62: Interference probability results for Wideband SRD outdoor (scenario C-5)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	0.2	0.7
	250	0.2	0.7
	100	0.1	0.6
Maximum	500	1.8	6.1
	250	1.5	5.2
	100	1.2	4.2

Table 63: Interference probability results for LPWAN-UNB NAP (500 mW) to TN (scenario C-6)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	0	0.1
Maximum	100	0.1	0.4

Table 64: Interference probability results for LPWAN-UNB TN (25 mW) to NAP (scenario C-7)

Scenario	e.r.p. (mW)	Duty Cycle (%)			
		1	2.5	10	50
Typical	500	22	24	34	46
	100	16	16.4	31	42
	25	13.7	18	26	37.4
Maximum	500	24	30.4	40	52
	100	17.3	22.8	32	43
	25	13.7	18	26.1	37.4

Table 65: Comparison with NAP interferer at 25 mW without the Power control

Scenario	e.r.p. (mW)	Duty Cycle (%)			
		1	2.5	10	50
Typical	500	22	24	34	46
	100	16	16.4	31	42
	25	31.8			
Maximum	500	24	30.4	40	52
	100	17.3	22.8	32	43
	25	38.3			

Table 66: Interference probability results for LPWAN-UNB TN (500 mW) to NAP (scenario C-7)

Scenario	e.r.p. (mW)	Duty Cycle (%)			
		1	2.5	10	50
Typical	500	3.7	5.5	9	16
Maximum	500	8	12.2	20	31

Table 67: Interference probability results for NBN NAP (500 mW) to NN (scenario C-8)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	0.5	2.1
Maximum	500	0.1	0.6

6.3.2 Interferer NAP LPWAN-UNB 500 mW

Table 68: Interference probability results for RFID (scenario C-1)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	0	0,1
Maximum	500	0	0.2

Table 69: Interference probability results for SRD indoor (scenario C-2)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	0.1	0.3
Maximum	500	0.1	0.5

Table 70: Interference probability results for SRD outdoor (scenario C-3)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	0	0.1
Maximum	500	0.3	0.5

Table 71: Interference probability results for Wide SRD indoor (scenario C-4)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	0	0.2
Maximum	500	0.1	0.5

Table 72: Interference probability results for Wide SRD outdoor (scenario C-5)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	0.1	0.4
Maximum	500	0.3	1.1

Table 73: Interference probability results for NAP LPWAN-CSS (500 mW) to TN SF7 (scenario C-6)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	0	0.1
Maximum	500	0.1	0.3

Table 74: Interference probability results for NAP LPWAN-CSS (500 mW) to TN SF12 (scenario C-6)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	0	0
Maximum	500	0	0.1

Table 75: Interference probability results for NBN NAP (500 mW) to NN (scenario C-8)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	0	0.1
Maximum	500	0	0.2

Table 76: Interference probability results for LPWAN-CSS TN (25 mW) to NAP SF7 (scenario C-9)

Scenario	e.r.p. (mW)	Duty Cycle (%)			
		1	2.5	10	50
Typical	500	9	11.2	16	22
	100	6.2	8.5	12.6	18.3
	25	4.2	5.8	9.3	14.2
Maximum	500	9	11.9	16	22
	100	7.7	10.1	14.4	19.9
	25	6.4	8.6	12.7	18

Table 77: Interference probability results for 25 mW without power control

Scenario	e.r.p. (mW)	Duty Cycle (%)			
		1	2.5	10	50
Typical	500	9	11.2	16	22
	100	6.2	8.5	12.6	18.3
	25	6.7			
Maximum	500	9	11.9	16	22
	100	7.7	10.1	14.4	19.9
	25	10.5			

Table 78: Interference probability results for LPWAN-CSS (500 mW) to NAP SF7 (scenario C-9)

Scenario	e.r.p. (mW)	Duty Cycle (%)			
		1	2.5	10	50
Typical	500	3.1	5.8	7.2	12
Maximum	500	3.4	5.9	7.3	12

Table 79: Interference probability results for LPWAN-CSS TN (25 mW) to NAP SF12 (scenario C-9)

Scenario	e.r.p. (mW)	Duty Cycle (%)			
		1	2.5	10	50
Typical	500	2.8	4.5	6.9	11
	25	0.9	2.6	2.7	5.4
Maximum	500	2.9	4.5	6.9	11
	25	1.7	2.7	4.6	8.2

Table 80: Interference probability results for 25 mW without power control

Scenario	e.r.p. (mW)	Duty Cycle (%)			
		1	2.5	10	50
Typical	500	2.8	4.5	6.9	11
	25	6.2			
Maximum	500	2.9	4.5	6.9	11
	25	6.3			

Table 81: Interference probability results for LPWAN (500 mW) to NAP SF12 (scenario C-9)

Scenario	e.r.p. (mW)	Duty Cycle (%)		
		1	10	50
Typical	500	0.7	2.1	4
Maximum	500	0.7	2.2	4.2

6.3.3 Interferer NBN (500 mW)

Table 82: Interference probability results for RFID (scenario C-1)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	4.4	16
Maximum	500	5.2	21

Table 83: Interference probability results for SRD indoor (scenario C-2)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	6.1	16
Maximum	500	7.7	23.6

Table 84 provides results of simulations considering two different propagation models on the SRD path in order to show the impact of this parameter on the results.

Table 84: Interference probability results for SRD outdoor (scenario C-3)

Scenario	e.r.p. (mW)	Duty Cycle (%)		Notes
		10	50	
Typical	500	7	20.1	Extended Hata SRD on SRD path
		1.1	5.2	Plugin model on SRD path
Maximum	500	8.6	24.4	Extended Hata SRD on SRD path
		1.4	6.9	Plugin model on SRD path

Table 85: Interference probability results for Wideband SRD indoor (scenario C-4)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	4.5	16.1
Maximum	500	5.8	19.5

Table 86 provides results of simulations considering two different propagation models on the SRD path in order to show the impact of this parameter on the results.

Table 86: Interference probability results for Wideband SRD outdoor (scenario C-5)

Scenario	e.r.p. (mW)	Duty Cycle (%)		Notes
		10	50	
Typical	500	5.94	17.4.	Extended Hata SRD on SRD path
		1	4.7	Plugin model on SRD path
Maximum	500	7.3	20.5	Extended Hata SRD on SRD path
		1.2	6	Plugin model on SRD path

Table 87: Interference probability results for LPWAN-CSS NAP (500 mW) to TN SF 7 (scenario C-6)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	1.1	2
Maximum	500	1.4	6

Table 88: Interference probability results for LPWAN-CSS NAP (500 mW) to TN SF 12 (scenario C-6)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	0.3	1.4
Maximum	500	0.4	1.8

Table 89: Interference probability results for LPWAN-UNB NAP (500 mW) to TN (scenario C-6)

Scenario	e.r.p. (mW)	Duty Cycle (%)	
		10	50
Typical	500	1	4.5
Maximum	500	1.2	5.5

Table 90: Interference probability results for LPWAN-UNB TN (25 mW) to NAP (scenario C-7)

Scenario	e.r.p. (mW)	Duty Cycle (%)			
		1	2.5	10	50
Typical	500	8	15.6	28.5	49
	100	6.8	12.4	25.1	45.6
	25	4.7	9.1	20.1	39.3
Maximum	500	8.8	14.2	30	49
	100	7.4	13.2	26.7	47.7
	25	6.1	11.5	23.8	44.3

Table 91: Interference probability results for 25 mW without Power Control

Scenario	e.r.p. (mW)	Duty Cycle (%)			
		1	2.5	10	50
Typical	500	8	15.6	28.5	49
	100	6.8	12.4	25.1	45.6
	25	27.5			
Maximum	500	8.8	14.2	30	49
	100	7.4	13.2	26.7	47.7
	25	36.2			

Table 92: Interference probability results for LPWAN-UNB TN (500 mW) to NAP (scenario C-7)

Scenario	e.r.p. (mW)	Duty Cycle (%)			
		1	2.5	10	50
Typical	500	2.2	4.5	12	27.6
Maximum	500	2.4	5	13	29.7

Table 93: Interference probability results for LPWAN-CSS TN (25 mW) to NAP SF7 (scenario C-9)

Scenario	e.r.p. (mW)	Duty Cycle (%)			
		1	2.5	10	50
Typical	500	5.3	8.5	15.4	27.8
	100	3	7.9	15.8	27.7
	25	2.9			
Maximum	500	5.6	9.	17.2	29.7
	100	4.7	8	17	27.1
	25	3.8			

Table 94: Interference probability results for 25 mW without Power Control

Scenario	e.r.p. (mW)	Duty Cycle (%)			
		1	2.5	10	50
Typical	500	5.3	8.5	15.4	27.8
	100	3	7.9	15.8	27.7
	25	2.9			
Maximum	500	5.6	9.4	17.2	29.7
	100	4.7	8	17	27.1
	25	7.3			

Table 95: Interference probability results for LPWAN-CSS TN (500 mW) to NAP SF7 (scenario C-9)

Scenario	e.r.p. (mW)	Duty Cycle (%)			
		1	2.5	10	50
Typical	500	1.5	2.9	7	15.3
Maximum	500	1.8	3.2	7.5	16.5

Table 96: Interference probability results for LPWAN-CSS TN (500 mW) to NAP SF7 (scenario C-9)

Scenario	e.r.p. (mW)	Duty Cycle (%)		
		1	10	50
Typical	500	2	7	11.2
Maximum	500	2	7.1	15.8

Table 97: Interference probability results for LPWAN-CSS TN (500 mW) to NAP SF12 (scenario C-9)

Scenario	e.r.p. (mW)	Duty Cycle (%)			
		1	2.5	10	50
Typical	500	0.3	0.9	2.2	6.3
Maximum	500	0.5	0.9	2.6	7

6.4 DISCUSSION

This section considers the case of NAP interferers operated up to 500 mW.

For interferer UNB NAPs operated at 500 mW and a Duty Cycle of 10% as well as 50%, a low level of interference is found for the following victims: RFID, SRD indoor, SRD outdoor, wideband indoor, wideband outdoor.

For interferer NBN NAPs operated at 500 mW and a Duty Cycle of 10% as well as 50% in maximum density, the interference probability can exceed 5% for the following victims: SRD indoor, SRD outdoor, wideband indoor, wideband outdoor, RFID.

For interferer CSS NAPs operated at 25mW and 500 mW and a Duty Cycle of 50% in maximum density, the interference probability can exceed 5% for the following victims: SRD indoor, SRD outdoor, wideband indoor. The main issue is the compatibility between NAP transmitting and NAP receiving from different technologies deployed in the same area where the corresponding TN transmitter is operated at 25 mW. Current practical deployment guidance is to avoid this situation by separating 500 mW high power transmitters and receiver of 25 mW TN by frequency. This suggests segmentation of the band into high power and low power ranges.

Simulations were carried out with the Power Control for the 500 mW and 100 mW NAP interferer cases and without power control for the 25 mW NAP interferer case, corresponding to the current regulations for comparison. The results given in the following table show that APC reduces the interference resulting from NAP operated at power higher than 25 mW.

Table 98: Interference probability from NAP (NBN, LPWAN-UNB and LPWAN-CSS) (500 mW)

Scenario	Interferer	LPWAN-CSS (NAP)		UNB (NAP)		NBN (NAP)		NBN (NAP)	
	Victim	UNB (NAP)		LPWAN-CSS (NAP – SF7)		UNB (NAP)		LPWAN-CSS (NAP – SF7)	
	e.r.p. (mW)	Duty Cycle (%)		Duty Cycle (%)		Duty Cycle (%)		Duty Cycle (%)	
		1	2.5	1	2.5	1	2.5	1	2.5
Typical density	500	22	24	9	11.2	8	15.6	5.3	8.5
	100	16	16.4	6.2	8.5	6.8	12.4	3	7.9
	25 (Note 1)	31.8		6.7		27.5		2.9	
Maximum density	500	24	30.4	9	11.9	8.8	14.2	5.6	9.4
	100	17.3	22.8	7.7	10.1	7.4	13.2	4.7	8
	25 (Note 1)	38.3		10.5		36.2		7.3	
Note 1: No power control									

7 SCENARIO SET D

7.1 DESCRIPTION

This section investigates the potential impact of Networked SRDs (NSRDs) NN and TN in the band 916.5-918.9 MHz on RFID systems that are currently deployed in the band 915-919 MHz.

This study uses traditional MCL analysis methods based upon transmission and receive parameters and path loss. In the process, worst-case scenarios for interference are defined and analysed.

The methodology incorporates statistical elements that attempt to provide more “real-world” predictions of interference. These methods are not intended to replace more sophisticated Monte Carlo techniques like those utilized in SEAMCAT. Whereas they are intended to provide a “sanity check” against the more sophisticated methods that are highly dependent upon the assumptions and parameters that are inputs into those models.

In summary, MCL is chosen as the analysis method in this study for the following reasons:

- MCL provides a worst-case, upper-bound to interference levels;
- MCL can give more direct insights into the factors that impact interference;
- It is not clear how SEAMCAT accounts for received RFID signals that arrive at the RFID interrogator in an upper and lower sideband;
- To compare to other investigations based on SEAMCAT.

7.2 TECHNICAL DETAILS

7.2.1 Calculation of Minimum Coupling Loss and Impact Range

The analysis of coexistence between interfering transmitters and victim receivers is based on the transmission equation presented in formula (5):

$$P_{Rx} = P_{Tx} * G_{Tx} * G_{Rx} * L \tag{5}$$

Where:

- P_{Rx} is the power at the (victim) receiver;
- P_{Tx} is the transmitter (interferer) power;
- G_{Tx} is the transmitter (interferer) antenna gain;
- G_{Rx} is the receiver antenna gain;
- L is the path loss.

In logarithmic form, the transmission equation used in this study is given by equation (6):

$$P_{Rx} = P_{Tx} + G_{Tx} + G_{Rx} - L \tag{6}$$

To achieve “interference free” operation, an interfering transmitter signal arriving at the victim receiver must be no greater than the victim receive sensitivity minus its minimum C/I ratio. This power level is given by formula (7):

$$\mathrm{I_{max}} = \mathrm{P_{Rx,sensitivity}} - \mathrm{(C/I)_{min}} \tag{7}$$

Therefore, the minimum path loss for interference free operation is given by formula (8):

$$L_{min} = P_{Tx} + G_{Tx} + G_{Rx} - I_{max} \tag{8}$$

This study uses the Extend Hata – SRD propagation model. This study also accounts for the wall (building) penetration loss between the interfering transmitter and victim receiver.

The SEAMCAT handbook provides formulas that compute path loss *L* for a distance *d*. Solving for d_{min} to provide L_{min}, the minimum range for interference free operation (impact range), results in the equation (9):

$$d_{min} = 1000 * 10^{\frac{[L_{min} - Lw - 69.6 - 26.2 log(f) + 13.82\, log(30) + a(Hm) + b(Hb)]}{44.9 - 6.55 log(30)}} \tag{9}$$

Where:

- d_{min} is the minimum range for interference free operation;
- L_{min} is minimum path loss;
- L_w is the wall penetration loss;
- *f* is the operating frequency (MHz);
- *a(Hm)* and *b(Hm)* are path loss correction factors (see ECC Report 252).

The impact area can be determined once the minimum range for interference free operation is known. Another refinement that is applied in this analysis is to limit the impact range to 300/500 meters. This is consistent with the methods used in previous studies.

7.2.2 Calculation of Probability of Interference

The general method of determining the probability of interference from an interfering transmitter to a victim receiver is to determine how many potential interferer devices (N) are within the impact range of a victim receiver and the probability of transmission on an interfering channel. To compute the number of potential interferer devices the formula (10) is used:

$$N = A_{impact} \; / \; A_{Interfering\ Device} = A_{impact} \; * \; D_{Interfering\ Device} \tag{10}$$

Where:

- *N* is the number of potential interferer devices;
- A_{impact} is the impact area;
- $D_{Interfering\ Device}$ is the density of interfering devices per square meter.

The probability of interference to a victim receiver is the probability that there is at least one active transmitter within its impact range and transmitting on an interfering channel. In the proposed coexistence arrangement between RFID and NSRDs, the NSRDs will randomly occupy one of twelve 200 kHz channels in the frequency band 916.5 – 918.9 MHz. For an RFID interrogator operating on the first interrogator channel, the probability that the interfering device will choose an interfering channel (within the receiver passband of the interrogator) is 4/12 (e.g. tag sideband transmissions received by an RFID interrogator operating on the first interrogator channel will be interfered with only if the SRD chooses to operate on a 200 kHz channels between 916.5 MHz and 917.3 MHz). Similarly, for an RFID interrogator operating on the third interrogator channel, the probability that the interfering device will choose an interfering channel is also 4/12 (when the NSRD operates on a 200 kHz channel between 917.7 MHz and 918.5 MHz). The situation is different for an RFID interrogator operating on the second interrogator channel since an NSRD will interfere on any of eight channels between 916.5 MHz and 917.3 MHz and between 917.7 MHz and 918.5 MHz.

It is worth noting that if a NSRD operates on a channel that is within any RFID interrogator channel, then no interference can occur. It is for this reason that this study assumes that all NAP devices will be restricted to operation only in interrogator channels 2 and 3, and that TN and NN devices will randomly select any of the twelve 200 kHz channels between 916.5 – 918.9 MHz.

Since RFID interrogators will randomly (and uniformly) occupy the three interrogator channels, the probability that it chooses a specific channel is 1/3. Therefore, the probability that an RFID interrogator may encounter an interfering NSRD is illustrated in the calculation (11):

$$p = \frac{1}{3} * \left(\frac{4}{12} + \frac{8}{12} + \frac{4}{12}\right) = \frac{4}{9} = 44.4\% \tag{11}$$

Where:

- p is the probability that an RFID interrogator may encounter an interfering NSRD.

The probability that the NSRD is active is simply its duty cycle. Therefore, the probability of interference to a victim receiver when there are N potential interferer devices within the impact range of the receiver, is given by formula (12):

$$p_{interference} = \frac{4}{9} * DC * N = \frac{4}{9} * DC * A_{impact} * D_{Interfering\ Device} \tag{12}$$

Where:

- $p_{interference}$ is the probability of interference to a victim receiver when there are N devices within the impact range of the receiver;
- N is the number of potential interferer devices;
- DC is the duty cycle of the NSRD;
- A_{impact} is the impact area;
- $D_{Interfering\ Device}$ is the density of interfering devices per square meter.

The above probability may not be valid for a large number of potential interferer devices (N) where simultaneous transmission by more than one device on the same channel is possible. In that case, the equation above will overstate the probability of interference.

7.2.3 Further refinements to the statistical analysis

Up to this point the probability of interference has been calculated based on the density and transmit power of interfering devices, by the victim receiver sensitivity and resulting impact range, and by the likelihood to the choice of channel occupancy by a NSRD that would lead to interference. In reality, the situation is more complex, and the probability of interference given by the previous analysis is often pessimistic due to the following:

a) Not all interfering transmitters are transmitting at full power, i.e. may employ power control;

b) The use of directional antennas (by either the interfering or victim devices);

c) Not all desired signal transmissions are received at the victim receiver at threshold sensitivity;

d) Additional path loss due to shielding, indoor-outdoor deployment scenarios, etc.;

e) Other factors, including site engineering practices.

This study attempts to address the first three items from the above list as described below.

To account for the case where not all interfering transmitters are transmitting at full power, this study makes the simplifying assumption that an interfering link transmitter (ILT) chooses its power from one of four equally probable levels of 50 mW, 100 mW, 250 mW, and 500 mW. Since higher transmit levels are more likely to be found when NSRD density is low, and lower transmit levels are more likely to be found when NSRD density is high, the assumption of equal probability of ILT transmit power with worst-case NSRD density is likely to overestimate the exact probability of interference.

To account for the directional antenna patterns used in all RFID installations (maximum beamwidth is specified in ETSI EN 302 208-2 [18]) the probability of interference is reduced by the antenna gain factor by $(10^{G/10})^{-1}$

where G is the victim receiver antenna gain. The antenna gain of fixed mounted interrogators is typically 6 dB (beamwidth less than 90 degrees) which is equivalent to an antenna gain factor of 0.25. This reduces the probability of interference by a factor of 4.

As stated above, not all desired signal transmissions are received at the victim receiver at threshold sensitivity. Intuitively, the impact range (and thus the probability of interference) is reduced when there is signal margin above threshold sensitivity in the victim receiver. In this study, the received ignal trength (rSS) cumulative distribution function (CDF) shown in Figure 66 is used to compute a more realistic probability of interference.

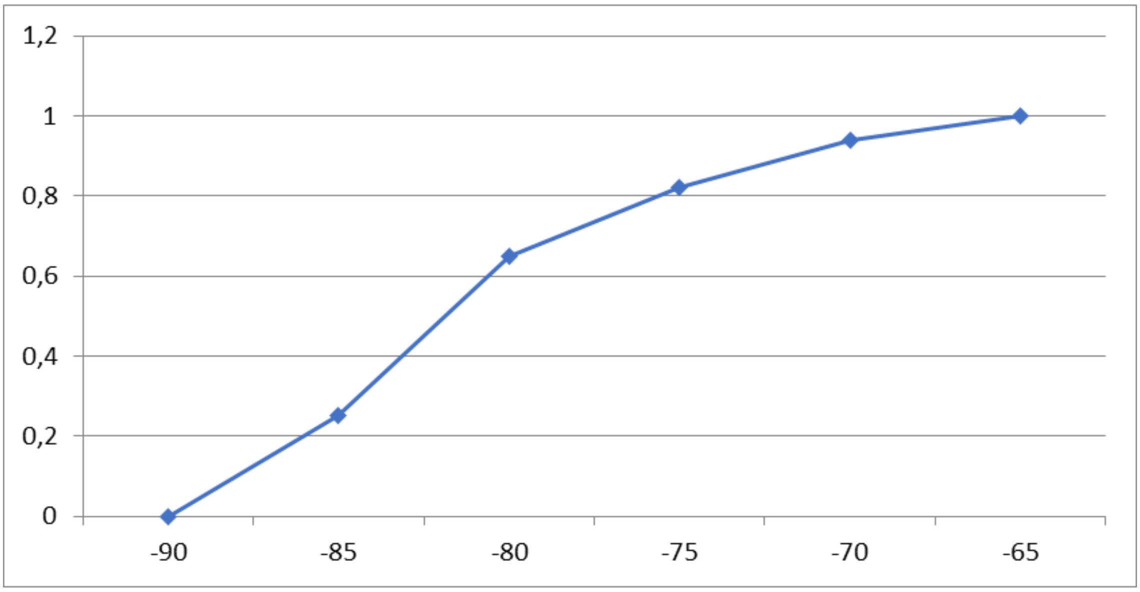


Figure 66: rSS CDF of victim RFID receivers

The other items listed above are not directly addressed, however, they should be considered in the context of the overall deployment scenario and the probability predicted for each specific scenario.

7.3 INPUT PARAMETERS

Table 34 in section 2.4 summarises the parameters used in this study for the RFID victim devices. Transmitter parameters are not shown since the study focuses only on RFID as a victim.

Table 99 summarises the parameters used in this study for the Network SRD devices.

Table 99: Networked SRD (Interferer) Parameters

Parameter	NN	TN
Frequency range (MHz)	916.5 to 918.9 MHz, 0.2 MHz steps (12 channels)	
ILT bandwidth	200 kHz	
ILT power, e.i.r.p.	50/100/250/500 mW	
ILT density per km^2	45 (typical), 90 (max)	950 (typical), 1900 (max)
ILT probability of transmission	≤ 2.5%	≤ 0.1%
Antenna height	3 m	
ILT → VLR interfering path	Extended Hata-SRD	

This study assumed that 1.05 MHz of spectrum is available to NSRD devices in the 865-870 MHz band, 0.4 MHz in the 874-874.4 MHz band, and 2.4 MHz in the 916.5-918.9 MHz band ("minimal EC Decision deployment") and that devices are deployed with equal likelihood across these bands. With this assumption, typical and maximum density is adjusted in the analysis by 2.4/3.85 = 62.3%.

In addition, the use of the Extended Hata – SRD model is likely to lead to a slightly increased probability of interference. The deployment of RFID and NSRD devices in a common geographic area is most likely non-line-of-sight (NLoS), and alternative path loss models, e.g., ITU-R P.1411, may lead to more realistic (higher) path loss. This in turn would reduce the probability of interference predicted in this study. The use of the Extended Hata model was chosen for its simplicity and since it is a proven and accepted propagation loss model.

7.4 RESULTS

The computations used in this study were calculated in Excel. The results are summarised in Table 100 and Table 101.

Table 100: Probability of Interference (300 m impact range)

Scenario	Probability of Interference
Typical Density, 50 mW ILT	2.6%
Typical Density, 50-500 mW ILT	3.3%
Maximum Density, 50 mW ILT	5.1%
Maximum Density, 50-500 mW ILT	6.6%

Table 101: Probability of Interference (500 m impact range)

Scenario	Probability of Interference
Typical Density, 50 mW ILT	2.9%
Typical Density, 50-500 mW ILT	5.6%
Maximum Density, 50 mW ILT	5.9%
Maximum Density, 50-500 mW ILT	11.2%

Therefore, this study predicts the probability of interference to be between 2.6% and 11.2%. These levels are consistent with those predicted by Monte Carlo techniques in SEAMCAT.

8 SCENARIO SET E (STUDY OF A REAL CASE)

The simulations in this scenario are made in MATLAB and in Annex 2 the different steps followed to run the simulations are described.

8.1 PROPAGATION MODEL

Most of the propagation models commonly used in CEPT and ITU-R coexistence studies are based on statistical approaches: e.g. the Okumura-Hata model has been elaborated following a set of measurement campaigns in densely populated areas in Japan. These semi-empirical models provide good results when the distance between the transmitter and the receiver is sufficiently large to average out the effect of individual buildings and other obstacles. However, in very specific cases, especially for short distances, the particularities of the configuration are disregarded by such models, which can ultimately lead to a poor evaluation of the path loss.

Recommendation ITU-R P.452-16 [2] was used to model propagation losses. This propagation model provides a prediction method for the evaluation of propagation losses from about 0.1 GHz to 50 GHz, accounting for both clear-air and hydrometeor scattering interference mechanisms.

The models within Recommendation ITU-R P.452-16 are designed to calculate propagation losses not exceeded for time percentages over the range $0.001 \le p \le 50\%$. This assumption does not imply the maximum loss will be at the used percentage of time of 50%. In this section, the used percentage of time is set to 20%.

Predicting with more accuracy the path loss, requires knowing the exact position of all obstacles including buildings in the path between the transmitter and the receiver. This can be achieved by using a national terrain and building database. In France, they are both provided by the “Institut National de l’Information Géographique et Forestière” (IGN), with a precision of 5 m (1 m is also possible, but it significantly increases the computation time and provides a level of accuracy that is not necessarily needed for the purposes of this Report).

Once the path profile between the transmitter and the receiver is determined, the Recommendation ITU-R P.452-16 is applied for a time percentage of 20%.

8.2 STUDY OF THE IMPACT OF HIGH-POWER SRDS IN AND BETWEEN THE RFID CHANNELS ON THE IN-BAND SRDS SYSTEMS

8.2.1 Mesh topology: NBN's impact

The simulations presented in this section considered, in addition to high power SRDs operating in the RFID channel, new opportunities of SRDs operating with lower DC and deployed with typical density between the RFID channels in 916.5-917.3 MHz and 917.7-918.5 MHz.

Adding new opportunities to high power SRDs could introduce more interference to the existing in-band systems.

Thus, the aim of this study is to assess the impact of the addition of the high-power SRD in between the RFID channels together with the contribution of the already available RFID channels at the two RFID channels centred respectively at 917.5 MHz and 918.7 MHz.

In this section, a realistic scenario of a real city will be considered, where fixed SRD interferes is deployed to cover the studied geographic area. Interference is assessed at each point in the study area. To have a finite/limited number of points, these will be spaced 5 m apart. The interference assessment in a geographic area amounts to calculating it at each point which defines a possible place for the victim.

NBN technology is characterised by a mesh topology where terminals (TN) are connected to access points (NAP) via relays (NN). In order to have equitable coverage of the area, the access points and relays were placed by forming a cellular network in a hexagonal grid as shown in Figure 67.

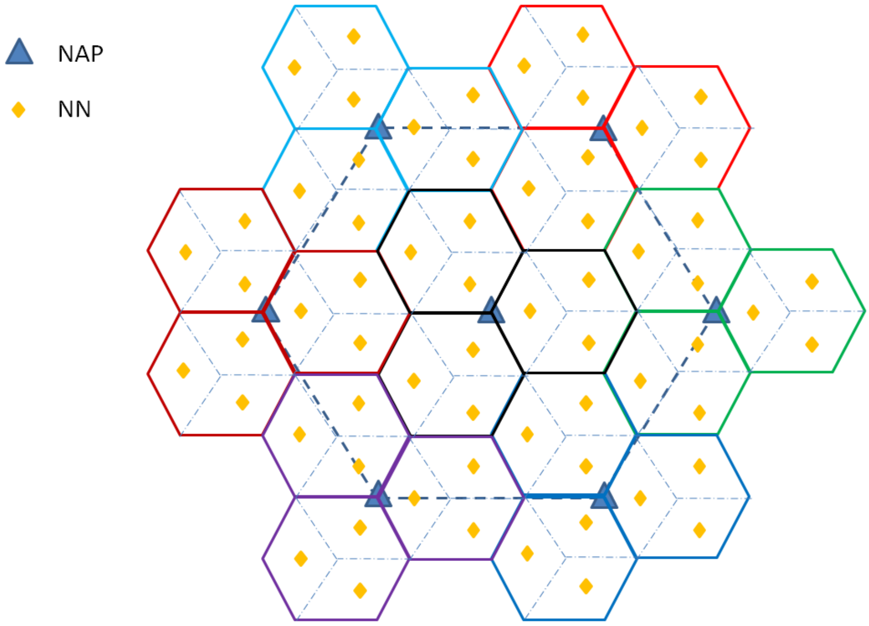


Figure 67: Positioning of an average density of NAPs and NNs

According to the device's density and the surface, the number of devices is determined and deployed, in mesh topology, equidistantly covering the studied area. The terminals devices are all placed indoor and distributed equidistantly.

Figure 68 shows the positioning of a maximal density of NBN devices in the studied area of 1.2 km^2, where NAPs are represented by blue points (10/km^2), NNs are represented by yellow points (90/mk^2) and indoor TNs are represented by green points (1900/km^2).

Figure 68: Positioning of a maximal density of NBN devices in the studied area

8.2.2 Star topology: LPWAN system

In this study, illustrated in Figure 69, the base stations i.e. NAPs, are deployed in the grid with cell radius (depicted R) that is deliberately much smaller than the achievable NAP service radius (R'). This ensures that a random (Aloha channel access type) transmission by any given TN (blue dot on the right-side portion of Figure 69) should be received and decoded by more than one NAP (blue connectors on the right-side portion of Figure 69). All NAPs forward all of their decoded data packets to network's central processing facility, which identifies, sorts, and retains/further acts on just one (verified) copy of a given originally transmitted data packet.

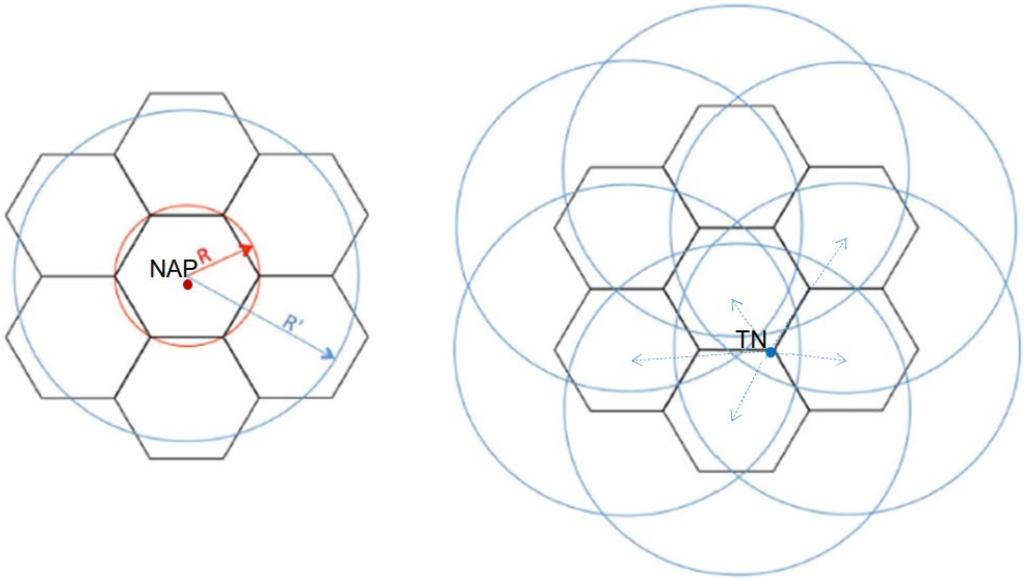


Figure 69: Illustration of LPWAN star network topology

This deployment concept means that sizing of the NAP grid is driven mostly by considerations of TN deployment density and their generated traffic rather than by what is allowed from pure link budget analysis perspective. To illustrate this concept with numbers, it is elucidated that the typical NAP density in urban areas should be approx. 0.1 NAP/km^2, which would represent an optimum balance for LPWAN-UNB radio interface technology between the coverage and TN traffic density considerations. This corresponds to cell radius R of approximately 1.7 km. Whereas realistic service coverage radius R' may be on the order of 5-10 km depending on local radio propagation environment. Comparing these two radiuses show the significant overlap between the service coverage areas of different NAPs.

8.2.3 Coexistence study between SRDs systems

To set the stage for simulating impact of introducing new opportunities for high-power SRDs between the interrogators RFID channels on the 25 mw devices, the same principle as in the previous section, where a star/mesh topology of the interferer system is deployed. Subsequently, the interference is assessed at each point in the study area. To have a finite/limited number of points, these will be spaced 5 m apart. The interference assessment in a geographic area amounts to calculating it at each point which defines a possible place for the victim.

8.2.3.1 Impact from NBN system

For the study of the impact of NBN on in-band SRD systems a full average density, distributed between the two middle RFID channels and in the band portions between the RFID channels, is considered. However, the devices (NAP, NN and TN) operate with their maximum DC in the RFID channels. Between the RFID channels, only the NN and TN are deployed with a percentage of their maximum DC.

Table 102: Deployment assumptions for NBN SRDs in dense urban environment

Network Element	DC %		Max Density /km2	Average Density /km^2	Antenna height (m)
	In RFID Channel	Between RFID Channel			
NAP	10	-	10	5	7
NN	2.5	x% of 2.5	90	45	1.5
TN	0.1	x% of 0.1	1900	950	1.5

The impact of the NBN devices NAP and NN on the TN (CSS) is evaluated. All the two types of NBN SRD devices, are deployed with max density and are either on the two middle RFID channels centred at 917.5 and 918.7 MHz with a power up to 500 mW or in the range between these two middle RFID channels from 917.7 MHz to 918.5 MHz with a power up to 100 mW.

8.2.3.2 Impact on TN (CSS-SRD) device

The victim's parameters are summarised in Table 103.

Table 103: Victim's parameters TN (CSS-SRD) device

Parameter	Values for SF7	Values for SF12
TN (CSS) frequency (MHz)	918.1	
Propagation model	ITU-R P.452-16 (p=20%)	
Reception bandwidth (kHz)	125	
Noise floor (dBm)	-116	
Sensitivity for 7 dB NF w/ N = -116 dBm (dBm)	-124	-137.9
Protection criterion (C/(N+I))	-8	-21.9

After positioning the NBN SRDs network according to the mesh topology, the performance is evaluated in each possible position of TN (CSS) in terms of probability of exceeding the protection criterion threshold (C/(N+I)).

Figure 70 illustrates the probability of exceeding the protection criterion threshold for an average density and a max DC (on the left side of the figure) and for a 50% of max DC for the TN and the NN in between the RFID channels (on the right side of the figure).

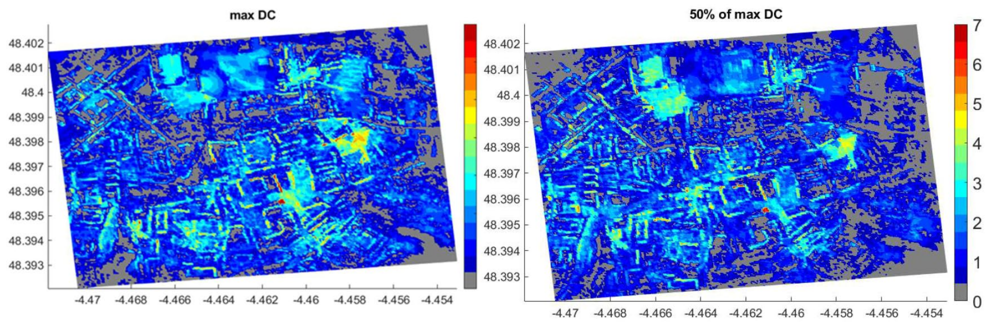


Figure 70: Probability of exceeding C/(I+N) for an average density and max DC (left) and 50% of max DC for the TN and the NN in between the RFID channels (right)

8.2.3.3 Impact on NAP (CSS-SRD) device

The victim's parameters are summarised in Table 104.

Table 104: Victim's parameters NAP (CSS-SRD) device

Parameter	Values for SF7
NAP (CSS) frequency (MHz)	918.1
Propagation model	ITU-R P.452-16 (p=20%)
Reception bandwidth (kHz)	125
Noise floor (dBm)	-118
Coverage radius (km)	3.7
Sensitivity for 7 dB NF w/N = -116 dBm (dBm)	-126
Protection criterion (C/(N+I))	-8

Figure 71 illustrates the probability of exceeding the protection criterion threshold for an average density and DCs set up to max DC, 50% of max DC, 20% of max DC and 10% of max DC, for the TN and the NN in between the RFID channels.

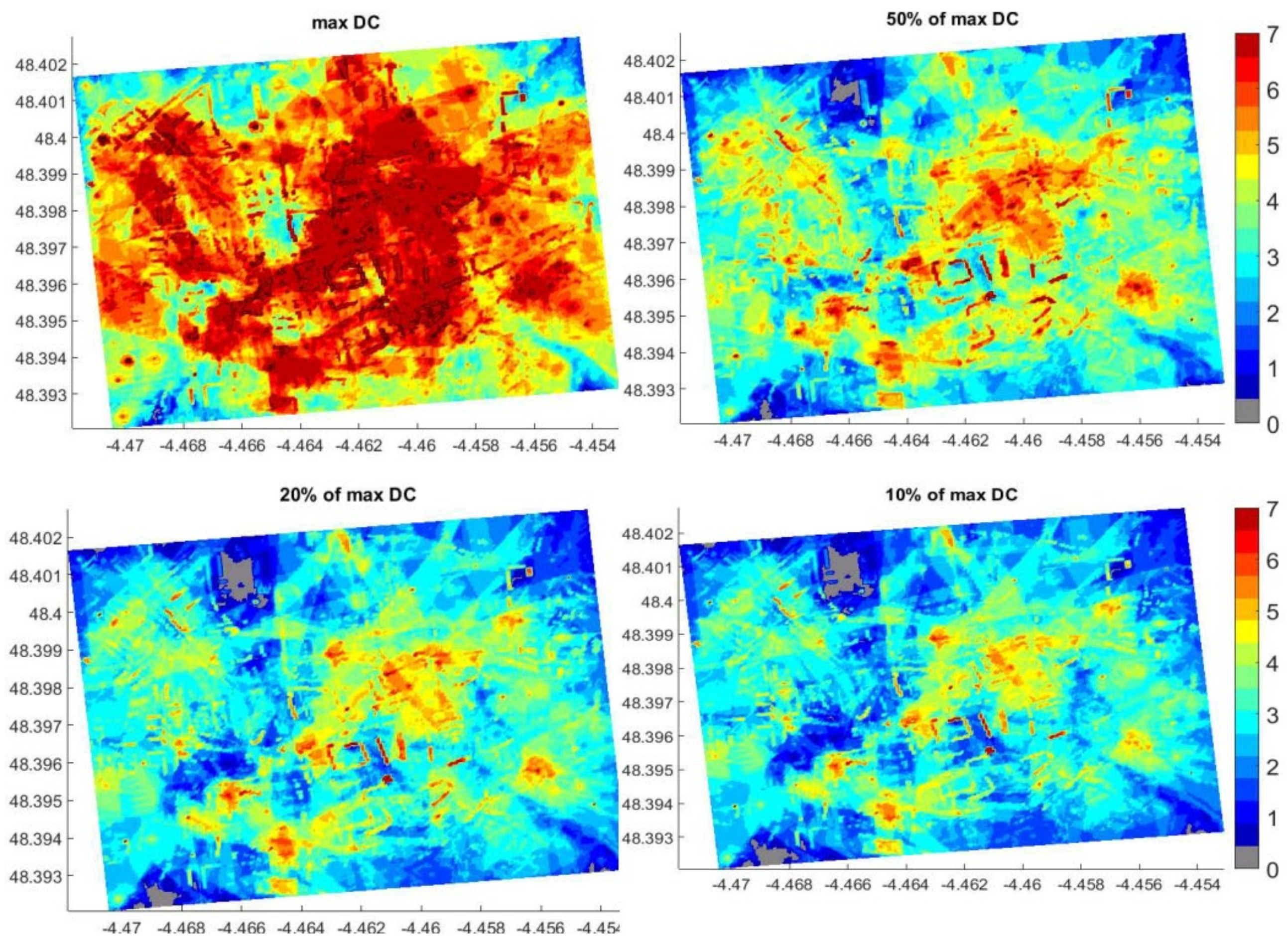


Figure 71: Probability of exceeding C/(I+N) for an average density and different DC for the TN and the NN in between the RFID channels

8.2.3.4 Impact on 25 mW Generic SRDs (200 kHz)

The victim's parameters are summarised in Table 105.

Table 105: Victim's parameters 25 mW Generic SRDs (200 kHz) device

Parameter	Values for SF7
Generic SRDs frequency (MHz)	917.9
Propagation model	ITU-R P.452-16 (p=20%)
Reception bandwidth (kHz)	200
Noise floor (dBm)	-114
Coverage radius (km)	0.1
Sensitivity for 7 dB NF w/N = -116 dBm (dBm)	-103
Protection criterion (C/(N+I))	-8

Figure 72 illustrates the probability of exceeding the protection criterion threshold for an average density and DCs set up to max DC and 70% of max DC, for the TN and the NN in between the RFID channels.

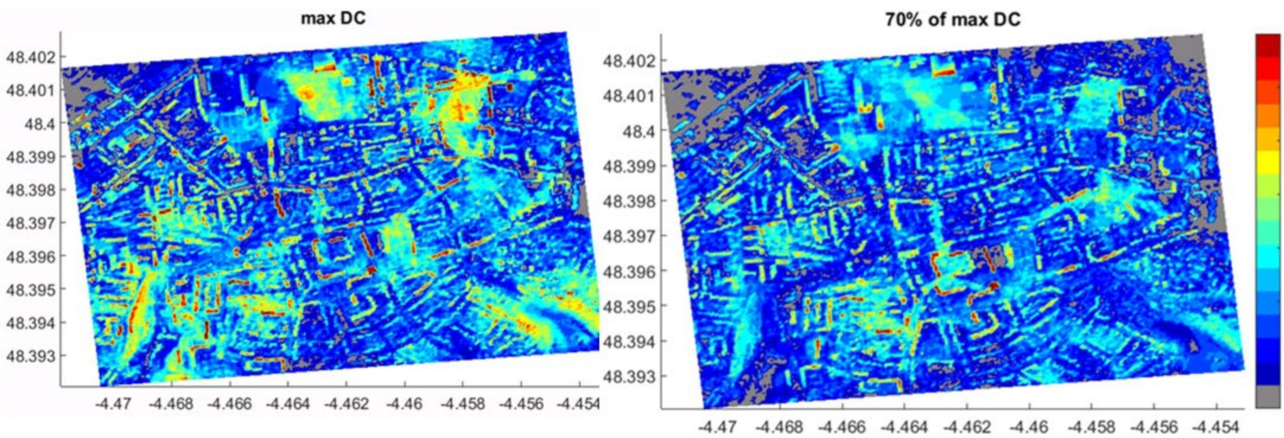


Figure 72: Probability of exceeding C/(I+N) for an average density and different DC for the TN and the NN in between the RFID channels

8.2.3.5 Impact on Wideband SRDs (1 MHz) indoor

Figure 73 illustrates the probability of exceeding the protection criterion threshold for an average density and DCs set up to max DC of wideband indoor SRDs, 40% of max DC of wideband indoor SRDs, 20% of max DC and 10% of max DC of wideband indoor SRDs, for the TN and the NN in between the RFID channels.

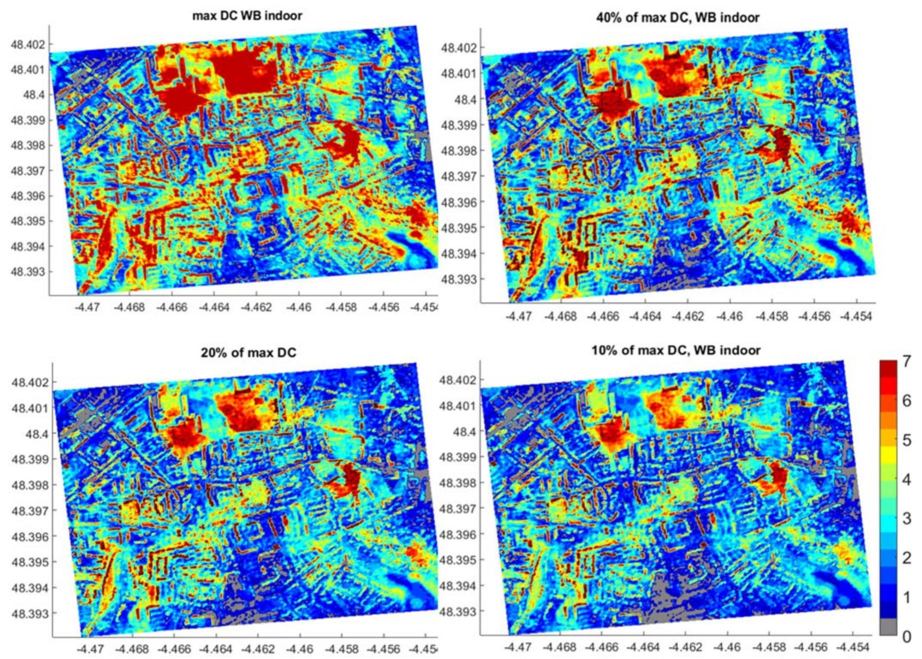


Figure 73: Probability of exceeding C/(I+N) for an average density and different DC for the TN and the NN in between the RFID channels

8.2.3.6 Impact on Wideband SRDs (1 MHz) outdoor

Figure 74 illustrates the probability of exceeding the protection criterion threshold for an average density and DCs set up to max DC of wideband outdoor SRDs, 40% of max DC of wideband outdoor SRDs, 20% of max DC and 10% of max DC of wideband outdoor SRDs, for the TN and the NN in between the RFID channels.

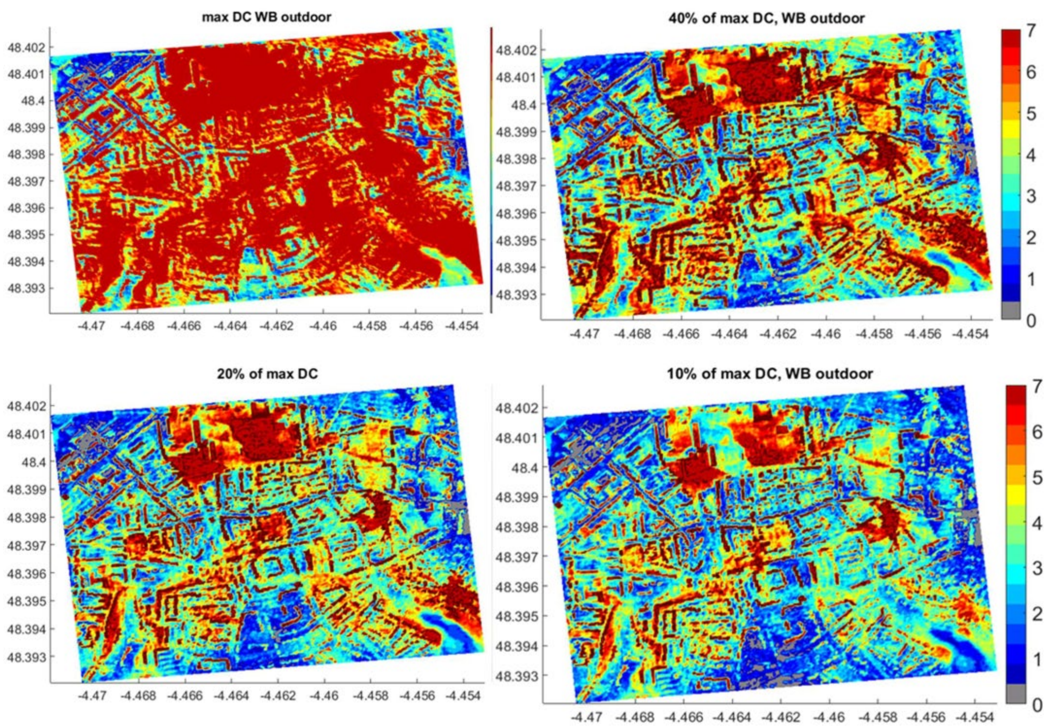


Figure 74: Probability of exceeding C/(I+N) for an average density and different DC for the TN and the NN in between the RFID channels

9 CONCLUSIONS

9.1 CONCLUSIONS REGARDING THE APC SENSITIVITY ANALYSIS RESULTS

The impact of 500 mW SRD on the incumbent SRDs depends on various parameter settings in the interfering system transmitters and receivers. It is shown that the receiver parameters have a significant impact and in some cases an even more important impact on the interference probability than the interfering transmitter signal e.i.r.p.. As an example, the reduction of the maximum interfering transmitter e.i.r.p. from 27 dBm to 17 dBm reduces the interference probability by less than 10% for one of the scenarios. For the same scenario, the reduction of the APC threshold value from -80 dBm (a conservative value used in the studies) to -90 dBm reduces the interference probability by more than 50%.

For some studies, an APC parameter value is considered in order to stabilize the receive power of the interfering system to a level of 15 dB above the considered reference sensitivity level of -95 dBm. Conducting studies with an interference system receiver reference sensitivity of -88 dBm[3] and configuring the APC for an interference system reception level of 18 dB above reference sensitivity, results in an interference probability increase of 24.2% when compared to the previous mentioned scenario.

9.2 CONCLUSIONS FROM SCENARIO SET A

It should be noted that the baseline interference levels are high for two such systems suggesting that they may either struggle to operate in these bands or are more robust than the modelling suggests. In particular, for wideband devices, even in the baseline scenarios, the victim bandwidth overlaps with the bandwidths operated by the possible interferer, resulting in high probably of interference. As expected, the interference level increases with the power, DC and density of interference. In many cases, it is above 5 %.

For RFID, results of the worst-case scenario correlate well with those calculated using an alternative spreadsheet-based analysis shown in section 7, and so long as activity levels equivalent to TN=0.05% (NN=2.5%), interference is acceptable.

9.3 CONCLUSIONS FROM SCENARIO SET B

Scenario set B addresses the coexistence of RFID, NBN, LPWAN-UNB and LPWAN-CSS systems, only in the case of typical values for node densities and duty cycles.

Interference results show that the coexistence of RFID, NBN, LPWAN-CSS and LPWAN-UNB systems is difficult to achieve, even with typical values for node density and duty cycle. Segmentation of high-power devices and low-power devices in different frequency bands give better results (i.e. less interference probability), but not for LPWAN-UNB systems that can operate at very low reception levels. LPWAN-UNB systems suffer less interference when LPWAN-UNB NAP density is significantly increased (from 0.01 to 0.05 NAP/km^2).

9.4 CONCLUSIONS FROM SCENARIO SET C

This section considers the case of NAP interferers operated up to 500 mW.

For interferer UNB NAPs operated at 500 mW and a Duty Cycle of 10% as well as 50%, a low level of interference is found for the following victims: RFID, SRD indoor, SRD outdoor, wideband indoor, wideband outdoor.

For interferer NBN NAPs operated at 500 mW and a Duty Cycle of 10% as well as 50% in maximum density, the interference probability can exceed 5% for the following victims: SRD indoor, SRD outdoor, wideband indoor, wideband outdoor, RFID.

---

[3] Calculated using ETSI EN 303 204 considering 100 kbps

For interferer CSS NAPs operated at 25mW and 500 mW and a Duty Cycle of 50% in maximum density, the interference probability can exceed 5% for the following victims: SRD indoor, SRD outdoor, wideband indoor.

The main issue is the compatibility between NAP transmitting and NAP receiving from different technologies deployed in the same area where the corresponding TN transmitter is operated at 25 mW. Current practical deployment guidance is to avoid this situation by separating 500 mW high power transmitters and receiver of 25 mW TN by frequency. This suggests segmentation of the band into high power and low power ranges.

Simulations were performed with the power control (PC) set up for the 500 mW and 100 mW NAP interferer cases and without PC for the 25 mW NAP interferer case, corresponding to the current regulations for comparison. The results given in Table 106 shows that APC reduces the interference resulting from NAP operated at power higher than 25 mW.

Table 106: Interference probability from NAP (NBN, LPWAN-UNB and LPWAN-CSS) (500 mW)

Scenario	Interferer	LPWAN-CSS (NAP)		UNB (NAP)		NBN (NAP)		NBN (NAP)	
	Victim	UNB (NAP)		LPWAN-CSS (NAP – SF7)		UNB (NAP)		LPWAN-CSS (NAP – SF7)	
	e.r.p. (mW)	Duty Cycle (%)		Duty Cycle (%)		Duty Cycle (%)		Duty Cycle (%)	
		1	2.5	1	2.5	1	2.5	1	2.5
Typical density	500	22	24	9	11.2	8	15.6	5.3	8.5
	100	16	16.4	6.2	8.5	6.8	12.4	3	7.9
	25 (Note 1)	31.8		6.7		27.5		2.9	
Maximum density	500	24	30.4	9	11.9	8.8	14.2	5.6	9.4
	100	17.3	22.8	7.7	10.1	7.4	13.2	4.7	8
	25 (Note 1)	38.3		10.5		36.2		7.3	
Note 1: No power control									

9.5 CONCLUSIONS FROM SCENARIO SET D

This study considers the impact of TN at 500 mW on RFID and predicts the probability of interference to be between 2.6% and 11.2%.

9.6 CONCLUSIONS FROM SCENARIO SET E

The fifth study (Scenario set E) presents a scenario considering a real city clutter and building data, where fixed SRD are deployed confirming to their topology to cover the studied geographic area. This study assesses the impact of the addition of the high-powers SRD, except NAP, in between the RFID channels together with the contribution of the already available RFID channels at the two RFID channels centred respectively at 917.5 MHz and 918.7 MHz. The results of the fifth study are summarised in Table 107.

Table 107: NBNs (TN and NN) DC allowing for a probability interference below 5% on the SRD victim

Interfering Tx power		500 mW
Density		**Average**
Victim	25 mW/ (200 kHz) Generic SRD system	70% of max DC
	25 mw Wide band SRD system (indoor)	Baseline exceeded
	25 mw Wide band SRD system (outdoor)	Baseline exceeded
	LPWAN-CSS, SF7 NAP	Baseline exceeded
	LPWAN-CSS, SF7 TN	50% of max DC

ANNEX 1: FULL RESULTS FROM SCENARIO SET A

The full set of simulations are listed below. For each scenario, both the Probability of interference (%) and Resultant noise floor (dBm) versus Activity Level (absolute) are shown at two different interfering powers (50 mW/ +17dBm, and 500 mW / +27dBm).

A1.1 VICTIM: RFID

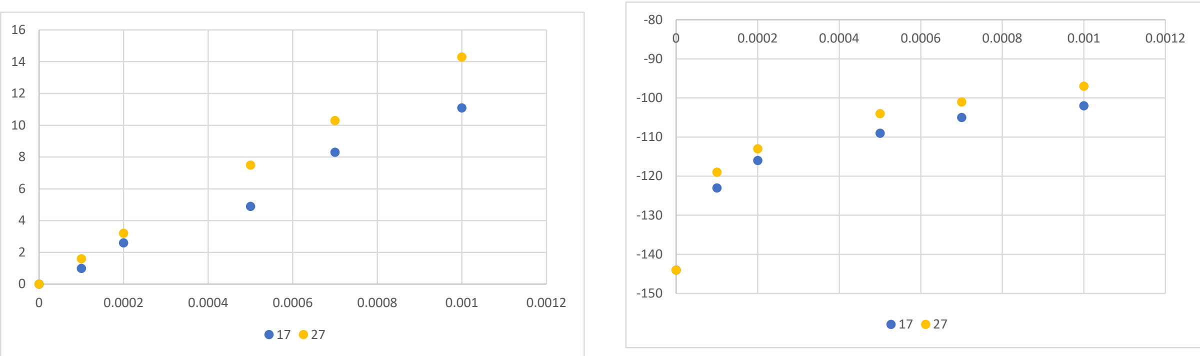


Figure 75: Minimum release / Maximum density

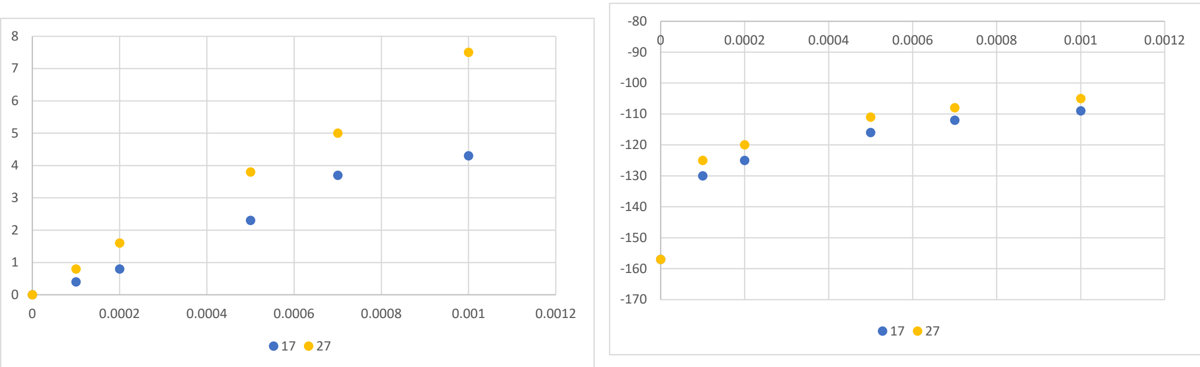


Figure 76: Full release / Maximum density

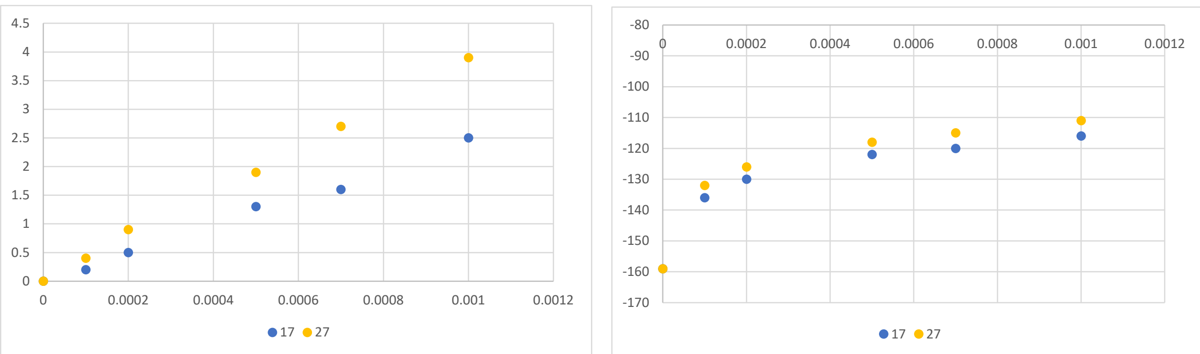


Figure 77: Full release / Average density

A1.2 VICTIM: WIDEBAND OUTDOORS

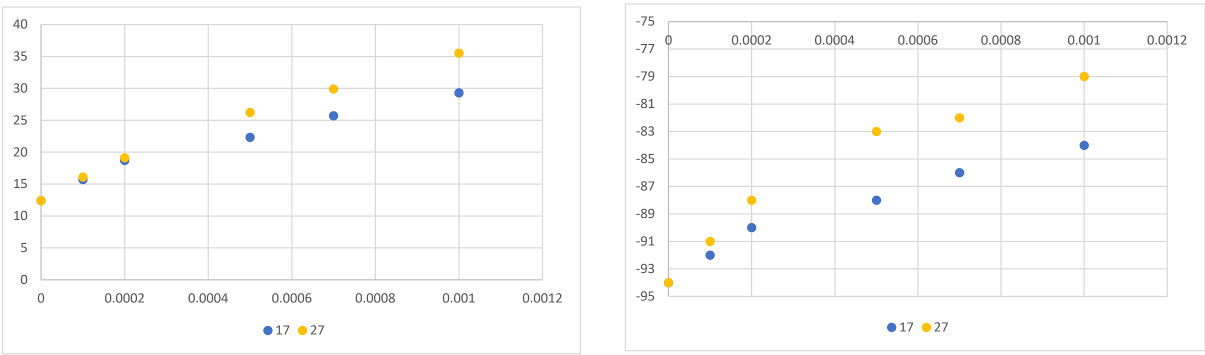


Figure 78: Minimum release / Maximum density

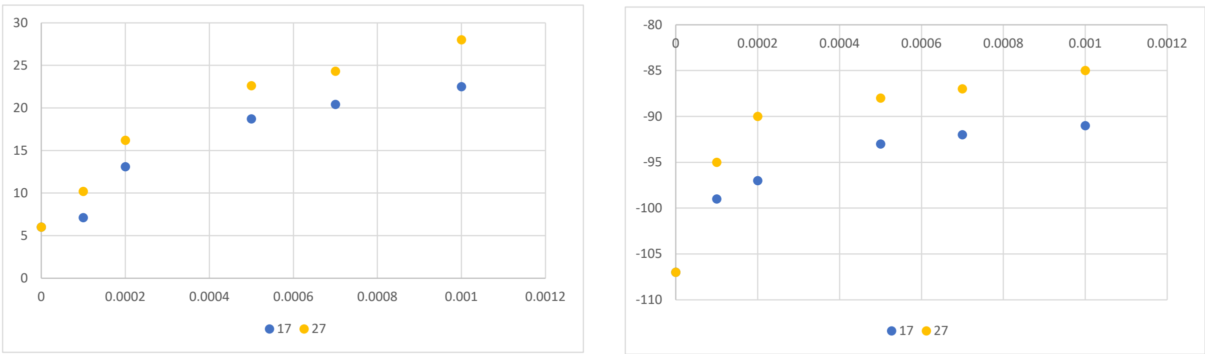


Figure 79: Full release / Maximum density

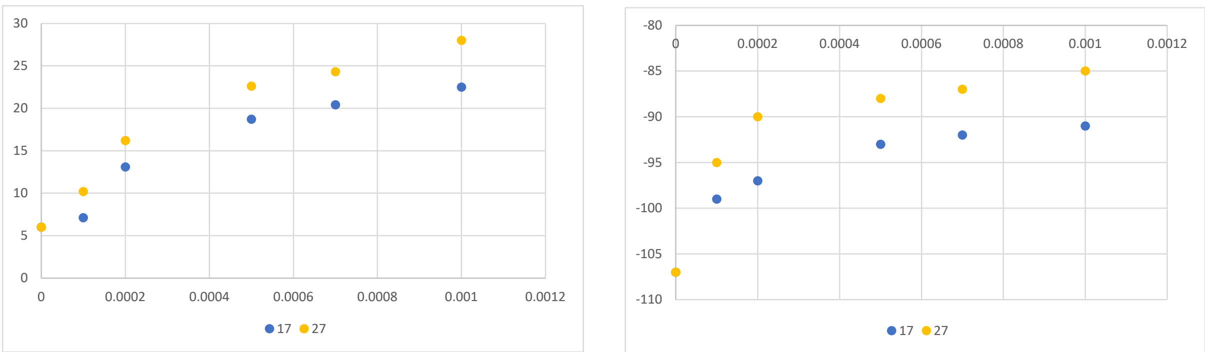


Figure 80: Full release / Average density

A1.3 VICTIM: WIDEBAND INDOORS

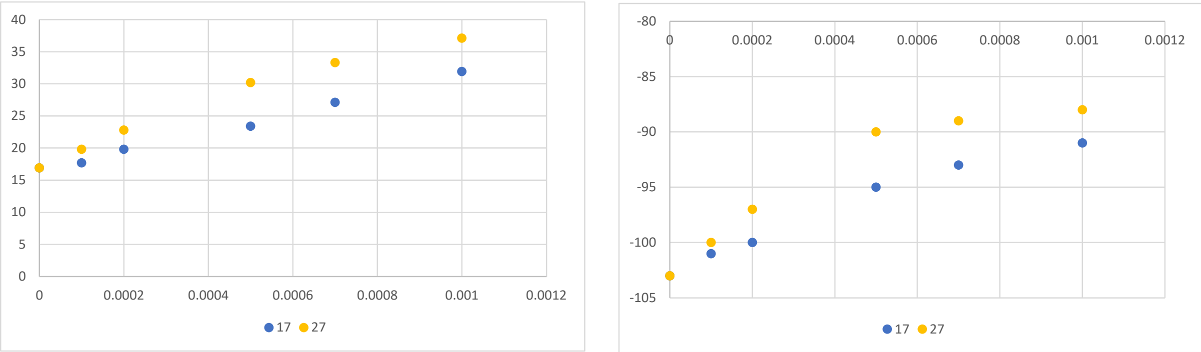


Figure 81: Minimum release / Maximum density

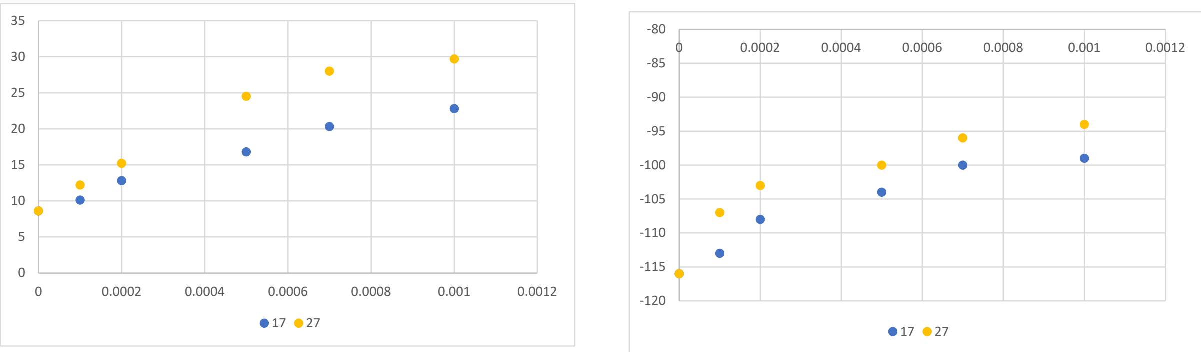


Figure 82: Full release / Maximum density

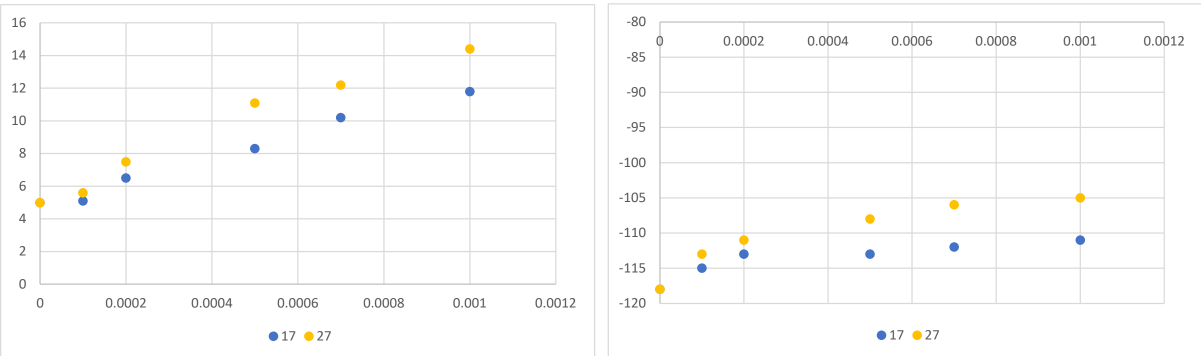


Figure 83: Full release / Average density

A1.4 VICTIM: NON SPECIFIC INDOORS

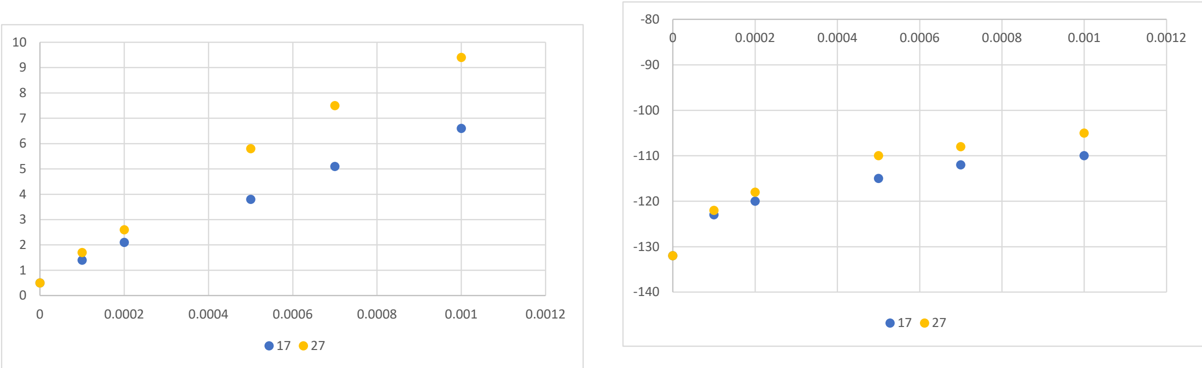


Figure 84: Minimum release / Maximum density

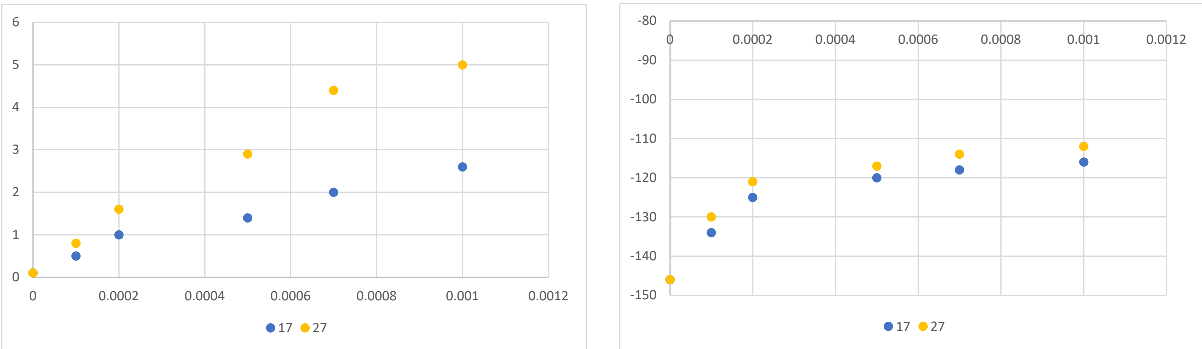


Figure 85: Full release / Maximum density

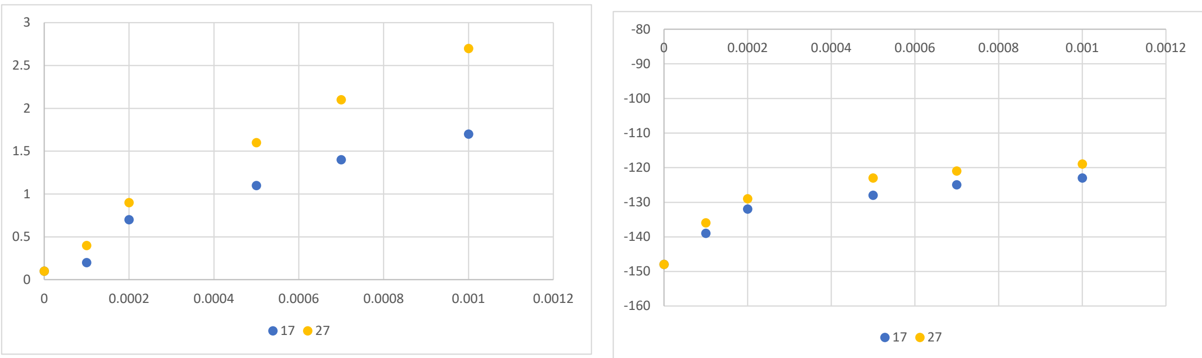
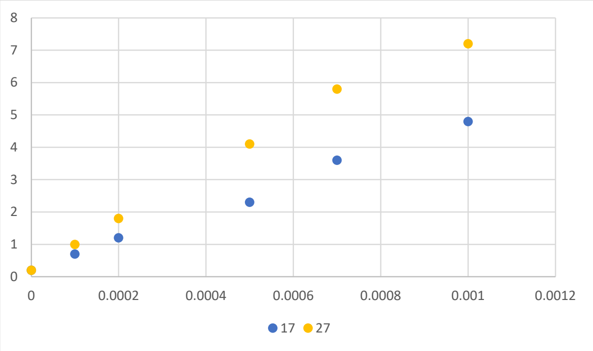


Figure 86: Full release / Average density

A1.5 VICTIM: NON SPECIFIC OUTDOORS



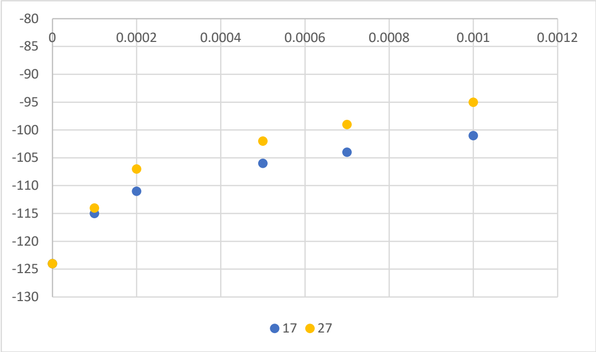
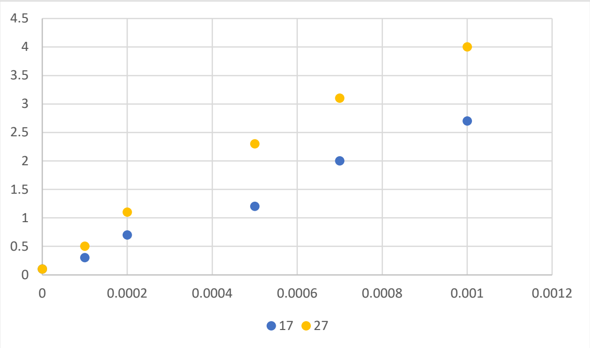


Figure 87: Minimum release / Maximum density



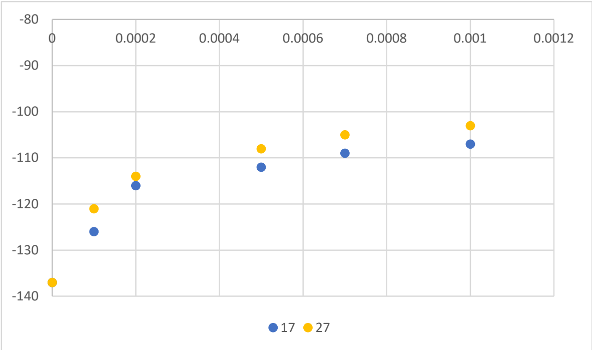
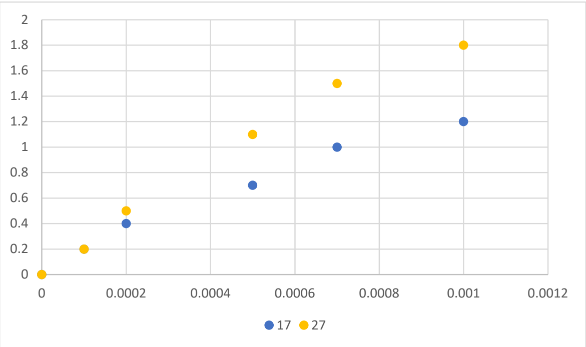


Figure 88: Full release / Maximum density



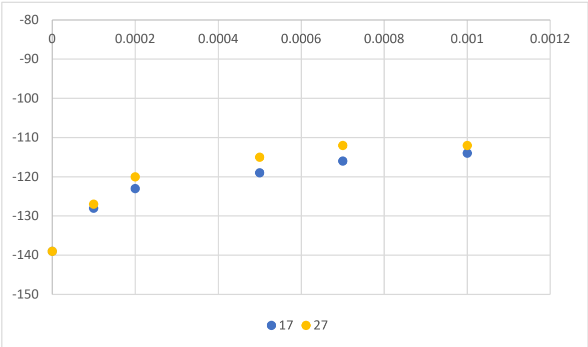


Figure 89: Full release / Average density

A1.6 VICTIM: LPWAN CSS SF12

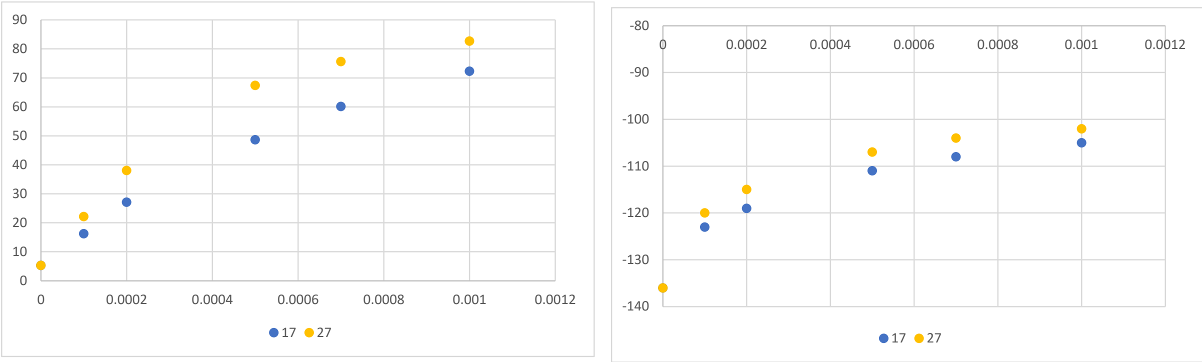


Figure 90: Minimum release / Maximum density

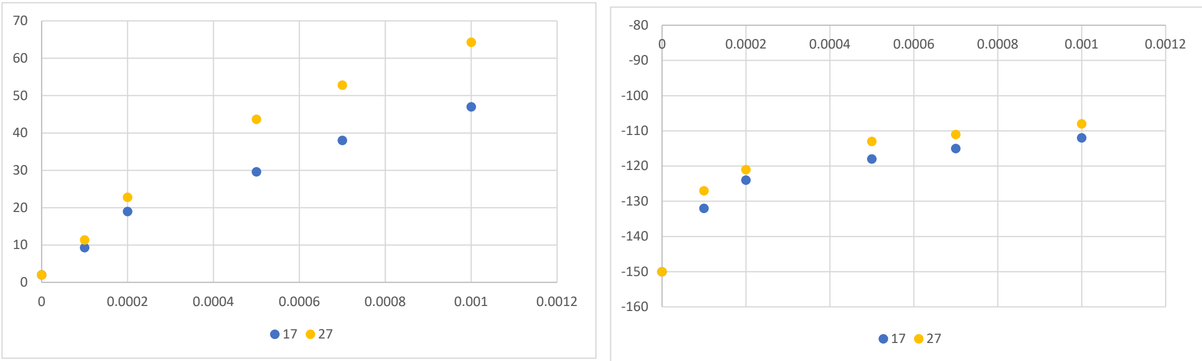


Figure 91: Full release / Maximum density

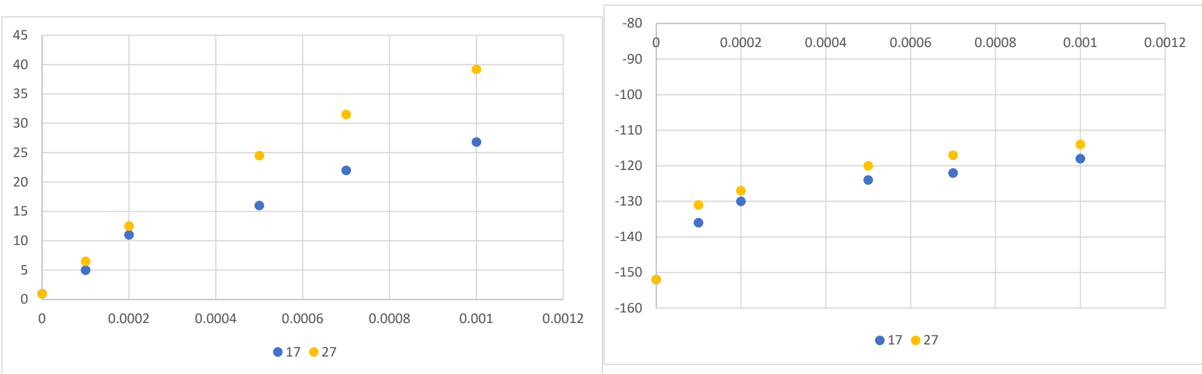


Figure 92: Full release / Average density

A1.7 VICTIM: LPWAN CSS SF7

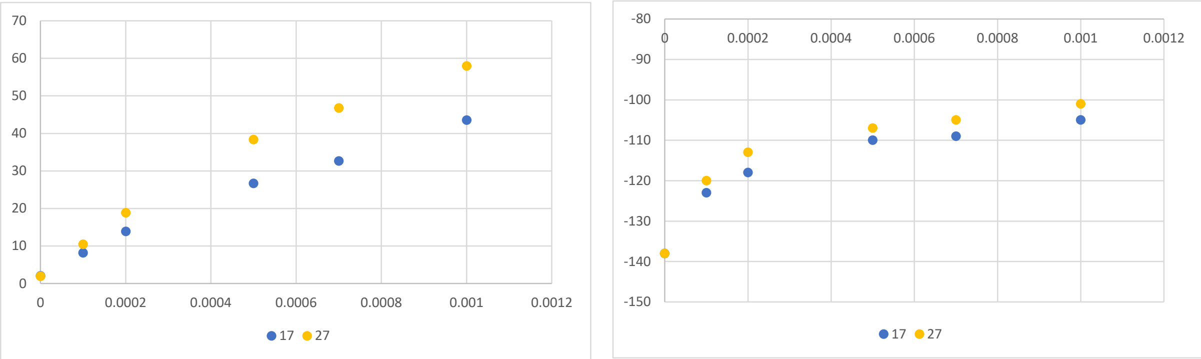


Figure 93: Minimum release / Maximum density

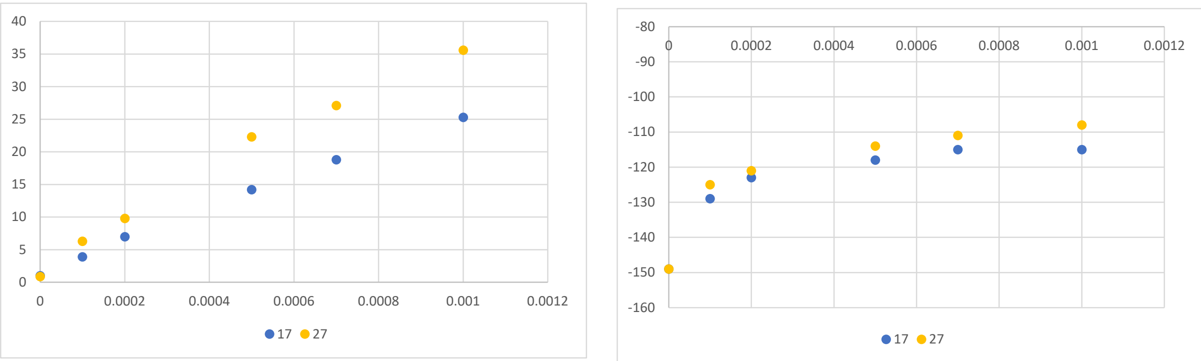


Figure 94: Full release / Maximum density

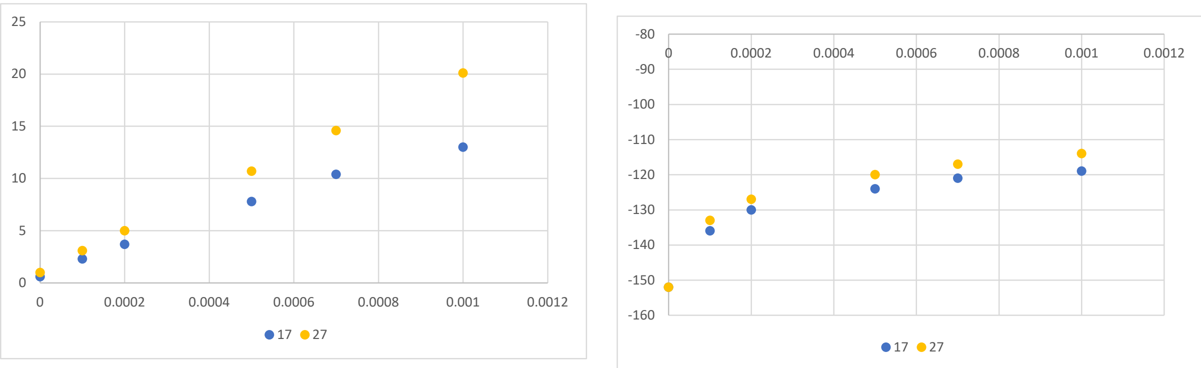


Figure 95: Full release / Average density

A1.8 VICTIM: LPWAN UNB

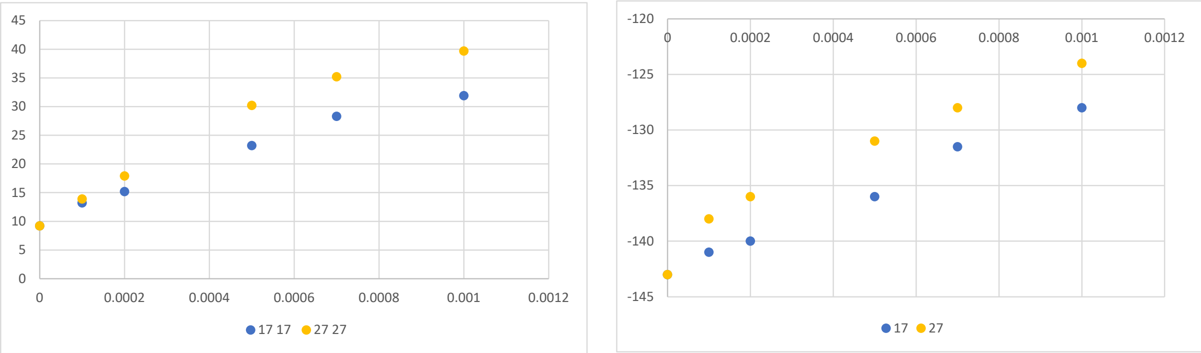


Figure 96: Minimum release / Maximum density

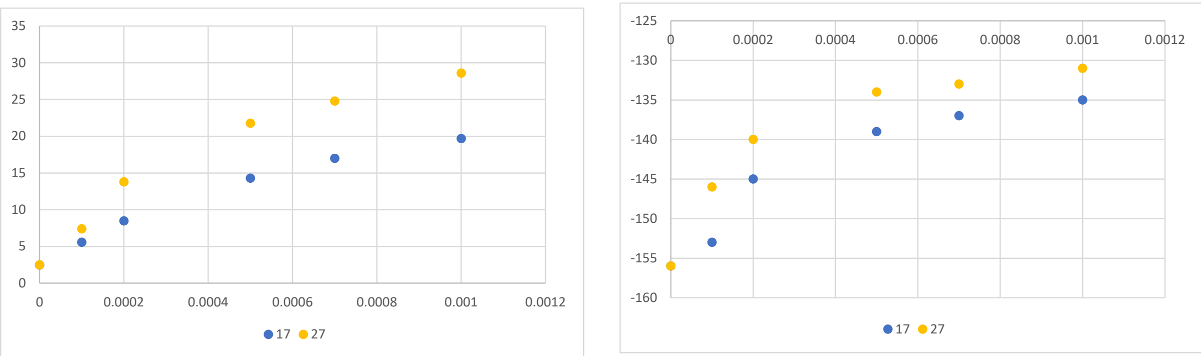


Figure 97: Full release / Maximum density

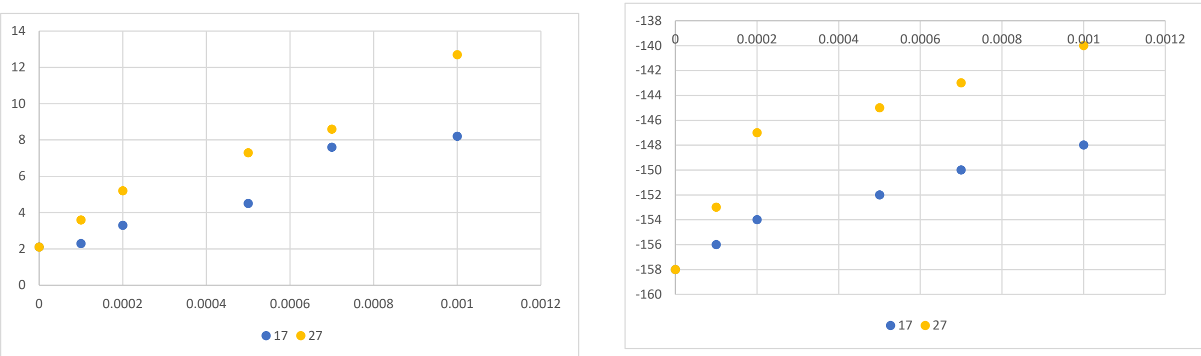


Figure 98: Full release / Average density

ANNEX 2: A STEP-BY-STEP GUIDE TO RE-OBTAIN THE SIMULATION RESULTS OF SET E

This section describes the different step to follow to re-obtain the simulation result.

To obtain the same result, the following data are needed:

- The terrain profile for the propagation model from Recommendation ITU-R P.452-16 [2], SRTM 5 Arc-Second Global DEM can be downloaded from U.S Geological Survey (USGS): https://earthexplorer.usgs.gov/
- Building database: could be downloaded from https://geoservices.ign.fr/
- The study area is a medium-sized city area, extends in latitude between 48.39° and 48.41° and in longitude between -4.47° and -4.44°

After choosing the zone/city of deployment:

1 Positioning of interferers according to network density and topology

The first step consists in placing the interferers (NAP and NN) according to their density and the network topology (Mesh topology for NBN system and star for LPWAN). The terminals (TN) are placed indoor.

2 Calculation of the average interference received in each possible position of the victim with a precision of 5 m

- for i = 1 to number of runs
  - In each victim (VLR) position in the studied area, with a 5 m cut-out, compute the useful signal strength “C” from the victim link transmitter (VLT) randomly drawn in an area limited to coverage radius (CR) around the VLR.
  - Attribution of the transmission frequencies to each interferer in an uniform manner.
  - Activation of a DC% of interferers to transmit.
  - Compute the power control in the interfering link and then deducing the transmitted power from each interferer device.
  - Compute the aggregated interference I generated from all the interferers
  - Compute and store the $C/(N+I)$ or C/I values, depending on the used protection criteria, at the considered position
  - end
- Deduce the probability of exceeding $\frac{C}{(N+I)_{threshold}}$ or $\frac{C}{I_{threshold}}$
- End

Display the probability of exceeding at the considered position.

ANNEX 3: PROPAGATION MODEL USED IN THE STUDIES

A3.1 PROPAGATION MODEL CONSIDERATIONS

For SRD compatibility studies, most often the “extended Hata” or “extended Hata SRD” propagation models are used. As stated in the SEMCAT handbook, the Hata model (also referred to as Okumura-Hata) was originally developed for NLoS paths in typical urban environments of mobile services - that is with low-height mobile terminals moving in cluttered environment. The validity ranges identified by COST 231 [20] based on the original work of Okumura and Hata should be applied when using the Extended Hata model in SEAMCAT, i.e. *Hm*: 1 to 10 m and *Hb*: 30 to 200 m (Note that the *Hb* is assumed to be above roof top).

The Hata-SRD variation was developed in CEPT for studies of Short Range Devices (SRD). The basis for modification was an assumption that although SRD devices are usually operated at low antenna heights (typically person-carried devices, i.e. with antenna height of ca. 1.5 m), but the interference would usually occur at relatively short distances (up to 100 m or so) when direct-LoS or near-direct-LoS might be assumed. Therefore the Hata-SRD model includes adjusted expression of the parameter *b (Hb)*, which in the standard Hata model would introduce significant additional path loss when transmitter antenna height is much less than 30 m. It was found that this additional loss is not justified in the considered SRD scenarios of short range and direct-LoS communication/coupling [8].

For the Simulation of Network SRD Systems in urban areas, the antenna heights of typical NBN deployments seem not to match to the specifications of the extended Hata and extended Hata SRD models. LPWAN-CSS and LPWAN-UNB deployments may be simulated with extended Hata model, because the NAP antenna height is just slightly below the specified value of extended Hata.

ITU-R developed the propagation model in Recommendation ITU-R P.1411 [13]. This Recommendation provides guidance on outdoor short-range propagation over the frequency range 300 MHz to 100 GHz. Information is provided on basic transmission loss models for LoS and NLoS environments, building entry loss, multipath models for both environments of street canyon and over roof tops, number of signal components, polarisation characteristics and fading characteristics. This Recommendation can also be used in compatibility studies.

Although the model assumes, that the terminal is mobile and most likely to be held by a pedestrian or located in a vehicle, the model seems well applicable for the current studies in this Report. The model distinguishes between different propagation path categories. It should be noted that the losses calculated according to Recommendation ITU-R P.1411, chapter 4.1.1 (for site general situations and antenna heights below roof top but not limited to street level) are independent of the antenna heights. This may be explained by the requirement that both antennas must be below roof top level. Propagation models according to Recommendation ITU-R P.1411 where either the Tx or Rx antenna height is above roof top are applicable only for the frequency range 2.2-73 GHz.

Table 108: Choice of propagation models for different deployments of NBN SRD

Technology	Antenna heights	Propagation Model	Remarks
CSS UL / DL	25 m 1.5 m	Extended Hata	Error due to a minimum antenna height of 25 m instead of 30 m required by the extended Hata model is negligible.
UNB UL / DL Scenario 1	7 m 1.5 m	P.1411 (Note 1)	7 m antenna height is considered below the roof top → propagation loss is independent of antenna heights.

Technology	Antenna heights	Propagation Model	Remarks
UNB UL / DL Scenario 2	25 m 1.5 m	Extended Hata	Error due to a minimum antenna height of 25 m instead of 30 m required by the extended Hata model is negligible.
NBN NAP -NN	7 m 5 m	P.1411 (Note 1)	7 m and 5 m antenna height is considered to be below roof top → propagation losses are independent of antenna heights.
NBN NN -TN	5 m 1.5 m	P.1411 (Note 1)	5 m antenna height is considered below the roof top → propagation losses are independent of antenna heights.
CSS NAP ←→UNB NAP	25 m 25 m	Free Space + 5.7 dB	LoS probability is very high. The additional losses of 5.7 dB are valid for 1 km propagation distance but are applied to all distances although at shorter propagation distance the additional loss would be less. The derivation of that value is shown in section A3.2
NBN NAP ← → CSS NAP / UNB NAP	7 m 25 m	Extended Hata and Free Space + 5.7 dB	The additional losses of 5.7 dB are valid for 1 km propagation distance but are applied to all distances although at shorter propagation distance the additional loss would be less. The derivation of that value is shown in section A3.2
NBN NN ← → CSS NAP / UNB NAP	5 m 25 m		
TN ← → TN (UNB, CSS, NBN)	1.5 m 1.5 m	P.1411 (Note 1)	-
TN ← → Non-Specific SRD, wide band	1.5 m 1.5 m	P.1411 (Note 1)	-
CSS NAP and UNB NAP ←→ Non-Specific SRD	25 m / 1.5 m	Extended Hata	-
NBN NAP ←→ Non-Specific SRD	7 m / 5 m / 1.5 m	P.1411 (Note 1)	7 m antenna height is considered below the roof top → propagation losses are independent of antenna heights.
Note 1: P.1411 represents the model described in Recommendation ITU-R P.1411 [13]			

A3.2 PROPAGATION MODEL SELECTION

Available propagation models for the use in short range devices interference simulations are tailored for specific deployment situations. The extended Hata model presumes scenarios where one of the antennas in the interference scenario is deployed at a height of more than 30 m while the other antenna moves at a height of 1.5 m in cluttered NLoS environments. The model according to Recommendation ITU-R P.1411 [13] is suitable for SRD radio wave propagation loss simulations for LoS and NLoS environments in street canyon and over roof tops.

To assess the propagation loss values calculated with the extended Hata (SRD) model when using parameter setting out of model specifications, a comparison with the propagation loss values calculated with the model form Recommendation ITU-R P.1411-10 is made, both with LoS and NLoS assumptions. Additionally, a comparison of results obtained with all three models is made, when the parameter settings comply with the propagation model specifications (Scenario 1). For comparison against Scenario 1, Scenarios 2-6 are shown in Table 109.

Table 109: Scenarios for propagation model comparison

Scenario type	Environment	Antenna heights h_{Tx} / h_{Rx}	Considered propagation models	Remarks
1	Urban	1.5 m / 1.5 m	▪ Extended Hata SRD ▪ P.1411-10 NLoS / LoS below roof top (See Note 1)	All parameters are within the model specifications.
2	Urban	7 m / 1.5 m	▪ Extended Hata SRD ▪ P.1411-10 NLoS / LoS below roof top (See Note 1)	h_{Tx} and h_{Rx} is out of specifications for the extended Hata SRD model
3	Urban	7 m / 1.5 m	▪ Extended Hata below roof top ▪ P.1411-10 NLoS / LoS below roof top (See Note 1)	h_{Tx} is out of specifications for the extended Hata model
4	Urban	25 m / 1.5 m	▪ Extended Hata above roof top ▪ P.1411-10 NLoS / LoS below roof top (See Note 1)	h_{Tx} is slightly out of specifications for the extended Hata model. Below roof top may not apply.
5	Urban	25 m / 1.5 m	▪ Extended Hata below roof top ▪ P.1411-10 NLoS / LoS below roof top (See Note 1)	h_{Tx} is slightly out of specifications for the extended Hata model. Below roof top may not apply.
6	Urban	25 m / 7 m		
Note 1: P.1411 represents the model described in Recommendation ITU-R P.1411 [13]				

Comparison of simulation results obtained using the extended Hata, extended Hata – SRD and Recommendation ITU-R P.1411 [13] shows, that all three models calculate the same path attenuation or, consistent path attenuations respectively, as long as the propagation models are used with parameter settings within the specified value ranges. The results obtained by the extended Hata and extended Hata – SRD models can be interpreted as results for NLoS scenarios for distances longer than 100 m and LoS scenarios for distances shorter than 40 m. For a distance range between 40 m and 100 m it seems that the model assumes a mix of LoS and NLoS propagation conditions. Further, no antenna height dependent LoS condition probabilities and according path attenuations are considered in the Hata models, but an average LoS/NLoS path attenuation type seems to be assumed. If the extended Hata model is used with both antennas (Tx and Rx) deployed at heights significantly below 30 m (out of extended Hata specified parameter range), the differences of calculated path attenuation between the different models may be higher than 20 dB, even for propagation path lengths below 200 m.

Based on the observations made above , it can be concluded that the application of the propagation Model from Recommendation ITU-R P.1411 [13] is more appropriate than the application of the extended Hata, respectively the extended Hata – SRD, especially for the scenario types B and C.

All propagation models can be configured for above or below roof top scenarios. To select the appropriate respective scenario, the urban clutter height according to Recommendation ITU-R P.2108-1 [19] is considered.

The representative clutter height is 15 m for urban environments and 20 m for dense urban environments. Accordingly, only below roof top scenarios are considered for scenarios with NBN systems. For the scenarios considering LPWAN-UNB and LPWAN-CSS NAPs, above roof top applies.

The propagation attenuation results obtained with calculations based on the model according to Recommendation ITU-R P.1411-10 are compared to results obtained based on calculations with extended Hata model. The comparison is made for 5 different scenarios, while the different antenna height values and propagation conditions (below roof top / above roof top) are considered. The scenario descriptions are shown in Table 109.

A3.2.1 Scenario 1 (all parameter values within propagation model specifications)

Comparison results for the median path losses in Scenario 1 are shown in Figure 99, where the red curve represents the median path loss according to the model from Recommendation ITU-R P.1411-10 NLoS, the blue curve represents the median path loss according to the model from Recommendation ITU-R P.1411-10 LoS and the green curve represents the median path loss according to extended Hata SRD. It appears that for distances shorter than 40 m, the extended Hata SRD model assumes LoS conditions, while for distances longer than 100 m NLoS conditions are assumed.

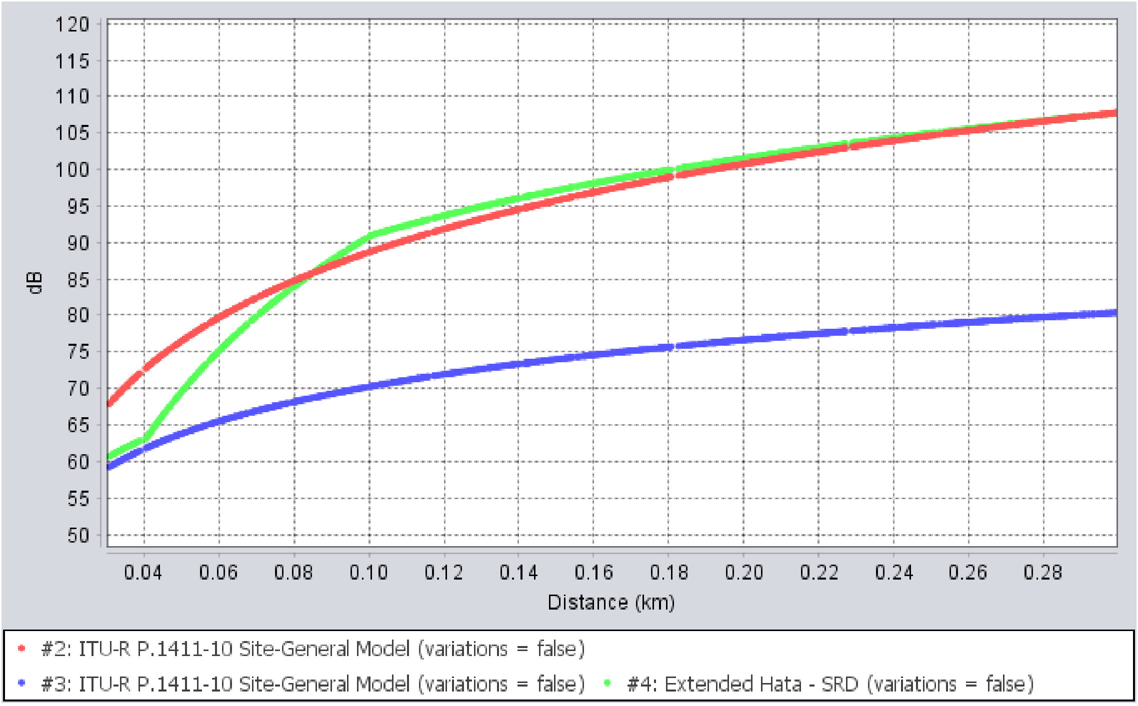


Figure 99: Median path loss for Scenario 1

A3.2.2 Scenario 2 (antenna height values are out of propagation model specifications)

Comparison results for the median path losses in Scenario 2 are shown in Figure 100, where the red curve represents the median path loss according to the model from Recommendation ITU-R P.1411-10 [13] NLoS, the blue curve represents the median path loss according to the model from Recommendation ITU-R P.1411-10 LoS and the green curve represents the median path loss according to extended Hata SRD. It seems that for distances shorter than 40 m, the extended Hata model assumes LoS conditions, while for distances longer than 40 m a kind of LoS (partially obstructed Fresnel ellipsoid) / NLoS conditions are assumed. It should be noted, that the antenna heights used in this scenario are out of specifications for the extended Hata SRD propagation model.

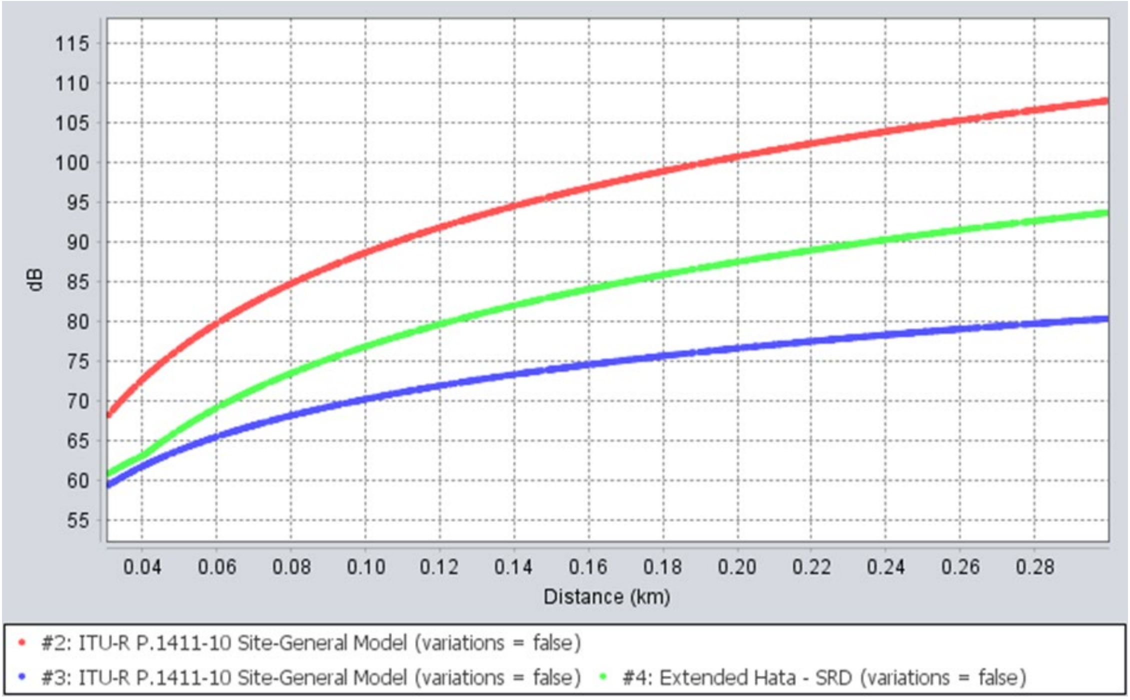


Figure 100: Median path loss for Scenario 2

A3.2.3 Scenario 3 (antenna height values are out of propagation model specifications)

Median path loss for Scenario 3 are shown in Figure 101, where the blue curve represents the median path loss according to the model from Recommendation ITU-R P.1411-10 [13] NLoS, the green curve represents the median path loss according to the model from Recommendation ITU-R P.1411-10 LoS and the red curve represents the median path loss according to extended Hata SRD. It seems that for distances shorter than 40 m, the extended Hata model assumes LoS conditions, while for distances longer than 100 m a kind of NLoS conditions are assumed. It can be interpreted, that for distances between 40 m and 100 m a mix between LoS and a kind of NLoS is assumed. However, the calculated propagation loss values calculated with extended Hata for distances longer than about 60 m are more than 10 dB higher than the values calculated with the model from Recommendation ITU-R P.1411-10.

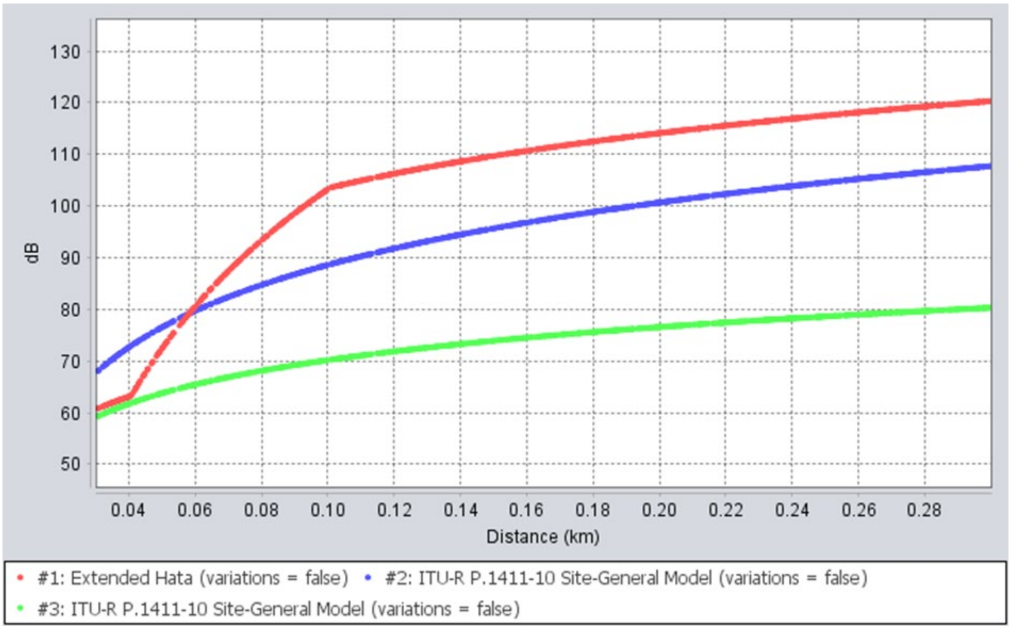


Figure 101: Median path loss for Scenario 3

A3.2.4 Scenario 4 and 5 (some parameter values just slightly out of propagation model specifications)

Median path loss for Scenario 4 and 5 are shown in Figure 102, where the blue curve represents the median path loss according to the model from Recommendation ITU-R P.1411-10 [13] NLoS, the green curve represents the median path loss according to the model from Recommendation ITU-R P.1411-10 LoS and the red curve represents the median path loss according to extended Hata SRD . For the Scenarios 4 and 5, one antenna height is slightly below the specified minimum value. Similar conclusions may be drawn, as were done for Scenario 1.

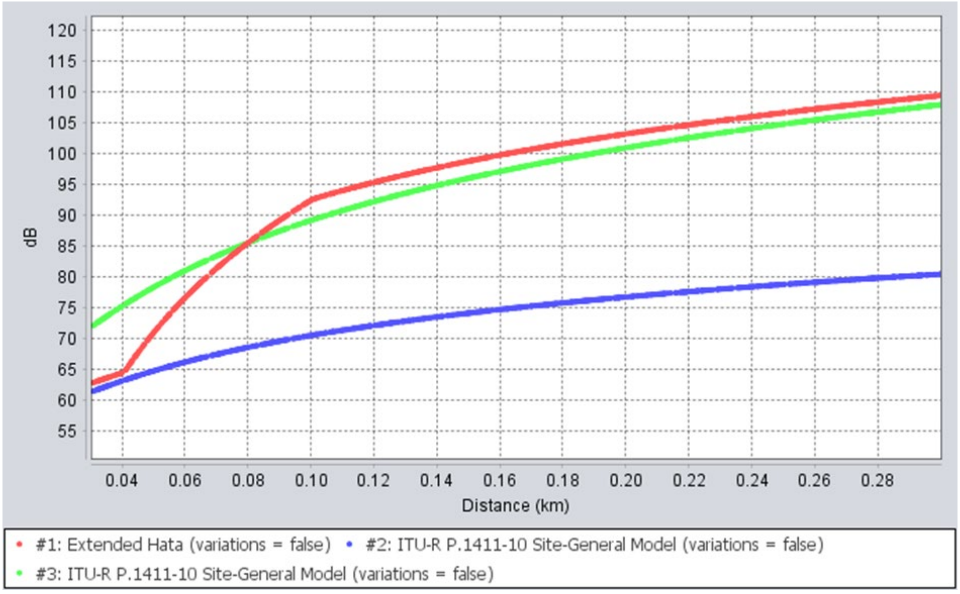


Figure 102: Median path loss for Scenario 4 and 5

A3.2.5 Scenario 6

For Scenario 6, the assumption that both antennas are below roof top, which is required by the Model according to Recommendation ITU-R P.1411-10, annex 1, section 4.1.1 [13], does not hold anymore. For Scenarios, where either the Tx or Rx antenna are operating above roof top, the model according to Recommendation ITU-R P.1411-10, annex 1, section 4.2.1, may be applied but only in frequency range above 2200 MHz. When analysing the model at a frequency of 2200 MHz, it can be observed that the losses calculated based on that model are very similar to losses calculated according the extended Hata model for NLoS propagation situation and for LoS propagation situations, the losses calculated according the model from Recommendation ITU-R P.1411-10, annex 1, section 4.2.1, are very similar to the losses calculated with the free space propagation model, when an additional loss of approximatively 5 dB is considered (for a 1 km propagation distance). This additional loss may be explained by LoS propagation conditions where the Fresnel ellipse is partially obstructed which generates diffraction attenuation. It may be assumed that in urban environments the obstruction of the Fresnel Ellipse is rather due to knife edge like obstacles than by smooth surfaces. The analysis of the diffraction attenuation is done in the following:

For a point at a given distance along the path of propagation, which introduces knife-edge diffraction, the radius of the first Fresnel zone can be determined by the equation (13):

$$R_{EFZ} = \sqrt{\frac{D_1 D_2}{D_1 + D_2}\lambda} \tag{13}$$

Where:

- λ is wavelength of the propagating signal;
- D_1 is the distance of the point from one end of the path;
- D_2 is the distance of the point from the opposite end of the path.

Given the parameters:
- f = 2200 MHz;
- D_1 = 0.5 km;
- D_2 = 0.5 km.

Using the above parameters, equation (13) gives R_{EFZ} = 5.83 m.

The Fresnel-Kirchhoff diffraction parameter is calculated using formula (14):

$$v = \mathrm{h}\sqrt{2\frac{D_1 + D_2}{\lambda D_1 D_2}} = h\frac{\sqrt{2}}{R_{EFZ}} \tag{14}$$

To calculate the diffraction loss, the Fresnel integral

$$f(v) = \int_v^{\infty} \left(\frac{1+j}{2}\right) e^{\left(\frac{-j\pi t^2}{2}\right)} dt \tag{15}$$

Can be approximated reasonably accurate for values of -1 <= v <= 0 by the formula (16)

$$Loss(v) = 20\log(0.5 - 0.62v) \tag{16}$$

Looking for a loss of 4.7 dB the following v is required

$$v = \frac{0.5 - 10^{\frac{-4.7}{20}}}{0.62} = -0.1324 \tag{17}$$

The required maximum clearance is calculated in the middle of the Fresnel ellipse as follows:

$$h = v\frac{R_{EFZ}}{\sqrt{2}} = -0.1324\,\frac{5.83}{1.414} = -0.546\ \mathrm{m} \tag{18}$$

When looking for scenarios with 1 km propagation distance, where the path loss due to knife edge diffraction is maximum 4.7 dB higher than free space loss, LoS conditions are selected for supposed transmitter and receiver antenna heights which are 0.546 m below effective antenna heights. The correction of the minimum clearance height for angles of arrival with a tilt smaller or larger than 0° can be neglected for the considered scenarios. Therefore, it can be concluded, that the diffraction loss of 4.7 dB at 1 km distance and at a frequency of 2200 MHz is due to LoS condition with a maximum clearance of 0.546 m.

If the diffraction loss due to the 0.546 m clearance is calculated for 900 MHz and 1 km propagation path distance, the following value for the additional probation loss is obtained:

$$Loss(v) = 20\log(0.5 - 0.62v) \;=\; 5.15\ \mathrm{dB, at}\ v \;=\; -0.0847, R_{EFZ} \;=\; 9.13\ \mathrm{m} \tag{19}$$

For 4000 m distance, the loss would be 5.7 dB.

Due to a missing propagation model suited for the Scenario 6 and based on the above findings, the following approximation is proposed:
- For NLoS propagation conditions in Scenario 6, the extended Hata propagation model is used;

- For LoS propagation conditions in Scenario 6, the free space propagation model with an additional diffraction loss of 5.7 dB is used.

Results of the propagation model comparison are shown in Figure 103, where the blue line represents the propagation losses calculated at a frequency of 2200 MHz for the free space model, the red line represents the propagation losses calculated at a frequency of 2200 MHz for the extended Hata model, the yellow line represents the propagation losses calculated at a frequency of 2200 MHz for the model according to Recommendation ITU-R P.1411-10, annex 1, section 4.2.1 NLoS and the green line represents the propagation losses calculated at a frequency of 2200 MHz for the model according to Recommendation ITU-R P.1411-10, annex 1, section 4.2.1 LoS.

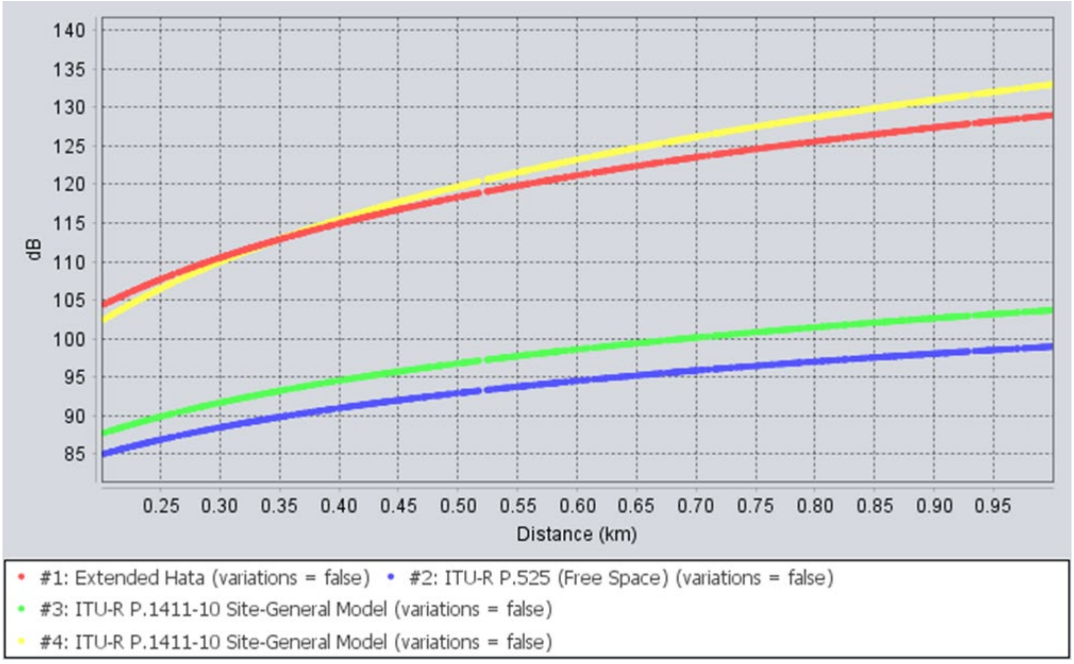


Figure 103: Comparison of propagation losses calculated at a frequency of 2200 MHz for different models

A3.3 LOS SCENARIO PROBABILITIES

The model according to Recommendation ITU-R P.1411 [13] considers wave propagation for LoS and NLoS environments. Accordingly the probabilities for LoS, respectively NLoS conditions need to be evaluated. In Report ITU-R M.2135-1 [14] a method to calculate the LoS probabilities for 5 G urban micro und macro cell is presented. Because the antenna height of urban micro cells and macro cells are assumed in Report ITU-R M.2135-1 to be at 10 m and 25 m and the antenna height of the user equipment is assumed to be 1.5 m, that LoS probability calculation method may also be applicable for the SRD Network systems in scenarios where TN are considered. The method may be not directly applicable for the interference scenario between the NAPs of different SRD technologies. Because of that, a LoS probability function need to be assumed which may be considered as reasonable for LoS probability estimations in scenarios dealing with interference between SRD NAPs. In Figure 104 the LoS probabilities for urban micro cell ($h_{ant\ BTS}$ = 10 m, $h_{ant\ MS}$ = 1.5 m), urban macro cell ($h_{ant\ BTS}$ = 25 m, $h_{ant\ MS}$ = 1.5 m) and for scenario with $h_{ant\ NAP1}$ = 7 m and $h_{ant\ NAP2}$ = 25 m are shown.

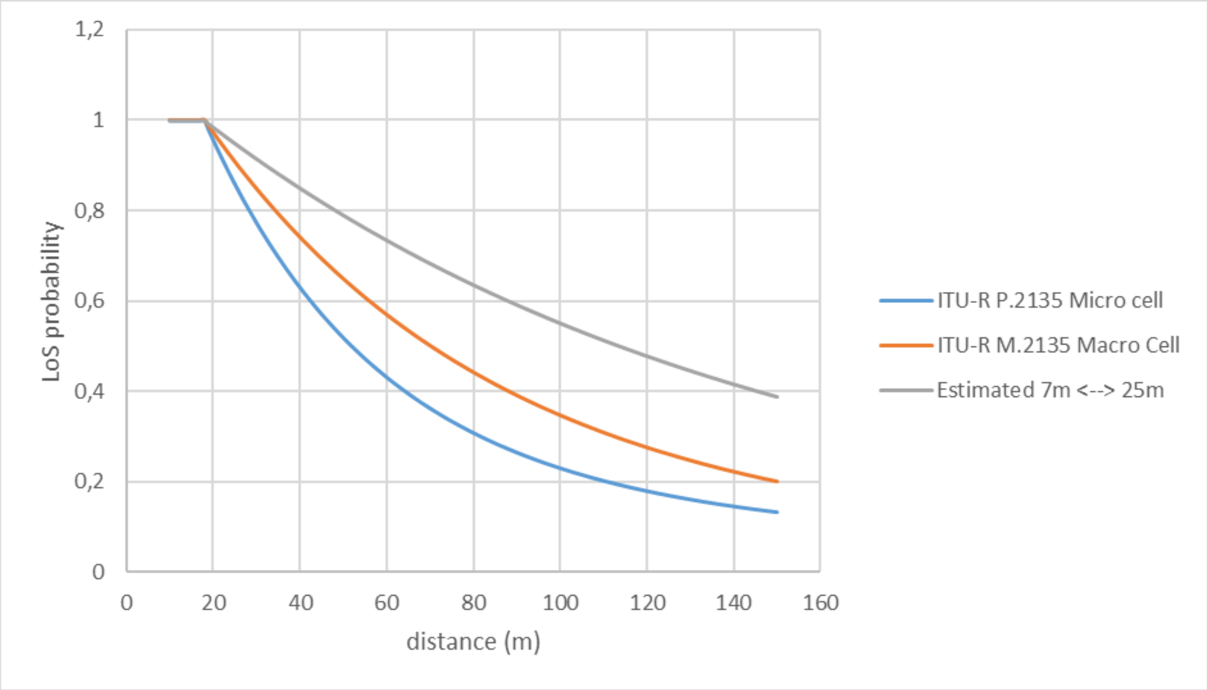


Figure 104: LoS probability according to Report ITU-R P.2135-1 and estimated function valid for antenna height

ANNEX 4: LIST OF REFERENCES

[1] ECC Report 200: “Co-existence studies for proposed SRD and RFID applications in the frequency band 870-876 MHz and 915-921 MHz”, approved September 2013

[2] Recommendation ITU-R P.452-16 (07/2015): “Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz”

[3] Commission Implementing Decision (EU) 2018/1538 of 11 October 2018 on the harmonisation of radio spectrum for use by short-range devices within the 874-876 and 915-921 MHz frequency bands

[4] ERC Recommendation 70-03: “Relating to the use of Short Ranges Devices (SRD)”, approved 1997, latest editorial update February 2022

[5] ECC Report 261: “Short Range Devices in the frequency range 862-870 MHz”, approved January 2017

[6] ETSI TR 103 435 v1.2.1 (2020-10): “System Reference document (SRdoc); Short Range Devices (SRD); Technical characteristics for Ultra Narrow Band (UNB) SRDs operating in the UHF spectrum below 1 GHz”

[7] ETSI EN 300 220-1 v3.1.1 (2017-02): “Short Range Devices (SRD) operating in the frequency range 25 MHz to 1 000 MHz; Part 1: Technical characteristics and methods of measurement”

[8] ECC Report 252: “Spectrum Engineering Advanced Monte Carol Analysis Tool – SEAMCAT Handbook Edition 2”, approved April 2016

[9] ECC Report 326: “Implementation conditions of SRD up to 500 mW in the first RFID interrogator channel centred at 916.3 MHz of the frequency band 915-919.4 MHz”, approved October 2021

[10] ETSI TR 103 526 V1.1.1 (2018-04): “System Reference document (SRdoc); Technical characteristics for Low Power Wide Area Networks Chirp Spread Spectrum (LPWAN-CSS) operating in the UHF spectrum below 1 GHz”

[11] Data sheets for Zebra UHF RFID Antennas

[12] ETSI TR 102 649-2 V1.3.1 (2012-08): “Electromagnetic compatibility and Radio spectrum Matters (ERM); Technical characteristics of Short Range Devices (SRD) and RFID in the UHF Band; System Reference Document for Radio Frequency Identification (RFID) and SRD equipment; Part 2: Additional spectrum requirements for UHF RFID, non-specific SRDs and specific SRDs”

[13] Recommendation ITU-R P.1411: “Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz”

[14] Report ITU-R M.2135-1 (12/2009): “Guidelines for evaluation of radio interface technologies for IMT-Advanced”

[15] Recommendation ITU-R P.2109: “Prediction of building entry loss”

[16] ECC Report 246: “Wideband and Higher DC Short Range Devices in 870-875.8 MHz and 915.2-920.8 MHz (companion to ECC Report 200)”, approved January 2017

[17] ETSI EN 303 204 v3.1.1 (2021-03): “Fixed Short Range Devices (SRD) in data networks; Radio equipment to be used in the 870 MHz to 876 MHz frequency range with power levels ranging up to 500 mW e.r.p.; Harmonised Standard for access to the radio spectrum”

[18] ETSI EN 302 208-2 V2.1.1 (2015-02): “Electromagnetic compatibility and Radio spectrum Matters (ERM); Radio Frequency Identification Equipment operating in the band 865 MHz to 868 MHz with power levels up to 2 W and in the band 915 MHz to 921 MHz with power levels up to 4 W; Part 2: Harmonised EN covering the essential requirements of article 3.2 of the R&TTE Directive”

[19] Recommendation ITU-R P.2108-1: “Prediction of clutter loss”

[20] COST Action 231 Digital mobile radio towards future generation systems: Final Report