



ECC Report **332**

Technical compatibility studies related to UAS (Unmanned Aircraft System) in the 1880-1920 MHz band

approved 28 January 2022

0 EXECUTIVE SUMMARY

The purpose of this ECC Report is to present results for the technical compatibility studies related to the UAS (Unmanned Aircraft System) for governmental use of command and control (C2) links as well as payload links in the 1880-1900 MHz and 1900-1920 MHz bands.

The UAS consists of ground station (GS) ("controller") and User Equipment (UE) ("drone"). Single GS-UE pair uses single frequency block with TDD (Time Domain Duplex) principle. The GS is assumed to be at ground level (1.5 m), and the maximum height of the UE is assumed to be 120 m.

Up to three drones are simultaneously deployed in an operational zone with radius of up to 5650 m in rural areas, and up to 1000 m in urban areas. Each drone is controlled by a dedicated GS. The drone and controller are assumed to constantly be in visual line of sight.

The frequency band 1880-1900 MHz is designated for DECT (Digital Enhanced Cordless Telecommunications) on licence-exempted basis, originally used for cordless phones, but which nowadays consists of huge variety of different enterprise and professional applications including voice and data services. The frequency band 1900-1910 MHz has been lately designated and harmonised for the RMR (Railway Mobile Radio). Adjacent frequency bands are harmonised for MFCN (Mobile Fixed Communication Network): 1710-1785/1805-1880 MHz and 1920-1980/2110-2170 MHz. This Report considers in-band and adjacent band co-existence studies between UAS and these systems.

This report suggests different interference mitigations possibilities for improving co-existence of UAS with systems operating in the band 1880-1920 MHz and in adjacent bands. Noting that the UAS controller to drone (C2) only requires low bitrate, it has been shown that lowering the power of the UAS GS to 10 dBm improves co-existence with all involved systems. This however comes with a higher susceptibility of the drone to interference (see co-existence with MFCN in section 5.3). Power control applied to the UAS drone also showed improved co-existence with other systems. Similar gain could be expected by also applying power control to the UAS controller, although this has not been studied. Co-existence gain can also be obtained by ensuring separation distances were feasible, or by imposing additional constraints on UAS spectrum emission (see FRMCS studies in Annex 13) and/or UAS spectrum selectivity (see MFCN studies in section 5.3). Potential use of DECT-2020 NR technology based UAS is expected to improve co-existence, but is has not been fully studied.

0.1 UAS AND DECT

MCL (Minimum Coupling Loss) study on impact from UAS GS and UE for DECT indoor, outdoor and DECT WLL (Wireless Local Loop, which assumes the drone is in the main lobe of a 12 dBi DECT antenna) is in Sections 5.1.2 and 5.1.6. Separation distance are calculated for two different DECT wanted signal levels -75 dBm and -65 dBm¹. An UAS GS transmit power of 10 dBm and 30 dBm, and an UAS UE transmit power of 28 dBm is assumed.

The results of the MCL studies are presented in Table 1.

¹ -65 dBm being a typical receiving level for low range indoor applications, while -75 dBm is considered for a typical receiving level for more sensitive indoor and outdoor applications. DECT devices have a sensitivity level down to -93 dBm.

Table 1: Summary of MCL separation distances between UAS using LTE and DECT

DECT Protection criterion	UAS GS or UE	UAS Tx power	DECT Rx power	DECT Indoor	DECT outdoor	DECT WLL
SINR of 21 dB	GS	10 dBm	-65 dBm	0.08 to 0.12 km	0.48 to 0.67 km	1.9 to 2.68 km
			-75 dBm	0.27 to 0.38 km	1.51 to 2.14 km	6.05 to 8.56 km
		30 dBm	-65 dBm	0.85 to 1.2 km	4.8 to 6.8 km	Not studied
			-75 dBm	2.68 to 3.82 km	15.1 to 21.4 km	Not studied
	UE	28 dBm	-65 dBm	0.36 to 0.53 km	2.14 to 3.03 km	8.52 to 12.06 km
			-75 dBm	1.20 to 1.70 km	6.77 to 9.60 km	27.0 to 37.88 km
Measured C/I	GS/UE	30 dBm	-65 dBm	0.05 to 0.75 km	0.53 to 3.3 km	Not studied
			-75 dBm	0.17 to 2.1 km	1.7 to 9.42 km	Not studied

SEAMCAT study (Annex 5) shows the probability that DECT is interfered, dBm for various values of DECT transmit power (between 4 and 24 dBm). Due to transmit power control, the worst situation is when the UE is furthest away from the GS. The following probabilities of interference were computed for outdoor DECT distributed between 0 and 300 m from the UAS GS:

- Equal or less than 10.3%, UAS GS transmit power of 10 dBm, urban environment;
- 14% (random distribution of DECT channels) and 42% (co-channel) , UAS GS transmit power of 30 dBm, urban environment;
- 80% (random distribution of DECT channels) and 100% (co-channel), UAS GS transmit power of 30 dBm, rural environment.

For indoor DECT, the following probabilities of interference were computed for indoor DECT distributed between 0 and 300m from the UAS GS:

- 0.8% (random distribution of DECT channels) and 2.2% (co-channel), UAS GS transmit power of 10 dBm, urban environment;
- 2.8% (random distribution of DECT channels) and 7.9% (co-channel), UAS GS transmit power of 30 dBm, urban environment.

Monte Carlo study (Annex 6) with residential DECT presented takes into account the instant Dynamic Channel Selection (iDCS) capability of DECT were carried out. It is assumed that 5% of DECT devices are located outdoor. In this context, DECT devices are able to avoid channels occupied by nearby UAS. The interference probability is

- between 0.1% and 2.3% when one drone is deployed in the 1880-1900 MHz band; ,
- between 0.2% and 6.5% when two drones are deployed in the 1880-1900 MHz band.

In the other direction, there is negligible interference from DECT devices to UAS GS and UE.

Monte Carlo study (Annex 6) with a call-center (indoor only) deployment of DECT in an urban environment shows that interference mainly comes from the UAS GS, and its probability can be lower than 1% for distances:

- higher than 100 m for single and double (two) UAS deployments and UAS GS transmit power of 30 dBm;
- as low as 10 m for single UAS deployments and UAS GS transmit power of 10 dBm;
- higher than 20 m for double (two) UAS deployment and UAS GS transmit power of 10 dBm.

The results presented here are based on UAS using LTE technology and its impact on legacy DECT, not on DECT-2020 NR. There are also initial studies (see section 6 and Annex 13) assuming UAS using DECT-2020 NR technology.

0.2 UAS AND RMR/FRMCS (FUTURE RAILWAY COMMUNICATION SYSTEM)

0.2.1 Co-channel operation

The MCL studies (Annex 11) show that a co-channel operation of UAS in the FRMCS band 1900-1910 MHz is not feasible and will lead to a significant interference risk towards the FRMCS operation. Under a free space loss model, all UAS in distances up to 354 km to a FRMCS BS will lead to a desensitization of at least 3 dB. In practice, the radio horizon would limit the separation distance but that does not change the conclusion. For the cab radio the separation distance is 63 km.

0.2.2 Adjacent channel operation

Monte Carlo study of the possible impact of an UAS deployed in the frequency band 1910-1920 MHz to an FRMCS deployment in the band 1900-1910 MHz is presented in Annex 10. Because of the symmetry of the FRMCS BEM and UAS SEM, these results at 1915 MHz also apply for interference from an UAS deployed at 1895 MHz. Simulations show that interference from UAS to FRMCS UE is negligible. On the contrary, interference to the FRMCS BS is more likely.

When using a UAS GS transmit power of 10 dBm, the probability of interfering the FRMCS BS is:

- less than 1% when the distance to the tracks is between 100 and 300 m in urban areas;
- less than 1% when the distance to the tracks is between 300 and 500 m in rural areas.

When using a UAS GS transmit power of 30 dBm, the probability of interfering the FRMCS BS is:

- less than 1% when the distance to the tracks is between 300 and 500 m in urban areas;
- around 10% when the distance to the tracks is between 500 and 1000 m in rural areas.

Considering the impact of the UAS UE, the probability of interfering the FRMCS BS is:

- lower than 1% when the UAS UE is between 300 and 500 m from the tracks (horizontal distance) if the range is limited to 500 m in rural areas (1000 m if 10 MHz channel is used);
- lower than 1% when the UAS UE is between 300 and 500 m from the tracks (horizontal distance) in urban areas.

0.3 UAS AND MFCN

0.3.1 Co-existence between UAS and MFCN below 1880 MHz

SEAMCAT simulations (Annex 5) show that important levels of interference may happen from MFCN DL (1860-1880 MHz) to both UAS aerial UE and GS 10 MHz channel operating in 1880-1890 MHz. Noting that these levels of interference translate to UE (drone) throughput loss between 87.7% and 99.5% and GS (controller) throughput loss between 50% and 88%, considering the UAS channel centered at 1885 MHz and a UAS in the range of 1000 m.

SEAMCAT simulations (Annex 5) show that the interference from MFCN DL (1860-1880 MHz) to both UAS aerial UE and GS 10 MHz channel operating in 1890-1900 MHz is reduced. If the UAS UE/GS receiver selectivity can be improved with an additional filter (ACS₂ = 66 dB), the interference from MFCN DL can be reduced, as shown in section 5.3.1.

Interference from UAS aerial UE to MFCN DL (UE reception) does not appear as a problem, including flying MFCN UE, as it translates to downlink throughput loss less than 0.1%.

Monte Carlo studies (Annex 8) taking into account UAS protection criterions in-line with UAS bitrate requirements (300 kbps for controller to drone, 5 Mbps for drone to controller) show an interference probability of the UE and the GS by MFCN DL lower than 10% (but the range has to be limited to 1000 m in rural environments), assuming a GS transmit power of 30 dBm.

MCL computations (section 5.3) has been performed to assess the interference from UAS GS to MFCN1800 DL (UE reception). For an UAS GS transmitting at 10 dBm, the I/N protection criterion of an MFCN UE is not exceeded at 50 m (urban environment) or 100 m (rural environment).. For an UAS GS transmitting at 30 dBm however, the MFCN UE protection criterion can be exceeded even when the separation distance is above 100 m.

Considering that, for a governmental drone, the highest data rate is transmitted from UAS UE to UAS GS, and in order to further protect the command and control signals received by UAS UE from MFCN interference, UAS command and control channel of a single drone deployment could be placed in the frequency range 1890-1900 MHz.

0.3.2 Co-existence between UAS and MFCN above 1920 MHz

SEAMCAT simulations (section 5.4) of interference from UAS UE to MFCN UL above 1920 MHz show athroughput loss between 8% and 25% for a UAS carrier frequency of 1917.5 MHz (5 MHz bandwidth).

SEAMCAT simulation show that interference from MFCN UEs to UAS GS and UAS UE translate to throughput losses between 0.1% to 1.6%.

Monte Carlo simulations (Annex 9) of interference from UAS UE show that the interference probability of the most impacted MFCN BS in the simulation area, considering a carrier frequency of 1915 MHz, can be limited to about 15% if the rural range is limited to 1000 m, and to 7% if the urban range is limited to 250 m.

MCL computations (section 5.4.1.3) has been performed to assess the interference from UAS GS to MFCN UL. For an UAS GS with a maximum transmit power of 10 dBm and maximum antenna gain of 5 dBi, the I/N protection criterion is generally not exceeded for a separation distance of 100 m (criterion is exceeded in urban settings using propagation model of Recommendation ITU-R P.1546 [24]). The interference from a UAS GS with a transmit power of 30 dBm, however, is above the MFCN UL protection criterion at a separation distance of 100 m.

Monte Carlo simulations (Annex 9) show that interference probability of the most impacted MFCN BS in the simulation area is around 0.4% for an UAS GS transmit power of 10 dBm², and around 5% to 6% for an UAS transmit power of 30 dBm.

0.4 UAS USING DECT-2020 NR

Initial MCL compatibility studies were carried in order to quantify the feasibility of deploying UAS using DECT-2020 in 1880-1900 MHz and 1910-1920 MHz.

Given the similarities between LTE and DECT-2020 waveforms, considering the lower transmit power of DECT-2020 (24 dBm), dynamic selection of time slots and frequency channels, and transmit power control on both UAS GS and UAS UE, it is expected that probabilities of interference of UAS using DECT-2020 NR to systems in adjacent bands would be lower than those computed using Monte Carlo studies with UAS using LTE.

² Here, when the UAS GS transmit power is reduced from 30 dBm to 10 dBm, it is assumed that the out of band radiations are also attenuated by 20 dB.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
3GPP	Third Generation Partnership Project
5G	Fifth Generation
ARQ	Automatic Repeat Request
BEL	Building Entry Loss
BEM	Block Edge Mask
BNetzA	Bundesnetzagentur, Federal Network Agency (Germany)
BS	Base Station
B_{UAS}	Bandwidth of Unmanned Aircraft System
C2	command and control
CEPT	European Conference of Postal and Telecommunications Administrations
DA2GC	Direct Air to Ground Communication
DCA	Dynamic Channel Allocation
DECT	Digital Enhanced Cordless Telecommunications
DL	Downlink
ECC	Electronic Communications Committee
e.i.r.p.	Equivalent Isotropic Radiated Power
EN	European Norm
ERC	European Radiocommunications Committee
ETSI	European Telecommunications Standards Institute
EU	European Union
FCA	Fixed Channel Allocation
FDD	Frequency Domain Duplex
FDMA	Frequency Domain Multiple Access
FRP	Fixed Radio Parts
FRMCS	Future Railway Mobile Communication System
GI	Guard Interval
GS	Ground Station
GSM	Global System for Mobile Communications
GSM-R	Global System for Mobile Communications – Railways
G_{UAS}	Gain of Unmanned Aircraft System
HPBW	Horizontal Half-Power Beamwidth
IMT	International Mobile Telecommunications
IoT	Internet of Things

Abbreviation	Explanation
ITU	International Telecommunication Union
IUC	International Union of Railways
LNA	Low Noise Amplifier
LTE	Long Term Evolution
MAC	Media Access Control
MCL	Minimum Coupling Loss
MFCN	Mobile/Fixed Communications Network
MIMO	Multiple In Multiple Out
mMTC	massive Machine Type Communications
NR	New Radio
OFDM	Orthogonal Frequency Division Multiplexing
PABX	Private Automated Branch Exchange (telephone system)
PL	Propagation Loss
PLMN	Public land mobile network
PMSE	Program Making and Special Events
PPDR	Public Protection and Disaster Relief
PP	Portable Parts
PSTN	Public Switched Telephone Network
P_{UAS}	Power of the Unmanned Aircraft System
QoS	Quality of Service
RED	Radio Equipment Directive
RIT	Radio Interface Technology
RMR	Railway Mobile Radio
Rx	Receiver
SEM	Spectrum Emission Mask
SINR	Signal to Interference and Noise Ratio
SNR	Signal to Noise Ratio
SOHO	Small Office / Home Office
SORA	Specific Operations Risk Assessment
SRD	Short Range Device
SRIT	Set of Radio Interface Technologies
TC	Technical Committee
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TPC	Transmit Power Control
TR	Technical Report
Tx	Transmitter

Abbreviation	Explanation
UAS	Unmanned Aircraft System
UE	User Equipment
UHF	Ultra High Frequency
UL	Uplink
UIC	International Union of Railways
ULE	Ultra Low Energy
UMTS	Universal Mobile Telecommunications System
URLLC	Ultra Reliable Low Latency Communications
WLL	Wireless Local Loop
MPEG-DASH	MPEG Dynamic Adaptive Streaming over HTTP
RTSP	Real-Time Streaming Protocol
RTP	Real-time Transport Protocol
RTCP	RTP Control Protocol

1 INTRODUCTION

The purpose of this ECC Report is to present results for the technical compatibility studies related to the governmental use of command and control (C2) links as well as payload links in the 1880-1900 MHz and 1900-1920 MHz bands by UAS (Unmanned Aircraft System) in the 1880-1920 MHz band:

- There are currently no dedicated frequencies for the use of UAS governmental (and professional) systems, therefore they rely mainly on common SRD frequencies (2.4 GHz and 5.7 GHz frequency bands), or on country specific frequencies, often on short term basis. In addition to this Report, ECC considers possibilities and conditions for the use of MFCN for UAS;
- The frequency band 1880-1900 MHz has been harmonised in Europe for unlicensed DECT use by and European Union Council Directive 91/287/EEC [9] and ERC Decision (98)22 [10]; also DECT is designated by ERC Decision (94)03 [8];
- The frequency band 1900-1910 MHz has been designated by ECC Decision (20)02 [35] for Railway Mobile Radio (RMR) on a non-exclusive basis;
- Adjacent frequency bands are harmonised for MFCN: 1710-1785 MHz/1805-1880 MHz by ECC Decision (06)13 [32] and 1920-1980 MHz/2110-2170 MHz by ECC Decision (06)01 [33].

In this Report, there are studies for in-band compatibility of UAS with DECT and FRMCS and adjacent-band compatibility studies with MFCN below 1880 MHz and above 1920 MHz.

2 FREQUENCY USAGE

2.1 FREQUENCY BAND 1880-1900 MHz

2.1.1 Frequency designation

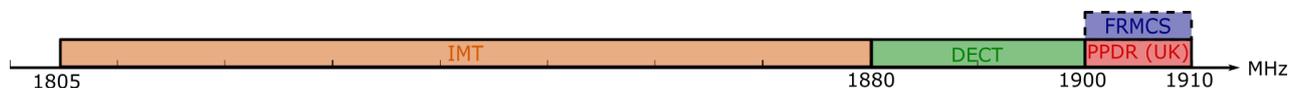


Figure 1: Current status in 1880-1900 MHz and adjacent bands

2.1.2 DECT

2.1.2.1 General description and regulatory aspects

The only band allocated to DECT in the CEPT member countries is 1880-1900 MHz.

Although originally conceived in the mid-80s as a multi-cell enterprise communication system, until the late 1990's, DECT was publicly known as a cordless telephone technology for commercial and domestic use, but increasingly in the last two decades, it has become a technology of choice for a large number of professional and enterprise voice-centric use-cases as well as IoT applications. It is approved as an IMT-2000 technology and has applied for ITU-approval as an IMT-2020 technology. Worldwide, upwards of 40 million new phone systems using DECT are sold each year with around 20 million systems in professional/enterprise markets including headsets, microphones, intercom systems. Professional/Enterprise usage is experiencing the main market growth and the highest user densities.

The standard for Digital Enhanced Cordless Telecommunications (DECT) was developed at the European Telecommunications Standards Institute (ETSI) in the early 1990s. The first version was released in 1992. DECT is a radio technology, which provides intra-building or campus connectivity, or access to an external network like the Public Switched Telephone Network (PSTN). Voice as well as data are supported. Since then DECT has widened to other usages as detailed below (see also Annex 1 and Annex 2). The technical specification for DECT is provided in ETSI EN 300 175-2 [4] (published 2017), whilst the presumption of conformity to the Radio Equipment Directive (RED) 2014/53/EU [5] can be obtained using ETSI EN 301 406 [6]. Given the significant number of co-existence studies realised at CEPT level, that involve DECT technology, ETSI has also published report ETSI TR 103 089 [7] which gathers additional parameters (published 2013, although this does not encompass the modern technology in use). Extensive use of this latter document will be made throughout this Report despite this TR does not represent modern systems.

For many years, the rule of thumb for range from DECT base station to DECT mobile has been 50 m indoors. This was based on the original commercial telephone technology that was designed for cost effective deployment (1997-2010). The limiting factor was non line of sight transmission with multipath interference. The ETSI EN 301 406 has minimum performance limits that reflect devices from the same period. The limits are contained within ETSI EN 300 175-2, section 6.

Modern well-designed radios have better than the minimum performance identified in ETSI EN 300 175-2. ETSI TR 103 089 already mentions this but ETSI TC-DECT is proposing to introduce an optional improved level of Rx sensitivity of -90 dBm or better that can be tested and manufacturers are now designing to that specification.

In order to achieve the quality of service required for high density installations, many systems reduce their maximum transmit power as low as 4 dBm to allow more base stations and portable units to be packed in an area or volume (i.e. multi-story buildings).

High density DECT systems use better sensitivity and antenna diversity to maintain radio link quality. In many situations density of deployment is more important than range and to optimise spectrum usage, systems will often limit their maximum power (this also improves battery run time).

The computing on DECT Rx sensitivity based on 50 m range in combination with a maximum 24 dBm RF output power is not valid for current high-density systems.

The common frequency band 1880-1900 MHz has been harmonised in Europe for unlicensed use by ERC Decision (94)03 [8] and European Union Council Directive 91/287/EEC [9] and subsequent ERC Decision (98)22 [10]. The infrastructure for DECT communications comprises one or several base stations called Fixed radio Parts (FP) which communicate with one or several handsets called Portable Parts (PP). Main applications of DECT technology can be defined as:

- **Residential Systems:** This represents the main application in residential and densely populated areas, typical a home telephone system;
In residential systems there usually multiple PP communicating with one FP (hence a unique cell). The base station can be stand alone or as is often the case integrated into the broadband Home Gateway. This will often include DECT smoke detectors and other DECT smart home sensors (e.g. security, lighting, heating, etc.). DECT is the technology of choice for many A/V baby monitors and panic alarms for elderly and infirm;
- **Professional/Enterprise Systems:** These systems are present in business premises including Offices, Education, Call Centres, Hospitals, emergency response centres, government buildings, large supermarkets, operating theatres, restaurants and support a variety of applications in aviation, power plants, health services, wearable epilepsy alarms, etc. Applications include telephony, alarm systems, vital signs communication, Intercom, conference systems, wireless microphones and headsets.
In Professional/Enterprise systems multiple base stations (FPs) are installed within the premises of an enterprise;
- **Internet of Things:** The Internet of Things, which includes smart city, smart home, and smart buildings is addressed by ULE (Ultra Low Energy DECT), which is a fully compatible DECT application following the harmonised requirements and standards;
- **PMSE and professional usage:** Some audio-PMSE applications (e.g. live/stage microphones on live events), where latency and other high-quality technical specifications are not too stringent, can be supported by DECT. DECT usage includes Audio for conferencing microphones or speakers and intercom (talkback) covering a permanent or temporary installation such as theatres or outdoor events (stadium, music festival, F1, demonstrations, Theme Parks etc.). Intercom/Talkback use has grown exponentially since the digital dividend reallocation.

In most enterprise and professional scenarios, DECT operates with full spectrum capacity, thus occupying all channels.

DECT Usage Scenarios are described in Annex 1 and Annex 2. Of particular importance is the use of DECT by Blue Light services as described in A1.6.

2.1.2.2 Recent Activities for DECT technology evolution within ETSI

ETSI TC-DECT has published TS 103 636 [11] standards parts 1 to 4 in July 2020 for release 1. In October 2021, DECT-2020 NR was recognised in Recommendation ITU-R M.2150 [44] as a component RIT fulfilling the IMT-2020 requirements of the IMT-2020 use scenarios URLLC and mMTC. The Set of Radio Interface Technology (SRIT) called "DECT 5G SRIT" is involving 3GPP NR and DECT-2020 NR.

DECT-2020 NR is a Radio Interface Technology (RIT) designed to provide a slim but powerful technology foundation for wireless applications deployed in various use cases and markets. This radio technology includes, but is not limited to Cordless Telephony, Audio Streaming Applications, Professional Audio Applications, consumer and industrial applications of Internet of Things (IoT) such as industrial and building automation and monitoring, utility and smart city applications, and in general solutions for local area indoor and outdoor deployments for Ultra-Reliable Low Latency Communication (URLLC) and massive Machine Type Communication (mMTC) as envisioned by ITU-R for IMT-2020 requirements.

In general, DECT-2020 NR as a technology foundation is targeted for local area wireless applications, which can be deployed anywhere by anyone at any time. The technology supports autonomous and automatic operation with minimal maintenance effort. Where applicable, interworking functions to Wide Area Networks (WAN). e.g. PLMN, satellite, fiber, and internet protocols foster the vision of a network of networks.

DECT-2020 NR can be used as a foundation for:

- Very reliable Point-to-Point and Point-to-Multipoint Wireless Links provisioning (e.g. cable replacement solutions);
- Local Area Wireless Access Networks following a star topology as in classical DECT deployment supporting URLLC use cases;
- Self-Organising Local Area Wireless Access Networks following a mesh network topology, which enables to support mMTC use cases.

DECT-2020 NR applies similar design principles as in legacy DECT and DECT ULE. The radio transmission bandwidths, radio frame lengths, and transmission slot lengths are aligned with legacy DECT to ensure efficient spectrum use and minimize interference. Especially the inherent feature of automatic interference management allows deployments without extensive frequency planning. The Mesh networking capability of DECT-2020 NR enables application-driven network topologies and deployments in e.g. IoT and mMTC use scenarios such that the link budget of the classical cellular base station to user equipment constellations is no longer a limiting factor.

The DECT-2020 NR physical layer supports frequency bands below 6 GHz. The physical layer employs Cyclic Prefix Orthogonal Frequency Division Multiplexing (CP-OFDM) combined with Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) in a Time Division Duplex (TDD) communication manner. The physical layer can support multiple numerologies, with different subcarrier spacings and corresponding Cyclic Prefix lengths and FFT sizes, allowing operation with different channel bandwidths, and can be optimised for operations in different frequencies bands and propagation environments. The physical layer supports advanced channel coding (Turbo coding) for both control and physical channels and Hybrid ARQ with incremental redundancy, enabling fast re-transmission schemes. Advanced channel coding together with Hybrid ARQ ensures very reliable communication for URLLC use. Additionally, the physical layer supports transmit and receiver diversity, as well as MIMO operations up to 8 streams.

Subcarrier spacing is defined by the subcarrier scaling factor μ , resulting either in 27 kHz, 54 kHz, 108 kHz or 216 kHz OFDM subcarriers spacing. In addition, the Fourier transform scaling factor β can be set to allow different transmission bandwidths for each configuration of the subcarrier spacing. This results in the support of nominal RF bandwidth from 1.728 MHz, 3.456 MHz, 6.912 MHz up to 221.184 MHz. The modulation schemes are BPSK, QPSK, 16 QAM, 64 QAM, 256 QAM and 1024 QAM.

The channel coding scheme for transport blocks in all physical channels is Turbo Coding with a coding rate of $R = 1/3$, two 8-state constituent encoders, and a turbo code internal interleaver. Trellis termination is used for the turbo coding. Before the turbo coding, transport blocks are segmented into byte-aligned segments with a maximum information block size. Error detection is supported by the use of 16 or 24 bit CRC.

The radio channel numbering scheme enables to assign channels from 450 MHz up to 5875 MHz organised into 19 different operating bands.

The transmitter's maximum allowed output power is up to +23 dBm and it can be adapted to different types of application requirements and support use cases like battery-powered, lower output power levels for industrial applications enabling the support for high equipment density use cases. The RX-TX transition time operates within the Guard Interval (GI), which enables a very competitive low latency operation with hybrid ARQ.

The receiver requirement defines the minimum performance for the radio device with hybrid ARQ support. The reference sensitivity levels for single RX devices scale depending on the operating bandwidths from -99.9dBm@1.728 MHz, -96.9 dBm@3.456 MHz, and -93.9dBm@6.912 MHz. RX diversity will further improve reference sensitivity.

Radio device measurement requirements are defined for channel access purposes and to support radio environment quality reporting for mobility and mesh routing purposes.

DECT-2020 NR (i.e. PHY layer numerology and MAC algorithms) is designed to enable co-existence with legacy DECT and DECT evolution in current frequency bands allocated to DECT. For co-existence between DECT-2020 NR systems, the standard supports advanced features enabling autonomous, time-accurate interference avoidance schemes.

Overview of the parts of DECT-2020 Technical Specifications

Release 1 of the DECT-2020 NR technical specifications defines the Radio Interface Technology (RIT) by the following parts:

- ETSI TS 103 636-1 [11]: "DECT-2020 New Radio (NR); Part 1: Overview";
- ETSI TS 103 636-2: "DECT-2020 New Radio (NR); Part 2: Radio Reception and Transmission requirements";
- ETSI TS 103 636-3: "DECT-2020 New Radio (NR); Part 3: Physical layer";
- ETSI TS 103 636-4: "DECT-2020 New Radio (NR); Part 4: Medium Access Control layer";
- ETSI TS 103 636-5: "DECT-2020 New Radio (NR); Part 5: DLC and Convergence layers".

ETSI TS 103 636 series will be accompanied by a feature and/or application-driven technical specification set, which is organised as a multi-part deliverable, delivering profiles and application-specific solutions for various industries:

- ETSI TS 103 636-1 presents the system and functional overview;
- ETSI TS 103 636-2 establishes the minimum RF requirements for DECT-2020 New Radio (NR) Radio Devices (RDs). These requirements cover both Fixed Termination point (FT) as well as Portable Termination point (PT). This document also provides a list of supported frequency bands;
- ETSI TS 103 636-3 specifies the physical layer (PHY) and interaction between PHY and MAC layer;
- ETSI TS 103 636-4 specifies MAC layer and interaction between MAC layer and physical layer and higher layers;
- ETSI TS 103 636-5 specifies the Data Link Control (DLC) and Convergence layers.

DECT-2020 NR Wireless Point-to-Point and Point-to-Multipoint Links

Wireless Point-to-Point links involve two radio devices communicating with each other. A typical application is the cable replacement by a wireless link established between two radio devices requiring communicating with each other.

Compared to wireline systems, wireless comes with the benefit that point to multipoint communication is an inherent feature of radio propagation so that the support of broadcast and multicast messages from one point to multiple points is just a matter of protocol.

The radio connection between two or more radio devices is enabled by one RD selecting to operate in FT mode (RDFT) and initiate radio resource coordination and beacon transmissions. Other RD(s) perform association procedures in PT mode (RDPT) with the RDFT. FT mode device (RDFT) controls the radio resources and PT mode device (RDPT) follows these commands.

DECT-2020 NR Local Area Wireless Access Networks in Cellular Network Topology

A single-cell network topology involves in principle two types of Radio Devices (RDs): an RD operates in FT mode (RDFT) as a base station, which is a component of the fixed network infrastructure, other RDs operate PT mode (RDPT).

RDFT is coordinating radio resources and serves as a communication cell by being the central communication point for, RDPT, which can be a portable device.

A multi-cell topology is a deployment of multiple RDFT as base stations in a fixed network infrastructure, where each base station is serving its own dedicated cell area and RDPT can move from one cell area to the other.

DECT-2020 NR Mesh network topology

In DECT-2020, mesh network devices can communicate directly to each other extending the range of the network and increasing the reliability of communication. The mode of the involved radio devices may change autonomously depending on the context of the communication. Each radio device can act as a node transmitting a message, as a node forwarding any message from another radio device, or as a node being the destination of a message. Each radio device can communicate directly (device to device) or, if not in range,

indirectly - via other radio devices establishing a communication route - with each other which is minimizing the probability of outage.

Mesh topology can support very high device densities and the autonomous routing decisions in each device provides the ability to adapt dynamically for mobile users in the system as well as varying interference conditions.

The key requirements how the scalability can be achieved are:

- All radio devices can route data. Whether RD is routing data is based on an autonomous decision of the RD. In addition, an RD may be configured to operate in PT mode only, e.g. due to low battery resources;
- Radio devices take local decisions of the radio resources, e.g. how radio devices use Hybrid ARQ, selects modulation and coding, and so forth in each radio link;
- Radio devices may change their operating mode between FT mode (RDFT), PT mode (RDPT), or both FT and PT modes (RDFT, PT), autonomously based on local decisions;
- No central coordinator(s), enabling the massive scale of the network;
- Radio device operating in RDFT or RDFT, PT mode coordinates local radio resources;
- Support of multiple backends connected Radio devices that operate in FT mode (RDFT);
- RDs can operate with multiple radio channels.

2.2 FREQUENCY BAND 1900-1920 MHZ

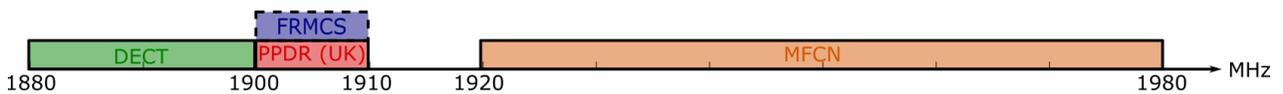


Figure 2: Current status in the band 1900-1920 MHz and adjacent bands

3 TECHNICAL CHARACTERISTICS

3.1 EXISTING SYSTEMS

3.1.1 DECT

3.1.1.1 DECT characteristics (professional intercom systems-outdoor)

Table 2 summarises the system parameters of DECT devices. These parameters are taken from the specification ETSI EN 300 175-2 [4] or from previous ECC Reports involving DECT technology. The specification does not make distinction between FRPs and PPs, so they are treated similarly in this Report.

DECT mobile devices can connect on the fly to the best fixed-point signal. In the cases where the fixed-point may be on a different floor which may lead to lower received signal, this could lead to received power level of -79 dBm, about 15 dB lower than the -65 dBm reference value defined in ETSI TR 103 089 [7].

DECT equipment sensitivity is lower than -83 dBm, as specified in ETSI EN 301 406 [6], whilst typical values of existing systems are lower than -95 dBm. Those low Rx sensitivity levels are required for several use cases / applications; e.g. considering body absorption effects and other RF effects.

Table 2: Technical parameters to be considered in compatibility studies (DECT)

Parameters	Values
Transmitter power	24 dBm
Frequency band	1880-1900 MHz
Antenna gain:	0 dBi
Radiated power e.i.r.p.	24 dBm
Bandwidth	1.152 MHz
Environment	Indoor, outdoor
Rx indoor receiving level	-65 dBm, -75 dBm (Note 1, 2),
Rx outdoor receiving level	-65 dBm (LoS); mean value with body absorption is -75 dBm (Note 2)
Rx sensitivity	ETSI EN 301 406: minimum -83 dBm (Note 4) Typical: -95 dBm
Emission mask	ETSI EN 300 175-2, section 5.5.1
Blocking mask	ETSI TR 103 089, table B.2 ETSI EN 300 172-2, table 5
C/(I+N) protection criterion	21 dB (Note 3)

Note 1: ECC Report 314 [12]

Note 2: -65 dBm is the received power level computed at 50 m using the propagation model provided in ETSI TR 103 089 annex B.4 [7] This propagation model can be used in both residential and enterprise scenarios. To reach 100 m using the propagation model, a level of -75 dBm has to be considered. -65 dBm is calculated for outdoor systems considering free space loss model and a distance of 350 m., It should be noted however, that the free space model (LOS) cannot be considered appropriate for typical outdoor installations as it does not include e.g. body absorption (ECC Report 286). In non-LoS situations lower receiving level than -75 dBm will be encountered ETSI TR 103 089 is the application of Recommendation ITU-R P.1238 [13] for office without floor separation between the FRP and the PP (at least one FRP per floor in professional use).

Note 3: At the start of a DECT reception the gain of the LNA will be set according to the signal strength received in the first bits of the preamble. Assuming a low signal from a DECT transmitter far away or shielded by walls, the LNA gain would be set high to receive the low signal correctly. Usually there is no DECT band filter in front of the LNA so any signal falling into the bandwidth of the LNA will raise the radio signal strength detected in the DECT receiver. The LNA gain will be reduced accordingly, not to overdrive the receiver input. So, any interferer falling into the LNA bandwidth will reduce the LNA gain, making it impossible to receive low DECT signals. DECT systems operated close from the sensitivity require higher protection criterion. This is not considered in the studies.

Note 4: ETSI EN 301 406 [6], clause 4.5.7.1.1

3.1.2 FRMCS

Future Railway Mobile Communication System (FRMCS) is a radio access technology for Railway Mobile radio (RMR). It has been designed as a successor for Global System for Mobile Communications - Railways (GSM-R) by the International Union of Railways (UIC). Much like GSM-R is built upon GSM, FRMCS will be built upon either 4G LTE E-UTRA or 5G NR (see ETSI TR 103 459 [14] and ETSI TR 103 333 [15]).

Co-existence between FRMCS in the band 1900-1920 MHz and systems in adjacent bands is the subject of ECC Report 314 [12]. In ECC Report 314, section 2.2.3, it is noted that, from a spectrum compatibility point of view, 4G LTE E-UTRA and 5G NR are mostly similar.

Table 3 and Table 4, as well as accompanying figures, give system and deployment-related parameters to be used in co-existence studies involving FRMCS, as extracted from ECC Report 314, section 2.4 [12]. It is assumed that FRMCS uses 4G LTE E-UTRA.

Table 3: FRMCS system parameters.

Parameter	Value
Operating band	E-UTRA TDD operating band n°33
Carrier centre frequency	1905 MHz
Channel bandwidth	10 MHz
TDD configuration	frame configuration 0 special subframe configuration 6
Maximum number of Resource Blocks	50
Occupied bandwidth	9 MHz
FRMCS BS	
Maximum output power per antenna connector	46 dBm
Unwanted emissions	Given in 3GPP TS 36.104 [16], table 6.6.3.2.1-6 (OBUE for Category B Option 1 BS) and table 6.6.4.2.1-1 (spurious emissions)
FRMCS on-board equipment	
Maximum output power per antenna connector	31 dBm
Unwanted emissions	Given by 3GPP TS 36.101, table 6.6.2.1.1-1 (SEM) and table 6.6.3.1-2 (spurious emissions) [17]
Noise Figure (NF)	5 dB
Noise floor per Resource Block	-116.4 dBm
Third-order intermodulation intercept point (IIP3)	-20.6 dBm

Table 4: FRMCS deployment-related parameters.

Parameter	Value
FRMCS radio sites	Same sites as for GSM-R coverage
Frequency reuse scheme	See Figure 4
Parameters of FRMCS BS	
Feeder loss	4 dB
Antenna height, azimuth and tilt	Two antennas per FRMCS site (see Figure 3). Same height, azimuth and tilt as already deployed antennas for GSM-R coverage
Antenna type	Passive sectoral panel antennas
Transmit diversity gain	3 dB
Antenna pattern	Recommendation ITU-R F.1336-5 [18], section 3.1.1 or 3.1.2 with improved side-lobe efficiency: $k_p = 0.7$; $k_a = 0.7$; $k_h = 0.7$; $k_v = 0.3$
Antenna pattern parameters	Peak gain = 18 dBi / Horizontal Half-Power Beamwidth (HPBW) = 65° / Vertical HPBW = 8.5°
Parameters of on-board equipment	
Hardware losses	3 dB
Antenna pattern	HUBER+SUHNER 1399.99.0121 see Figure 5.
Antenna height above the rail track	4 m

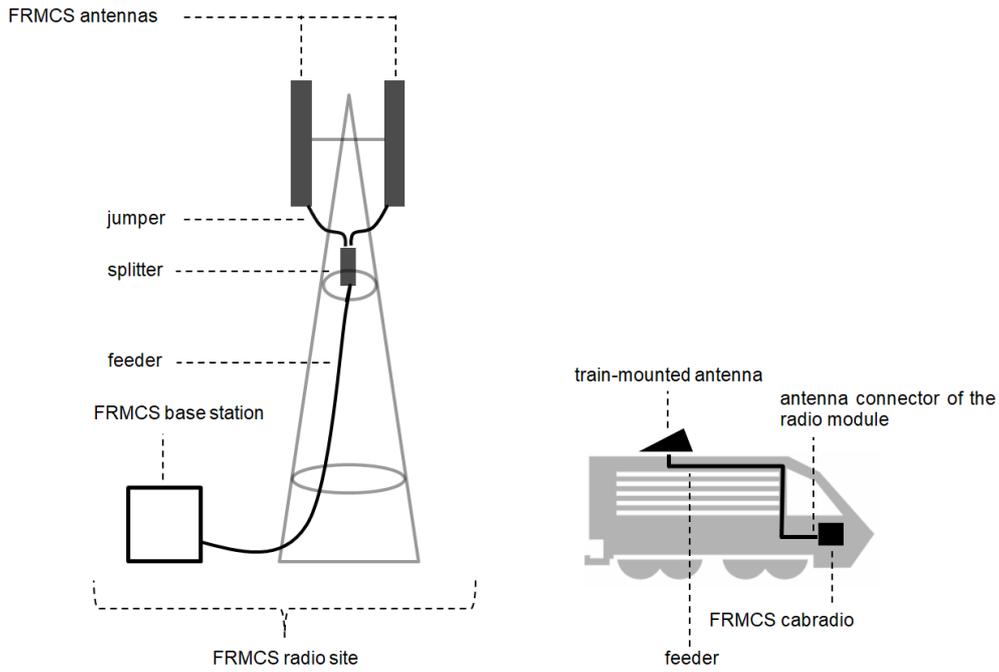


Figure 3: FRMCS radio site and on-board equipment

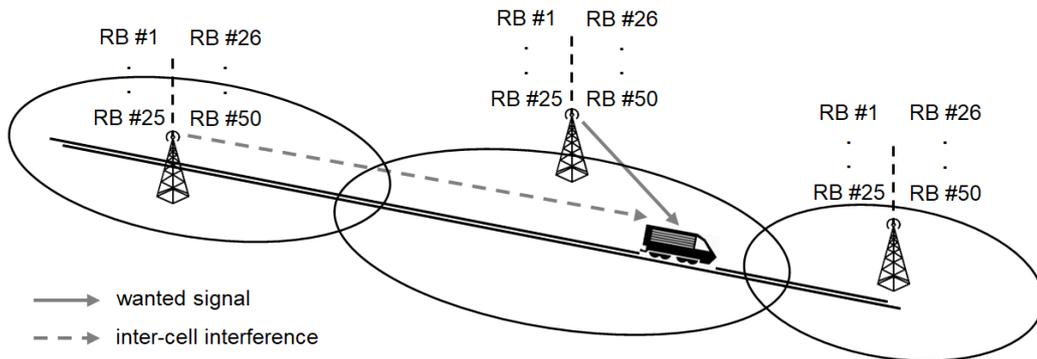


Figure 4: Assumed frequency reuse scheme and inter-cell interference

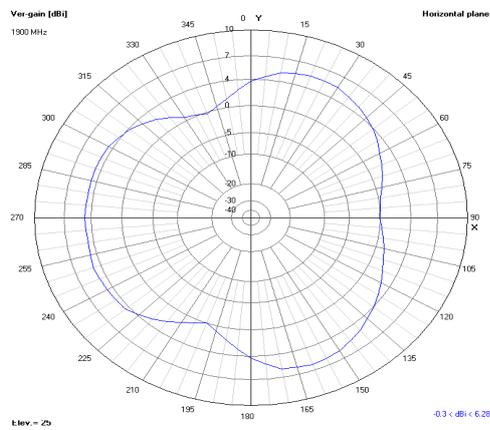


Figure 5: Horizontal radiation pattern of the train-mounted antenna at an elevation angle of 25° at f=1900 MHz

3.1.3 MFCN-IMT

Table 5 gives technical parameters to take into consideration for compatibility studies involving MFCN in the frequency bands 1805-1880 and 1920-1980 MHz. The former band is the downlink (DL) part of the MSR FDD band III. The latter band is the uplink (UL) part of the MSR FDD band I.

Table 5: IMT and MFCN technical parameters

Parameter	Value for band 1920-1980 MHz	Value for band 1805-1880 MHz	Note
Duplex mode	FDD		3GPP TS 37.104 [19]
Channel bandwidth (MHz)	10 MHz (DL: 2110-2120 MHz) (UL: 1920-1930 MHz)	20 MHz	LTE 10 MHz channel for band I and 20 MHz channel for band III
Centre frequency (MHz)	UL: 1925 MHz	DL: 1870 MHz	
MIMO	2x2		
BS Tx Power	43 dBm/10 MHz per MIMO branch 46 dBm/10 MHz per BS	43 dBm/20 MHz per MIMO branch 46 dBm/20 MHz per BS	Report ITU-R M.2292 [20]
Non-AAS BS Antenna	Recommendation ITU-R F.1336 [18] (recommends 3.1) $k_a = 0.7$ $k_p = 0.7$ $k_h = 0.7$ $k_v = 0.3$ Horizontal 3 dB beamwidth: 65 degrees Vertical 3 dB beamwidth: determined from the horizontal beamwidth by equations in Recommendation ITU-R F.1336.		Report ITU-R M.2292 [20]
BS Antenna height (m)	25 (urban) 30 (rural)		Report ITU-R M. M.2292 [20] ITU-R WP5D 416 A [36]
Non-AAS BS Antenna gain (dBi)	16 (urban) 18 (rural)		
Non-AAS BS Feeder loss (dB)	3		Report ITU-R M.2292 [20]
BS Downtilt	10° (urban) 3° (rural)		Report ITU-R M.2292 [20] (urban) Based on national data (rural)
BS Noise figure	3		Typical
BS ACLR (dB)	45		3GPP TS 37.104, table 6.6.4.1-1 [19]

Parameter	Value for band 1920-1980 MHz	Value for band 1805-1880 MHz	Note
BS ACS	See 3GPP TS 36.104, table 7.5.1-3 [16]		
BS in-band selectivity and blocking	See 3GPP TS37.104, section 7.4 [19]		
BS out-of-band blocking (dB)	See 3GPP TS37.104, table 7.5.1-1 [19]		
BS Spectrum emission mask	See 3GPP TS 37.104, table 6.6.2.1-1 [19]	See 3GPP TS 37.104 , table 6.6.2.2-1 [19]	
Site type	Tri-sectorial		
Cell Range (m)	500 (urban) 3000 (rural)		Report ITU-R M.2292 [20]
Handover Margin (dB)	1		ECC PT1(10)128 [37]
SINR Minimum (dB)	-10		ECC PT1(10)128 [37] 3GPP TR 36.942 [21]
UE Tx Power (dBm)	23		3GPP TS 36.101, table 6.2.2-1 [17]
UE Antenna height (m)	For normal UE in urban: 1.5, 4.5, 7.5, 10.5, 13.5, 16.5, 19.5 m For normal UE in rural: 1.5 m		6 floors are considered in urban area ECC Report 309 [22]
UE Antenna gain (dBi)	-3		Report ITU-R M.2292 [20]
UE Minimum Tx Power (dBm)	-40		ECC PT1(10)128 [37]
UE noise figure (dB)	6		Typical
UE ACLR (dB)	30		3GPP TS 36.101, table 6.6.2.3.1-1 [17]
UE ACS (dB)	33		3GPP TS 36.101 ,table 7.5.1-1 [17]
UE spectrum emission mask	See 3GPP TS 36.101, table 6.6.2.1.1-1 [17]		3GPP TS 36.101 [17]
UE blocking response	See 3GPP TS 36.101, section 7.6 [17]		3GPP TS 36.101 [17]
Number of UE/Cell	1	1	ECC PT1(10)128 [37]
UE and drone transmission power scheme	Power control Algorithm over -40...23 dBm output power range		3GPP TR 36.942, section 12.1.4 [21] Recommendation ITU-R M.2101-0
Indoor/outdoor UEs	Urban: 70% indoor, 30% outdoor Rural: 50% indoor, 50% outdoor		Report ITU-R. M.2292 [20]
UEs distribution per floor (urban)	Ground floor (h = 1.5 m): 25% 1st floor (h = 4.5 m): 25%		ECC Report 309 [22]

Parameter	Value for band 1920-1980 MHz	Value for band 1805-1880 MHz	Note
	2nd floor (h = 7.5 m): 10% 3rd floor (h = 10.5 m): 10% 4th floor (h = 13.5 m): 10% 5th floor (h = 16.5 m): 10% 6th floor (h = 19.5 m): 10%		
Protection criteria	I/N = -6 dB in reference cell Or 5% Throughput loss		

3.2 UAS

It is assumed that the C2 link and payload are working permanently during the operational mission, including flight information and quality of service about link budget (QoS). For the technical studies, two technologies are considered: LTE in TDD mode, and DECT-2020.. The C2 link and payload (data) are on the same link. UAS are to be controlled within line of sight (LoS).

3.2.1 Deployment parameters

Deployments follow one of the two following mission type: routine, or critical:

- Routine missions are limited in time (up to a few hours), are necessarily medium range (1 km), and covers different locations each time;
- Critical missions cover exceptional situations (such as natural disasters), where multiple actors (police, firefighters, etc.) would need aerial coverage.

Also receiver or antenna diversity is commonly used.

Table 6: Deployment parameters

Parameter	Value			
	Routine		Critical	
Mission type	Routine		Critical	
Environment	Medium range	Long range	Medium range	Long range
Operating range (m)	1000	5650 (note 3)	1000	5650 (note 3)
Maximum flight altitude (m above ground level)	120 (note 1)			
Maximum height for the controller (GS) (m)	1.5			
Number of drones per controller	1			
Maximum number of drones within the operating range	1		3 (note 2)	
Note 1: as per EU 2019/947 [29], for drones in the "Open" category. Note 2: in the critical mission scenario, each drone uses a different channel (see Figure 7). Note 3: allows for the coverage of 10 000 ha of forest.				

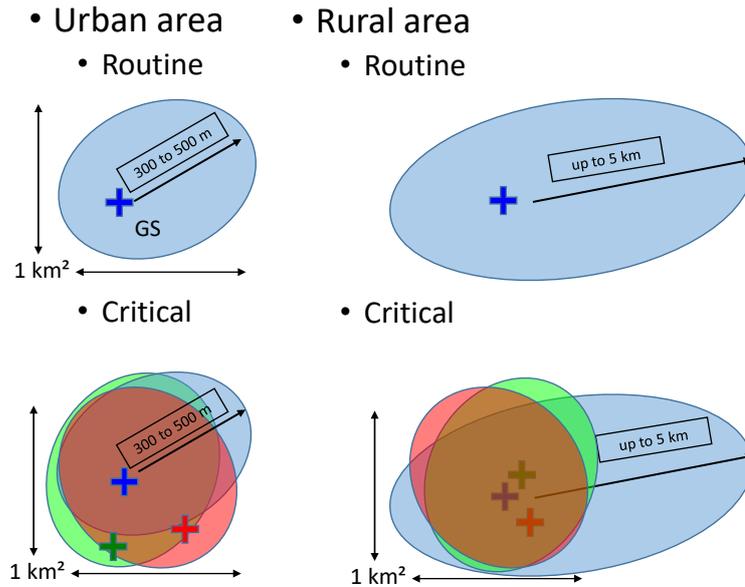


Figure 6: Scenarios for governmental UAS deployments

3.2.2 Technical parameters of LTE based UAS

The frequency band 1880-1920 MHz is referred as LTE operating band 39. Technical parameters are given in the Table below, and channelization can be found in Figure 7.

Table 7: Technical parameters to be considered in compatibility studies (LTE based)

Parameter	Ground station		Aerial vehicle	
	Long range	Medium range	Long range	Medium range
Environment	Long range	Medium range	Long range	Medium range
Maximum transmitted power	10 dBm 30 dBm		28 dBm with TPC	
Frequency band (MHz)	1880-1920			
Antenna gain (dBi)	5 (note 5, 7)	2 (note 6, 7)	0	
Maximum radiated power e.i.r.p. (dBm)	15, 35	12, 32	28	
Bandwidth (MHz)	5 / 10			
Noise figure (dB)	9 (note 2)			
Duplex mode	TDD			
TDD configuration	Frame configuration 0 (note 1)			
Target bitrate	300 kbps for C2, 5 Mbps for payload (note 3)			
SINR protection criteria (dB)	16 dB for 5 MHz channels 8 dB for 10 MHz channels		-2 dB for 5 MHz channels -6 dB for 10 MHz channels	
Spectrum emission mask (SEM)	3GPP 36.104, Table 6.6.3.2C-6 ACLR: 3GPP 36.104, table 6.6.2.1-2 (Note 8)		3GPP 36.101, table 6.6.3.2C-6 [17] ACLR: 3GPP 36.101, Section 6.6.2.2 (for power class 1 UEs) (Note 9) [17]	

Parameter	Ground station	Aerial vehicle
Blocking mask	3GPP 36.104: Table 7.2.1-2 (reference sensitivity levels), Table 7.5.1-6 (ACS) Table 7.6.1.1-c and 7.6.1.1-2 (CW blocking)	3GPP 36.101 [17]: Table 7.5.1-1 (ACS) Table 7.6.2.1-1 (out-of-band blocking) Table 7.2.3.1-1 (narrowband blocking)

Note 1: out of the 8 TDD frame configurations defined in 3GPP TS 36.211, table 4.2-2 [26], the configuration 0 allows for the highest uplink bitrate. This is relevant as downlink only supports C2, while uplink also supports telemetry and payload, when necessary.

Note 2: See 3GPP TR 36.777, table A.1-1 [27].

Note 3: 5 Mbps is considered sufficient for 30 fps full HD (1080p) video streaming using ITU-T H.264 [28] (see, for instance, <https://stream.twitch.tv/encoding/>). 5 Mbps is also considered sufficient for compressed video links (also using ITU-T H.264) involving racing drones (see section 9.2 "Video compression optimised for racing drones", section 9.2 [38])

Note 4: See 3GPP 36.101, section 6.6.2.2 (power class 1 UE) [17]

Note 5: Corresponds to the peak gain of quarter wavelength monopole antenna above a ground plate. Antenna diagrams taking into account non-finite ground plates can be found in "Radiation pattern and impedance of a quarter wavelength monopole antenna above a finite ground plane. 2012" [39]

Note 6: Corresponds to the peak gain of a half wavelength dipole antenna. Antenna patterns can be found in the classical literature, for instance, in "Analysis and Design", section 4.6 [40].

Note 7: As it is much easier for an operator to follow a drone in the azimuth plane than in the elevation plane, the antenna is rotated so that the plane of the radiation pattern having a quasi-constant gain coincide with the elevation plane.

Note 8: Original SEM is computed at 30dBm of transmit power. When using 10 dBm, the SEM is scaled accordingly (-20dB).

Note 9: Original SEM is computed at 30dBm of transmit power. When using lower transmit power due to TPC, the SEM is scaled accordingly.

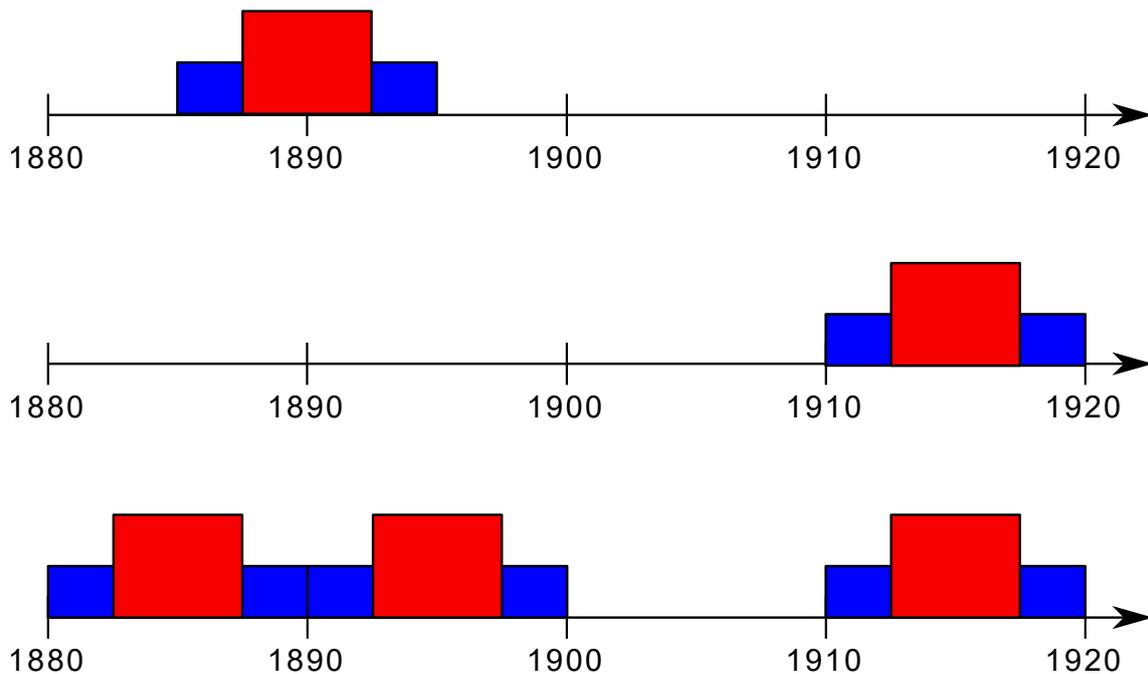


Figure 7: Example of a possible LTE-based UAS channelisation in critical scenario in the band 1880-1900 MHz, Blue rectangles symbolize 10 MHz channels, while red rectangles symbolizes 5 MHz channels. Simultaneous usage of the same carrier frequency by two UAS is not considered

3.2.3 Technical parameters of DECT-2020 based UAS

DECT-2020 is an evolution of DECT. It allows for higher bitrates and more flexible resource allocation. Its physical layer share similarities with 5G and LTE (turbo-coded CP-OFDM). However, it has multiple mechanisms allowing operation within interfered environments: dynamic channel selection (time slot and carrier frequency selection based on channel sensing), transmit power control and other-the-air time-synchronisation (allowing several DECT devices to operate isochronously, and thus minimise intra interference). Technical characteristics of UAS using DECT-2020 are given in Table 8.

Table 8: Technical parameters to be considered in compatibility studies (DECT-2020 based)

Parameter	Ground station		Aerial vehicle	
	Long range	Medium range	Long range	Medium range
Environment	Long range	Medium range	Long range	Medium range
Maximum transmitted power	24 dBm with TPC		24 dBm with TPC	
Frequency band (MHz)	1880-1920 (note 6)			
Antenna gain (dBi)	5 (note 2, 4)	2 (note 3, 4)	0	
Maximum radiated power e.i.r.p. (dBm)	29	26	24	
Bandwidth (MHz)	3.456			
Noise figure (dB)	7			
Target bitrate	300 kbps for C2, 5 Mbps for payload (note 1)			
SINR protection criteria (dB)	10 (note 5)		4 (note 5)	
Spectrum emission mask	ETSI TS 103 636-2, section 6.5.3, table 6.5.3-2 [11] (Note 8)			
Blocking mask	ETSI TS 103 636-2, section 7.4, table 7.4-1 [11] ETSI TS 103 636-2, section 7.5.3, tables 7.5.3-1, 7.5.3-2 and 7.5.3-3 [11]			
<p>Note 1: 5 Mbps is considered sufficient for 30 fps full HD (1080p) video streaming using ITU-T H.264 [28] (see, for instance, https://stream.twitch.tv/encoding/). 5 Mbps is also considered sufficient for compressed video links (also using ITU-T H.264) involving racing drones (see section 9.2 of Theolin, H., « Video compression optimized for racing drones », Luleå University of Technology, 2018).</p> <p>Note 2: Corresponds to the peak gain of quarter wavelength monopole antenna above a ground plate. Antenna diagrams taking into account non-finite ground plates can be found in "Radiation pattern and impedance of a quarter wavelength monopole antenna above a finite ground plane" [39]</p> <p>Note 3: Corresponds to the peak gain of a half wavelength dipole antenna. Antenna patterns can be found in the classical literature, for instance, "Analysis and Design" section 4.6 [40]</p> <p>Note 4: As it is much easier for an operator to follow a drone in the azimuth plane than in the elevation plane, the antenna is rotated so that the plane of the radiation pattern having a quasi-constant gain coincide with the elevation plane.</p> <p>Note 5: These SINR are based on results of ETSI MSGEVAL(21)002004, showing SNR requirements under a Rician channel, and assuming 2x2 MIMO, MCS-2 over 5 subslots for C2, and MCS-4 over 6 subslots for payload. Lower SNR can achieve same or higher bitrates under different channel condition, time slot allocation and MIMO configuration.</p> <p>Note 6: Channelization is defined in ETSI TS 103 636-2, section 5.4.2 [11]. In 1880-1900 MHz, 3 MHz DECT-2020 carrier frequencies are chosen in the center between two (non-2020) DECT channels.</p> <p>Note 8 : Original SEM is computed at 24 dBm of transmit power. When using lower transmit power (including when TPC is considered), the SEM is scaled accordingly.</p>				

4 COMPATIBILITY SCENARIOS

4.1 INBAND COMPATIBILITY SCENARIOS OF UAS WITH SYSTEMS IN 1880-1920 MHZ

4.1.1 Co-existence with DECT

In-band sharing between UAS and DECT.

Studying the impact of UAS in the 1880-1900 MHz band on:

- a) DECT systems for enterprise (Including Call Centres, Large hospitals, and Conference facilities). This will deal specifically with the conference use case.
- b) DECT systems for outdoor events. This will deal specifically with intercom systems for fixed outdoor events like Disneyland in Paris.
- c) DECT systems for race events.

4.1.1.1 Impact of drones (UAS) on enterprise systems using DECT

In many residential use cases, the density of users in the DECT air space is reasonable and channel occupancy is relatively low.

DECT in the enterprise is typified by professional use cases that imply high channel occupancy. Examples include call centres, hospitals and large open plan offices. These systems are designed to get the absolute maximum in channel availability.

DECT Indoor scenario - Enterprise/conferencing: the use case described Report (see Figure 9) shows four adjoining rooms in a conferencing area, each of which houses 20-24 microphones on 4 parallel tables where the participants are seated. Each room is equipped with 4 base stations fixed to the ceiling and 1 handheld/bodypack for the speaker.

Channel Occupancy

In the European DECT band (20 MHz of bandwidth means 240 available slots (10 carriers x 12 Channels *2(Duplex)), with 2 slots required for each microphone and additional handover slots. (e.g. base stations can support up to 8 connections per base)

In a typical call centre scenario, occupancy is above 90%, with some slots being re-used depending on availability.

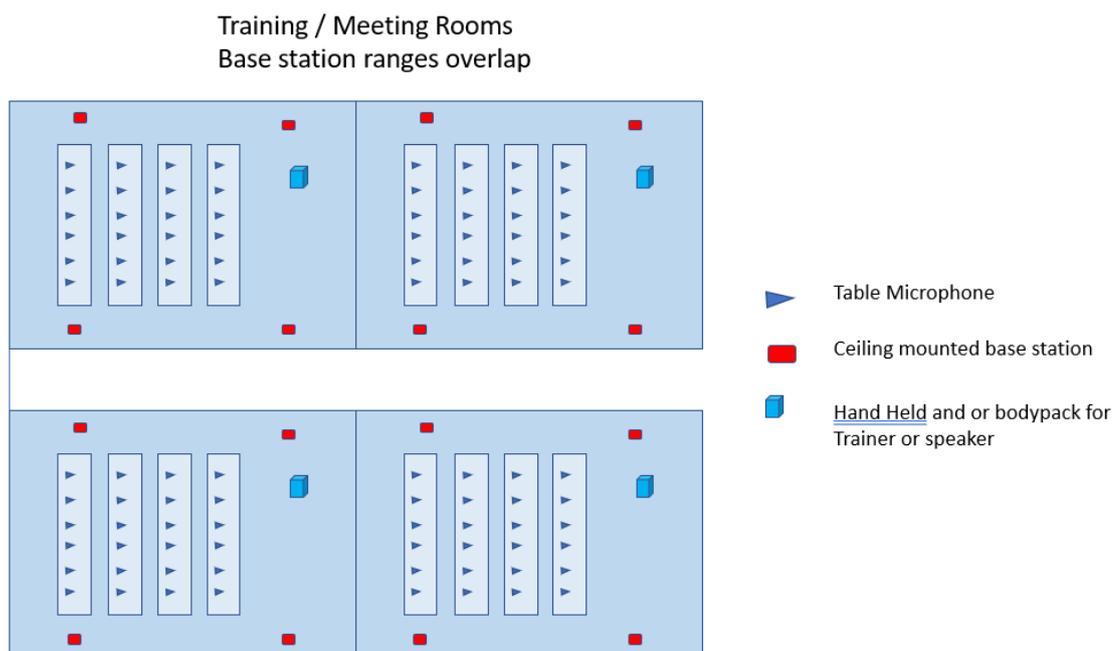


Figure 8: Typical Conferencing Use Case. 4 adjoining rooms each with 24 microphones and 4 base stations

Such conferencing solutions are used intensively by organisations placing a high premium on communication clarity, efficiency and security and include:

- Large global HQs and their global offices and subsidiaries;
- Banking and financial trading centres;
- EU and National government debating chambers;
- Legal courtrooms;
- Large university campuses;
- Large hotel and conference centres.

4.1.1.2 Impact of drones (UAS) on theme parks using DECT

DECT Outdoor scenario: the proposed use of drones by government agencies in case of emergency should carefully consider the impact of the drone on the event taking place (professional Intercom solutions: e.g. car race track and Theme Parks).

Staff on the ground are usually communicating with belt packs as described in Figure 9.

This outdoor scenario covers use-cases such as:

- Rail track maintenance intercom systems;
- Racing Events;
- Theme Parks;
- Music and Street Festivals;
- Political and other demonstrations;
- Blue light services (Fire and ambulance).

The impact on these DECT systems is shown in section 5.1.

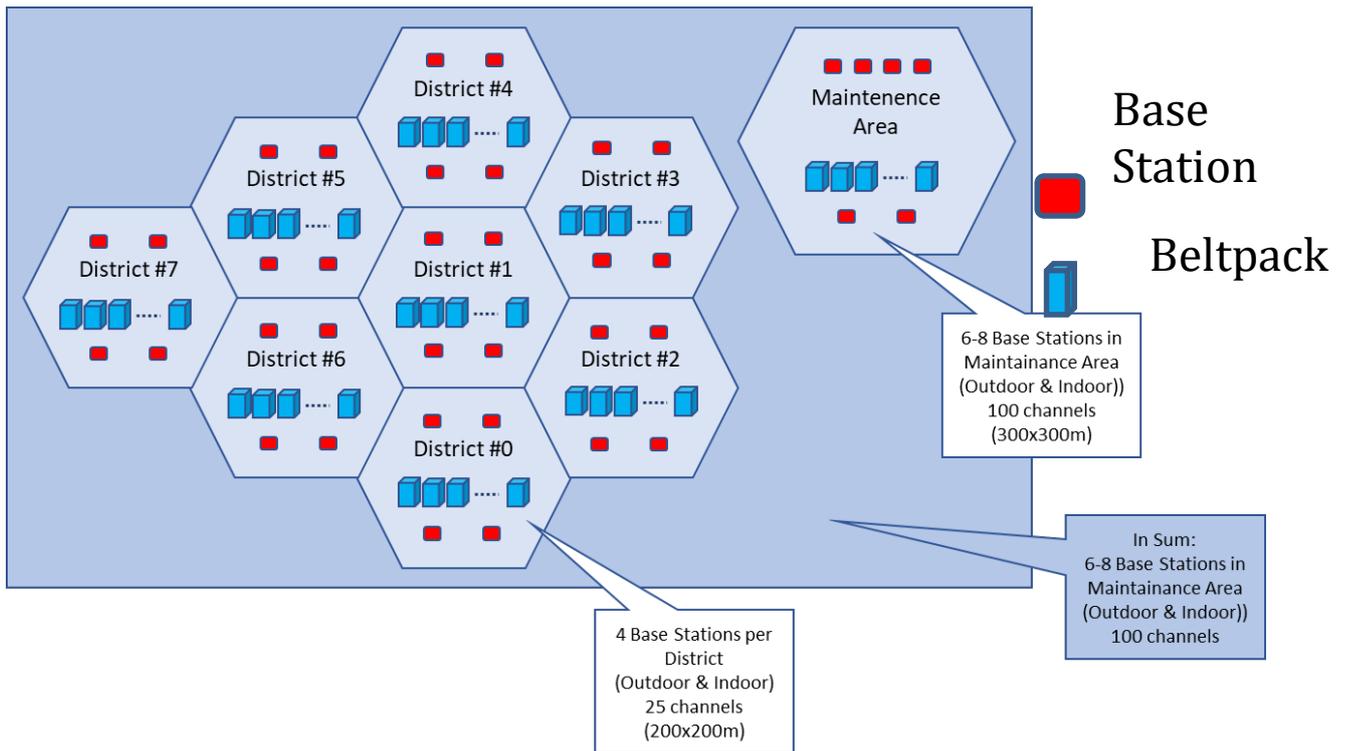


Figure 9: Theme Park case

The outdoor scenario depicted in Figure 9 relies on 100% DECT channel occupancy with the re-use of channels in some instances.

In the case of theme Parks (e.g. Disneyland, Europa Park etc.) with base station ranges overlapping, DECT communications are used for:

- Technical staff;
- Stewards;
- Artists;
- Blue light services (Emergency).

Values for Channel Occupancy:

- 1 slot for each;
- Beltpack plus handover slots;
- 375 channels (20 MHz, EU);
- Occupancy: 100% (re-use of channels in high density areas e.g. district 1);
- In this scenario, DECT will continue to be used in case of any emergency.

For some applications, channel occupancy is extremely high and 20 MHz is too little bandwidth. In such scenarios, the re-use of channels is normal.

4.1.1.3 Impact of drones (UAS) on car race events using DECT

Figure 10 illustrates the deployment of Beltpack DECT equipment during a Formula 1 event.

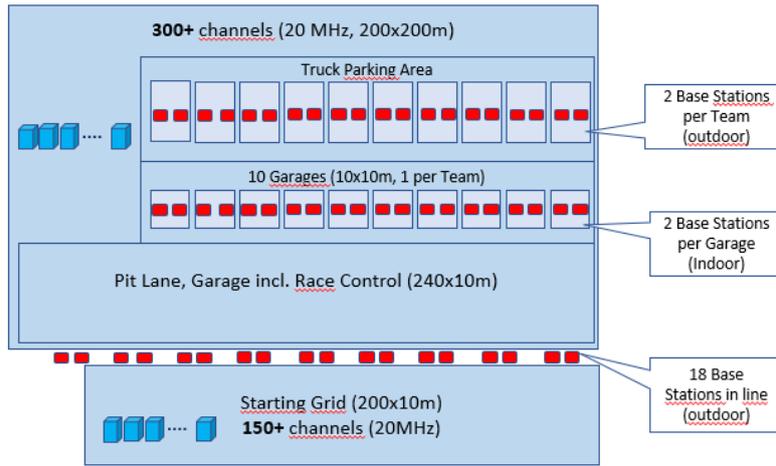


Figure 10: Outdoor scenario: F1 racing track

Communication channels are used for:

- Team;
- Officials;
- Blue light services (Emergency);
- Broadcast.

4.1.2 Co-existence with FRMCS

Adjacent band co-existence with FRMCS in 1900–1910 MHz..

4.2 ADJACENT BAND COMPATIBILITY SCENARIOS

4.2.1 Co-existence with MFCN below 1880 MHz

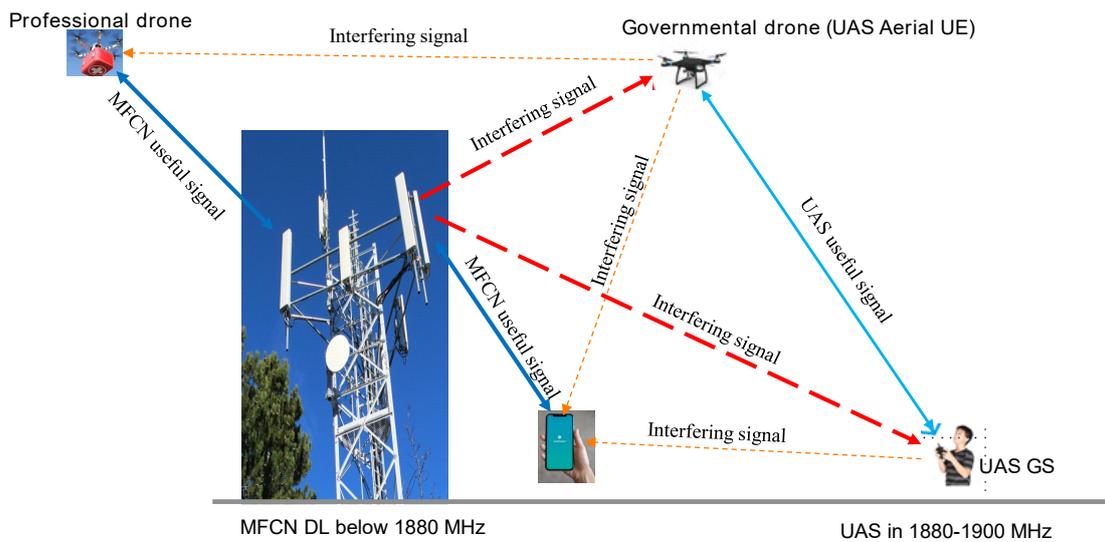


Figure 11: Adjacent band co-existence between UAS and MFCN at 1880 MHz

As shown in Figure 11, the adjacent band co-existence with IMT below 1880 MHz consists the following scenarios:

- Potential interference from MFCN DL operating in 1805-1880 MHz to UAS aerial UE operating in 1880- 1900 MHz;
- Potential interference from MFCN DL operating in 1805-1880 MHz to UAS GS (Ground station) operating in 1880-1900 MHz;
- Potential interference from UAS aerial UE operating in 1880-1900 MHz to MFCN DL operating in 1805- 1880 MHz including normal UE on the ground or within buildings, and/or flying aerial UE connected to MFCN base stations;
- Potential interference from UAS GS (Ground station) operating in 1880-1900 MHz to MFCN DL operating in 1805-1880 MHz including normal UE on the ground or within buildings, and/or flying aerial UE connected to MFCN base stations.

The simulation results of these potential interference scenarios are presented and analysed in section 5.3.

4.2.2 Co-existence with MFCN above 1920 MHz

The co-existence situation between UAS operating in 1900-1920 MHz and MFCN above 1920 MHz is illustrated in Figure 12.

As shown in Figure 12, two adjacent band interference scenarios from UAS operating in 1900-1920 MHz to MFCN operating in 1920-1980 MHz need to be investigated:

- Potential interference from UAS aerial UE operating in 1900-1920 MHz to MFCN UL operating above 1920 MHz;
- Potential interference from UAS GS (Ground station) operating in 1900-1920 MHz to MFCN UL operating above 1920 MHz.

The simulation results of these potential interference scenarios are presented and analysed in section 5.4.

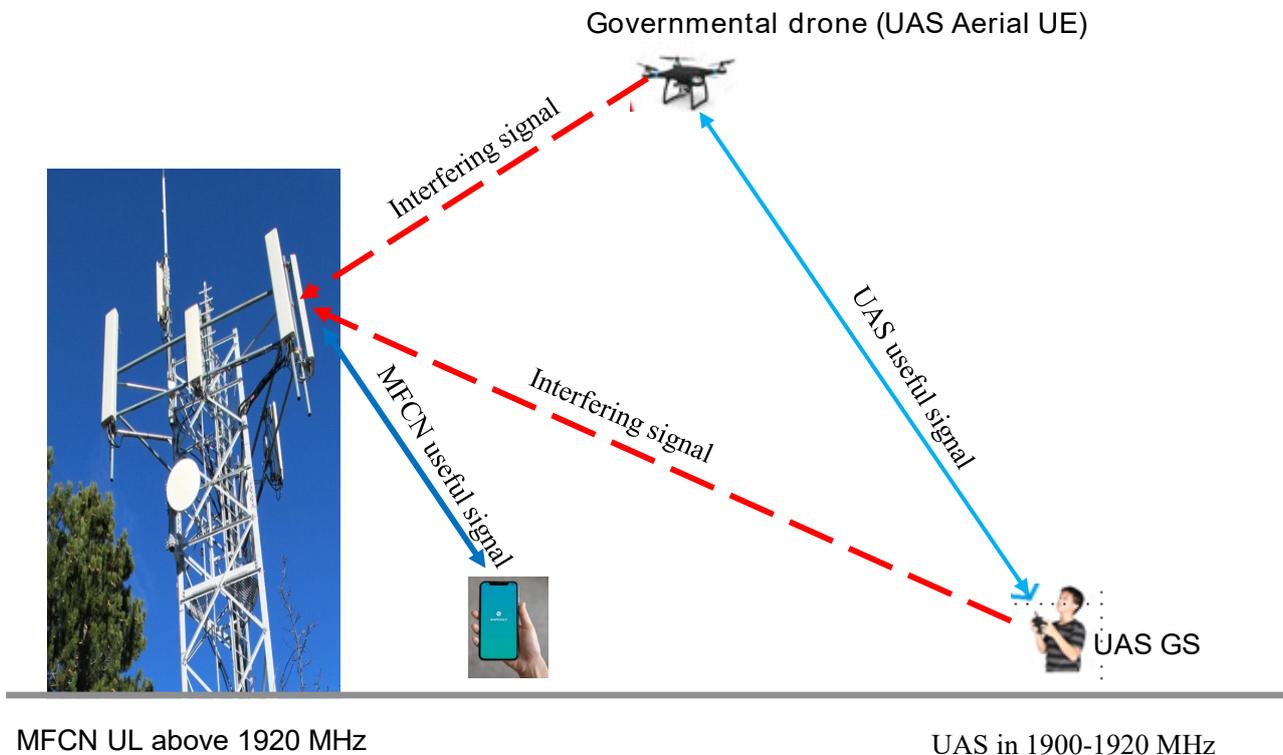


Figure 12: Adjacent band co-existence between UAS and MFCN at 1920 MHz

5 COMPATIBILITY STUDIES INVOLVING LTE-BASED UAS

5.1 SHARING BETWEEN LTE-BASED UAS AND DECT IN 1880-1900 MHZ

5.1.1 Introduction

This section provides results to the studies relating to the impact of UAS on DECT.

5.1.2 MCL study

In this study, MCL calculations were performed, resulting in separation distances between DECT receiver and UAS transmitter.

The assumptions are based on the values in sections 3 and 4. Two different bandwidths are considered for the UAS transmitter (5 MHz and 10 MHz).

The propagation model is free space.

Assumed DECT Rx signal level is -65 dBm and -75 dBm. $C/(N+I)$ is 21 dB.

Wall losses attenuations is 15 dB.

The following tables provide separation distances for the DECT indoor case.

Table 9: Separation distances - DECT indoor - UAS base station 10 dBm

Parameters	UAS – 10 MHz	UAS – 10 MHz	UAS – 5 MHz	UAS – 5 MHz
Tx power (dBm)	10	10	10	10
UAS Bandwidth (MHz)	10	10	5	5
Tx Power in DECT bandwidth (dBm)	0.61	0.61	3.62	3.62
UAS GS Gain (dBi)	5	5	5	5
e.i.r.p. in the DECT channel (dBm)	5.61	5.61	8.62	8.62
Rx DECT receiving level dBm)	-75	-65	-75	-65
$C/(I+N)$ (dB)	21	21	21	21
I (dBm)	-96.97	-86.09	-96.97	-86.09
Wall attenuation (dB)	15	15	15	15
MCL (dB)	86.61	76.61	89.62	79.62
Distance (km)	0.27	0.08	0.38	0.12

Table 10: Separation distances - DECT indoor - UAS Base station 30 dBm

Parameters	UAS – 10 MHz	UAS – 10 MHz	UAS – 5 MHz	UAS – 5 MHz
Tx power (dBm)	30	30	30	30
UAS Bandwidth (MHz)	10	10	5	5
Tx Power in DECT receiver (dBm)	20.61	20.61	23.62	23.62
Gain (dBi)	5	5	5	5
EIRP in the DECT channel (dBm)	25.61	25.61	28.62	28.62
Rx DECT receiving level (dBm)	-75	-65	-75	-65
C/(N+I) (dB)	21	21	21	21
I (dBm)	-96.97	-86.09	-96.97	-86.09
Wall attenuation (dB)	15	15	15	15
MCL (dB)	106.61	96.61	109.62	99.62
Distance (km)	2.68	0.85	3.82	1.20

Table 11: Separation distances - DECT indoor - UAS drone 28 dBm

Parameters	UAS – 10 MHz	UAS – 10 MHz	UAS – 5 MHz	UAS – 5 MHz
Tx power (dBm)	28	28	28	28
UAS Bandwidth (MHz)	10	10	5	5
Tx Power in DECT bandwidth (dBm)	18.61	18.61	21.62	21.62
UAS UE Gain (dBi)	0	0	0	0
e.i.r.p. in the DECT channel (dBm)	18.61	18.61	21.62	21.62
Rx DECT receiving level (dBm)	-75	-65	-75	-65
C/(I+N) (dB)	21	21	21	21
I (dBm)	-96.97	-86.09	-96.97	-86.09
Wall attenuation (dB)	15	15	15	15
MCL (dB)	99.61	89.61	102.62	92.62
Distance (km)	1.20	0.36	1.70	0.53

Table 12 and Table 13 provide separation distances for the DECT outdoor case.

Table 12: Separation distances - DECT outdoor - UAS base station 10 dBm

Parameters	UAS – 10 MHz	UAS – 10 MHz	UAS – 5 MHz	UAS – 5 MHz
Tx power (dBm)	10	10	10	10
UAS Bandwidth (MHz)	10	10	5	5
Tx Power in DECT bandwidth (dBm)	0.61	0.61	3.62	3.62
UAS GS Gain (dBi)	5	5	5	5
e.i.r.p. in the DECT channel (dBm)	5.61	5.61	8.62	8.62
Rx DECT receiving level (dBm)	-75	-65	-75	-65
C/(I+N) (dB)	21	21	21	21
I (dBm)	-96.97	-86.09	-96.97	-86.09
MCL (dB)	101.61	91.61	104.62	94.62
Distance (km)	1.51	0.48	2.14	0.67

Table 13: Separation distances - DECT outdoor - UAS Base station 30 dBm

Parameters	UAS – 10 MHz	UAS – 10 MHz	UAS – 5 MHz	UAS – 5 MHz
Tx power (dBm)	30	30	30	30
UAS Bandwidth (MHz)	10	10	5	5
Tx Power in DECT receiver (dBm)	20.61	20.61	23.62	23.62
Gain (dBi)	5	5	5	5
EIRP in the DECT channel (dBm)	25.61	25.61	28.62	28.62
Rx DECT receiving level (dBm)	-75	-65	-75	-65
C/(N+I) (dB)	21	21	21	21
I (dBm)	-96.97	-86.09	-96.97	-86.09
MCL (dB)	121.61	111.61	124.62	114.62
Distance (km)	15.07	4.80	21.35	6.79

Table 14: Separation distances - DECT outdoor - UAS drone 28 dBm

Parameters	UAS – 10 MHz	UAS – 10 MHz	UAS – 5 MHz	UAS – 5 MHz
Tx power (dBm)	28	28	28	28
UAS Bandwidth (MHz)	10	10	5	5
Tx Power in DECT bandwidth (dBm)	18.61	18.61	21.62	21.62
UAS UE Gain (dBi)	0	0	0	0
e.i.r.p. in the DECT channel (dBm)	18.61452	18.61452	21.62482	21.62
Rx DECT sensibility (dBm)	-75	-65	-75	-65
C/(I+N) (dB)	21	21	21	21
I (dBm)	-96.97	-86.09	-96.97	-86.09
MCL (dB)	114.61	104.61	117.62	107.62
Distance (km)	6.77	2.14	9.60	3.03

The following calculations were performed using DECT outdoor antenna gain of 12 dBi as per ETSI EN 301 406 [6]. Calculated for 5 MHz and 10 MHz interferers at -75 dBm and -65 dBm receiving level as per other calculations. These calculations can be considered as special case, but are essential for a comprehensive understanding of interference and necessary separation distances.

Table 15: Separation distances - DECT outdoor (12 dBi) - UAS base station 10 dBm

Parameters	UAS – 10 MHz	UAS – 10 MHz	UAS – 5 MHz	UAS – 5 MHz
Tx power (dBm)	10	10	10	10
UAS Bandwidth (MHz)	10	10	5	5
Tx Power in DECT bandwidth (dBm)	0.61	0.61	3.62	3.62
UAS GS Gain (dBi)	5	5	5	5
e.i.r.p. in the DECT channel (dBm)	5.61	5.61	8.62	8.62
Rx DECT receiving level (dBm)	-75	-65	-75	-65
C/(I+N) (dB)	21	21	21	21
I (dBm)	-96.97	-86.09	-96.97	-86.09
PMSE Gain (dBi)	12	12	12	12
MCL (dB)	113.61	103.61	116.62	106.62
Distance (km)	6.05	1.90	8.56	2.68

Table 16: Separation distances - DECT outdoor (12 dBi) - UAS drone 28 dBm

Parameters	UAS – 10 MHz	UAS – 10 MHz	UAS – 5 MHz	UAS – 5 MHz
Tx power (dBm)	28	28	28	28
UAS Bandwidth (MHz)	10	10	5	5
Tx Power in DECT bandwidth (dBm)	18.61	18.61	21.62	21.62
UAS UE Gain (dBi)	0	0	0	0
e.i.r.p. in the DECT channel (dBm)	18.61	18.61	21.62	21.62
Rx DECT receiving level (dBm)	-75	-65	-75	-65
C/(I+N) (dB)	21	21	21	21
I (dBm)	-96.97	-86.09	-96.97	-86.09
PMSE Gain (dBi)	12	12	12	12
MCL (dB)	126.61	116.61	129.62	119.62
Distance (km)	27.01	8.52	37.88	12.06

5.1.3 SEAMCAT study

The interference from UAS at 1890 MHz to DECT in 1880-1900 MHz has been studied in Annex 5. The results of the simulations can be summarised as follows:

Compatibility between UAS and outdoor deployment:

- Simulations show that as soon as the GS is nearby an area where there is deployment of DECT outdoor devices, the risk of interference is high. The situation is getting worse when considering 30 dBm GS transmitter compared to 10 dBm transmitter.

Compatibility between UAS and indoor deployment:

- Simulations show that as soon as the GS is nearby a building where there is deployment of DECT indoor devices, the risk of interference is high. The situation is getting worse when considering 30 dBm GS transmitter compared to 10 dBm transmitter. The level of interference is lower compared to the outdoor cases. The risk of interference is lower for the drone case compared to the GS case.

The number of drones deployed in a given area will impact on the risk of interference. Simulations are based on SEAMCAT tool, therefore a single victim was considered in the simulations. This implies that in dense deployment (outdoor event, DECT office deployment, hospital use), the risk of interference will apply to each of the stations belonging to the DECT network, resulting in a drastic degradation of the whole network.

It is important to highlight that if a given DECT slot in a system of (say) 40, experiences interference, that this can constitute a failure, or degradation of the whole system such that in the example where the probability of interference in any given slot of a DECT band is (say) 10%, then the probability of degradation of the whole system using 40 slots is $1 - (1 - 0.1)^{40} = 98.5\%$.

5.1.4 Monte Carlo study with residential DECT

Monte Carlo compatibility studies of DECT and UAS taking into account DECT dynamic channel selection (DCS) can be found in Annex 6 for one UAS centered at 1890 MHz, and Annex 7 for two UAS centered at 1885 MHz and 1895 MHz, respectively.

Both studies shows that DECT devices are able to effectively avoid channels occupied by nearby UAS.

Both studies show no interference from DECT to UAS GS and UAS UE. This is thanks to DECT DCS allowing DECT devices to select channels and time slots that does not interfere with nearby UAS GS and UE, resulting in negligible SINR degradation of the latters.

The probability of interference of the worst interfered DECT device is comprised between 0.1 and 2.3% when one UAS is deployed in the simulation area. The probability of interference of the worst interfered DECT device comprised between 0.2 and 6.5% when two UAS are deployed in the simulation area.

Table 17: Summary of UAS 1890 MHz interference probability to DECT in 1880-1900 MHz

Environment	Range (m)		Bandwidth (MHz)	UAS BS Tx power (dBm)	Max. UAS UE Tx power (dBm)	Probability for the worst impacted DECT device to be interfered (%)
Rural	5650		5	30	28	0.1
				10		0.1
			10	30		0.2
				10		0.1
	1000		5	30		0.2
				10		0.2
			10	30		0.6
				10		0.3
	500		5	30		1.3
				10		1.2
			10	30		2.3
				10		1.2
Urban	1000		5	30	0.2	
				10	0.4	
			10	30	0.4	
				10	0.4	
	300		5	30	1	
				10	0.5	
			10	30	0.6	
				10	0.7	
	250		5	30	1	
				10	1	
			10	30	1.1	
				10	0.6	

Table 18: Summary of two UAS at 1885 MHz and 1895 MHz interference probability to DECT in 1880-1900 MHz

Environment	Range (m)	Bandwidth (MHz)	UAS BS Tx power (dBm)	Max UAS UE Tx power (dBm)	Probability for the worst impacted DECT device to be interfered (%)
Rural	5650	5	30	28	0.2
			10		0.2
		10	30		0.2
			10		0.2
	1000	5	30		1
			10		1.3
		10	30		1.7
			10		1.1
	500	5	30		2.5
			10		4
		10	30		6.5
			10		6
Urban	1000	5	30	0.4	
			10	0.4	
		10	30	0.4	
			10	0.4	
	300	5	30	1.2	
			10	1.4	
		10	30	1.5	
			10	1.4	
	250	5	30	2.2	
			10	2.7	
		10	30	3	
			10	3.3	

5.1.5 Monte Carlo with professional DECT

Results of the studies of Annex 12 are summarised in Table 19 and Table 20. They show that the UAS UE as a low impact on DECT devices (interference lower than 1% in all scenarios), due to its power control algorithm. UAS GS very close to the building can affect several communications within the DECT building. Using 30 dBm of transmit power, and assuming LoS between UAS GS and the DECT building, a separation distance of 100 m (around 90 m from the walls) between the UAS GS and the center of the DECT building allows the interference probability to be under 1%. Using 10 dBm of transmit power, this distance drops to 20 m (around 10 m from the walls).

Table 19: Summary of Single LTE-based UAS GS in 1880-1900 MHz interference probability to professional DECT

UAS BS Tx power (dBm)	Bandwidth (MHz)	Max UAS UE Tx power (dBm)	UAS to center of DECT building distance (m)	Mean percentage of interfered DECT devices (%) – Distance to UAS GS	Mean percentage of interfered DECT devices (%) – Distance to UAS UE
30	5	28	10-20	10.1	0
			20-50	3.8	0
			50-100	1.3	0
			100-200	0.1	0
			200-300	0	0
	10		10-20	18.3	0
			20-50	8.9	0
			50-100	2.7	0
			100-200	0.2	0
			200-300	0	0
10	5		10-20	0	0
			20-50	0	0
			50-100	0	0
			100-200	0	0
			200-300	0	0
	10		10-20	0.1	0
			20-50	0	0
			50-100	0	0
			100-200	0	0
			200-300	0	0

Table 20: Summary of Two LTE-based UAS GS in 1880-1900 MHz interference probability to professional DECT

UAS BS Tx power (dBm)	Bandwidth (MHz)	Max UAS UE Tx power (dBm)	UAS to center of DECT building distance (m)	Mean percentage of interfered DECT devices (%) – Distance to closest UAS GS	Mean percentage of interfered DECT devices (%) – Distance to closest UAS UE
30	5	28	10-20	15.6	0
			20-50	7.7	0.1

UAS BS Tx power (dBm)	Bandwidth (MHz)	Max UAS UE Tx power (dBm)	UAS to center of DECT building distance (m)	Mean percentage of interfered DECT devices (%) – Distance to closest UAS GS	Mean percentage of interfered DECT devices (%) – Distance to closest UAS UE	
			50-100	2.5	0	
			100-200	0.3	0	
			200-300	0	0.1	
			10-20	29.3	0	
			20-50	13.6	0	
			50-100	4.9	0.1	
	10			100-200	0.6	0.1
				200-300	0	0.1
				10-20	1.1	0
				20-50	0	0
				50-100	0	0
				100-200	0	0
10	5		200-300	0	0	
			10-20	2.1	0	
			20-50	0	0	
			50-100	0	0	
			100-200	0	0	
			200-300	0	0	
	10			10-20	0	0
				20-50	0	0
				50-100	0	0
				100-200	0	0
				200-300	0	0
				200-300	0	0

5.1.6 MCL study using measured protection ratio

5.1.6.1 Introduction

This study describes the calculations of minimum protection distances in a worst-case scenario between the UAS systems (ground station, aerial vehicles) and the DECT systems (base stations and mobiles). The parameters Sensitivity (C_{DECT}) and protection ratio (carrier-to-interference ratio = C-I) were the results derived from the measurement campaign of the BNetzA given in ECC Report 314, annex 4 [12]. Therefore, the DECT parameters are those of the systems tested in the measurement campaign. All the other parameter, i.e. power, antenna gain, are as defined in this Report.

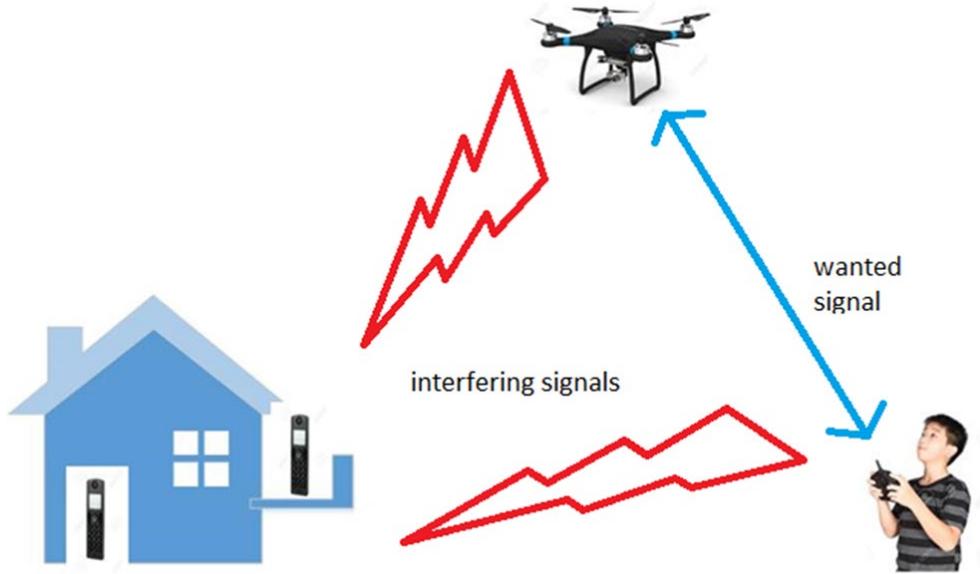


Figure 13: Scenario UAS interfere DECT base station / mobile

5.1.6.2 System parameters

Table 21: Parameters

Parameter	Unit	Value	Reference
Receiving level DECT mobile ($C_{DECT, mobile}$)	dBm	-74 (sensitive) / -65 (typical)	ECC Report 314 annex 4.4; chapter 6.3 [12]
Receiving level DECT base station ($C_{DECT, basestation}$)	dBm	-75 (sensitive) / -65 (typical)	ECC Report 314, annex 4.4; chapter 6.3 [12]
Measured protection ratio DECT ($C_{dB} - I_{dB}$)	dB	-2.5 up to 5.5	ECC Report 314, annex 4.4, table 28 [12]
$P_{UAS, groundstation}$	dBm	30	Table 3
$P_{UAS, aerial_vehicle}$	dBm	30	Table 3
Antenna gain UAS groundstation $G_{UAS, groundstation}$	dB	5 (rural) / 2 (urban) (LR=10 km / SR=1.5 km)	Table 3 LR = long range (rural) SR = short range (urban)
Antenna gain UAS areal vehicle $G_{UAS, areal_vehicle}$	dB	0 (Rural / Urban)	Table 3 LR = long range (rural) SR = short range (urban)
$P_{UAS, groundstation} (e. i. r. p.)$	dBm	35 / 32	Table 3
$P_{UAS, areal_vehicle} (e. i. r. p.)$	dBm	30	Table 3
Bandwidth	MHz	5 / 10	Table 3
Frequency band	MHz	1880-1900	Table 3

In Table 21, the system parameters are collected that are used in the following calculations. The DECT parameters (sensitivities, carrier-to-interference ratio) are those of the systems tested in the measurement

campaign from BNetzA, see ECC Report 314, annex 4 [12]. All the other parameters, i.e. power, antenna gain, bandwidths are as defined in this Report.

5.1.6.3 Propagation model

The free-space propagation is a fundamental reference for radio-engineering. The basic calculation of the free-space attenuation is provided in Recommendation ITU-R P.525 [25]. The basic transmission loss is referred to free-space attenuation between isotropic antennas and is a function of the frequency and the distance between the isotropic antennas.

$$L_{fs} = 32.45 + 20 \log_{10} \left(\frac{d}{km} \right) + 20 \log_{10} \left(\frac{f}{MHz} \right) \quad (1)$$

$$\frac{d}{km} = 10^{\left(\frac{L_{fs} - 32.45 - 20 \log_{10} \left(\frac{f}{MHz} \right)}{20} \right)} 10^{\left(\frac{L_{fs} - 32.45 - 20 \log_{10} \left(\frac{f}{MHz} \right)}{20} \right)} \quad (2)$$

Noting that the free space attenuation is independent of the antenna heights and is depending only on the frequency and direct radio path considered, i.e. no multi-path propagation is addressed.

Recommendation ITU-R P.2109 [23] on Building Entry Loss (BEL) provides a method for estimating building entry loss at frequencies between about 80 MHz and 100 GHz. The method is not site-specific, and is primarily intended for use in sharing and compatibility studies. This is a rather new Recommendation, adopted in 2017.

The penetration loss at 1900 MHz is about 13 dB for traditional houses and 28 dB for thermally efficient houses. The chosen value is 13 dB and 20 dB.

5.1.6.4 MCL analysis

The interference on DECT base station / mobile in outdoor / indoor case is determined with MCL methodology for a worst-case scenario. The parameters for DECT systems are based on measurement campaign from BNetzA, see ECC Report 314, annex 4 [12]. The basic transmission loss (Path Loss) $L_{PL,Rural}$, $L_{PL,Urban}$ can be determined by

$$L_{fs,x,z} = \frac{P_{UAS,x}}{B_{UAS}} + G_{UAS,z} - BEL - \frac{I_{DECT,y}}{B_{UAS}} \quad (3)$$

The parameter $\left(\frac{C_{DECT,y}}{B_{DECT}}; \left(\frac{C_{DECT,y}}{B_{DECT}} - \frac{I_{LTE,FDD}}{B_{LTE,10MHz}} \right) \right)$ of interference criteria for DECT systems $I_{DECT,y}$ are given from measurement campaign (ECC Report 314, annex 4 [12]) is calculated by

$$\text{For } B_{UAS} = 10 \text{ MHz: } \frac{I_{DECT,y}}{B_{UAS}} = \frac{C_{DECT,y}}{B_{DECT}} - \left(\frac{C_{DECT,y}}{B_{DECT}} - \frac{I_{LTE,FDD}}{B_{LTE,10MHz}} \right) \quad (4)$$

$$\text{For } B_{UAS} = 5 \text{ MHz: } \frac{I_{DECT,y}}{B_{UAS}} = \frac{C_{DECT,y}}{B_{DECT}} - \left(\frac{C_{DECT,y}}{B_{DECT}} - \frac{I_{LTE,FDD}}{B_{LTE,10MHz}} \right) - Bcf \quad (5)$$

The bandwidth conversion factor Bcf is used for UAS bandwidth of 5 MHz ($B_{UAS} = 5 \text{ MHz}$) to convert the carrier-to-interference ratio $(C - I)_{dB} = \left(\frac{C}{I} \right)_{dB}$ from the 10 MHz bandwidth of LTE interference signal $B_{LTE,10MHz}$ into a 5 MHz bandwidth $B_{LTE,5MHz}$ signal. This is possible, when the characteristics of the interference signal are the same. That means, that carrier-to-interference ratios are 3 dB higher as the values of the measurement campaign from BNetzA, ECC Report 314, annex 4 [12].

$$Bcf = 10\log_{10} \left(\frac{B_{LTE,10MHz}}{B_{LTE,5MHz}} \right) = 3 \text{ dB} \tag{6}$$

Where:

- L_{fs} = Basic transmission loss (free – space);
- $P_{UAS,x}$ = Transmitted power for Tx UAS (x = ground station, aerial vehicle) in dBm;
- B_{UAS} = Occupied Bandwidth for UAS Systems in MHz;
- $G_{UAS,z}$ = Antenna gain for Tx UAS (z = rural, urban) in dBi;
- BEL = Building entry loss in dB;
- $I_{DECT,y}$ = Interference criteria for Rx DECT (y = base station, mobile systems) in dBm;
- Bcf = Bandwidth conversion factor for UAS bandwidth of 5 MHz in dB;
- B_{DECT} = Occupied Bandwidth of DECT Systems in MHz;
- $C_{DECT,y}$ = Sensitivity for Rx DECT systems in dBm;
- $(C - I)_{dB} = (C/I)_{dB}$ = Protection ratio (Carrier – to – Interference ratio) in dB;
- $I_{LTE,FDD}$ = LTE interference signal from the measurement campaign by the BNetzA;
- FDD = Frequency Division Duplex Mode;
- $B_{LTE,10MHz}$ = 10 MHz bandwidth of the LTE interference signal;
- $B_{LTE,5MHz}$ = 5MHz bandwidth of the LTE interference signal;
- x = ground station, aerial vehicle;
- z = rural, urban;
- y = base station, mobile.

Table 22: Summary of the results – outdoor scenarios

Scenario Outdoor	Occupied Bandwidth UAS [MHz]	Antenna Gain UAS [dB]	Distances [km] for sensitive DECT-Systems with Rx power of -75 dBm (base station) / -74 dBm (mobile station)	Distances [m] for typical DECT Systems with Rx power of -65 dBm
UAS,ground station interfere to DECT,y (rural)	10	5	2.98 to 6.67	0.94 to 2.36
UAS,ground station interfere to DECT,y (urban)	10	2	2.11 to 4.72	0.67 to 1.67
UAS,aerial vehicle interfere to DECT,y (rural, urban)	10	0	1.67 to 3.75	0.53 to 1.33
UAS,ground station interfere to DECT,y (rural)	5	5	4.21 to 9.42	1.33 to 3.34
UAS,ground station interfere to DECT,y (urban)	5	2	2.98 to 6.67	0.94 to 2.37
UAS,aerial vehicle interfere to DECT,y (rural, urban)	5	0	2.37 to 5.30	0.75 to 1.88

y = mobile / base station

Note: All scenarios are related to Recommendation ITU-R P.525

Table 23: Summary of the results – indoor scenarios

Scenario Indoor	Building Entry Loss	Occupied Bandwidth UAS [MHz]	Antenna Gain UAS [dB]	Distances [m] for sensitive DECT-Systems with Rx power of -75 dBm (base station) / -74 dBm (mobile station)	Distances [m] for typical DECT Systems with Rx power of -65 dBm
UAS,ground station interfere to DECT,y (rural)	13	10	5	0.67 to 1.49	0.21 to 0.53
UAS,ground station interfere to DECT,y (urban)	13	10	2	0.47to 1.06	0.15 to 0.37
UAS,aerial vehicle interfere to DECT,y (Rural,urban)	13	10	0	0.37 to 0.84	0.12 to 0.30
UAS,ground station interfere to DECT,y (rural)	13	5	5	0.94 to 2.11	0.30 to 0.75
UAS,ground station interfere to DECT,y (urban)	13	5	2	0.67 to 1.59	0.21 to 0.53
UAS,aerial vehicle interfere to DECT,y (Rural, Urban)	13	5	0	0.53 to 1.19	0.17 to 0.42
UAS,ground station interfere to DECT,y (rural)	20	10	5	0.30 to 0.67	0.09 to 0.24
UAS,ground station interfere to DECT,y (urban)	20	10	2	0.21 to 0.47	0.07 to 0.17
UAS,aerial vehicle interfere to DECT,y (Rural, Urban)	20	10	0	0.17 to 0.37	0.05 to 0.13
UAS,ground station interfere to DECT,y (rural)	20	5	5	0.42 to 0.94	0.13 to 0.33
UAS,ground station interfere to DECT,y (Urban)	20	5	2	0.30 to 0.67	0.09 to 0.24
UAS,aerial vehicle interfere to DECT,y (Rural, Urban)	20	5	0	0.24 to 0.53	0.074 to 0.19

y = mobile / base station
Note: All scenarios are related to Recommendation ITU-R P.525

5.1.7 Conclusions of Sharing between UAS and DECT MCL study

MCL (Minimum Coupling Loss) study on impact from UAS GS and UE for DECT indoor, outdoor and DECT WLL (Wireless Local Loop, which assumes the drone is in the main lobe of a 12 dBi DECT antenna) is in

sections 5.1.2 and 5.1.6. Separation distance are calculated for two different DECT wanted signal levels -75 dBm and -65 dBm³. An UAS GS transmit power of 10 dBm and 30 dBm, and an UAS UE transmit power of 28 dBm is assumed.

The results of the MCL studies are presented in Table 24.

Table 24: Summary of MCL separation distances between UAS using LTE and DECT

DECT Protection criterion	UAS GS or UE	UAS Tx power	DECT Rx power	DECT Indoor	DECT outdoor	DECT WLL
SINR of 21 dB	GS	10 dBm	-65 dBm	0.08 to 0.12 km	0.48 to 0.67 km	1.9 to 2.68 km
			-75 dBm	0.27 to 0.38 km	1.51 to 2.14 km	6.05 to 8.56 km
		30 dBm	-65 dBm	0.85 to 1.2 km	4.8 to 6.8 km	Not studied
			-75 dBm	2.68 to 3.82 km	15.1 to 21.4 km	Not studied
	UE	28 dBm	-65 dBm	0.36 to 0.53 km	2.14 to 3.03 km	8.52 to 12.06 km
			-75 dBm	1.20 to 1.70 km	6.77 to 9.60 km	27.0 to 37.88 km
Measured C/I	GS/UE	30 dBm	-65 dBm	0.05 to 0.75 km	0.53 to 3.3 km	Not studied
			-75 dBm	0.17 to 2.1 km	1.7 to 9.42 km	Not studied

5.2 SHARING BETWEEN LTE-BASED UAS AND FMRCs AT 1900-1910 MHz

5.2.1 Requirements on FRMCS cab-radios

The maximum interfering power P that an FRMCS cab-radio must be able to deal with at its antenna connector can be calculated from formula (7):

$$P = P_{out} + G_{UAV} - PL + G_{cab-radio} - HWlosses \tag{7}$$

Where:

- $P_{out} = 30$ dBm is the maximum output power (see Table 17);
- $G_{UAV} = 5$ dBi is the peak gain at the UAS antenna (see Table 17);
- PL is the path loss between the UAV and the FRMCS antenna;
- $G_{cab-radio} = 6.6$ dBi is the peak gain of the FRMCS antenna in this frequency band (see Figure 5);
- $HWlosses = 3$ dB is the hardware loss of the FRMCS embedded receiver (see Table 5).

This blocking level should be acceptable for 2 dB desensitisation. The maximum interfering power P is calculated for different separation distances and converted for 3 dB desensitisation in Table 25 (using the conversion formula (7)). Co-channel compatibility between UAS and FRMCS is not studied in this Report.

³ -65 dBm being a typical receiving level for low range indoor applications, while -75 dBm is considered for a typical receiving level for more sensitive indoor and outdoor applications. DECT devices have a sensitivity level down to -93 dBm.

Table 25 ensures the robustness of FRMCS cab-radio receiver against governmental UAS operating in 1890-1900 MHz or in 1910-1920 MHz, depending on the technical feasibility of such filtering in the cab-radio receiver. The impact of UAS out-of-band emissions on FRMCS is yet to be assessed.

Table 25: Requirements on FRMCS cab-radio receiver characteristics

Distance	PL	Blocking level for 2 dB desensitisation	Blocking level for 3 dB desensitisation
30 m	67.5 dB	-28.9 dBm	-26.6 dBm
100 m	78.0 dB	-39.4 dBm	-37.1 dBm
300 m	87.5 dB	-48.9 dBm	-46.6 dBm
500 m	92.0 dB	-53.4 dBm	-51.1 dBm
700 m	94.9 dB	-56.3 dBm	-54.0 dBm
The antenna connector of the radio module is the reference point. This requirement covers both blocking and 3rd-order intermodulation.			

5.2.2 Interference from adjacent UAS to FRMCS

Compatibility between UAS and FRMCS when FRMCS is the victim was studied in Annex 10.

This study considered an I/N protection criterion of -6 dB for the FRMCS BS and -3 dB for the FRMCS UE.

The simulation show that interference from UAS to FRMCS UE is negligible. On the contrary, interference to the FRMCS BS is more likely.

When using a UAS GS transmit power of 10 dBm, the probability of interfering the FRMCS BS is less than 1% when the distance to the tracks is between 100 and 300 m in urban areas. In rural areas, this figure is reached when the distance to the tracks is between 300 and 500 m.

When using a UAS GS transmit power of 30 dBm, the probability of interfering the FRMCS BS is also less than 1% when the distance to the tracks is between 100 and 300 m in urban areas. However, at a distance between 500 and 1000 m, the interference probability is still around 10% in rural areas.

Considering the impact of the UAS UE, the interference probability is lower than 1% when the UAS UE is between 500 and 1000 m from the tracks (horizontal distance) if the range is limited to 500 m in rural areas (1000 m is only 10 MHz channel is used). In urban areas, the probability of interference is less than 1% when the UAS UE is between 300 and 500 m from the tracks (horizontal distance).

In order to reduce interference from UAS GS or UE to FRMCS BS, further limitation of the UAS out-of-band and FRMCS blocking requirements could be implemented taking into account in the next three tables. In addition, some operational guidance could be defined to avoid UAS operations close to railtracks.

Table 26: UAS GS out-of-band emissions limits in 1900-1910 MHz based on MCL

D (m)	UAS GS OoB emissions (dBm/MHz)	OoB emissions of 3GPP 36.104, table 6.6.3.2C-1 and table 6.6.2.1-2 (dBm/MHz) (Tx power of 30 dBm)		Additional requirements w.r.t 3GPP 36.104 (dB)	
		B=5 MHz	B=10 MHz	B=5 MHz	B=10 MHz
30	-68.3	-23.4	-24.9	44.9	43.4
100	-57.9			34.5	33.0
300	-48.3			24.9	23.4
500	-43.9			20.5	19.0
700	-41.0			17.6	16.1

Table 27: UAS UE out-of-band emissions limits in 1900-1910 MHz based on MCL

D (m)	UAS UE OoB emissions (dBm/MHz)	OoB emissions of 3GPP 36.101 table 6.6.2.1.1-1 and section 6.6.2.2 (dBm/MHz) [17] (Tx power of 30 dBm)		Additional requirements w.r.t 3GPP 36.101 (dB) [17]	
		B=5 MHz	B=10 MHz	B=5 MHz	B=10 MHz
30	-63.3	-15.8	-16.9	47.5	46.4
100	-52.9			37.1	36.0
300	-43.3			27.5	26.4
500	-38.9			23.1	22.0
700	-36.0			20.2	19.1

Table 28: FRMCS BS blocking requirements in 1880-1900 MHz and 1910-1920 MHz

D (m)	FRMCS BS Blocking requirement for 1 dB desentization (dBm)
30	-18.63
100	-29.09
300	-38.63
500	-43.07
700	-45.99

5.2.3 Interference from FRMCS to adjacent UAS

Given the similarities of the two systems, elements of compatibility of FRMCS and UAS when UAS is the victim can be found in section 5.2.2.

5.2.4 Interference from co-channel UAS to FRMCS

Studies of Annex 11 show that a cochannel operation of UAS in the FRMCS band is not feasible and will lead to a significant interference risk towards the FRMCS operation. Under a free space loss model, all UAS in distances up to 354 km to a FRMCS BS will lead to a desensitization of at least 3 dB. In practice, the radio horizon would limit the separation distance but that does not change the conclusion. For the cab radio the separation distance is 63 km.

5.2.5 Conclusion on compatibility between UAS and FRMCS

Studies of Annex 11 show that a cochannel operation of UAS in the FRMCS band is not feasible and will lead to a significant interference risk towards the FRMCS operation.

Monte Carlo study of the possible impact of an UAS deployed in the frequency band 1910-1920 MHz to an FRMCS deployment in the band 1900-1910 MHz is presented in Annex 10. Because of the symmetry of the FRMCS BEM and UAS SEM, these results at 1915 MHz also apply for interference from an UAS deployed at 1895 MHz. Simulations show that interference from UAS to FRMCS UE is negligible. On the contrary, interference to the FRMCS BS is more likely.

When using a UAS GS transmit power of 10 dBm, the probability of interfering the FRMCS BS is:

- less than 1% when the distance to the tracks is between 100 and 300 m in urban areas;
- less than 1% when the distance to the tracks is between 300 and 500 m in rural areas.

When using a UAS GS transmit power of 30 dBm, the probability of interfering the FRMCS BS is:

- less than 1% when the distance to the tracks is between 300 and 500 m in urban areas;
- Around 10% when the distance to the tracks is between 500 and 1000 m in rural areas.

Considering the impact of the UAS UE, the probability of interfering the FRMCS BS is:

- lower than 1% when the UAS UE is between 300 and 500 m from the tracks (horizontal distance) if the range is limited to 500 m in rural areas (1000 m if 10 MHz channel is used).
- lower than 1% when the UAS UE is between 300 and 500 m from the tracks (horizontal distance) in urban areas.

5.3 ADJACENT BAND SHARING BETWEEN LTE-BASED UAS AND MFCN AT 1880 MHZ

The following interference scenarios are considered in the Monte Carlo simulations and interference calculations.

- 1 MFCN DL to LTE-based UAS aerial UE (urban and rural)
- 2 MFCN DL to LTE-based UAS GS (urban and rural)
- 3 LTE-based UAS aerial UE to MFCN DL (MFCN UE reception, professional drone reception connected to MFCN network) (urban and rural)
- 4 LTE-based UAS GS to MFCN DL (MFCN UE reception) (urban and rural)

5.3.1 SEAMCAT simulation of interference from MFCN DL to LTE-based UAS aerial UE

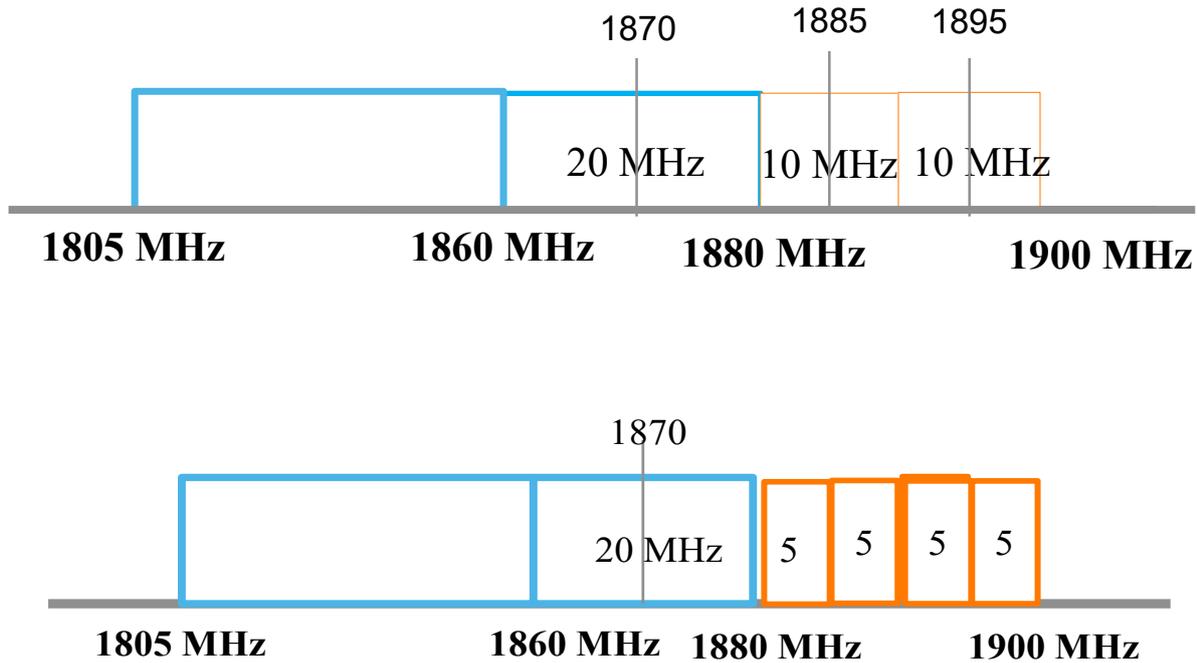


Figure 14: Adjacent band co-existence between UAS and MFCN at 1880 MHz

As shown in the above figure, in the interference simulations for the co-existence between MFCN and LTE-based UAS, two cases are considered:

- Two 10 MHz UAS channels (central frequencies placed at 1885 MHz and 1895 MHz) and one 20 MHz MFCN channel at 1870 MHz;
- Four 5 MHz UAS channels (central frequencies placed at 1882.5 MHz, 1887.5 MHz, 1892.5 MHz and 1897.5 MHz) and one 20 MHz MFCN channel at 1870 MHz.

By considering MFCN deployment 1710-1785/1805-1880 MHz frequency band with both non-AAS and AAS BS have been regulated by CEPT framework, in the following co-existence analysis between LTE-based UAS and MFCN at 1880 MHz, only the simulation results for non-AAS MFCN deployment scenario are provided.

In the interference simulations for the co-existence between MFCN and LTE-based UAS, two 10 MHz UAS channels (central frequencies placed at 1885 MHz and 1895 MHz) and one 20 MHz MFCN channel at 1870 MHz are considered, as shown in the above figure. By considering MFCN deployment 1710-1785/1805-1880 MHz frequency band with both non-AAS and AAS BS have been regulated by CEPT framework, in the following co-existence analysis between LTE-based UAS and MFCN at 1880 MHz, below only the simulation results for non-AAS MFCN deployment scenario are provided.

As shown in Figure 15, the simulated case in urban is a UAS GS is placed at 250 m (middle of the MFCN cell range in urban area) from a MFCN1800 BS (1860-1880 MHz), UAS UE (1880-1890 MHz) is flying randomly from 25 to 120 m around the UAS GS at 1.5 m in a range of 1000 m.

In rural area, UAS GS is placed at 1.5 km from MFCN BS (middle of the MFCN cell range in rural area). UAS aerial UE flying in a medium range of 1000 m is simulated, the UAS aerial UE flying height is randomly between 30 and 120 m in rural area.

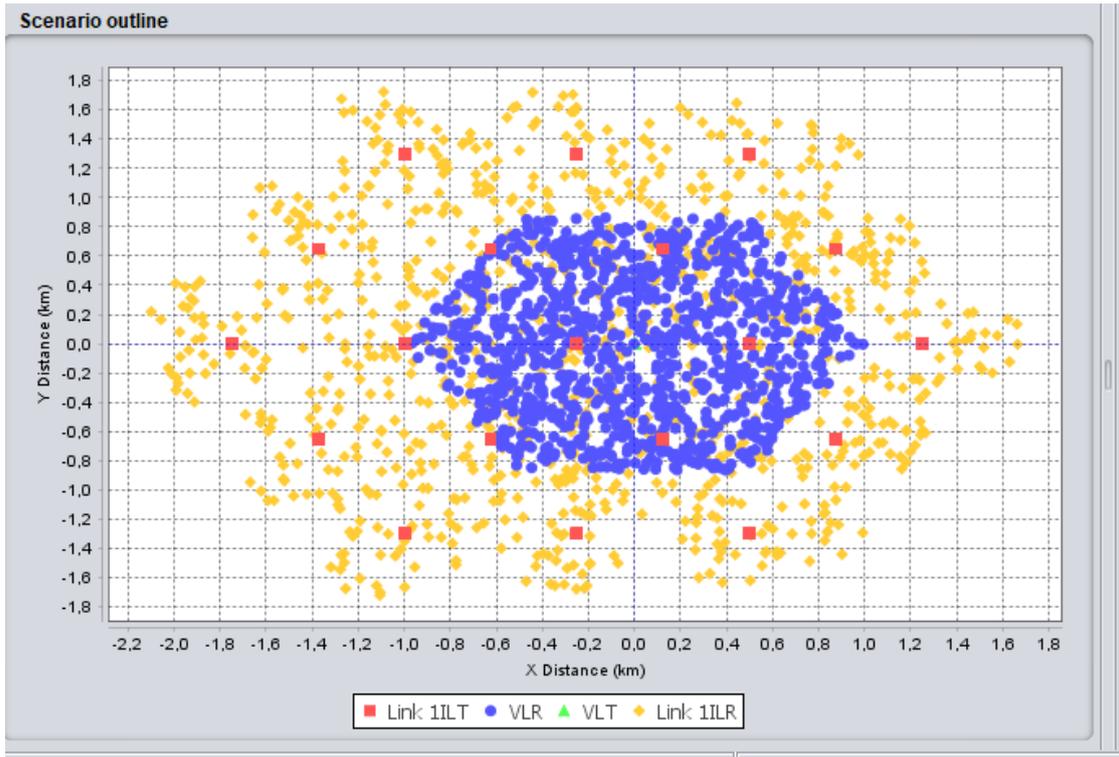


Figure 15: Simulation scenario 1800 MHz band MFCN BS to UAS UE (1880-1900 MHz)

The simulation results are given in Table 29 for different UAS 10 MHz channel at 1885 MHz with GS transmit power (12 dBm, 35 dBm/10 MHz e.i.r.p.) and UAS UE receiver selectivity (ACS=33 dB and in-band blocking level at -44 dBm).

Table 29: Simulation results from MFCN non-AAS BS DL to LTE-based UAS aerial UE (10 MHz at 1885 MHz)

UAS 10 MHz at 1885 MHz Aerial UE flying range: 1 km	Urban		Rural	
	UAS GS H=1.5 e.i.r.p.=12 dBm UAS UE ACS=33 dB ACS_2 (in-band blocking)=46.2 dB	UAS GS H=1.5 e.i.r.p.=35 dBm UAS UE ACS=33 dB ACS_2 (in-band blocking)=46.2 dB	UAS GS H=1.5 e.i.r.p.=12 dBm UAS UE ACS=33 dB ACS_2 (in-band blocking)=46.2 dB	UAS GS H=1.5 e.i.r.p.=35 dBm UAS UE ACS=33 dB ACS_2 (in-band blocking)=46.2 dB
iRSS_unwanted (dBm)	-81.3	-81.3	-88.1	-88.2
iRSS_blocking (dBm)	-67.5	-68.4	-74.9	-74.8
UAS UE TP Loss (%)	99.55	95.88	98.85	86.55

Simulation results in Table 29 show that 10 MHz channel UAS aerial UE at the centre frequency of 1885 MHz suffer high interference from 20 MHz channel MFCN DL at 1870 MHz. The limiting factor is UAS aerial UE receiver selectivity.

The simulation results of interference from MFCN DL (20 MHz channel at the centre frequency of 1870 MHz) to UAS aerial UE (10 MHz channel) at the centre frequency of 1895 MHz in urban and rural are given in the Table 31 and Table 32.

Table 30: Simulation results from MFCN non-AAS BS DL to LTE-based UAS aerial UE (10 MHz at 1895 MHz) (urban)

UAS (10 MHz channel) at 1895 MHz with flying range=1000 m in Urban area	UAS GS H=1.5 e.i.r.p.=12 dBm UAS UE ACS_1=33 dB ACS_2=46.2 dB	UAS GS H=1.5 e.i.r.p.=35 dBm UAS UE ACS_1=33 dB ACS_2=46.2 dB	UAS GS H=1.5 e.i.r.p.=12 dBm UAS UE ACS_1= 33 dB ACS_2=66 dB	UAS GS H=1.5 e.i.r.p.=35 dBm UAS UE ACS_1=33 dB ACS_2=66 dB
iRSS_unwanted (dBm)	-99.7	-99.7	-99.7	-99.7
iRSS_Blocking	-77.1	-77.1	-99.3	-99.3
UAS UE TP Loss (%)	97.55	87.17	49.62	22.57

Table 31: Simulation results from MFCN non-AAS BS DL to LTE-based UAS aerial UE (10 MHz at 1895 MHz) (rural)

UAS (10 MHz channel) at 1895 MHz with flying range=1000 m in Rural area	UAS GS H=1.5 e.i.r.p.=12 dBm UAS UE ACS_1=33 dB ACS_2=46.2 dB	UAS GS H=1.5 e.i.r.p.=35 dBm UAS UE ACS_1=33 dB ACS_2=46.2 dB	UAS GS H=1.5 e.i.r.p.=12 dBm UAS UE ACS_1= 33 dB ACS_2=66 dB	UAS GS H=1.5 e.i.r.p.=35 dBm UAS UE ACS_1=33 dB ACS_2=66 dB
iRSS_unwanted (dBm)	-106.2	-106.2	-106.2	-106.2
iRSS_Blocking	75.7	-83.5	-105.7	-105.7
UAS UE TP Loss (%)	93.98	64.63	24.31	5.26

The simulation results in Table 30 and Table 31 show that

- 1 The LTE-based UAS aerial UE 10 MHz channel (1890-1900 MHz) is in MFCN BS spurious emission domain (-30 dBm/MHz is much lower than the ACLR of 45 dB).
- 2 With an improved LTE-based aerial UE receiver selectivity (ACS_2=66 dB), the interference from MFCN DL to LTE-based UAS aerial UE is largely reduced.

The simulation results of interference from MFCN DL at 1880 MHz to LTE-based UAS aerial UE 5 MHz channels placed at different frequency points of 1882.5 MHz, 1887.5 MHz, 1892.5 MHz, and 1897.5 MHz respectively are given in Table 32.

Table 32: Simulation results from MFCN non-AAS BS DL below 1880 MHz to LTE-based UAS aerial UE (5 MHz channel) (urban)

UAS (5 MHz channel) with flying range=1000 m in Urban area	UAS GS H=1.5 e.i.r.p.=35 dBm 1882.5 MHz UAS UE ACS_1=33 dB ACS_2=49.2 dB at 15 MHz offset from band edge	UAS GS H=1.5 e.i.r.p.=35 dBm 1887.5 MHz UAS UE ACS_1=33 dB ACS_2=49.2 dB at 15 MHz offset from band edge e	UAS GS H=1.5 e.i.r.p.=35 dBm 1892.5 MHz UAS UE ACS_1= 33 dB ACS_2=66 dB below band edge 1880 MHz	UAS GS H=1.5 e.i.r.p.=35 dBm 1897.5 MHz UAS UE ACS_1=33 dB ACS_2=66 dB below band edge 1880 MHz
iRSS_unwanted (dBm)	-84.7	-84.7	-102.7	-102.7
iRSS_Blocking	-70.2	-99.3	-99.2	-99.3
UAS UE TP Loss (%)	94.97	72.17	24.77	24.99

The simulation results in Table 32 show that

- 1 LTE-based UAS UE 5 MHz channel at 1887.5 MHz even with an improved receiver selectivity ACS_2=66 dB below 1880 MHz still suffer important interference, because it is within the frequency range of MFCN BS ACLR, it suffers interference from MFCN BS first adjacent channel leakage out of band emissions.
- 2 LTE-based UAS channel at 1892.5 MHz and 1897.5 MHz with improved receiver selectivity ACS_2=66 dB below 1880 MHz have much reduced interference impact, these two channels are in the spurious emissions domain (10 MHz away from the MFCN DL band edge), the spurious emission level - 30 dBm/MHz is much lower than the ACLR of the MFCN BS.

The UAS operation from UAS GS to UAS aerial UE is mainly control and command channel, no need to transmit high data rate. In order to ensure a good reception of command and control channel by UAS aerial UE, it is suggested to use the upper part of the band 1890-1900 MHz to transmit command and control channel.

5.3.1.1 Monte Carlo Simulation of interference from MFCN DL to LTE-based UAS aerial UE

Interference from MFCN DL to LTE-based UAS aerial UE at 1885 MHz has been studied in Annex 8. The results are summarised in Table 33. They are given as the probability of interference of the LTE-based UAS UE. The SINR protection criterion considered are:

- -2 dB for UAS UE operating at 5 MHz;
- -6 dB for UAS UE operating at 10 MHz.

Detailed results are given in Table 33. It shows a high probability of interference to LTE-based UAS GS with a range of 5650 m (more than 45% and up to 79%). In any other scenario, the probability of interference is between 1.5 and 8%. In this regard, it is likely that the drone operator will maintain a certain margin in its operation, (through limiting the distance, ensure field of view, etc.) to ensure the quality of the transmission so that worst case interference will not materialise. Note also that the LTE-based UAS GS receives a video flux from the LTE-based UAS UE. This means that interference on this link would result in the loss of video frames. Furthermore, there exist several ways to dynamically adapt the video compression ratio (which impact the video quality) to the channel state, such as MPEG-DASH⁴ or RTSP [41] along with RTP [42] and RTCP [42].

⁴ MPEG Dynamic Adaptive Streaming over HTTP

Table 33: Summary of MFCN BS in 1805-1880 MHz interference probability to LTE-based UAS GS at 1885 MHz

Environment	Range	Bandwidth (MHz)	UAS UE max. Tx power (dBm)	Probability of interference (%)
Rural	5650	5	28	78.4
		10		47.36
	1000	5		6.21
		10		7.37
	500	5		4.78
		10		7.08
Urban	1000	5		5.82
		10		3.78
	500	5		1.9
		10		2.48
	300	5		1.61
		10		2.21

5.3.1.2 SEAMCAT Simulation of interference from MFCN DL to LTE-based UAS GS

The interference from MFCN DL to UAS GS is simulated in urban and rural area. In the simulation, UAS GS is randomly located from the MFCN BS to the cell edge, as shown in Figure 15.

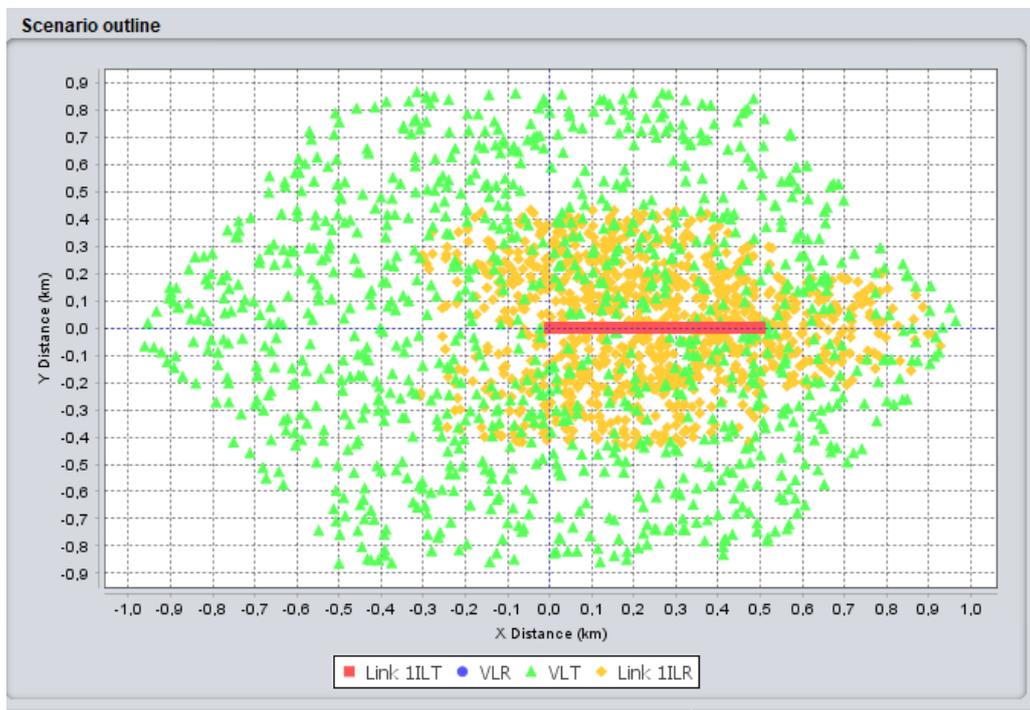


Figure 16: Simulation scenario of interference from MFCN1800 non-AAS BS to LTE-based UAS GS

The simulation results of potential interference from MFCN non-AAS BS DL to LTE-based UAS GS (10 MHz channel) in urban and rural area are given in Table 34 and Table 35.

Table 34: Simulation results from MFCN non-AAS BS DL to LTE-based UAS GS (10 MHz channel) (urban)

Urban	UAS GS at 1885 MHz ACS_1=45 dB ACS_2=45 dB	UAS GS at 1895 MHz ACS_1=45 dB ACS_2=45 dB	UAS GS at 1895 MHz ACS_1=45 dB ACS_2=66 dB
iRSS_unwanted (dBm)	-91	-109.5	-109.3
iRSS_Blocking (dBm)	-87.5	-88.0	-108.9
UAS UL TP Loss (%)	88.48	84.59	36.61

Table 35: Simulation results from MFCN non-AAS BS DL to LTE-based UAS GS (10 MHz channel) (rural)

Rural	UAS GS at 1885 MHz ACS_1=45 dB ACS_2=45 dB	UAS GS at 1895 MHz ACS_1=45 dB ACS_2=45 dB	UAS GS at 1895 MHz ACS_1=45 dB ACS_2=66 dB
iRSS_unwanted (dBm)	-104.1	-121.2	-122.0
iRSS_Blocking (dBm)	-100.6	-99.8	-121.6
UAS UL TP Loss (%)	50.14	46.60	11.11

The simulation results in Table 34 and Table 35 show for the UAS 10 MHz channel in 1890-1920 MHz with an improved receiver selectivity (ACS_2=66 dB), the LTE-based UAS UL throughput loss is also largely reduced.

5.3.1.3 Monte Carlo Simulation of interference from LTE-based MFCN DL to UAS GS

Interference from MFCN DL to LTE-based UAS GS at 1885 MHz has been studied in ANNEX 8:. The results are summarised in Table 36. They are given as the probability of interference of the LTE-based UAS GS. They are given as the probability of interference of the LTE-based UAS UE. The SINR protection criterion considered are:

- 16 dB for UAS GS operating at 5 MHz;
- 8 dB for UAS GS operating at 10 MHz.

Results summarised in Table 36 that the rural scenario with a range of 5650 m exhibits a high probability of interference (between 14% and 98%). In other scenarios, a lower LTE-based UAS GS transmit power of 10 dBm also leads to significant probabilities of interference (between 2% and 90%). Keeping an LTE-based UAS GS transmit power of 30 dBm yields an interference probability between 0.03% to 4% (excluding scenarios with a range of 5650 m).

Table 36: Summary of MFCN BS in 1805-1880 MHz interference probability to LTE-based UAS UE at 1885 MHz

Environment	Range (m)	Bandwidth (MHz)	UAS BS Tx power (dBm)	Probability of interference (%)
Rural	5650	5	30	23.29
			10	97.47
		10	30	14.07
			10	94.62
	1000	5	30	0.54
			10	29.01
		10	30	0.29
			10	14.75
	500	5	30	0.08
			10	5.08
		10	30	0.03
			10	2.07
Urban	1000	5	30	3.26
			10	90.49
		10	30	1.25
			10	80.66
	300	5	30	0.28
			10	64.66
		10	30	0.06
			10	36.73
	250	5	30	0.05
			10	28.94
		10	30	0.03
			10	8.82

5.3.1.4 SEAMCAT Simulation of interference from LTE-based UAS aerial UE to MFCN DL

The simulation results of interference from LTE-based UAS aerial UE to MFCN DL (ground UE) are given in Table 37. The simulation results show very few MFCN DL throughput loss caused by LTE-based UAS aerial UE, there is no impact from LTE-based UAS aerial UE on MFCN DL ground UEs.

The simulation results of interference from LTE-based UAS aerial UE to MFCN DL (MFCN aerial UE flying randomly from 25 to 120 m in urban area, and flying randomly from 30 to 120 m in rural area) are given in Table 38. The simulation results show very few MFCN DL (flying aerial UEs) throughput loss caused by LTE-based UAS aerial UE, there is no impact from UAS aerial UE on MFCN DL flying aerial UEs.

Table 37: Simulation results from LTE-based UAS aerial UE(10 MHz at 1885 MHz) to MFCN DL (Ground UE)

MFCN normal UE	Urban	Rural
iRSS_unwanted (dBm)	-136.4	-148.4
iRSS_blocking (dBm)	-135.4	-147.4
DL TP Loss Loss (%)	0.003	0.037

Table 38: Simulation results from LTE-based UAS aerial UE(10 MHz at 1885 MHz) to MFCN DL (MFCN aerial UE)

MFCN aerial UE	Urban	Rural
iRSS_unwanted (dBm)	-103	-113
iRSS_blocking (dBm)	-102	-112
DL TP Loss (%)	0	0.03

5.3.1.5 Calculation of interference from LTE-based UAS GS to MFCN DL

The potential interference from LTE-based UAS GS to MFCN UE depend largely the separation distance from LTE-based UAS GS to MFCN UE. The possible interference may more likely happen to the MFCN UEs in the close proximity of UAS GS.

Table 39 and Table 40 give the calculations of interference from LTE-based UAS GS to MFCN UE at a separation distance of 100 m and 50 m. The calculated results in Table 39 and Table 40 show that the impact on MFCN UE by a UAS GS transmitting at 10 dBm does not appear as a problem. For UAS GS transmitting 30 dBm may cause some performance degradation to MFCN UE, in particular at a separation distance less than 50 m.

Table 39: Calculation of interference from LTE-based UAS GS to MFCN UE (100 m distance)

100 m between UAS GS and MFCN UE	Urban		Rural	
UAS GS Tx Power (dBm)	10	30	10	30
UAS GS antenna gain (dBi)	5	5	5	5
UAS GS Tx antenna height (m)	1.5	1.5	1.5	1.5
UAS GS e.i.r.p. (dBm)	15	35	15	35
UAS GS ACLR (dB)	45	45	45	45
MFCN UE ACS (dB)	33	33	33	33
ACIR	32.7	32.7	32.7	32.7
MFCN UE antenna gain (dBi)	-4	-4	-4	-4
MFCN outdoor UE antenna height (m)	1.5	1.5	1.5	1.5
UAS GS to MFCN BS distance (m)	50	50	50	50

100 m between UAS GS and MFCN UE	Urban		Rural	
MFCN UE Noise figure (dB)	9	9	9	9
MFCN channel bandwidth (MHz)	18	18	18	18
Noise level (dBm)	-92.4	-92.4	-92.4	-92.4
PL (dB) at 100 m distance (P1546)	98.6	87.5	95.6	95.6
PL (dB) at 100 m distance (E-Hata-SRD)	101,8	101,8	79.6	79.6
I (dBm) (P1546)	-120,3	-89.2	-117,3	-97,3
I (dBm) (E-Hata SRD)	-123.5	-103.5	-101,3	-81,3
I/N (dB) (P1546)	-27.9	3.2	-24.9	-4.9
I/N (dB) (E-Hata SRD)	-31.1	-11.1	-8.9	11.1

Table 40: Calculation of interference from LTE-based UAS GS to MFCN UE (50 m distance)

50 m between UAS GS and MFCN UE	Urban		Rural	
UAS GS Tx Power (dBm)	10	30	10	30
UAS GS antenna gain (dBi)	5	5	5	5
UAS GS Tx antenna height (m)	1.5	1.5	1.5	1.5
UAS GS e.i.r.p. (dBm)	15	35	15	35
UAS GS ACLR (dB)	45	45	45	45
MFCN UE ACS (dB)	33	33	33	33
ACIR	32.7	32.7	32.7	32.7
MFCN UE antenna gain (dBi)	-4	-4	-4	-4
MFCN outdoor UE antenna height (m)	1.5	1.5	1.5	1.5
UAS GS to MFCN BS distance (m)	50	50	50	50
MFCN UE Noise figure (dB)	9	9	9	9
MFCN channel bandwidth (MHz)	18	18	18	18
Noise level (dBm)	-92.4	-92.4	-92.4	-92.4
PL (dB) at 50 m distance (P1546)	76.9	76.9	76.1	76.1
PL (dB) at 50 m distance (E-Hata-SRD)	101.5	101.5	73.4	73.4
I (dBm) (P1546)	-98.6	-78.6	-97,8	-77,8
I (dBm) (E-Hata SRD)	-123.2	-103.2	-95.1	-75.1
I/N (dB) (P1546)	-6.2	13,8	-5.4	14.6
I/N (dB) (E-Hata SRD)	-30,8	-10,8	-2.7	17,3

5.3.1.6 Conclusion

SEAMCAT simulations (Annex 5) show that important levels of interference may happen from MFCN DL (1860-1880 MHz) to both UAS aerial UE and GS 10 MHz channel operating in 1880-1890 MHz. Noting that these levels of interference translate to UE (drone) throughput loss between 87.7% and 99.5% and GS (controller) throughput loss between 50% and 88%, considering the UAS channel centered at 1885 MHz and a UAS in the range of 1000 m. Additional Monte Carlo studies taking into account UAS protection criterions in-line with the bitrate requirements (300 kbps for controller to drone, 5 Mbps for drone to controller) show an interference probability of the UE and the GS lower than 10% (when the range is limited to 1000 m in rural environments), assuming a GS transmit power of 30 dBm.

SEAMCAT simulations (Annex 5) show that the interference from MFCN DL (1860-1880 MHz) to both UAS aerial UE and GS 10 MHz channel operating in 1890-1900 MHz is reduced. If the UAS UE/GS receiver selectivity can be improved with an additional filter (ACS_2 = 66 dB), the interference from MFCN1800 DL can be reduced, as shown in section 5.3.1.

Interference from UAS aerial UE to MFCN1800 DL (UE reception) does not appear as a problem, including flying MFCN UE, as it translates to downlink throughput loss less than 0.1%.

Monte Carlo studies (Annex 8) taking into account UAS protection criterions in-line with UAS bitrate requirements (300 kbps for controller to drone, 5 Mbps for drone to controller) show an interference probability of the UE and the GS by MFCN DL lower than 10% (but the range has to be limited to 1000 m in rural environments), assuming a GS transmit power of 30 dBm.

MCL computations (Section 5.3) has been performed to assess the interference from UAS GS to MFCN1800 DL (UE reception). For an UAS GS transmitting at 10 dBm, the I/N protection criterion of an MFCN UE is not exceeded at 50 m (urban environment) or 100 m (rural environment). For an UAS GS transmitting at 30 dBm however, the MFCN UE protection criterion can be exceeded even when the separation distance is above 100 m.

Considering that, for a governmental drone, the highest data rate is transmitted from UAS UE to UAS GS, and in order to further protect the command and control signals received by UAS UE from MFCN interference, UAS command and control channel of a single drone deployment could be placed in the frequency range 1890-1900 MHz.

5.4 ADJACENT BAND SHARING BETWEEN LTE-BASED UAS AND MFCN AT 1920 MHZ

As shown in the below figure, UAS operation in the frequency band 1910-1920 MHz is adjacent to MFCN UL operating in 1920-1980 MHz. The potential interference is from UAS Aerial UE and GS to MFCN UL.

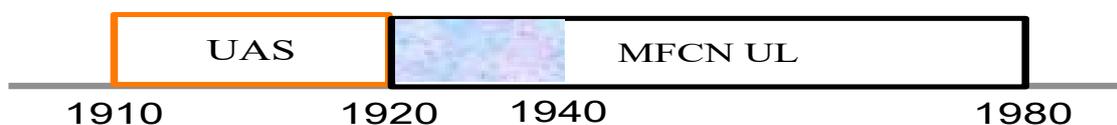


Figure 17: Co-existence between UAS and MFCN at 1920 MHz

5.4.1.1 SEAMCAT Simulation of interference from LTE-based UAS aerial UE to MFCN UL

As shown in Figure 18, the interference from LTE-based UAS aerial UE (5 MHz channel) to MFCN (10 MHz channel placed at 1925 MHz) is simulated. The simulation results are given in Table 41. LTE-based UAS GS is placed at 100 m from the MFCN reference cell BS (central cell). LTE-based UAS aerial UE is randomly flying from 25 to 120 m in urban area and from 30 to 120 m in rural area. In urban area, UAS medium range of 1000 m is simulated. In Rural area, both the medium range of 1000 m and wide range of 5650 m flying radius are simulated.

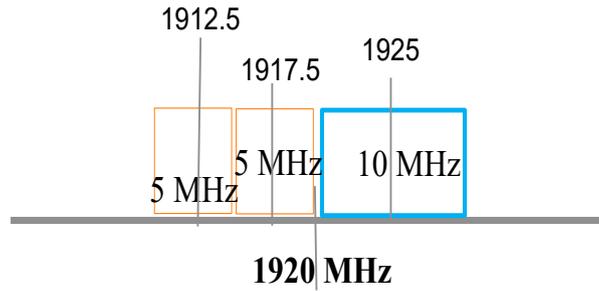


Figure 18: Channel arrangement for interference scenario from LTE-based UAS to MFCN UL

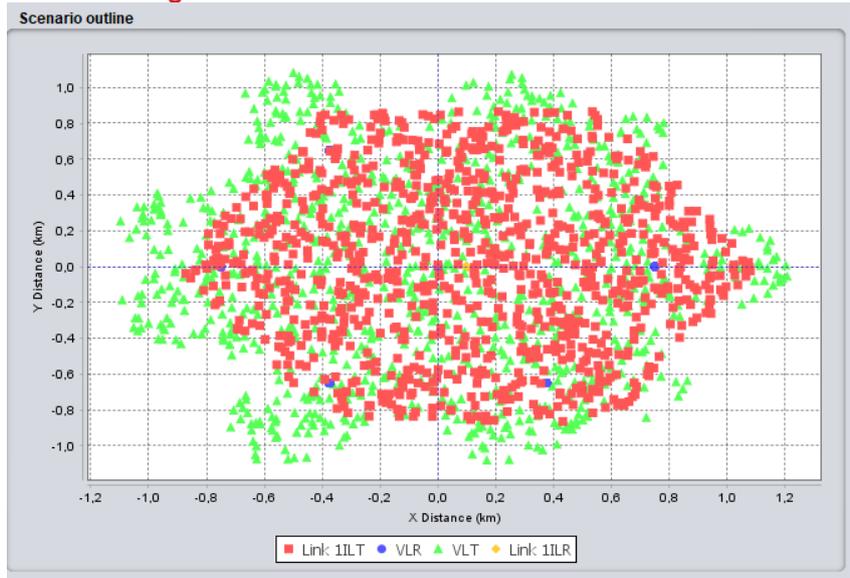


Figure 19: Simulation of interference from LTE-based UAS (5 MHz channel) to MFCN UL (10 MHz channel at 1925 MHz)

In the simulation, two power control parameters settings are used to test the sensitivity of simulation results depending on the power control.

PC1 is using 90% coupling loss percentile: 125.241 dB for LTE-based UAS aerial UE power control.

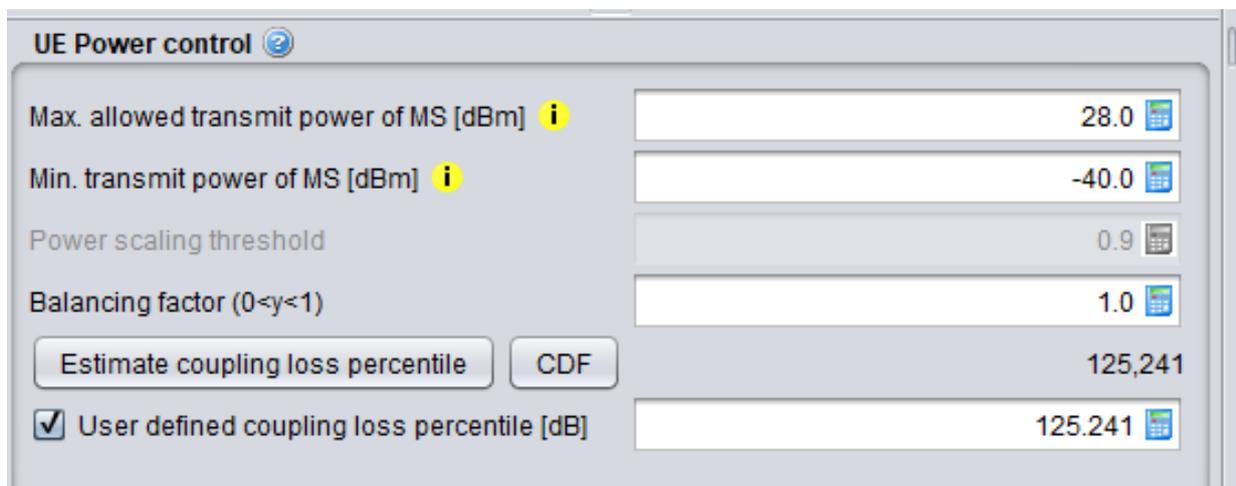


Figure 20: Settings for LTE-based UAS UE power control using 90% coupling loss percentile PC2 is using 50% coupling loss percentile: 117.7 dB for LTE-based UAS aerial UE power control

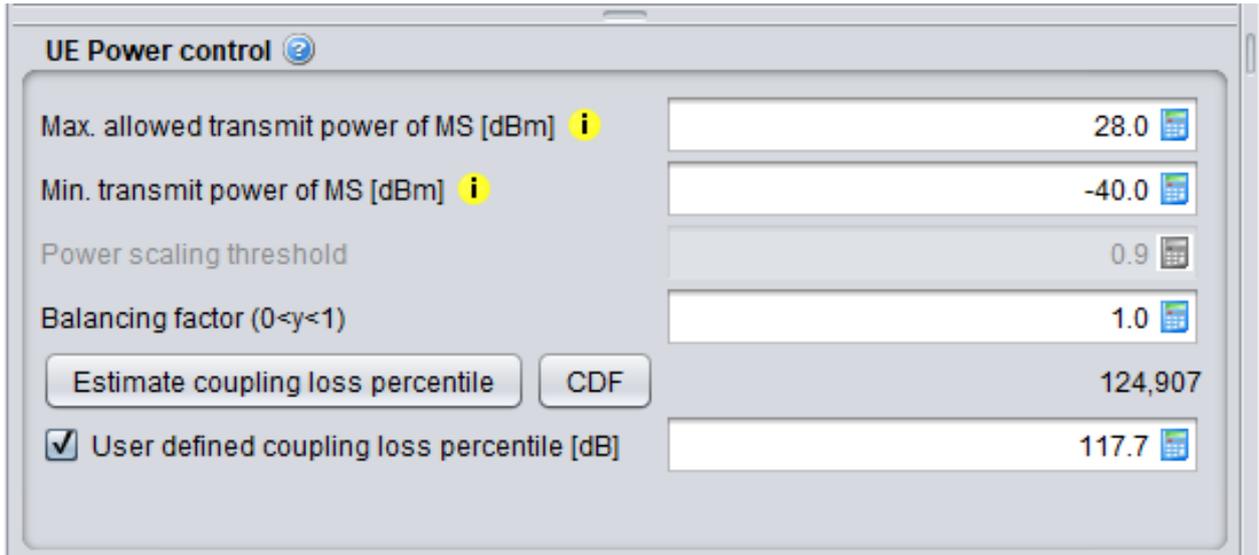


Figure 21: Settings for LTE-based UAS UE power control using 50% coupling loss percentile

The simulation results are given in Table 41. The simulation results show that LTE-based UAS aerial UE with an ACLR=37 dB create significant interference to MFCN uplink reception 1920-1930 MHz. The simulation results depend on the power control algorithm and parameter setting. The simulation results with PC2 are much worse than that with PC1.

Table 41: Simulation results of interference from LTE-based UAS UE (TxP=28 dBm) to MFCN UL

Parameter	Urban		Rural	
	UAS Cell Range 1000 m GS 2 dBi 1917.5 MHz PC1	UAS Cell Range 1000 m GS 2 dBi 1917.5 MHz PC2	UAS Cell Range 1000 m GS 2 dBi 1917.5 MHz PC1	UAS Cell Range 5650 m GS 2 dBi 1917.5 MHz PC1
iRSS_unwanted (dBm)	-99.9	-94.5	-102.5	-102.5
iRSS_blocking (dBm)	-100.9	-105.9	-113.5	-113.5
Ref Cell UL TP Loss (%)	16.77	28.28	15.63	15.33
MFCN system UL TP Loss (%)	16.18	25.47	15.63	11.15

Table 42: Simulation results of interference from LTE-based UAS UE (TxP=28 dBm and TxP=23 dBm) to MFCN UL

Parameter	Urban		
	UAS Cell Range 1000 m GS 2 dBi 1917.5 MHz PC1 UAS UE TxP=28 dBm ACLR_1=37 dB ACLR_2=37 dB	UAS Cell Range 1000 m GS 2 dBi 1917.5 MHz PC1 UAS UE TxP=23 dBm ACLR_1=37 dB ACLR_2=37 dB	UAS Cell Range 1000 m GS 2 dBi 1912.5 MHz PC1 UAS UE TxP=23 dBm ACLR_1=37 dB ACLR_2=45 dB
iRSS_unwanted (dBm)	-99.9	-104.7	-112.8
iRSS_blocking (dBm)	-100.9	-115.7	-115.8
Ref Cell UL TP Loss (%)	16.77	8.55	2.89
System UL TP Loss (%)	16.18	8.71	3.43

Table 42 gives the simulation results on the MFCN UL throughput loss caused by one LTE-based UAS aerial UE with different transmit power and ACLR_2 values. The results show for UAS channel 1910-1915 MHz with a transmit power of 23 dBm, ACLR_1 (1910-1915 MHz)=37 dB and ACLR_2 (1920-1930 MHz)=45 dB/5 MHz, the MFCN UL throughput loss is below 5%.

Table 43 and Table 44 gives the simulation results of interference from two LTE-based UAS aerial UEs of 5 MHz channel placed respectively at 1912.5 MHz and 1917.5 MHz to MFCN 10 MHz channel uplink in urban and rural area.

Table 43: Simulation results of interference from 2 UAS UE (TxP=23 dBm and TxP=30 dBm) to MFCN UL in Urban area

UAS (5 MHz channel) with flying range=1000 m in Urban area UAS GS H=1.5 with 2 dBi antenna gain	2 Aerial UE Tx Power=23 dBm At 1912.5 MHz and 1917.5 MHz ACLR_1=30 dB SEM (TS36.101) [17]	2 Aerial UE Tx Power=23 dBm At 1912.5 MHz and 1917.5 MHz ACLR_1=37 dB SEM (TS36.101) [17]	2 Aerial UE Tx Power=30 dBm At 1912.5 MHz and 1917.5 MHz ACLR_1=37 dB SEM (TS36.101) [17]
iRSS_unwanted (dBm)	-96.1	-98.8	-98.1
iRSS_Blocking	-109.7	-109.7	-104.6
UAS UE TP Loss (%)	26.54	19.98	23.54

Table 44: Simulation results of interference from 2 UAS UE (TxP=23 dBm and TxP=30 dBm) to MFCN UL in Rural area

UAS (5 MHz channel) with flying range=1000 m in Rural area	2 Aerial UE Tx Power=23 dBm At 1912.5 MHz and 1917.5 MHz	2 Aerial UE Tx Power=23 dBm At 1912.5 MHz and 1917.5 MHz	2 Aerial UE Tx Power=30 dBm At 1912.5 MHz and 1917.5 MHz
UAS GS H=1.5 with 2 dBi antenna gain	ACLR_1=30 dB SEM (TS36.101) [17]	ACLR_1=37 dB SEM (TS36.101) [17]	ACLR_1=37 dB SEM (TS36.101) [17]
iRSS_unwanted (dBm)	-94.3	-97.1	-94.6
iRSS_Blocking	-107.5	-107.8	-100.8
UAS UE TP Loss (%)	59.79	50.822	61.738

The simulation results in Table 43 and Table 44 show without additional measures (further reduction of UAS UE Out of band emissions above 1920 MHz), even with 23 dBm transmit power, the interference from two LTE-based UAS 5 MHz channels placed at 1917.5 MHz and 1912.5 MHz to MFCN UL above 1920 MHz is still above the expected protection ratio.

5.4.1.2 Monte Carlo Simulation of interference from LTE-based UAS aerial UE to MFCN UL

Interference from LTE-based UAS aerial UE to MFCN UL at 1920 MHz has been studied in Annex 9. The results are summarised in Table 45. They are given as the probability of interference of the MFCN BS receiving the highest level of interference, based on an I/N protection criterion of -6 dB.

In this scenario, thanks to TPC, the worst case interference happens when the LTE-based UAS UE is at its maximum range. Hence, reducing the maximum range facilitate the Co-existence between LTE-based UAS UE and MFCN BS. In this regard, it is likely that the drone operator will maintain a certain margin in its operation, (through limiting the distance, ensure field of view, etc.) to ensure the quality of the transmission so that worst case interference will not materialize. Also, because of the difference of the target SNR for TPC depending on the UAS bandwidth, setting it to 5 MHz instead of 10 MHz only marginally ease the Co-existence. Note that because the UAS UE is meant to move in its range, the worst interfered MFCN BS will likely be different at different instant in time.

Table 45: Summary of UAS UE in 1910-1920 MHz interference probability to MFCN BS in 1920-1980 MHz

Environment	Range (m)	Bandwidth (MHz)	Max Tx power (dBm)	Probability for the worst impacted MFCN BS to be interfered (%)
Rural	5650	5	28	80.84
		10		60.66
	1000	5		15.24
		10		4.9
	500	5		3.21
		10		0.95
Urban	1000	5	66.63	

Environment	Range (m)	Bandwidth (MHz)	Max Tx power (dBm)	Probability for the worst impacted MFCN BS to be interfered (%)
	300	10		33.07
		5		26.03
		10		7.08
	250	5		7.77
		10		1.56

5.4.1.3 Calculation of interference from LTE-based UAS GS to MFCN UL

The potential interference from LTE-based UAS GS to MFCN UL depend the separation distance from UAS GS to MFCN BS.

Table 46 gives the calculations of interference from LTE-based UAS GS to MFCN BS at a separation distance of 100 m. The calculated results in Table 46 show that the impact on MFCN BS by an LTE-based UAS GS transmitting at 10 dBm does not appear as a problem. For LTE-based UAS GS transmitting 30 dBm may cause some performance degradation to MFCN BS.

Table 46: Calculation of interference from LTE-based UAS GS to MFCN BS (100 m distance)

Parameter	Urban		Rural	
UAS GS Tx Power (dBm)	10	30	10	30
UAS GS antenna gain (dBi)	5	5	5	5
UAS GS Tx antenna height (m)	1.5	1.5	1.5	1.5
UAS GS e.i.r.p. (dBm)	15	35	15	35
UAS GS ACLR (dB)	45	45	45	45
MFCN BS ACS (dB)	45	45	45	45
ACIR	42.0	42.0	42.0	42.0
MFCN BS Antenna Maximum gain (dBi)	16	16	18	18
MFCN BS antenna height (m)	25	25	30	30
Feeder loss (dB)	3	3	3	3
BS antenna downtilt (°)	-10	-10	-3	-3
UAS GS to MFCN BS distance (m)	100	100	100	100
Vertical angle (0°)	13.2	13.2	15.9	15.9
Effective gain (dBi)	15.1	15.1	1.7	1.7
MFCN BS NF (dB)	5	5	5	5
MFCN channel bandwidth (MHz)	9	9	9	9
Noise level (dBm)	-99.5	-99.5	-99.5	-99.5

Parameter	Urban		Rural	
PL (dB) at 100 m distance (P1546)	87.5	87.5	85.5	85.5
PL (dB) at 100 m distance (Hata)	103.5	103.5	79	79
I (dBm) (P1546)	-102.4	-82.4	-113,8	-93,8
I (dBm) (Hata)	-118.4	-98.4	-107,3	-87,3
I/N (dB) (P1546)	-2.9	17.1	-14,3	5.7
I/N (dB) (Hata)	-18.9	1.1	-7,8	12.2

5.4.1.4 Monte Carlo simulation of interference from LTE-based UAS GS to MFCN UL

Interference from LTE-based UAS GS to MFCN UL at 1920 MHz has been studied in ANNEX 9:. The results are summarised in Table 47. They are given as the probability of interference of the MFCN BS receiving the highest level of interference, based on an I/N protection criterion of -6 dB.

In this scenario, the probability for the closest MFCN BS to be interfered remains limited (2% to 5.6% for transmit power of 30 dBm and less than 0.2% for the transmit power of 10 dBm). It is noted that, using the drone propagation model of [4], the reduction of transmit power to 10 dBm would not allow the link from the LTE-based UAS BS to the LTE-based UAS GS to reach the target bitrate with a range of 5650 m (see Figure 76). UAS bandwidth of 5 MHz instead of 10 MHz has little impact on the Co-existence of the two system.the reduction of transmit power from 30 to 10 dBm, as proposed in ANNEX 3: greatly relax the interference probability to MFCN BS. UAS bandwidth of 5 MHz instead of 10 MHz moderately facilitates the Co-existence of the two system.

Table 47: Summary of LTE-based UAS GS in 1910-1920 MHz interference probability to MFCN BS in 1920 - 1980 MHz

Environment	Bandwidth (MHz)	Tx power (dBm)	Probability for the worst impacted MFCN BS to be interfered (%)
Rural	5	30	5.6
		10	0.4
	10	30	5.04
		10	0.38
Urban	5	30	2.08
		10	0.19
	10	30	1.99
		10	0.17

5.4.1.5 Simulation of interference from MFCN UL to LTE-based UAS aerial UE

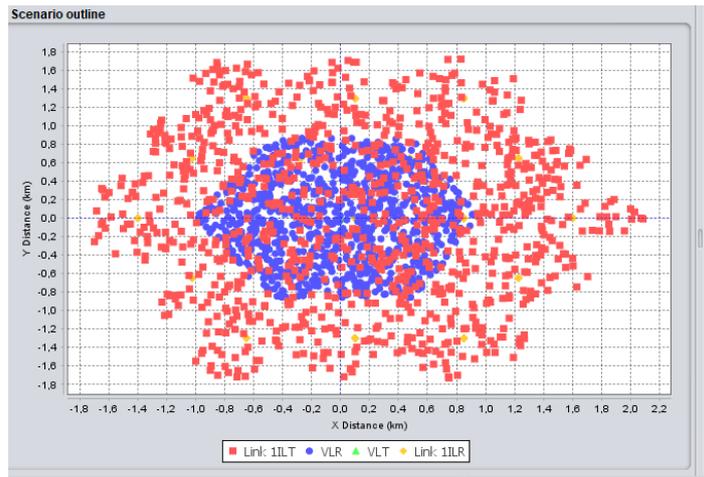


Figure 22: Simulation of interference from MFCN UE (10 MHz channel at 1925 MHz) to LTE-based UAS aerial UE (5 MHz channel at 1917.5 MHz)

Simulation results of interference from MFCN UE (10 MHz channel at 1925 MHz) to LTE-based UAS aerial UE (5 MHz channel at 1917.5 MHz) are given in Table 48. The simulation results show the interference from MFCN UE (10 MHz channel at 1925 MHz) to LTE-based UAS aerial UE (5 MHz channel at 1917.5 MHz) is not a problem.

Table 48: Simulation results of interference from MFCN UE (10 MHz channel at 1925 MHz) to LTE-based UAS aerial UE (5 MHz channel at 1917.5 MHz)

Parameter	Urban	Rural
iRSS_unwanted (dBm)	-130.6	-144.8
iRSS_blocking (dBm)	-131.8	-146.0
Ref Cell UL TP Loss (%)	1.632	0.177
MFCN system UL TP Loss (%)	1.632	0.177

5.4.1.6 Simulation of interference from MFCN UL to LTE-based UAS GS

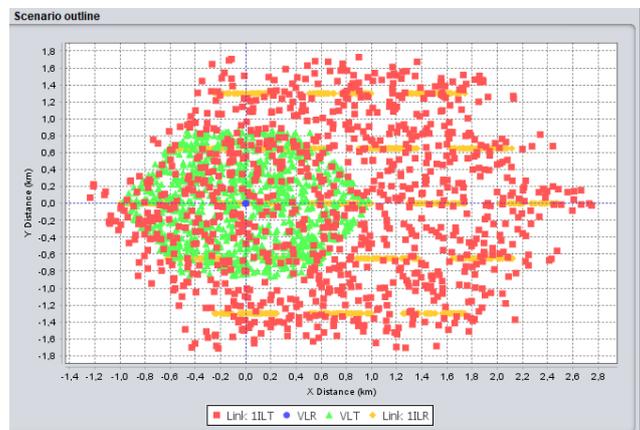


Figure 23: Simulation of interference from MFCN UE (10 MHz channel at 1925 MHz) to LTE-based UAS GS (5 MHz channel at 1917.5 MHz)

As shown in Figure 23, LTE-based UAS GS is randomly located from MFCN BS to the cell edge.

Simulation results of interference from MFCN UE (10 MHz channel at 1925 MHz) to LTE-based UAS GS (5 MHz channel at 1917.5 MHz) are given in Table 49. The simulation results show the interference from MFCN UE (10 MHz channel at 1925 MHz) to LTE-based UAS GS (5 MHz channel at 1917.5 MHz) is not a problem.

Table 49: Simulation results of interference from MFCN UE (10 MHz channel at 1925 MHz) to UAS GS (5 MHz channel at 1917.5 MHz)

Parameter	Urban	Rural
iRSS_unwanted (dBm)	-153	-177.6
iRSS_blocking (dBm)	-166.8	-191.4
Ref Cell UL TP Loss (%)	0.196	0.090
MFCN system UL TP Loss (%)	0.196	0.090

5.4.1.7 Conclusion

SEAMCAT simulations (Section 5.4) of interference from UAS UE to MFCN UL above 1920 MHz show a throughput loss between 8% and 25% for a UAS carrier frequency of 1917.5 MHz (5 MHz bandwidth).

SEAMCAT simulation show that interference from MFCN UEs to UAS GS and UAS UE translate to throughput losses between 0.1% to 1.6%

Monte Carlo simulations (Annex 9) of interference from UAS UE show that the interference probability of the most impacted MFCN BS in the simulation area, considering a carrier frequency of 1915 MHz, can be limited to about 15% if the rural range is limited to 1000 m, and to 7% if the urban range is limited to 250 m.

MCL computations (section 5.3.1.5) has been performed to assess the interference from UAS GS to MFCN UL. For an UAS GS with a maximum transmit power of 10 dBm and maximum antenna gain of 5 dBi, the I/N protection criterion is not exceeded for a separation distance of 100 m. The interference from a UAS GS with a transmit power of 30 dBm, however, is above the MFCN UL protection criterion at a separation distance of 100 m.

Monte Carlo simulations (Annex 9) show that interference probability of the most impacted MFCN BS in the simulation area is around 0.4% for an UAS GS transmit power of 10 dBm⁵, and around 5% to 6% for an UAS transmit power of 30 dBm.

⁵ Here, when the UAS GS transmit power is reduced from 30 dBm to 10 dBm, it is assumed that the out of band radiations are also attenuated by 20 dB.

6 COMPATIBILITY STUDIES INVOLVING DECT-2020 BASED UAS

Details on MCL compatibility studies with DECT-2020 can be found in Annex 13.

6.1 ADJACENT BAND COMPATIBILITY BETWEEN DECT-2020 BASED UAS AND FRMCS AT 1900-1910 MHZ

Co-existence between FRMCS in 1900-1910 MHz and UAS using DECT-2020 in 1880-1900MHz and 1910-1920 MHz shows that the UAS UE (drone) has higher impact on the co-existence as it is more susceptible to interfere (in particular, the FRMCS BS), and more susceptible to be interfered (in particular, from FRMCS BS).

In urban areas, separation distances between UAS GS and FRMCS BS/UE are always lower than 200 m.

Regarding UAS UE in urban areas, and both UAS GS and UE in rural areas, the following applies:

- On DECT-2020 carriers between 1896.48 MHz and 1914.624 MHz (excluding the band 1900-1910 MHz), the interference received by either UAS GS or UAS UE (or both) is high enough that they are unlikely to be selected by DECT-2020 dynamic channel selection (DCS), unless the UAS operates very far away from the railways (up to 10 km);
- Using channels at 1893.024 MHz, 1894.752 MHz, and above 1915.488 MHz (included) leads to a MCL separation distance lower than 3 km to protect the FRMCS BS (it also protects FRMCS UE, and UAS GS/UE);
- Using channels between 1882.656 MHz and 1891.296 MHz (included), separation distances of 500m protects the FRMCS BS and UE. However, MCL computations in a rural context suggest that a range 5650 m cannot be attained when the UAS GS/UE are 1000 m or closer from an FRMCS BS. A range of 1000 m in rural areas allows for separation distances less than 500 m.

6.2 ADJACENT BAND SHARING BETWEEN DECT-2020 BASED UAS AND MFCN AT 1880 MHZ

The interference from DECT-2020 UAS operating on channels in 1880-1900 MHz to MFCN UE in 1805-1880 MHz leads to maximum separation distances of 2 m in an urban context, and 85 m in a rural environment. These separation distances gets lower when using DECT-2020 channels farther away from 1880 MHz.

The interference from MFCN BS in 1805-1880 MHz to UAS using DECT-2020 in 1880-1900 MHz leads to a maximum separation distance of 200 m in urban scenarios, and around 3 km in rural scenarios. The separation distance between MFCN BS and UAS GS never goes under 1250 m, no matter the DECT channel chosed in 1880-1900 MHz. Separation distance in rural scenarios can be reduced by reducing the UAS range. For instance, reducing the UAS range to 1 km in rural areas leads to maximum separation distances of around 500 m for all carriers higher than 1886.112 MHz (included).

6.3 ADJACENT BAND SHARING BETWEEN DECT-2020 BASED UAS AND MFCN AT 1920 MHZ

MFCN UE transmitting in 1920-1980MHz leads to maximum separation distances with UAS GS or UE of 2 m.

Using a transmit power of 24 dBm leads to separation distances up to:

- 2400 m between UAS UE and MFCN BS in urban areas;
- 200 m between UAS GS and MFCN BS in urban areas;
- 7500 m between UAS UE and MFCN BS in rural areas;
- 3000 m between UAS GS and MFCN BS in rural areas.

In urban areas, if the transmit power is reduced to 10 dBm⁶, then separation distances are lower than:

- 400 m between UAS UE and MFCN BS;

⁶ Assuming that the spectrum emission mask scales accordingly with respect to the original spectrum emission mask at 24 dBm.

- 100 m between UAS GS and MFCN BS.

In rural areas, if the transmit power is reduced to 10 dBm and the range limited to 1000 m, then separation distances are lower than:

- 1300 m between UAS UE/GS and MFCN BS;
- if the carrier frequency is lower than 1914.624 MHz (included):
 - 150 m between UAS UE and MFCN BS;
 - 610 m between UAS GS and MFCN BS.

7 CONCLUSIONS

The purpose of this ECC Report is to present results for the technical compatibility studies related to the UAS (Unmanned Aircraft System) for governmental use of Command and Control (C2) links as well as payload links in the 1880-1900 MHz and 1900-1920 MHz bands.

The UAS consists of Ground Station (GS) ("controller") and User Equipment (UE) ("drone"). Single GS-UE pair uses single frequency block with TDD (Time Domain Duplex) principle. The GS is assumed to be at ground level (1.5 m), and the maximum height of the UE is assumed to be 120 m.

Up to three drones are simultaneously deployed in an operational zone with radius of up to 5650 m in rural areas, and up to 1000 m in urban areas. Each drone is controlled by a dedicated GS. The drone and controller are assumed to constantly be in visual line of sight.

The frequency band 1880-1900 MHz is designated for DECT (Digital Enhanced Cordless Telecommunications) on licence-exempted basis, originally used for cordless phones, but which nowadays consists of huge variety of different enterprise and professional applications including voice and data services. The frequency band 1900-1910 MHz has been lately designated and harmonised for the RMR (Railway Mobile Radio). Adjacent frequency bands are harmonised for MFCN (Mobile Fixed Communication Network): 1710-1785/1805-1880 MHz and 1920-1980/2110-2170 MHz. This Report considers in-band and adjacent band co-existence studies between UAS and these systems.

This report suggests different interference mitigations possibilities for improving co-existence of UAS with systems operating in the band 1880-1920 MHz and in adjacent bands. Noting that the UAS controller to drone (C2) only requires low bitrate, it has been shown that lowering the power of the UAS GS to 10 dBm improves co-existence with all involved systems. This however comes with a higher susceptibility of the drone to interference (see co-existence with MFCN in section 5.3). Power control applied to the UAS drone also showed improved co-existence with other systems. Similar gain could be expected by also applying power control to the UAS controller, although this has not been studied. Co-existence gain can also be obtained by ensuring separation distances were feasible, or by imposing additional constraints on UAS spectrum emission (see FRMCS studies in Annex 13) and/or UAS spectrum selectivity (see MFCN studies in section 5.3). Potential use of DECT-2020 NR technology based UAS is expected to improve co-existence, but is has not been fully studied.

7.1 UAS AND DECT

MCL (Minimum Coupling Loss) study on impact from UAS GS and UE for DECT indoor, outdoor and DECT WLL (Wireless Local Loop, which assumes the drone is in the main lobe of a 12 dBi DECT antenna) is in Sections 5.1.1.2 and 5.1.1.6. Separation distance are calculated for two different DECT wanted signal levels - 75 dBm and -65 dBm⁷. An UAS GS transmit power of 10 dBm and 30 dBm, and an UAS UE transmit power of 28 dBm is assumed.

The results of the MCL studies are presented in Table 50.

⁷ -65 dBm being a typical receiving level for low range indoor applications, while -75 dBm is considered for a typical receiving level for more sensitive indoor and outdoor applications. DECT devices have a sensitivity level down to -93 dBm.

Table 50: Summary of MCL separation distances between UAS using LTE and DECT

DECT Protection criterion	UAS GS or UE	UAS Tx power	DECT Rx power	DECT Indoor	DECT outdoor	DECT WLL
SINR of 21 dB	GS	10 dBm	-65 dBm	0.08 to 0.12 km	0.48 to 0.67 km	1.9 to 2.68 km
			-75 dBm	0.27 to 0.38 km	1.51 to 2.14 km	6.05 to 8.56 km
		30 dBm	-65 dBm	0.85 to 1.2 km	4.8 to 6.8 km	Not studied
			-75 dBm	2.68 to 3.82 km	15.1 to 21.4 km	Not studied
	UE	28 dBm	-65 dBm	0.36 to 0.53 km	2.14 to 3.03 km	8.52 to 12.06 km
			-75 dBm	1.20 to 1.70 km	6.77 to 9.60 km	27.0 to 37.88 km
Measured C/I	GS/UE	30 dBm	-65 dBm	0.05 to 0.75 km	0.53 to 3.3 km	Not studied
			-75 dBm	0.17 to 2.1 km	1.7 to 9.42 km	Not studied

SEAMCAT study (Annex 5) shows the probability that DECT is interfered, dBm for various values of DECT transmit power (between 4 and 24 dBm). Due to transmit power control, the worst situation is when the UE is furthest away from the GS. The following probabilities of interference were computed for outdoor DECT distributed between 0 and 300 m from the UAS GS:

- Equal or less than 10.3%, UAS GS transmit power of 10 dBm, urban environment;
- 14% (random distribution of DECT channels) and 42% (co-channel), UAS GS transmit power of 30 dBm, urban environment;
- 80% (random distribution of DECT channels) and 100% (co-channel), UAS GS transmit power of 30 dBm, rural environment.

For indoor DECT, the following probabilities of interference were computed for indoor DECT distributed between 0 and 300 m from the UAS GS:

- 0.8% (random distribution of DECT channels) and 2.2% (co-channel), UAS GS transmit power of 10 dBm, urban environment;
- 2.8% (random distribution of DECT channels) and 7.9% (co-channel), UAS GS transmit power of 30 dBm, urban environment.

Monte Carlo study (Annex 6) with residential DECT presented takes into account the instant Dynamic Channel Selection (iDCS) capability of DECT were carried out. It is assumed that [34]. 5% of DECT devices are located outdoor. In this context, DECT devices are able to avoid channels occupied by nearby UAS. The interference probability is

- between 0.1% and 2.3% when one drone is deployed in the 1880-1900 MHz band;
- between 0.2% and 6.5% when two drones are deployed in the 1880-1900 MHz band.
- In the other direction, there is negligible interference from DECT devices to UAS GS and UE.

Monte Carlo study (Annex 6) with a call-center (indoor only) deployment of DECT in an urban environment shows that interference mainly comes from the UAS GS, and its probability can be lower than 1% for distances:

- higher than 100 m for single and double (two) UAS deployments and UAS GS transmit power of 30 dBm;
- as low as 10 m for single UAS deployments and UAS GS transmit power of 10 dBm;
- higher than 20 m for double (two) UAS deployment and UAS GS transmit power of 10 dBm.

The results presented here are based on UAS using LTE technology and its impact on legacy DECT, not on DECT-2020 NR. There are also initial studies (Section 6 and Annex 13) assuming UAS using DECT-2020 NR technology.

7.2 UAS AND RMR/FRMCS (FUTURE RAILWAY COMMUNICATOIN SYSTEM)

7.2.1 Co-channel operation

The MCL studies (Annex 11) show that a co-channel operation of UAS in the FRMCS band 1900-1910 MHz is not feasible and will lead to a significant interference risk towards the FRMCS operation. Under a free space loss model, all UAS in distances up to 354 km to a FRMCS BS will lead to a desensitization of at least 3 dB. In practice, the radio horizon would limit the separation distance but that does not change the conclusion. For the cab radio the separation distance is 63 km.

7.2.2 Adjacent channel operation

Monte Carlo study of the possible impact of an UAS deployed in the frequency band 1910-1920 MHz to an FRMCS deployment in the band 1900-1910 MHz is presented in Annex 10.

Due to the symmetry of the FRMCS BEM and UAS SEM, these results at 1915 MHz also apply for interference from an UAS deployed at 1895 MHz. Simulations show that interference from UAS to FRMCS UE is negligible. On the contrary, interference to the FRMCS BS is more likely.

When using a UAS GS transmit power of 10 dBm, the probability of interfering the FRMCS BS is:

- less than 1% when the distance to the tracks is between 100 and 300 m in urban areas;
- less than 1% when the distance to the tracks is between 300 and 500 m in rural areas.

When using a UAS GS transmit power of 30 dBm, the probability of interfering the FRMCS BS is:

- less than 1% when the distance to the tracks is between 300 and 500 m in urban areas;
- Around 10% when the distance to the tracks is between 500 and 1000 m in rural areas.

Considering the impact of the UAS UE, the probability of interfering the FRMCS BS is:

- lower than 1% when the UAS UE is between 300 and 500 m from the tracks (horizontal distance) if the range is limited to 500 m in rural areas (1000 m if 10 MHz channel is used).
- lower than 1% when the UAS UE is between 300 and 500 m from the tracks (horizontal distance) in urban areas.

7.3 UAS AND MFCN

7.3.1 Co-existence between UAS and MFCN below 1880 MHz

SEAMCAT simulations (Annex 5) show that important levels of interference may happen from MFCN DL (1860-1880 MHz) to both UAS aerial UE and GS 10 MHz channel operating in 1880-1890 MHz. Noting that these levels of interference translate to UE (drone) throughput loss between 87.7% and 99.5% and GS (controller) throughput loss between 50% and 88%, considering the UAS channel centered at 1885 MHz and a UAS range of 1000 m. Additional Monte Carlo studies taking into account UAS protection criterions in-line with the bitrate requirements (300 kbps for controller to drone, 5 Mbps for drone to controller) show an interference probability of the UE and the GS lower than 10% (when the range has to be limited to 1000 m in rural environments), assuming a GS transmit power of 30 dBm.

SEAMCAT simulations (Annex 5) show that the inteference from MFCN DL(1860-1880 MHz) to both UAS aerial UE and GS 10 MHz channel operating in 1890-1900 MHz is reduced. If the UAS UE/GS receiver selectivity can be improved with an additional filter (ACS_2 = 66 dB), the interference from MFCN1800 DL can be reduced, as shown in 5.3.

Interference from UAS aerial UE to MFCN1800 DL (UE reception) does not appear as a problem, including flying MFCN UE, as it translates to downlink throughput loss less than 0.1%.

MCL computations (section 5.3) has been performed to assess the interference from UAS GS to MFCN1800 DL(UE reception). For an UAS GS transmitting at 10 dBm, the I/N protection criterion of an MFCN UE is not exceeded at 50 m (urban environment) or 100 m (rural environment). For an UAS GS transmitting at 30 dBm however, the MFCN UE protection criterion can be exceeded even when the separation distance is above 100 m.

Considering that, for a governmental drone, the highest data rate is transmitted from UAS UE to UAS GS, , and in order to further protect the command & control signals received by UAS UE from MFCN interference, UAS command and control channel of a single drone deployment could be placed in the frequency range 1890-1900 MHz.

7.3.2 Co-existence between UAS and MFCN above 1920 MHz

- 1 SEAMCAT simulations (section 5.4) of interference from UAS Aerial UE to MFCN UL above 1920 MHz show a throughput loss between 8% and 25% for a UAS carrier frequency of 1917.5 MHz (5 MHz bandwidth).
- 2 SEAMCAT simulation show that interference from MFCN UEs to UAS GS and Aerial UE translate to throughput losses between 0.1% to 1.6%
- 3 Monte Carlo simulations (Annex 9) of interference from UAS UE show that the interference probability of the most impacted MFCN BS in the simulation area, considering a carrier frequency of 1915 MHz, can be limited to about 15% if the rural range is limited to 1000 m, and to 7% if the urban range is limited to 250 m.
- 4 MCL computations (section 5.3.1.5) has been performed to assess the interference from UAS GS to MFCN UL. For an UAS GS with a maximum transmit power of 10 dBm and maximum antenna gain of 5 dBi, the I/N protection criterion is generally not exceeded for a separation distance of 100 m (criterion is exceeded in urban settings using propagation model of Rec ITU-R P.1546). The interference from a UAS GS with a transmit power of 30 dBm, however, is above the MFCN UL protection criterion at a separation distance of 100 m.
- 5 Monte Carlo simulations (Annex 9) show that interference probability of the most impacted MFCN BS in the simulation area is around 0.4% for an UAS GS transmit power of 10 dBm⁸, and around 5% to 6% for an UAS transmit power of 30 dBm.

7.4 UAS USING DECT-2020 NR

Initial MCL compatibility studies were carried in order to quantify the feasibility of deploying UAS using DECT-2020 in 1880-1900 MHz and 1910-1920 MHz.

Given the similarities between LTE and DECT-2020 waveforms, considering the lower transmit power of DECT-2020 (24 dBm), dynamic selection of time slots and frequency channels, and transmit power control on both UAS GS and UAS UE, it is expected that probabilities of interference of UAS using DECT-2020 NR to systems in adjacent bands would be lower than those computed using Monte Carlo studies with UAS using LTE.

⁸ Here, when the UAS GS transmit power is reduced from 30 dBm to 10 dBm, it is assumed that the out of band radiations are also attenuated by 20 dB.

ANNEX 1: DECT OUTDOOR APPLICATIONS

A1.1 DECT IN PROFESSIONAL WIRELESS OUTDOOR INTERCOM APPLICATIONS

Outdoor applications rely on highest possible channel usage to serve densely populated event scenarios, which can only be provided with uninterrupted radio connectivity. Any frequency interference in-band or in the adjacent band will so negatively impact the application as to render it unfit for purpose.

The nature of the DECT radio spectrum band coupled with the ability to self-configure make DECT very suitable for intercom systems.

E.g. Blue light services (ambulance etc.), technical staff and catering need this secure audio communication to guarantee a seamless production and the security of thousands of customers. If television broadcasters are on site, DECT communication is in use for communication between their team members.

In sharp contrast to the domestic/consumer market for DECT phones, DECT technology as it is used today in professional user scenarios typically:

- a) have far more serious consequences of failure
- b) have far higher user densities
- c) occupy a much larger proportion of the available DECT band
- d) operate with far lower RF receiver sensitivity levels resulting in a higher susceptibility to 'non-DECT' transmitter interference

The following section aims to provide a clear real-life representation of typical DECT professional user scenarios and bring to the foreground, a better understanding, of the very much higher probability and more serious consequences of interference from the proposed usage of the DECT spectrum for government drones. Some background on the four issues is listed above:

A1.2 DECT USAGE WHEN FAILURE IS NOT AN OPTION

The customer need which is addressed and is common amongst all professional uses of DECT, is for outstanding robustness of communication. "It must work every time – without fail". The usual quality of service experienced by all of us using mobile phones or indeed Bluetooth or Wi-Fi, is simply not good enough for professional user scenarios where any dropout due to interference would have serious consequences.

Professional DECT communication systems (intercom) are used in many blue light emergencies, for fire teams battling to save lives in major incidents, for crowd control at mass gatherings, for command and control at rock concerts, in the Formula-1 pit-lane where split-second clear responses from team members are essential. They are also increasingly used in medical settings in operating theatres (alongside DECT phone communication in hospital campuses) and they are also used in many retail scenarios, in superstores and drive-throughs where fast clear communication is essential to process consumers efficiently.

Corporate conferencing and conferencing events also rely on DECT microphone systems delivering flawless sound. All professional DECT systems need the outstanding robustness and reliability, but the unrivalled robustness of DECT completely relies on all systems in the DECT band adhering to standards and protocols that ensure near-perfect Co-existence between systems using the band. Any high-powered 'non-DECT' system in the DECT band would cause havoc with all of these systems by causing dropouts and a lack of availability which cannot be tolerated.

For examples of typical 'high-stakes' DECT Professional User Scenarios, see A1.5 and A1.6

A1.3 DENSITY

The great majority of professional DECT user scenarios require a high concentration of users – sometimes in areas as dense as 1 user /m² (theoretically 1 million / km²). This user density is many orders of magnitude greater than the domestic use of DECT phones (hundreds or thousands per sq. km). Hence any interference caused by non-DECT systems in a DECT band used by professional systems has the potential to disrupt the communication of dozens of users in one location - and a mobile non-DECT interferer like a drone, could tear through the communications of many many more. One corporate or medical campus or even one call centre floor can have active user populations of over well over 100 and up to 250 per floor in some cases. Such high densities use two spectrum efficiency 'density' techniques to cram as many users into a space as is required – these techniques lead to the following remaining two issues in the above summary, DECT Band Occupancy and DECT Receiver sensitivity:

A1.3.1 Density Technique 1: Synchronised Overlapping Multicell Systems

In order to support a high number of users in one installation, several DECT base stations are required. Typically, a DECT base station may support 4-12 concurrent (live) bi-directional audio paths (typically spread out over all 10 carriers), therefore installations with the need to support (say) 100 live users in a very densely packed physical area, may employ ~10-20 base stations whose operating range (or 'cells') may almost completely overlap. Many installations require that all of these audio channels must form one cohesive system, so all base stations are connected typically by an ethernet backbone to connect audio paths, resulting in a complex multi-cell system. If these base stations/cells are accurately synchronised, then each base station's DECT frame/timeslots are mutually synchronised and do not collide with timeslots from another base station. This way, the whole system can populate almost the entire available DECT band (which has 24 timeslots per carrier and 5-10 carriers = 120-240 timeslots).

Typically, site surveys are done to determine how much of the DECT band is already occupied before installation and the installation design will typically make efficient use of the portion of the DECT band that is available. Hence even if one professional DECT installation uses (say) 40% of the available band, another may then almost totally fill the remainder.

DECT-based communication and conferencing systems are available on the market today that use the synchronised overlapping multicell technique and comfortably support up to 100 users in one densely-packed area – without spectrum re-use.

Current professional DECT communication systems (intercom) deployments using the synchronised overlapping multicell technique can exceed 60 access points (e.g. Disneyland, Paris), where in high-density areas, 10 access points within 50 meters radius can support up to 100 users.

A1.3.2 DECT Band Occupancy

These synchronised multicell systems described above, can efficiently pack a large number of concurrent active RF connections into the available DECT band's carriers and timeslots and in doing so take the reliance on adherence to the DECT standards to the zenith, and the DECT band in the area of use can be easily >90% occupied by live audio with the remained reserved for handover.

NOTE: typically a large DECT system will be designed such that no more than 85% - 90% loading leaving all of the spare slots available for 'handover' which occurs when a DECT system avoids interference. Thus 85% loading may mean 100% utilisation of the band.

It is important to highlight that if a given DECT slot in a system of (say) 40, experiences interference, that this can constitute a failure, or degradation of the whole system such that in the example where the probability of interference in any given slot of a DECT band is (say) 10%, then the probability of degradation of the whole system using 40 slots is $1 - (1 - 0.1)^{40} = 98.5\%$.

If the interferer was another DECT system adhering to the DECT regulations, the failure would be temporary and the interferer and the interfered systems would self-organise to avoid on another. However, this would not

be the case for a non-DECT system like drone and the probability of failure would remain high as long as the interfering signal persisted.

A1.3.3 Density Technique 2: Spectrum re-use

In order to further maximise the number users in an installation (for either synchronised or unsynchronised systems) it is commonplace in professional DECT systems to reduce the working RF range of each 'cell' of users, thereby allowing re-use of a given cell's DECT frequencies by another cell which is well out of range of the first. This means that the output power may be around 4 dBm (in contrast to the maximum allowed for DECT which is 24 dBm (250 mW)). However, in order to maintain a good RF Link Margin that will still deliver a good quality of service at this low power, typically receiver sensitivity is consequently lower than the minimum required by the DECT harmonised standard. Hence commonly receiver sensitivities in densely deployed professional DECT systems can be around -75 dBm. Indeed, DECT systems are being designed today that will have receiver sensitivity of around -90 dBm.

Many very large professional DECT systems use both density techniques above.

A1.4 DECT PROFESSIONAL USER SCENARIO SUMMARY:

Table 51: DECT Professional User Scenario Summary

User scenario type	Typical number of active users in an installation (2 connections required per user)	DECT band time slot utilization across all 10 carriers (active + reserved for handover)	Special Features	Operational cell margin Sensitivity dBm (better than)
Wireless PABX (hospitals, corporate)	3000	Up to 100% in some areas	Large synchronised multi-cell system with spectrum re-use	-75 dBm
Call centre	2500	100% - highly active band where any spare slots are used for 'handover'	Large and highly dense (1 /m ²) installation of a large number of unsynchronised small personal 'cells' with very low transmit power	-75 dBm
Outdoor intercom/talkback/ team communication	250	80% + 20% extra reservation for repeaters and intercell handover and roaming	Large synchronised multi-cell system with spectrum re-use	-75 dBm
Corporate and government conferencing	300 across 70 rooms		Large synchronised multi-cell system with spectrum re-use	-75 dBm

A1.5 DECT PROFESSIONAL USER SCENARIOS

A1.5.1 Sport Stadium (e.g. Soccer (Stade de France), FIFA, UEFA)

Modern stadia are multi-purpose arenas with crowds of up to 80000 people. DECT is used for communication between large teams of event organisers. Stadium facilities include corporate meetings and social events. In addition, referees, officials and coaches use DECT devices to communicate.

DECT wireless intercom solutions are used to deliver simple and reliable connectivity in these modern arenas, and support security concepts to enable the organizers, blue light service, contractors and other involved person. Multi-cell handover systems with up to approx. 16 access points all across the Stadium provide these communications.

User Groups:

- Referees;
- Officials/Production;
- Show technicians (Light, Sound, Power, Rigging, Firework & Effects etc.);
- Safety Cueing;
- Security;
- Blue light/Emergency services;
- Broadcast Teams.

Density:

- On the day of a sport event, more than 50 beltacks are simultaneously in use;
- Before, during and after a concert up to 100 beltacks are simultaneously in use and fill the spectrum completely around the stage/field area.



Figure 24: Caption Referee Communication, Stadium Game day, Music Concert

A1.5.2 Outdoor Sport Events (e.g. Downhill Skiing Events, Bicycle Races, Red Bull Crashed Ice, International Games, Olympics etc.)

Outdoor sport events: Wireless communication systems are essential for broadcast services to coordinate all workers during setup and camera operators during production. A wide working range is necessary to cover areas of e.g. a downhill racing mountain.

Multiple DECT systems operate side by side when an international event is broadcast by multiple stations. 10 to 20 access points are installed across the track and especially in the finish area.

User Groups:

- Production;
- Technicians (Light, Sound, Power etc.);
- Security;
- Blue light/Emergency services;

- Broadcast Teams.

Density:

- Before, during and after the sport event 50 to 100 users/beltpacks are simultaneously in use. These systems are widely spread across the complete track and finish area, the DECT spectrum is approx. 50% in use at a certain point.



Figure 25: Cameraman Summer and Winter Sport Events, Olympic Games Marathon

A1.5.3 Motorsport Event (e.g. Formula 1, DTM, Air Race etc.)

Motorsports impose exacting demands on man and machine. Multiple communication technologies are in use to make a simultaneous use of more than 1000 communication channels in smallest environment possible. DECT is used by all teams to enable failure-free communications between race control, teams and drivers.

Normally one operator provides a fully controlled multi-cell handover system with up to approx. 40 access points for all users. Up to 250 beltpack users work simultaneously in the pit lane area. The DECT spectrum frequencies are re-used multiple times to achieve these numbers of parallel users. DECT microcells are necessary to achieve the customer request. Additional to the formula staff some broadcasters use the same infrastructure to do live broadcasting via the DECT network.

User Groups:

- Production staff;
- Motorsport teams (Mercedes, Ferrari, Red Bull, Porsche etc.);
- Security staff;
- Blue Light/Emergency services staff (e.g. Ambulance);
- Broadcast teams.

Density:

- Up to approx. 250 DECT beltpacks are simultaneously in use and fill the spectrum completely in the pit lane area multiple times.



Figure 26: Formula 1 Team, Broadcast Cameraman, Interview via wireless Intercom

A1.5.4 Music Festival e.g. Wacken (GER), Hell fest Open Air (FRA), Glastonbury (UK)

At large open air music festivals, security and seamless production is a major concern. DECT wireless intercom solutions are the main communication channel for the staff to guarantee flawless operation in all parts of these events. Additional TV and Radio broadcasters communicate with their own DECT communication equipment to coordinate their people and do live reports. All of them need and expect highest level of communication reliability.

In these venues multiple unsynchronised multi-cell handover intercom systems are build-up by different parties. Approx. 15 Base Stations work in parallel. Very often 150 beltpack users work simultaneously across the event area and beyond. These users use 100% of the spectrum. As the frequencies are in use multiple times the working range of the beltpacks are already decreased in some areas. Sometimes microcells need to be installed to increase the quantity of beltpacks. User Groups:

- Production;
- Show technicians (Light, Sound, Power, Rigging, Firework & Effects etc.);
- Security;
- Blue Light/Emergency services;
- Broadcast Teams.

Density:

- Before, during and after the concert 100 beltpacks and more are simultaneously in use and fill the spectrum completely around the stage.



Figure 27: Hellfest music festival in France (Clisson)

A1.5.5 Amusement Parks (Disneyland Paris, Europa Park, Legoland etc.)

This profile includes also other theme parks (Europa Park, Legoland etc.)

Profile: All amusement parks, from large through medium to smaller-sized theme parks are directly aimed at smaller children. All of them share the same need of reliable communication to coordinate the employees, stage shows and especially crowd control / security.

Professional/Enterprise (synchronised multicell) solutions are deployed with more than 60 access points and up to 250 live users/beltpacks across the park. Access points are installed every 15 to 30 meters and frequencies are re-used multiple times during high user density shows/parade.

User Groups:

- Show technicians (Light, Sound, Power, Effects etc.);
- Show staff;
- Security;
- Blue Light/Emergency services.

Density:

- Every day 50 to 250 beltacks are in use. Especially during high user density shows/parade the spectrum is 50% to 80% in use.

A1.5.6 Hospital

Profile: A large health park located on the Barcelona coast, the Centre is comprised of over 10 different buildings with varying fields and functions.

Requirements: Integrate and streamline communications and processes across the different sites.

Solution: Mobility, external contact centre, internal contact centre (IT helpdesk), a solution for virtual meeting rooms, as well as CEBP (Communications Enabled Business Process) for automation of SOS processes, CRA (Cardiorespiratory arrest) and Stroke, plus a full IP Nurse Call system integrated within the platform. The nurse call solution was installed together with VoIP with around 2500 extensions to allow communications between nurse calls and professionals. In addition, a security solution was implemented, allowing the hospital to automate hospital procedures including critical communication processes such as in case of a heart attack. Using a geolocation feature, the hospital is able to monitor residing patients and occupancy of emergency beds and hence improve waiting times and overall quality of service.

A1.5.7 Universities Learning and Teaching Hub 1

Profile: Large Urban 22 story building central court

Requirements: The courthouse required a dense deployment of DECT microphones that could accommodate over 300 channels across 71 courtrooms in a heavily populated and complex RF environment in an urban environment.

Solution: Automatic frequency coordination, selectable transmission rate, transmission encryption. Ability to operate on over 80 channels in a highly populated environment to eliminate potential RF interference.

Uses synchronised multicell technique with receiver sensitivity better than -75 dBm.

A1.5.8 Universities Learning and Teaching Hub 2

Profile: Large campus with dispersed buildings

Requirements: Provide seamless communication for users as they roam throughout the campus. The DECT signals had to be routed amongst three separate areas within the building, with long distances between buildings.

Solution: Uses synchronised multicell technique with receiver sensitivity better than -75 dBm.

A1.5.9 Conference Centre 1

Profile: A conference venue with highest spec DECT equipment for seminars, lectures, exhibitions, and conferences. The venue is comprised of nine conference rooms,

Requirements: The Conference Centre required a wireless solution that could operate 20 channels, license-free, on the same floor and also support flexible room setups. Sound quality, design, and particularly system stability and to ensure security for clients who are concerned about confidentiality. Requires quality RF receiver sensitivity.

Solution: Automated Frequency Coordination to automatically scan and assign available frequencies for all wireless transmitters. Uses synchronised multicell technique with receiver sensitivity better than -75 dBm.

A1.5.10 Conference Centre 2

Profile: Conference Centre for Doctors

Requirements: To create a flexible, easily deployed, microphone system with high quality sound for the facility's large audioconferencing area, which can be divided into two or three independent meeting rooms used simultaneously.

Solution: Automatic frequency coordination, easy operation, high sound quality, remote monitoring and control for IT Dept., and smart charging docks for transmitter storage to accommodate the maximum of 64 participants in the conference centre, systems are deployed with 8 channels in each of the two smaller conference rooms and 16 channels in the larger central meeting room.

A1.6 RESCUE AND SAFEGUARD COMMAND VEHICLE

The command vehicle coordinate's all available blue light services at an incident. The leading team usually consists of links to Fire, Police, and other Emergency services and communicates with the advantage of a full functional private intercom system, which also enables direct point to point communication, including phone call integration and a full integration of the various blue light services attending the incident.

The DECT wireless intercom beltacks increase the working range of the leading team without reducing the communication possibilities when outside the command vehicle. Each vehicle supports 5 to 10 DECT beltacks which are distributed to the command team members and two base stations are mounted on top of the truck. UHF wireless devices are integrated via bridges into the intercom system.

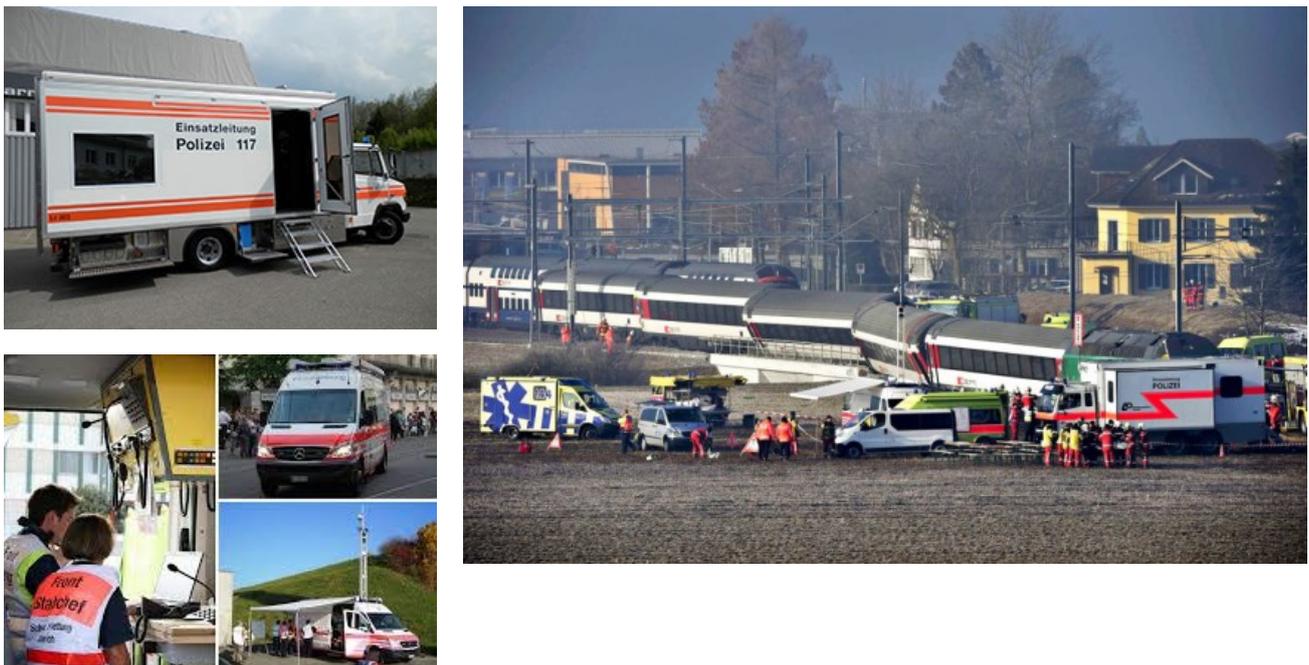


Figure 28: DECT in Mission Critical Systems

Train crash in Rafz, Switzerland on 20 February 2015, a very successful communication operation with three command vehicles on site. The ultimate goal is to have one vehicle for all organisations (Fire Department, Police and Emergency) beltacks can accept incoming calls on a main number where the beltack is the first incoming-call priority.

Audio encryption in the DECT system fits the customer's security standards.

A1.7 STANDARD WORKING RANGE OF WIRELESS INTERCOM SOLUTIONS

For many years, the rule of thumb for range from base station to mobile has been 50 m indoors. This was based on the original commercial telephone technology that was designed for cost effective deployment (1997-2010). The limiting factor was non line of sight transmission with multipath interference. The ETSI EN 301 406 [6] has minimum performance limits that reflect devices from the same period. The limits are contained within EN 300 175-2, section 6 [4].

Modern well-designed radios have better than the minimum performance identified in EN 300 175-2. TR 103 089 already mentions this but ETSI TC-DECT is proposing to introduce an optional improved level of sensitivity of -90 dBm or better that can be tested and manufacturers are designing to that specification.

High density systems use better sensitivity and antenna diversity to improve range. In many situations density of deployment is more important than range and to optimize spectrum usage, systems will often limit their maximum power (this also improves battery run time). Many systems reduce their maximum transmit power as low as 4 dBm to allow more base stations and portable units to be packed in an area or volume (i.e. multi-story buildings). This results in the operational range to a -75 dBm edge of cell limit in the protected DECT band.

The computing on Rx sensitivity based on 50 m in combination with 24 dBm RF output power is not valid for current high density systems.

A1.8 CONCLUSION

It should be noted that in some scenarios the the band 1880-1900 MHz designated to DECT is already heavily occupied and does not fulfil the demand of outdoor events and modern productions. Any frequency interference will disturb these productions and will negatively impact the performance to the extent where it is no longer fit for purpose. Therefore, big events already control the use of UHF as well as DECT wireless equipment during production time to guarantee a flawless performance.

The high user density DECT outdoor applications must be taken into consideration, as these are the typical use-case scenarios.

Capacity has already been reduced to the outdoor venues since UHF frequencies were made available to the mobile service providers.

ANNEX 2: DECT USAGE INDOOR SCENARIOS

A2.1 RESIDENTIAL / HOME GATEWAY AND SOHO (SMALL OFFICE / HOME OFFICE)

When operators started to migrate their networks from PSTN to IP in the noughties, DECT Forum anticipated the migration of the DECT radio into the broadband Home Gateway with the introduction of the technology initiative CAT-iq. ETSI produced the DECT New Generation standard to accompany CAT-iq and many operators across Europe have adopted the standard that replicates SIP supplementary services for Voice over IP over DECT, like conferencing, call transfer, multiple lines and event notification. In addition, it standardised G.722 [30] as the codec for HD Voice. The CAT-iq certification program ensures that the CAT-iq products are compliant with the requirements of GSA HD Voice, and guarantee interoperability between different manufacturers and HD Voice wideband audio quality across mobile and fixed networks.

ULE (Ultra Low Energy) was introduced by the ULE Alliance, which was founded and standardised in 2013. ULE operates on the DECT spectrum, and uses data communication capabilities of the DECT standard, which were only partially used in legacy DECT. The ULE specification enables the use of DECT for devices which are primarily battery powered. ULE addresses the low power requirements of sensor applications typically found in the smart home. In recent years, European operators in France, Germany, Switzerland, Belgium, Turkey and the UK as well as many other CEPT countries have been rolling out Home Gateways (or Smart Hubs) that not only support CAT-iq-based voice applications including HD Voice, but also use the same DECT radio to enable SOHO and Smart Home security services like smoke alarms and motion sensors using ULE. Hence modern SOHO and Smart Home DECT systems often comprise of a local-area network of multiple wireless devices communicating over fixed-line/broadband via the Home Gateway/Hub for voice and data services.

In the Assisted Living market, Regional Governments' Social Services in many European countries have deployed DECT-based Emergency Pendants that are used by elderly, infirm and disabled people, reliant on social services for their health monitoring, safety and security.

A2.2 DECT PROFESSIONAL / ENTERPRISE

Private and public companies whose business depends on professional and enterprise voice applications are deploying DECT based systems due to their reliability and quality of service. Emergency '112' Service centres and FAA/Eurocontrol Flight Control centres use DECT systems for safety-critical communications. Many large hospitals across France, Germany, Scandinavia and the rest of Europe rely on DECT for mission-critical emergency services. These are not only limited to Enterprise voice applications such as intercom and telephony, DECT is also used for the transmission of vital signs data, and for patient alarms, for essential patient health services. In the hospitality segment, hotels and ships use DECT to provide location services for lone workers and other staff. Similarly, industrial manufacturing plants, R&D facilities, large commercial office buildings, conference centres, , prisons, power stations, schools and university campuses are just installations that rely on DECT for quality of service, reliable wireless coverage, and client density.

A2.3 THE NATURE OF DECT PROFESSIONAL HIGH USER-DENSITY APPLICATIONS

The nature of the DECT radio spectrum band coupled with the ability to self-configure make DECT very suitable for intercom systems. These are widely used in indoor and outdoor scenarios (see section 4). DECT is also in use in Call Centre and Conferencing systems where quality and reliability of communication is essential for very high densities of users. Unified Communication and PMSE (Program Making and Special Events) industries where DECT is increasingly used in many mission-critical applications like 'Talk-back' structured intercom for Broadcasters, (which previously used 470-862 MHz channels) Translation Systems, Assistive Listening systems (for the hard of hearing) wireless performance microphones, wireless loudspeakers and headphones.

The density of users supported by these professional DECT systems can be expressed in the following ways

- a) User Density Per Installation (Live = Rx + Tx streaming // Connected = Rx + Tx control/data only):

Concurrent Live Users per deployed system - without frequency re-use: can exceed 60 - all within a radius of 15 m - or around one DECT radio per 10 m². Within one conference room, the density can exceed one radio per 2 m².

Concurrent Live Users per deployed system - with frequency re-use: is unlimited but single installations of >100 live users is not uncommon, with several hundred registered users. Within a call centre, the density can be as high as one radio per 5 m².

Connected Users: the number of connected users can far exceed the number of live users above - the 'connected' state meaning that users' equipment that is not Transmit-streaming, may be receiving broadcast audio or data and continues to exchange control data with base stations. The number of connected users can be measured in many 100s per installation (presentation/debating hall scenario)

b) Access Point Density Per Installation

The distribution of access points and base stations in an installation adds to the above density of active DECT radios. In Enterprise and Conferencing installations, the density is typically around one DECT radio per 20-30 m² with the density of base stations in call centres as high as one per 5 m² (doubling the density of live user radios)

c) Spectrum Occupancy within an operating system's range

DECT spectrum occupancy can exceed 80% (> 160 of 200 available channels - the practical limit of a fully managed DECT spectrum) when full use of DECT's Dynamic Channel Allocation (see Annex 1) and synchronised accessed points is deployed. It is crucial to note that this extraordinarily high spectrum occupancy is only possible when the DECT spectrum is only occupied by DECT radios (that adhere to DECT regulations).

As conclusion, in these high-density deployments, a very careful survey of the spectrum is carried out beforehand and typically steps are taken to design the installation to get the maximum throughput (number of voice channels) whilst maintaining very high QoS. Any new higher-power interferer that does not adhere to the DECT band's regulations would immediately render these high-density systems unusable.

For this reason, in order to make this ECC Report sufficiently accurate, these high user density scenarios should be part of any tests or simulations carried out to determine the extent of adjacent or in-band interference. The simulations should take account of the various density factors mentioned above. In addition, for the professional use-case scenarios such as Intercom & Enterprise, simulations should be conducted indoor and outdoor.

A2.4 TYPICAL HIGH DENSITY DECT PROFESSIONAL INSTALLATIONS

- a) Call Centres: (DECT Headset Systems) used for Emergency Services, Sales, Customer Support, and Technical, typically housed in large dense open-plan offices within city centres or increasingly in business parks on city/town peripheries.
- b) Intercom Systems: (used for live multichannel handsfree teamwork) covering a permanent or temporary installation. Sites include broadcasting/film studios 'talk-back', theatres, outdoor events, and command/control for operations, including airports - and the very extensive network of drive-thru restaurants etc. Special note should be taken here concerning outdoor use.
- c) Conferencing Systems: (networked and stand-alone microphone systems) used in city centre corporate boardrooms & conferencing rooms, hotels and meeting venues, schools and higher education.
- d) Professional Enterprise Communication: (seamless multicell local area voice communication network) used in hospitals, prisons, large company office estates and university campuses (indoor and outdoor)

As conclusion, a significant number of High Density DECT installations are deployed by large commercial companies and public service organisations whose operations are essential for the national and regional economy, safety and health services of European countries. Disruption caused by any new higher-power

interferer will have consequent and far-reaching impacts of which regional and national governments should be forewarned.

A2.5 DECT TECHNOLOGY AND USE OF THE DECT SPECTRUM

As mentioned above, compared with cellular phone systems and other wireless local area networks used for data services, very high (live) user densities delivering with QoS are achieved. This is made possible by a number of features and techniques deployed in DECT systems - only a few of which are mentioned here.

A2.5.1 DCA: Dynamic Channel Allocation:

One main characteristic of DECT is the instant DCA (live with an active call/connection). DECT in Europe has 10 carriers available on a 20 MHz bandwidth (1880-1900 MHz). Each carrier is divided in frames of 24 full-slot time slots (12 in one direction and 12 in the other direction for symmetric duplex services). A DECT access channel is defined by a carrier frequency and a time slot. If for example, 10 DECT carriers are allocated, as in the frequency band 1880 - 1900 MHz, a total of 120 full-slot duplex access channels will be provided. Conferencing or Intercom Systems can deploy asymmetric frame structures to make the most efficient use of available spectrum.

During a live connection, the DECT traffic channel selection is made by the user equipment's radio. The radio's 'channel manager' continually scans all available time slots for interference and will collaborate through a 'back-channel' with the connected base station or access point, if and when a switch to a clearer time slot is necessary to maintain or improve quality of service (QoS). During this switch to an improved time-slot both 'old' and 'new' slots will be temporarily be active, to ensure a continuous and seamless connection. This ability (which is not for example native to technologies employing Fixed Channel Allocation (FCA) mechanisms - such as UHF systems that don't have a 'back-channel') is what makes DECT suitable for microphone manufacturers who traditionally have used UHF technology where pre-scanning before every connection set-up is required and where typically, interference can (even after pre-scanning) still impact QoS.

In summary, with DCA, so long as different applications and different operators are 'playing by the DECT rules', they can dynamically and efficiently share the same spectrum resource without prior distribution of channels to specific services or base stations.

A2.5.2 Multi-cell / redundancy:

When multiple overlapping base stations or access points are deployed, The user equipment's radio can also keep track of the strongest detected signal from available base stations, and with a similar mechanism to DCA, can switch with seamless 'hand-off' from one base station to another. Cellular technologies such as GSM were designed with a very similar capability, but the typical physical DECT cell spacing can be small enough to provide very high densities of users with very high QoS.

A2.5.3 Frequency Re-use:

Many large-scale or high-density DECT systems can deploy very large numbers of user equipment by frequency re-use techniques. Just one example is call centre headset systems, that dynamically control the 'size' of the active DECT cell depending on the needs of the active connection. This is achieved by dynamically controlling (reducing) the RF power of both the user equipment's radio and the base station, thus 'shrinking' the cell size to the minimum required to maintain good QoS. Thus in a large and high density installation, the carriers and timeslots of the DECT frequencies can be utilized many times over. It is important to note that in this very low-power state, call centre headsets (as mentioned - some of which are being used for emergency services) would be especially vulnerable to a non-DECT high-power interferer.

It is also important to note here that the above features and techniques deployed in any DECT systems that facilitate large numbers and high densities of users, were designed for DECT operation and co-existence of users within one DECT system and between independent DECT compliant systems. They were never designed to handle arbitrary adjacent band (or worse, in-band) interference by other technologies and applications

ANNEX 3: DETERMINATION OF LTE-BASED UAS UE AND UAS BS MAXIMUM TRANSMIT POWER

In this annex, a maximum UAS transmit power of both drones (UAS UE) and controller (UAS BS) is determined, allowing to meet the bitrate requirements of Table 7, at the maximum ranges described in Table 6.

A3.1 METHODOLOGY

The following steps allows to derive a transmit power level P_e (in dBm) from a target bitrate D (in bps):

- 1 Compute the spectral efficiency η (in bps/Hz) needed to meet the target bitrate D_T , taking into account:
 - The bandwidth of the transmission B (in Hz),
 - TDD ratio η_{TDD} ,
 - Some margin η_{margin} ,
 - η is then found as the solution of $D_T = \eta \cdot \eta_{TDD} \cdot \eta_{margin} \cdot B$
- 2 From the curve giving the spectral efficiency of the modulation η as a function of the received SNR, determine the minimum target SNR: SNR_T .
- 3 Determine the transmit power level P_e allowing to reach the target SNR SNR_T for the maximum range of the system, as the solution of $SNR_T = P_r - N_{dB} = P_e - L(d) - P_N$, where P_N (dB) is the noise power in the receiver, and $L(d)$ (in dB) includes all the losses in the propagation path (including antenna gain, path loss, building entry loss, etc.).

A3.2 DERIVATION OF UAS MAXIMUM TRANSMIT POWER LEVEL

A3.2.1 Target spectral efficiency

From Table 7, the following parameters is obtained:

- Target bitrate is:
 - $D_T = 300$ kbps for downlink (controller to drone);
 - $D_T = 300 + 5000$ kbps = 5.3 Mbps for uplink (drone to controller).
- Bandwidth $B = 5$ or $B = 10$ MHz.
- TDD ratio follows LTE frame configuration 0. In this configuration, 6 out of 10 slots are dedicated to the uplink, and 2 out of 10 slots are dedicated to the downlink. Hence, the following has been reached:
 - $\eta_{TDD} = 0.6$ for uplink;
 - $\eta_{TDD} = 0.2$ for downlink.

In order to take into account other spectral efficiency loss (e.g.: signalling, cyclic prefix, etc.) It has been proposed to take a margin $\eta_{margin} = 0.9$. Using these values, the target spectral efficiencies of Table 52 are obtained.

Table 52: Uplink and downlink UAS target spectral efficiencies

Bandwidth of UAS system (MHz)	Uplink target spectral efficiency (bps/Hz)	Downlink target spectral efficiency (bps/Hz)
5	1.96	0.33
10	0.98	0.17

A3.2.2 Target SNR

Relationship between spectral efficiency and SNR can be found in the LTE linked level performance described in ETSI 3GPP TR 36.942, Annex A, It is proposed to use the following formula:

$$\eta(SNR) = \min\left(\eta_{max}, \begin{cases} 0 & \forall SNR \leq SNR_{min} \\ \alpha \log_2(1 + SNR) & \forall SNR \in]SNR_{min}, SNR_{max}[\end{cases}\right) \quad (8)$$

With α , SNR_{min} and η_{max} , given in Table 53.

Table 53: Parameters describing baseline Link Level performance for E-UTRA Co-existence simulations (from ETSI 3GPP TR 36.942 [21], annex A, table A.1)

Parameter	Downlink	Uplink	Notes
α	0.6	0.4	Represents implementation losses
SNR_{min} (dB)	-10	-10	Based on QPSK, 1/8 rate (DL) and 1/5 rate (UL)
η_{max} (bps/Hz)	4.4	2.0	Based on 64 QAM 4/5 (DL) and 16 QAM 3/4 (UL)

Using this formula, determining the target SNR is a matter of resolving the formula above, using the target spectral efficiencies given in Table 52. Results are given in Table 54.

Table 54: Uplink and downlink UAS target SNR

Bandwidth of UAS system (MHz)	Uplink target spectral efficiency (bps/Hz)	Uplink target SNR (dB)	Downlink target spectral efficiency (bps/Hz)	Downlink target SNR (dB)
5	1.96	14.6	0.33	-3.28
10	0.98	6.51	0.17	-6.73

A3.2.3 Transmit power level

From a target SNR (dB), a noise power P_N (dBm) and a given path loss $PL(d)$, (dB) function of the distance d (m) between the transmitter and the receiver, one can determine the minimum transmit power P_e (dBm) as:

$$SNR = P_e - PL(d) - P_N \Leftrightarrow P_e = SNR + PL(d) + P_N, \quad (9)$$

Where:

- $P_N = 10 \cdot \log_{10}(kT_0B) + F + 30$ (dBm)
 - k : Boltzmann's constant (J/K).
 - $T_0 = 290$ Base noise temperature (K).
 - F : Noise factor of the receiver (dB).
- $PL(d) = 20 \cdot \log_{10}(4\pi df_0/c_0) - G_{tx} - G_{rx}$ (dB), assuming free space path loss.
 - G_{tx} : gain of the transmitting antenna (dBi)
 - $G_{tx} = 0$ dBi when UAS UE transmits
 - $G_{tx} = 2$ dBi (medium range) or $G_{tx} = 5$ dBi when UAS BS transmits
 - G_{rx} : gain of the receiving antenna (dBi)
 - $G_{rx} = 0$ dBi when UAS UE receives
 - $G_{rx} = 2$ dBi (medium range) or $G_{rx} = 5$ dBi when UAS BS receives

- $f_0 = 1890 \cdot 10^6$ Carrier frequency (Hz).
- c_0 : speed of light in a vacuum (m/s).

In order to determine the minimum transmit power allowing to reach a given range r , it must be taken into account both the range, the maximum altitude of the drone (a_{max} , in m), and the altitude of the controller ($a_{controller}$, in m) in the distance, as

$$d = \sqrt{r^2 + (a_{drone,max} - a_{controller})^2}. \tag{10}$$

Using values of Table 7, the noise power will be shown in Table 55, and path loss will be shown in Table 56.

Table 55: UAS system noise power

Bandwidth of UAS system (MHz)	Noise factor F (dB)	Boltzmann's constant k (j/K)	Base noise temperature T_0 (K)	Noise power P_N (dBm)
5	9	1.38065E-23	290	-97.99
10	9	1.38065E-23	290	-94.98

Table 56: Maximum path loss at UAS range

Range r (km)	Drone maximum altitude $a_{drone,max}$ (m)	Controller altitude $a_{controller}$ (m)	TX <-> RX maximum distance d (m)	$G_{tx} + G_{rx}$ (dBi)	TX <-> RX maximum path loss $PL(d)$ (dB)
1	120	1.50	1007	2	96.04
10	120	1.50	5651	5	108.02

Using values of Table 55 and Table 56 allows, in turn, to determine the maximum transmit power for UAS drone and controller, in the different scenarios (Table 57 and Table 58).

Table 57: UAS UE (drone) transmit power and e.i.r.p. necessary to reach target bitrates at full range

	Noise power P_N (dBm)	TX <-> RX maximum path loss $PL(d)$ (dB)	Uplink Target SNR (dB)	UAS UE transmit power P_e (dBm)	UAS UE antenna gain (dBi)	UAS UE e.i.r.p. (dBm)
$r = 1000$ m, $B = 5$ MHz	-97.99	96.04	15	13	0	13
$r = 5650$ m, $B = 5$ MHz	-97.99	108.02	15	25	0	25
$r = 1000$ m, $B = 10$ MHz	-94.98	96.04	7	8	0	8
$r = 5650$ m, $B = 10$ MHz	-94.98	108.02	7	20	0	20

Table 58: Minimum UAS BS (controller) transmit power

	Noise power P_N (dBm)	TX <-> RX maximum path loss $PL(d)$ (dB)	Downlink Target SNR (dB)	UAS BS transmit power P_e (dBm)	UAS BS antenna gain (dBi)	UAS BS e.i.r.p. (dBm)
$r = 1000$ m, $B = 5$ MHz	-97.99	96.04	-3	-5	2	-3
$r = 5650$ m, $B = 5$ MHz	-97.99	108.02	-3	7	5	12
$r = 1000$ m, $B = 10$ MHz	-94.98	96.04	-7	-6	2	-4
$r = 5650$ m, $B = 10$ MHz	-94.98	108.02	-7	6	5	11

A3.3 PROPOSED VALUES OF UAS TRANSMIT POWER

Based on the results of Table 57 and Table 58, it is retained propose to take different transmit power values of UAS UE and UAS BS. These values are taken as the maximum values of each table, plus a margin of 3 dB.

Table 59: UAS UE and BS maximum transmit power values

	Maximum transmit power (dBm)	Maximum e.i.r.p. (dBm)
UAS UE	28	28
UAS BS	10	15 (long range, 5 dBi antenna) / 12 (medium range, 2 dBi antenna)

A3.4 NEW MCL CALCULATIONS

Minimum coupling loss between a UAS and DECT, when UAS is the interferer and DECT the victim, is given by:

$$\begin{aligned}
 & MCL \quad (11) \\
 & = P_{e,UAS} + G_{tx,UAS} + G_{rx,DECT} - BEL \\
 & + 10 \cdot \log_{10} \left(\frac{B_{DECT}}{B_{UAS}} \right) - 10 \cdot \log_{10} \left(10^{(P_{rx,DECT} + G_{rx,DECT} - SINR_{th,DECT})/10} - 10^{P_{N,DECT}/10} \right)
 \end{aligned}$$

With:

- $P_{e,UAS}$ (dBm): UAS transmit power, 10 dBm for BS, 28 dBm for UE;
- $G_{tx,UAS}$ (dBi): UAS antenna gain, 2 dBi for BS in medium range scenario, 5 dBi in long range scenario, 0 dBi for UE;
- $G_{rx,DECT}$ (dBi): DECT antenna gain, 0 dBi or 12 dBi;
- BEL (dB): Building Entry Loss: 0 dB for outdoor scenario, 15 dB for indoor scenario;
- B_{DECT} (Hz): DECT bandwidth (1.152 MHz);
- B_{UAS} (Hz): UAS bandwidth (5 MHz or 10 MHz);
- $P_{rx,DECT} = 65$ dBm: Power of the DECT signal at the receiver;
- $SINR_{th,DECT}$ (dB): DECT SINR protection criterion;
- $P_{N,DECT} = -103$ dBm: receiver noise floor (as given in annex B.4 of ETSI 103 089 [7]).

Table 60: MCL Study: separation distances assuming FSPL propagation

Description	B_{UAS} (MHz)	$P_{e,UAS}$ (dBm)	$G_{tx,UAS}$ (dBi)	BEL (dB)	$G_{rx,DECT}$ (dBi)	MCL (dB)	d FSPL (km)
UAS UE interferes with outdoor DECT	5	28	0	0	0	107.71	3.07
	10	28	0	0	0	104.70	2,17
UAS UE interferes with indoor DECT	5	28	0	15	0	92.71	0.55
	10	28	0	15	0	89.70	0.39
UAS UE interferes with outdoor DECT (high gain DECT antenna)	5	28	0	0	12	107.63	3.04
	10	28	0	0	12	104.62	2.15
UAS UE interferes with indoor DECT (high gain DECT antenna)	5	28	0	15	12	92.63	0.54
	10	28	0	15	12	89.62	0.38
UAS BS (medium range) interferes with outdoor DECT	5	10	2	0	0	91.71	0.49
	10	10	2	0	0	88.70	0.34
UAS BS (medium range) interferes with indoor DECT	5	10	2	15	0	76.71	0.09
	10	10	2	15	0	73.70	0.06
UAS BS (medium range) interferes with outdoor DECT (high gain DECT antenna)	5	10	2	0	12	91.63	0.49
	10	10	2	0	12	88.62	0.34
UAS BS (medium range) interferes with indoor DECT (high gain DECT antenna)	5	10	2	15	12	76.63	0.09
	10	10	2	15	12	73.62	0.06
UAS BS (long range) interferes with outdoor DECT	5	10	5	0	0	94.71	0.69
	10	10	5	0	0	91.70	0.49
UAS BS (long range) interferes with indoor DECT	5	10	5	15	0	79.71	0.12
	10	10	5	15	0	76.70	0.09
UAS BS (long range) interferes with outdoor DECT (high gain DECT antenna)	5	10	5	0	12	94.63	0.69
	10	10	5	0	12	91.62	0.49
UAS BS (long range) interferes with indoor DECT (high gain DECT antenna)	5	10	5	15	12	79.63	0.12
	10	10	5	15	12	76.62	0.09

ANNEX 4: DETAILED MCL CALCULATIONS FOR CO-EXISTENCE BETWEEN LTE-BASED UAS AND DECT USING MEASURED C/I RATIO

Effects on DECT Mobiles 1- 5 and DECT Base Stations 1-4 are investigated. Protection distances are derived. The sensitivities of DECT Mobiles 1-4 and DECT base stations 1-4, respective carrier-to-interference ratio were determined in the BNetzA measurement campaign presented in the ECC Report 314 [12], annex 4.

Table 61: Outdoor Distance = f (B_{UAS} = 5 MHz; C_{DECT} = -65 dBm...)

Nr	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
1	Bandwidth B _{UAS} [MHz]	5	5	5	5	5	5	5	5	Table 7
2	Bandwidth B _{LTE,5 MHz} [MHz]	5	5	5	5	5	5	5	5	see 5.1.2
3	Bandwidth B _{LTE,10 MHz} [MHz]	10	10	10	10	10	10	10	10	ECC Report 314, annex 4 [12]; see 5.1.2
4	Bandwidth correction factor Bcf= B _{LTE,10 MHz} - B _{LTE,5 MHz} [dB]	3	3	3	3	3	3	3	3	=10*LOG10(B _{LTE,10 MHz} / B _{LTE,5 MHz}) see 5.1.2
5	P _{UAS,x} [dBm] x=ground station /aerial vehicle	30	30	30	30	30	30	30	30	Table 7
6	G _{e,ground station,rural} [dB] (rural)	5	5	5	5	5	5	5	5	Table 7
7	G _{UAS,ground station,urban} [dB] (urban)	2	2	2	2	2	2	2	2	Table 7
8	G _{UAS, aerial vehicle} [dB] (urban, rural)	0	0	0	0	0	0	0	0	Table 7
9	P _{UAS,ground station} [dBm] (e.i.r.p.) (rural)	35	35	35	35	35	35	35	35	= P _{UAS,x} [dBm] + G _{UAS,ground station,rural} [dB] see 5.1.2
10	P _{UAS,ground station} [dBm] (e.i.r.p.) (urban)	32	32	32	32	32	32	32	32	= P _{UAS,x} [dBm] + G _{UAS,ground station,urban} [dB]
11	P _{UAS,aerial vehicle} [dBm] (e.i.r.p.) (urban, rural)	30	30	30	30	30	30	30	30	= P _{UAS,x} [dBm]+ G _{UAS, aerial vehicle} [dB] see 5.1.2

Nr	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
12	BEL [dB]	0	0	0	0	0	0	0	0	Building Entry loss, P.2109-1, figure 1 [23]
13	C _{DECT} [dBm]	-65	-65	-65	-65	-65	-65	-65	-65	Table 2
14	Measured protection ratio: (C/I) [dB]=C [dB]-I [dB]	1.5	-0.5	2.5	2.5	5.5	0.5	-2.5	0.5	Protection ratio @ 1897.344 MHz ECC Report 314, annex 4, table 28 [12]
15	I _{DECT} [dBm]	-69.5	-67.5	-70.5	-70.5	-73.5	-68.5	-65.5	-68.5	= C _{DECT} - (C[dB]-I[dB]) - Bcf
16	Lfs,ground station,rural [dB]	104.5	102.5	105.5	105.5	108.5	103.5	100.5	103.5	= P _{UAS,ground station,Rural} (e.i.r.p.) - BEL - I _{DECT}
17	Lfs,ground station,urban [dB]	101.5	99.5	102.5	102.5	105.5	100.5	97.5	100.5	= P _{UAS,ground station,Urban} (e.i.r.p.) - BEL - I _{DECT}
18	Lfs,aerial vehicle,urban,rural [dB]	99.5	97.5	100.5	100.5	103.5	98.5	95.5	98.5	= P _{UAS,aerial vehicle,rural,urban} (e.i.r.p.) - BEL - I _{DECT}
19	distance [m] (Lfs,ground station,rural)	2109.9	1676.0	2367.3	2367.3	3344.0	1880.4	1331.3	1880.4	ITU-R P.525 [25] LPL=32.45+20log(d/km)+20log(f/MHz)
20	distance [m] (Lfs,ground station,urban)	1493.7	1186.5	1676.0	1676.0	2367.3	1331.3	942.5	1331.3	ITU-R P.525 [25] LPL=32.45+20log(d/km)+20log(f/MHz)
21	distance [m] (Lfs,aerial vehicle,urban,rural)	1186.5	942.5	1331.3	1331.3	1880.4	1057.5	748.6	1057.5	ITU-R P.525 [25] LPL=32.45+20log(d/km)+20log(f/MHz)

Table 62: Outdoor Distance = f (B_{UAS} = 5 MHz; C_{DECT} = -65/-75 dBm...)

Nr	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
1	Bandwidth BUAS [MHz]	5	5	5	5	5	5	5	5	Table 7
2	Bandwidth B _{LTE,5 MHz} [MHz]	5	5	5	5	5	5	5	5	see 5.1.2
3	Bandwidth B _{LTE,10 MHz} [MHz]	10	10	10	10	10	10	10	10	ECC Report 314, annex 4 [12]; see 5.1.2
4	Bandwidth correction factor B _{cf} =B _{LTE,10 MHz} - B _{LTE,5 MHz} [dB]	3	3	3	3	3	3	3	3	=10*LOG10(B _{LTE,10 MHz} /B _{LTE,5 MHz}) see 5.1.2
5	P _{UAS,X} [dBm] x=ground station /aerial vehicle	30	30	30	30	30	30	30	30	Table 7
6	G _{UAS,ground station,rural} [dB] (rural)	5	5	5	5	5	5	5	5	Table 7
7	G _{UAS,ground station,urban} [dB] (urban)	2	2	2	2	2	2	2	2	Table 7
8	G _{UAS, aerial vehicle} [dB] (urban, rural)	0	0	0	0	0	0	0	0	Table 7
9	P _{UAS,ground station} [dBm] (e.i.r.p.) (rural)	35	35	35	35	35	35	35	35	= P _{UAS,X} [dBm] + G _{UAS,ground station,rural} [dB] see 5.1.2
10	P _{UAS,ground station} [dBm] (e.i.r.p.) (urban)	32	32	32	32	32	32	32	32	= P _{UAS,X} [dBm] +,ground station,urban [dB] see 5.1.2

Nr	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
11	$P_{UAS, aerial\ vehicle} [dBm]$ (e.i.r.p.) (urban, rural)	30	30	30	30	30	30	30	30	$= P_{UAS,x} [dBm] + G_{UAS, aerial\ vehicle} [dB]$ see 5.1.2
12	BEL [dB]	0	0	0	0	0	0	0	0	Building Entry loss, P.2109-1, figure 1 [23]
13	$C_{DECT} [dBm]$	-74	-74	-74	-74	-74	-75	-75	-75	Table 2
14	Measured protection ratio: $(C/I) [dB] = C [dB] - I [dB]$	1.5	-0.5	2.5	2.5	5.5	0.5	-2.5	0.5	Protection ratio @ 1897.344 MHz ECC Report 314, annex 4, table 28 [12]
15	$I_{DECT} [dBm]$	-78.5	-76.5	-79.5	-79.5	-82.5	-78.5	-75.5	-78.5	$= C_{DECT} - (C[dB] - I[dB]) - B_{cf}$
16	$L_{fs, ground\ station, rural} [dB]$	113.5	111.5	114.5	114.5	117.5	113.5	110.5	113.5	$= P_{UAS, ground\ station, Rural} (e.i.r.p.) - BEL - I_{DECT}$
17	$L_{fs, ground\ station, urban} [dB]$	110.5	108.5	111.5	111.5	114.5	110.5	107.5	110.5	$= P_{UAS, ground\ station, Urban} (e.i.r.p.) - BEL - I_{DECT}$
18	$L_{fs, aerial\ vehicle, urban, rural} [dB]$	108.5	106.5	109.5	109.5	112.5	108.5	105.5	108.5	$= P_{UAS, aerial\ vehicle, rural, urban} (e.i.r.p.) - BEL - I_{DECT}$
19	distance [m] ($L_{fs, ground\ station, rural}$)	5946.5	4723.5	6672.1	6672.1	9424.6	5946.5	4209.8	5946.5	ITU-R P.525 [25] $LPL = 32.45 + 20\log(d/km) + 20\log(f/MHz)$
20	distance [m] ($L_{fs, ground\ station, urban}$)	4209.8	3344.0	4723.5	4723.5	6672.1	4209.8	2980.3	4209.8	ITU-R P.525 [25] $LPL = 32.45 + 20\log(d/km) + 20\log(f/MHz)$
21	distance [m] ($L_{fs, aerial\ vehicle, urban, rural}$)	3344.0	2656.2	3752.0	3752.0	5299.8	3344.0	2367.3	3344.0	ITU-R P.525 [25] $LPL = 32.45 + 20\log(d/km) + 20\log(f/MHz)$

Nr.	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
3	G _{UAS} ,ground station,rural [dB] (rural)	5	5	5	5	5	5	5	5	Table 7
4	G _{UAS} ,ground station,urban [dB] (urban)	2	2	2	2	2	2	2	2	Table 7
5	G _{UAS} ,aerial vehicle [dB] (urban, rural)	0	0	0	0	0	0	0	0	Table 7
6	P _{UAS} ,ground station [dBm] (e.i.r.p.) (rural)	35	35	35	35	35	35	35	35	= P _{UAS,X} [dBm] + G _{UAS} ,ground station,rural [dB] see 5.1.2
7	P _{UAS} ,ground station[dBm] (e.i.r.p.) (urban)	32	32	32	32	32	32	32	32	= P _{UAS,X} [dBm] + G _{UAS} ,ground station,urban [dB] see 5.1.2
8	P _{UAS} ,aerial vehicle [dBm] (e.i.r.p.) (urban, rural)	30	30	30	30	30	30	30	30	= P _{UAS,X} [dBm]+ G _{UAS} , aerial vehicle [dB] see 5.1.2
9	BEL [dB]	0	0	0	0	0	0	0	0	Building Entry loss, P.2109-1, figure 1 [23]
10	C _{DECT} [dBm]	-74	-74	-74	-74	-74	-75	-75	-75	Table 2
11	Measured protection ratio: (C/I) [dB]=C [dB]-I [dB]	1.5	-0.5	2.5	2.5	5.5	0.5	-2.5	0.5	Protection ratio @ 1897.344 MHz ECC Report 314, annex 4, table 28
12	I _{DECT} [dBm]	-75.5	-73.5	-76.5	-76.5	-79.5	-75.5	-72.5	-75.5	= C _{DECT} - (C[dB]-I[dB])
13	L _{fs} ,ground station,rural [dB]	110.5	108.5	111.5	111.5	114.5	110.5	107.5	110.5	= P _{UAS} ,ground station,Rural (e.i.r.p.) - BEL- I _{DECT}
14	L _{fs} ,ground station,urban [dB]	107.5	105.5	108.5	108.5	111.5	107.5	104.5	107.5	= P _{UAS} ,ground station,Urban (e.i.r.p.) - BEL - I _{DECT}
15	L _{fs} ,aerial vehicle,urban,rural [dB]	105.5	103.5	106.5	106.5	109.5	105.5	102.5	105.5	= P _{UAS} ,aerial vehicle,rural,urban (e.i.r.p.) - BEL - I _{DECT}

Nr.	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
16	distance [m] (Lfs,ground station,rural)	4204.8	3340.0	4717.9	4717.9	6664.2	4204.8	2976.8	4204.8	ITU-R P.525 LPL=32.45+20log(d/km)+20log(f/MHz)
17	distance [m] (Lfs,ground station,urban)	2976.8	2364.5	3340.0	3340.0	4717.9	2976.8	2107.4	2976.8	ITU-R P.525 LPL=32.45+20log(d/km)+20log(f/MHz)
18	distance [m] (Lfs,aerial vehicle,urban,rural)	2364.5	1878.2	2653.1	2653.1	3747.5	2364.5	1674.0	2364.5	ITU-R P.525 LPL=32.45+20log(d/km)+20log(f/MHz)

Table 65: Indoor Distance = f (B_{UAS} = 10 MHz; C_{DECT} = -65 dBm, BEL = 13 dB...)

Nr.	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
1	Bandwidth B _{UAS} [MHz]	10	10	10	10	10	10	10	10	Table 7
2	P _{UAS,x} [dBm] x=ground station /aerial vehicle	30	30	30	30	30	30	30	30	Table 7
3	G _{UAS,ground station,rural} [dB] (rural)	5	5	5	5	5	5	5	5	Table 7
4	G _{UAS,ground station,urban} [dB] (urban)	2	2	2	2	2	2	2	2	Table 7
5	G _{UAS, aerial vehicle} [dB] (urban, rural)	0	0	0	0	0	0	0	0	Table 7
6	P _{UAS,ground station} [dBm] (e.i.r.p.) (rural)	35	35	35	35	35	35	35	35	= P _{UAS,X} [dBm] + G _{UAS,ground station,rural} [dB] see 5.1.2
7	P _{UAS,ground station} [dBm] (e.i.r.p.) (urban)	32	32	32	32	32	32	32	32	= P _{UAS,X} [dBm] + G _{UAS,ground station,urban} [dB] see 5.1.2

Nr.	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
2	Bandwidth $B_{LTE,5}$ MHz [MHz]	5	5	5	5	5	5	5	5	see 5.1.2
3	Bandwidth $B_{LTE,10}$ MHz [MHz]	10	10	10	10	10	10	10	10	see 5.1.2
4	Bandwidth correction factor $B_{cf}=B_{LTE,10}$ MHz - $B_{LTE,5}$ MHz [dB]	3	3	3	3	3	3	3	3	$=10 \cdot \text{LOG}_{10}(B_{LTE,10} \text{ MHz}/B_{LTE,5} \text{ MHz})$ See 5.1.2
5	$P_{UAS,X}$ [dBm] x=ground station /aerial vehicle	30	30	30	30	30	30	30	30	Table 7
6	$G_{UAS,ground}$ station,rural [dB] (rural)	5	5	5	5	5	5	5	5	Table 7
7	$G_{UAS,ground}$ station,urban [dB] (urban)	2	2	2	2	2	2	2	2	see 5.1.2
8	G_{UAS} , aerial vehicle [dB] (urban,rural)	0	0	0	0	0	0	0	0	see 5.1.2
9	$P_{UAS,ground}$ station [dBm] (e.i.r.p.) (rural)	35	35	35	35	35	35	35	35	$= P_{UAS,X} \text{ [dBm]} + G_{UAS,ground} \text{ station,rural [dB]}$ see 5.1.2
10	$P_{UAS,ground}$ station [dBm] (e.i.r.p.) (urban)	32	32	32	32	32	32	32	32	$= P_{UAS,X} \text{ [dBm]} + G_{UAS,ground} \text{ station,urban [dB]}$ see 5.1.2
11	$P_{UAS,aerial}$ vehicle [dBm] (e.i.r.p.) (urban,rural)	30	30	30	30	30	30	30	30	$= P_{UAS,X} \text{ [dBm]} + G_{UAS}, \text{ aerial vehicle [dB]}$ see 5.1.2
12	BEL [dB]	13	13	13	13	13	13	13	13	Building Entry loss,P.2109-1, figure 1 [23]
13	C_{DECT} [dBm]	-65	-65	-65	-65	-65	-65	-65	-65	Table 2
14	Measured protection ratio: (C/I) [dB]=C [dB]-I [dB]	1.5	-0.5	2.5	2.5	5.5	0.5	-2.5	0.5	Protection ratio @ 1897.344 MHz ECC Report 314, annex 4, table 28 [12]

Nr.	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
6	P _{UAS,ground station} [dBm] (e.i.r.p.) (rural)	35	35	35	35	35	35	35	35	= P _{UAS,x} [dBm] + G _{UAS,ground station,rural} [dB] see 5.1.2
7	P _{UAS,ground station} [dBm] (e.i.r.p.) (urban)	32	32	32	32	32	32	32	32	= P _{UAS,x} [dBm] + G _{UAS,ground station,urban} [dB] see 5.1.2
8	P _{UAS,aerial vehicle} [dBm] (e.i.r.p.) (urban,rural)	30	30	30	30	30	30	30	30	= P _{UAS,x} [dBm]+ G _{UAS, aerial vehicle} [dB] see 5.1.2
9	BEL [dB]	13	13	13	13	13	13	13	13	Building Entry loss,P.2109-1, figure 1 [23]
10	C _{DECT} [dBm]	-74	-74	-74	-74	-74	-75	-75	-75	Table 2
11	Measured protection ratio: (C/I) [dB]=C [dB]-I [dB]	1.5	-0.5	2.5	2.5	5.5	0.5	-2.5	0.5	Protection ratio @ 1897.344 MHz ECC Report 314, annex 4, table 28 [12]
12	I _{DECT} [dBm]	-75.5	-73.5	-76.5	-76.5	-79.5	-75.5	-72.5	-75.5	= C _{DECT} - (C[dB]-I[dB])
13	Lfs,ground station ,rural [dB]	97.5	95.5	98.5	98.5	101.5	97.5	94.5	97.5	= P _{UAS,ground station,rural} (e.i.r.p.) - BEL- I _{DECT}
14	Lfs,ground station ,urban [dB]	94.5	92.5	95.5	95.5	98.5	94.5	91.5	94.5	= P _{UAS,ground station,urban} (e.i.r.p.) - BEL - I _{DECT}
15	Lfs,aerial vehicle,urban,rural [dB]	92.5	90.5	93.5	93.5	96.5	92.5	89.5	92.5	= P _{UAS,aerial vehicle,rural,urban} (e.i.r.p.) - BEL - I _{DECT}
16	distance [m] (Lfs,ground station ,rural)	941.3	747.7	1056.2	1056.2	1491.9	941.3	666.4	941.3	ITU-R P.525 LPL=32.45+20log(d/km)+20log(f/MHz)
17	distance [m] (Lfs,ground station ,urban)	666.4	529.4	747.7	747.7	1056.2	666.4	471.8	666.4	ITU-R P.525 LPL=32.45+20log(d/km)+20log(f/MHz)
18	distance [m] (Lfs,aerial vehicle,urban,rural)	529.4	420.5	593.9	593.9	839.0	529.4	374.8	529.4	ITU-R P.525 LPL=32.45+20log(d/km)+20log(f/MHz)

Table 68: Indoor Distance = f (B_{UAS} = 5 MHz; C_{DECT} = -74/-75 dBm, BEL = 13 dB...)

Nr.	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
1	Bandwidth B _{UAS} [MHz]	5	5	5	5	5	5	5	5	Table 7
2	Bandwidth B _{LTE,5 MHz} [MHz]	5	5	5	5	5	5	5	5	see 5.1.2
3	Bandwidth B _{LTE,10 MHz} [MHz]	10	10	10	10	10	10	10	10	ECC Report 314, annex 4 see 5.1.2
4	Bandwidth correction factor B _{cf} =B _{LTE,10 MHz} - B _{LTE,5 MHz} [dB]	3	3	3	3	3	3	3	3	=10*LOG10(B _{LTE,10 MHz} /B _{LTE,5 MHz}) see 5.1.2
5	P _{UAS,X} [dBm] x=ground station /aerial vehicle	30	30	30	30	30	30	30	30	Table 7
6	G _{UAS,ground station,rural} [dB] (rural)	5	5	5	5	5	5	5	5	Table 7
7	G _{UAS,ground station,urban} [dB] (urban)	2	2	2	2	2	2	2	2	Table 7
8	G _{UAS, aerial vehicle} [dB] (urban,rural)	0	0	0	0	0	0	0	0	Table 7
9	P _{UAS,ground station} [dBm] (e.i.r.p.) (rural)	35	35	35	35	35	35	35	35	= P _{UAS,X} [dBm] + G _{UAS,ground station,rural} [dB] see 5.1.2
10	P _{UAS,ground station} [dBm] (e.i.r.p.) (urban)	32	32	32	32	32	32	32	32	= P _{UAS,X} [dBm] + G _{UAS,ground station,urban} [dB] see 5.1.2

Nr.	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
11	$P_{UAS, aerial\ vehicle} [dBm]$ (e.i.r.p.) (urban, rural)	30	30	30	30	30	30	30	30	$= P_{UAS, X} [dBm] + G_{UAS, aerial\ vehicle} [dB]$ see 5.1.2
12	BEL [dB]	13	13	13	13	13	13	13	13	Building Entry loss, P.2109-1, figure 1 [23]
13	$C_{DECT} [dBm]$	-74	-74	-74	-74	-74	-75	-75	-75	Table 2
14	Measured protection ratio: (C/I) [dB]=C [dB]-I [dB]	1.5	-0.5	2.5	2.5	5.5	0.5	-2.5	0.5	Protection ratio @ 1897.344 MHz ECC Report 314, annex 4, table 28 [12]
15	$I_{DECT} [dBm]$	-78.5	-76.5	-79.5	-79.5	-82.5	-78.5	-75.5	-78.5	$= C_{DECT} - (C[dB]-I[dB]) - B_{cf}$
16	$L_{fs, ground\ station, rural} [dB]$	100.5	98.5	101.5	101.5	104.5	100.5	97.5	100.5	$= P_{UAS, ground\ station, rural} (e.i.r.p.) - BEL - I_{DECT}$
17	$L_{fs, ground\ station, urban} [dB]$	97.5	95.5	98.5	98.5	101.5	97.5	94.5	97.5	$= P_{UAS, ground\ station, urban} (e.i.r.p.) - BEL - I_{DECT}$
18	$L_{fs, aerial\ vehicle, urban, rural} [dB]$	95.5	93.5	96.5	96.5	99.5	95.5	92.5	95.5	$= P_{UAS, aerial\ vehicle, rural, urban} (e.i.r.p.) - BEL - I_{DECT}$
19	distance [m] ($L_{fs, ground\ station, rural}$)	1331.3	1057.5	1493.7	1493.7	2109.9	1331.3	942.5	1331.3	ITU-R P.525 $LPL=32.45+20\log(d/km)+20\log(f/MHz)$
20	distance [m] ($L_{fs, ground\ station, urban}$)	942.5	748.6	1057.5	1057.5	1493.7	942.5	667.2	942.5	ITU-R P.525 $LPL=32.45+20\log(d/km)+20\log(f/MHz)$
21	distance [m] ($L_{fs, aerial\ vehicle, urban, rural}$)	748.6	594.6	840.0	840.0	1186.5	748.6	530.0	748.6	ITU-R P.525 $LPL=32.45+20\log(d/km)+20\log(f/MHz)$

Table 69: Indoor Distance = f ($B_{UAS} = 10$ MHz; $C_{DECT} = -74/-75$ dBm, BEL = 20 dB...)

Nr.	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
1	Bandwidth B_{UAS} [MHz]	10	10	10	10	10	10	10	10	Table 7
2	$P_{UAS,x}$ [dBm] x=ground station /aerial vehicle	30	30	30	30	30	30	30	30	Table 7
3	$G_{UAS,ground station,rural}$ [dB] (rural)	5	5	5	5	5	5	5	5	Table 7
4	$G_{UAS,ground station,urban}$ [dB] (urban)	2	2	2	2	2	2	2	2	Table 7
5	$G_{UAS, aerial vehicle}$ [dB] (urban, rural)	0	0	0	0	0	0	0	0	Table 7
6	$P_{UAS,ground station}$ [dBm] (e.i.r.p.) (rural)	35	35	35	35	35	35	35	35	= $P_{UAS,x}$ [dBm] + $G_{UAS,ground station,rural}$ [dB] see 5.1.2
7	$P_{UAS,ground station}$ [dBm] (e.i.r.p.) (urban)	32	32	32	32	32	32	32	32	= $P_{UAS,x}$ [dBm] + $G_{UAS,ground station,urban}$ [dB] see 5.1.2
8	$P_{UAS, aerial vehicle}$ [dBm] (e.i.r.p.) (urban, rural)	30	30	30	30	30	30	30	30	= $P_{UAS,x}$ [dBm]+ $G_{UAS, aerial vehicle}$ [dB] see 5.1.2
9	BEL [dB]	20	20	20	20	20	20	20	20	Building Entry loss,P.2109-1, figure 1 [23]
10	C_{DECT} [dBm]	-74	-74	-74	-74	-74	-75	-75	-75	Table 2
11	Measured protection ratio: (C/I) [dB]=C [dB]-I [dB]	1.5	-0.5	2.5	2.5	5.5	0.5	-2.5	0.5	Protection ratio @ 1897.344 MHz ECC Report 314, annex 4, table 28 [12]
12	I_e [dBm]	-75.5	-73.5	-76.5	-76.5	-79.5	-75.5	-72.5	-75.5	= $C_e - (C[dB]-I[dB])$
13	$L_{fs,ground station ,rural}$ [dB]	90.5	88.5	91.5	91.5	94.5	90.5	87.5	90.5	= $P_{UAS,ground station,Rural}$ (e.i.r.p.) - BEL- I_{DECT}

Nr.	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
14	Lfs,ground station ,urban [dB]	87.5	85.5	88.5	88.5	91.5	87.5	84.5	87.5	= P _{UAS,ground station,Urban} (e.i.r.p.) - BEL - I _{DECT}
15	Lfs,aerial vehicle,urban,rural [dB]	85.5	83.5	86.5	86.5	89.5	85.5	82.5	85.5	= P _{UAS,aerial vehicle,rural,urban} (e.i.r.p.) - BEL - I _{DECT}
16	distance [m] (Lfs,ground station ,rural)	420.5	334.0	471.8	471.8	666.4	420.5	297.7	420.5	ITU-R P.525 LPL=32.45+20log(d/km)+20log(f/MHz)
17	distance [m] (Lfs,ground station ,urban)	297.7	236.5	334.0	334.0	471.8	297.7	210.7	297.7	ITU-R P.525 LPL=32.45+20log(d/km)+20log(f/MHz)
18	distance [m] (Lfs,aerial vehicle,urban,rural)	236.5	187.8	265.3	265.3	374.8	236.5	167.4	236.5	ITU-R P.525 LPL=32.45+20log(d/km)+20log(f/MHz)

Table 70: Indoor Distance = f (B_{UAS} = 10 MHz; C_{DECT} = -65 dBm, BEL = 20 dB...)

Nr.	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
1	Bandwidth B _{UAS} [MHz]	10	10	10	10	10	10	10	10	Table 7
2	P _{UAS,x} [dBm] x=ground station /aerial vehicle	30	30	30	30	30	30	30	30	Table 7
3	G _{UAS,ground station,rural} [dB] (rural)	5	5	5	5	5	5	5	5	Table 7
4	G _{UAS,ground station,urban} [dB] (urban)	2	2	2	2	2	2	2	2	Table 7
5	G _{UAS, aerial vehicle} [dB] (urban, rural)	0	0	0	0	0	0	0	0	Table 7
6	P _{UAS,ground station} [dBm] (e.i.r.p.) (rural)	35	35	35	35	35	35	35	35	= P _{UAS,x} [dBm] + G _{UAS,ground station,rural} [dB] see 5.1.2

Nr.	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
7	$P_{UAS,ground\ station}$ [dBm] (e.i.r.p.) (urban)	32	32	32	32	32	32	32	32	= $P_{UAS,x}$ [dBm] + $G_{UAS,ground\ station,urban}$ [dB] see 5.1.2
8	$P_{UAS,aerial\ vehicle}$ [dBm] (e.i.r.p.) (urban, rural)	30	30	30	30	30	30	30	30	= $P_{UAS,x}$ [dBm]+ $G_{UAS,aerial\ vehicle}$ [dB] see 5.1.2
9	BEL [dB]	20	20	20	20	20	20	20	20	Building Entry loss,P.2109-1, figure 1 [23]
10	C_{DECT} [dBm]	-65	-65	-65	-65	-65	-65	-65	-65	Table 2
11	Measured protection ratio: (C/I) [dB]=C [dB]-I [dB]	1.5	-0.5	2.5	2.5	5.5	0.5	-2.5	0.5	Protection ratio @ 1897.344 MHz ECC Report 314, annex 4, table 28 [12]
12	I_{DECT} [dBm]	-66.5	-64.5	-67.5	-67.5	-70.5	-65.5	-62.5	-65.5	= $C_{DECT} - (C[dB]-I[dB])$
13	$L_{fs,ground\ station,rural}$ [dB]	81.5	79.5	82.5	82.5	85.5	80.5	77.5	80.5	= $P_{UAS,ground\ station,rural}$ (e.i.r.p.) - BEL - I_{DECT}
14	$L_{fs,ground\ station,urban}$ [dB]	78.5	76.5	79.5	79.5	82.5	77.5	74.5	77.5	= $P_{UAS,ground\ station,Urban}$ (e.i.r.p.) - BEL - I_{DECT}
15	$L_{fs,aerial\ vehicle,urban,rural}$ [dB]	76.5	74.5	77.5	77.5	80.5	75.5	72.5	75.5	= $P_{UAS,aerial\ vehicle,rural,urban}$ (e.i.r.p.) - BEL - I_{DECT}
16	distance [m] ($L_{fs,ground\ station,rural}$)	149.2	118.5	167.4	167.4	236.5	133.0	94.1	133.0	ITU-R P.525 $LPL=32.45+20\log(d/km)+20\log(f/MHz)$
17	distance [m] ($L_{fs,ground\ station,urban}$)	105.6	83.9	118.5	118.5	167.4	94.1	66.6	94.1	ITU-R P.525 $LPL=32.45+20\log(d/km)+20\log(f/MHz)$
18	distance [m] ($L_{fs,aerial\ vehicle,urban,rural}$)	83.9	66.6	94.1	94.1	133.0	74.8	52.9	74.8	ITU-R P.525 $LPL=32.45+20\log(d/km)+20\log(f/MHz)$

Table 71: Indoor Distance = f (B_{UAS} = 5 MHz; C_{DECT} = -65 dBm, BEL = 20 dB...)

Nr.	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
1	Bandwidth B _{UAS} [MHz]	5	5	5	5	5	5	5	5	Table 7
2	Bandwidth B _{LTE,5 MHz} [MHz]	5	5	5	5	5	5	5	5	see 5.1.2
3	Bandwidth B _{LTE,10 MHz} [MHz]	10	10	10	10	10	10	10	10	ECC Report 314, annex 4 see 5.1.2
4	Bandwidth correction factor Bcf=B _{LTE,10 MHz} - B _{LTE,5 MHz} [dB]	3	3	3	3	3	3	3	3	=10*LOG10(B _{LTE,10 MHz} /B _{LTE,5 MHz}) See 5.1.2
5	P _{UAS,X} [dBm] x=ground station /aerial vehicle	30	30	30	30	30	30	30	30	Table 7
6	G _{UAS,ground station,rural} [dB] (rural)	5	5	5	5	5	5	5	5	Table 7
7	G _{UAS,ground station,urban} [dB] (urban)	2	2	2	2	2	2	2	2	Table 7
8	G _{UAS, aerial vehicle} [dB] (urban, rural)	0	0	0	0	0	0	0	0	Table 7
e	P _{UAS,ground station} [dBm] (e.i.r.p.) (rural)	35	35	35	35	35	35	35	35	= P _{UAS,X} [dBm] + G _{UAS,ground station,rural} [dB] see 5.1.2
10	P _{UAS,ground station} [dBm] (e.i.r.p.) (urban)	32	32	32	32	32	32	32	32	= P _{UAS,X} [dBm] + G _{UAS,ground station,urban} [dB] see 5.1.2
11	P _{UAS,aerial vehicle} [dBm] (e.i.r.p.) (urban, rural)	30	30	30	30	30	30	30	30	= P _{UAS,X} [dBm]+ G _{UAS, aerial vehicle} [dB] see 5.1.2
12	BEL [dB]	20	20	20	20	20	20	20	20	Building Entry loss,P.2109-1, figure 1

Nr.	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
13	C _{DECT} [dBm]	-65	-65	-65	-65	-65	-65	-65	-65	Table 2
14	Measured protection ratio: (C/I) [dB]=C [dB]-I [dB]	1.5	-0.5	2.5	2.5	5.5	0.5	-2.5	0.5	Protection ratio @ 1897.344 MHz ECC Report 314, annex 4, table 28 [12]
15	I _{DECT} [dBm]	-69.5	-67.5	-70.5	-70.5	-73.5	-68.5	-65.5	-68.5	= C _{DECT} - (C[dB]-I[dB]) - Bcf
16	Lfs,ground station ,rural [dB]	84.5	82.5	85.5	85.5	88.5	83.5	80.5	83.5	= P _{UAS} PUAS,ground station,Rural (e.i.r.p.) - BEL - I _{DECT}
17	Lfs,ground station ,urban [dB]	81.5	79.5	82.5	82.5	85.5	80.5	77.5	80.5	= P _{UAS} ,ground station,Urban (e.i.r.p.) - BEL - I _{DECT}
18	Lfs,aerial vehicle,urban,rural [dB]	79.5	77.5	80.5	80.5	83.5	78.5	75.5	78.5	= P _{UAS} ,aerial vehicle,rural,urban (e.i.r.p.) - BEL - I _{DECT}
19	distance [m] (Lfs,ground station ,rural)	211.0	167.6	236.7	236.7	334.4	188.0	133.1	188.0	ITU-R P.525 [25] LPL=32.45+20log(d/km)+20log(f/MHz)
20	distance [m] (Lfs,ground station ,urban)	149.4	118.6	167.6	167.6	236.7	133.1	94.2	133.1	ITU-R P.525 [25] LPL=32.45+20log(d/km)+20log(f/MHz)
21	distance [m] (Lfs,aerial vehicle,urban,rural)	118.6	94.2	133.1	133.1	188.0	105.7	74.9	105.7	ITU-R P.525 [25] LPL=32.45+20log(d/km)+20log(f/MHz)

Table 72: Indoor Distance = f (B_{UAS} = 5 MHz; C_{DECT} = -74/-75 dBm, BEL = 20 dB...)

Nr.	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
1	Bandwidth B _{UAS} [MHz]	5	5	5	5	5	5	5	5	Table 7
2	Bandwidth B _{ee} .5 MHz [MHz]	5	5	5	5	5	5	5	5	see 5.1.2
3	Bandwidth B _{LTE} , 10 MHz [MHz]	10	10	10	10	10	10	10	10	ECC Report 314, annex 4 see 5.1.2

Nr	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
4	Bandwidth correction factor $B_{cf} = B_{LTE, 10 \text{ MHz}} - B_{LTE, 5 \text{ MHz}}$ [dB]	3	3	3	3	3	3	3	3	$= 10 * \text{LOG}_{10}(B_{LTE, 10 \text{ MHz}} / B_{LTE, 5 \text{ MHz}})$ see 5.1.2
5	$P_{UAS, X}$ [dBm] X=ground station /aerial vehicle	30	30	30	30	30	30	30	30	Table 7
6	$G_{UAS, \text{ground station, rural}}$ [dB] (rural)	5	5	5	5	5	5	5	5	Table 7
7	$G_{UAS, \text{ground station, urban}}$ [dB] (urban)	2	2	2	2	2	2	2	2	Table 7
8	G_{UAS}	0	0	0	0	0	0	0	0	Table 7
9	$P_{UAS, \text{ground station}}$ [dBm] (e.i.r.p. rural)	35	35	35	35	35	35	35	35	$= P_{UAS, X} [\text{dBm}] + G_{UAS, \text{ground station, rural}} [\text{dB}]$ see 5.1.2
10	$P_{UAS, \text{ground station}}$ [dBm] (e.i.r.p.) (urban)	32	32	32	32	32	32	32	32	$= P_{UAS, X} [\text{dBm}] + G_{UAS, \text{ground station, urban}} [\text{dB}]$ see 5.1.2
11	$P_{UAS, \text{aerial vehicle}}$ [dBm] (e.i.r.p.) (urban, rural)	30	30	30	30	30	30	30	30	$= P_{UAS, X} [\text{dBm}] + G_{UAS, \text{aerial vehicle}} [\text{dB}]$ see 5.1.2
12	BEL [dB]	20	20	20	20	20	20	20	20	Building Entry loss, P.2109-1, figure 1
13	CDECT [dBm]	-74	-74	-74	-74	-74	-75	-75	-75	Table 2
14	Measured protection ratio: (C/I) [dB]=C [dB]-I [dB]	1.5	-0.5	2.5	2.5	5.5	0.5	-2.5	0.5	Protection ratio @ 1897.344 MHz ECC Report 314, annex 4, table 28 [12]
15	I_{DECT} [dBm]	-78.5	-76.5	-79.5	-79.5	-82.5	-78.5	-75.5	-78.5	$= C_{DECT} - (C[\text{dB}] - I[\text{dB}]) - B_{cf}$

Nr	Outdoor	Mobile 1	Mobile 2	Mobile 3	Mobile 4	Mobile 5	Base 1	Base 3	Base 4	References / Formulas
16	Lfs,ground station ,rural [dB]	93.5	91.5	94.5	94.5	97.5	93.5	90.5	93.5	= P _{UAS,ground station,Rural} (e.i.r.p.) - BEL- I _{DECT}
17	Lfs,ground station ,urban [dB]	90.5	88.5	91.5	91.5	94.5	90.5	87.5	90.5	= P _{UAS,ground station,Urban} (e.i.r.p.) - BEL - I _{DECT}
18	Lfs,aerial vehicle,urban,rural [dB]	88.5	86.5	89.5	89.5	92.5	88.5	85.5	88.5	= P _{UAS,aerial vehicle,rural,urban} (e.i.r.p.) - BEL - I _{DECT}
19	distance [m] (Lfs,ground station ,rural)	594.6	472,3	667.2	667.2	942.5	594.6	421.0	594.6	ITU-R P.525 LPL=32.45+20log(d/km)+20log(f/MHz)
20	distance [m] (Lfs,ground station ,urban)	421.0	334.4	472,3	472,3	667.2	421.0	298.0	421.0	ITU-R P.525 LPL=32.45+20log(d/km)+20log(f/MHz)
21	distance [m] (Lfs,aerial vehicle,urban,rural)	334.4	265.6	375.2	375.2	530.0	334.4	236.7	334.4	ITU-R P.525 LPL=32.45+20log(d/km)+20log(f/MHz)

ANNEX 5: SEAMCAT STUDY OF THE POSSIBLE IMPACT OF AN LTE-BASED UAS DEPLOYED IN A CHANNEL CENTERED AT 1890 MHZ TO A DECT DEPLOYMENT IN 1880-1900 MHZ

A5.1 INTRODUCTION

. This contribution provides additional simulations relating to the impact of UAS on DECT, both systems are assumed to operate in the band 1880–1900 MHz. It should be noted that the blocking is not considered, only the impact of unwanted emissions is considered.

Simulations only consider the impact on one DECT channel and this gives an incorrect picture of the impact of interference for example simulations show a reduced risk of interference for a 10 MHz UAS channel but in use this would generate considerable denial of service and large interference to a busy system reducing spectrum availability by at least 50%. Similar issues arise with many other simulations and for real use should be taken into account when considering the “big picture” of co-channel use by UAS.

UAS base stations have been identified as using a 1.5 m height but in reality the UAS operator will seek the highest point with the clearest view which may well be some 100 m or more, greatly increasing the interference impact.

A5.2 METHODOLOGY

The simulations are performed using SEAMCAT. The tables of results provide results for the cases where the DECT are distributed over 10 frequencies (see Figure 29) and for the case where the DECT is “co-frequency” (DECT is set at 1890 MHz) with the possible interferer.

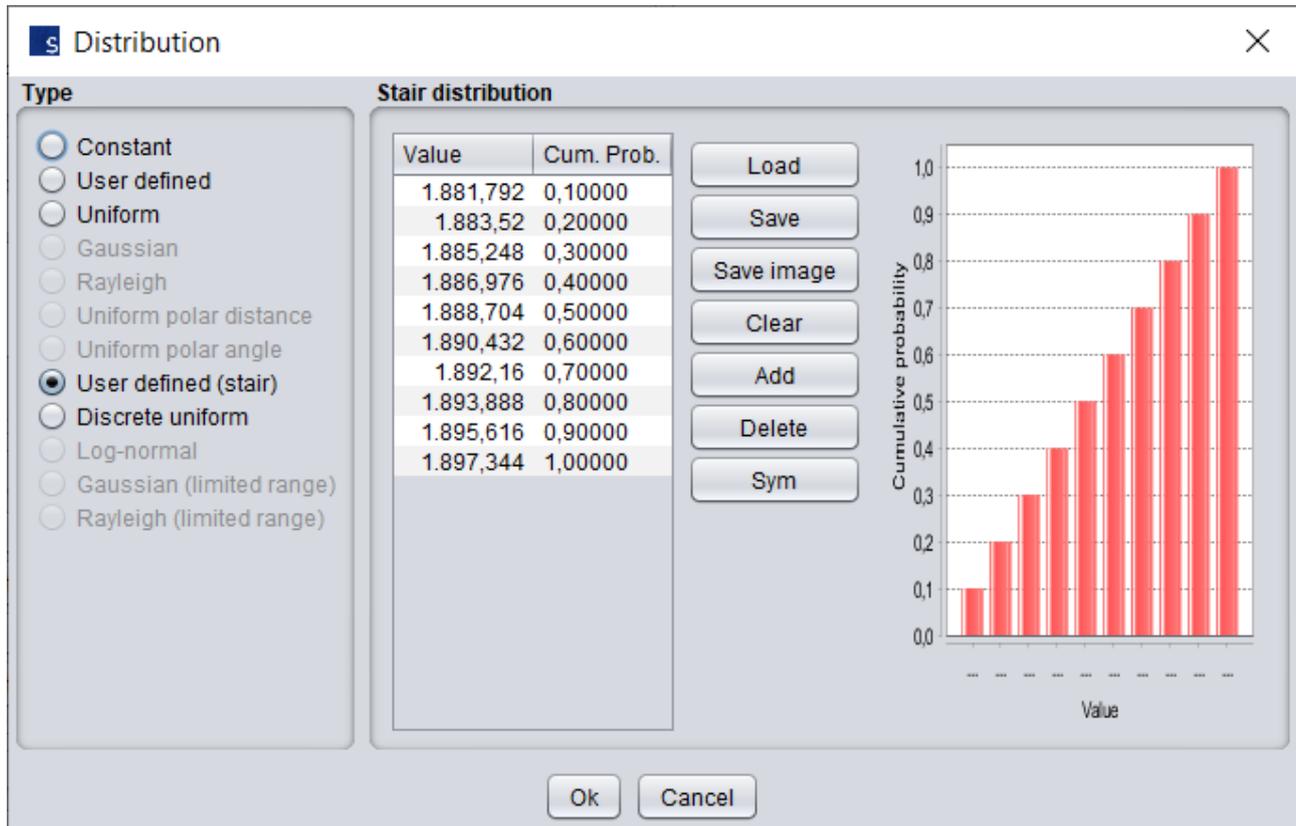


Figure 29: Distribution of frequencies for the DECT

A5.3 OUTDOOR SCENARIO

A5.3.1 Interferer GS – Tx power 10 dBm – urban environment

Assumptions on the DECT side:

- Antenna height Tx: 3 m and Rx: 1 m;
- C/(N+I): 21 dB.

Assumptions on the ground station (GS) side:

- 5 MHz / 10 MHz;
- Gain: 2 dBi;
- Center frequency 1890 MHz;
- BS antenna height: 1.5 m;
- Drone antenna height 25–120 m;
- 10 dBm Tx power;
- 1 km path;
- Unwanted emissions masks for 5 MHz and 10 MHz bandwidths are provided in Figure 30.

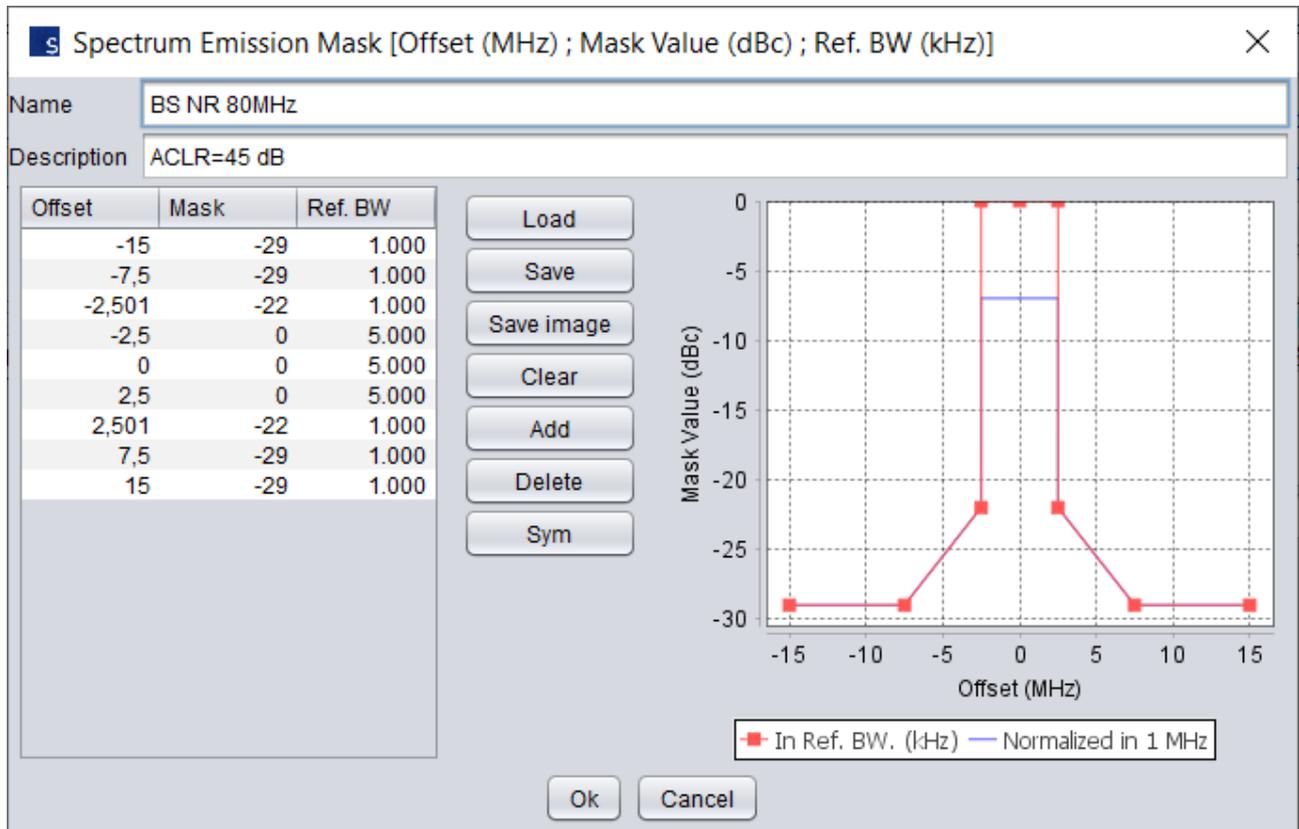


Figure 30: GS unwanted emissions mask – Tx 10 dBm – 5 MHz

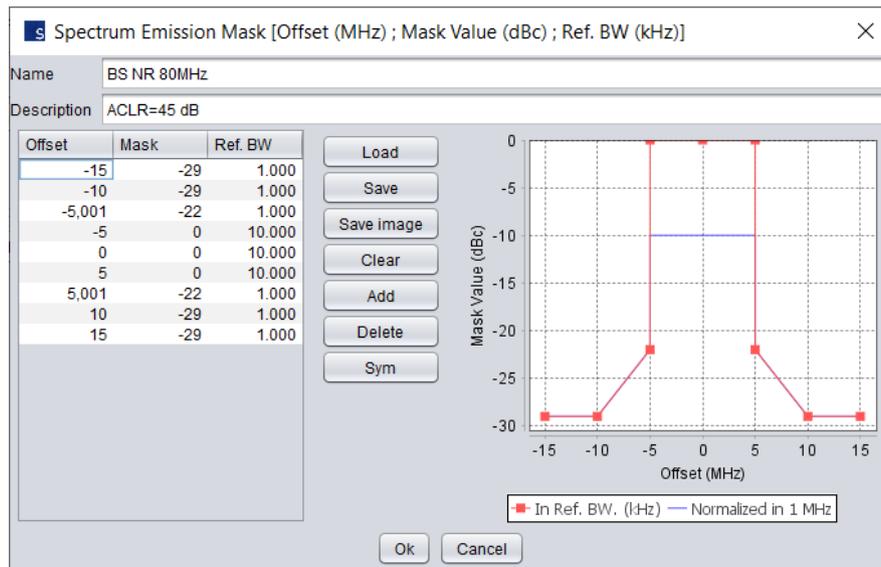


Figure 31: GS unwanted emissions mask – Tx 10 dBm – 10 MHz

Propagation models:

- GS to DECT: Extended Hata SRD-urban;
- GS to drone: ITU-R P.1546 – urban;
- DECT path: Extended Hata SRD-urban.

Scenario 1:

This scenario corresponds to a situation where the ground station is deployed in the same area where an outdoor event is happening.

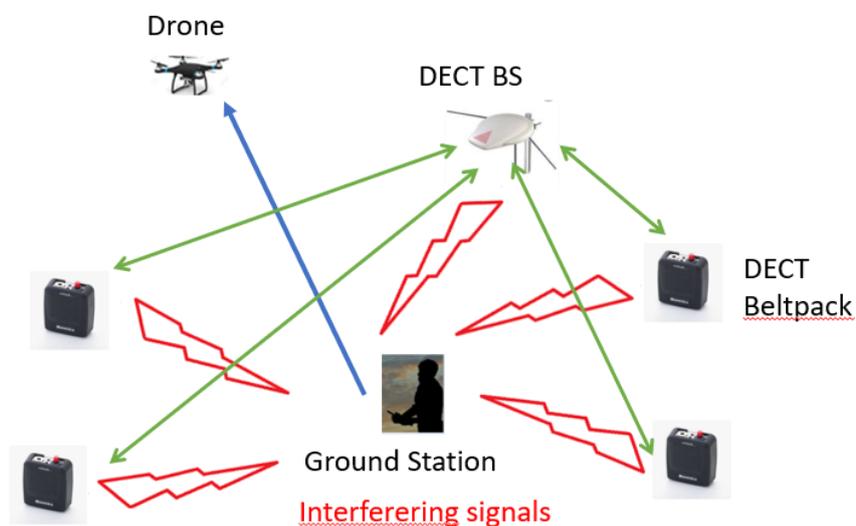


Figure 32: Impact of the ground station on DECT devices

DECT assumptions:

- Power is 24 dBm;
- Sensitivity: -75 dBm;
- The maximum DECT path is 200 m.

Table 73 provides results of simulations depending on the simulation radius⁹ for GS – 5 MHz – 10 dBm.

Table 73: Scenario 1 - Results of simulations depending on the simulation radius – GS – 5 MHz – 10 dBm

Simulation radius	DECT distributed over 10 frequencies		DECT co-channel	
	Probability of interference	Interfering power (mean)	Probability of interference	Interfering power (mean)
5 m	95.6%	-55.3 dBm	100%	-42.2 dBm
10 m	90.1%	-61.2 dBm	99.7%	-48.0 dBm
20 m	83.3%	-67.2 dBm	98.9%	-54.0 dBm
50 m	66.7%	-76.2 dBm	81.5%	-63.2 dBm
100 m	26.8%	-94.7 dBm	51.5%	-81.5 dBm
200 m	6.6%	-112.4 dBm	12.8%	-98.3 dBm
300 m	3.0%	-118.8 dBm	5.7%	-105.7 dBm

It should be noted that for the calculation of the probability of interference, only the DECT links where the received power is above -75 dBm are considered. The probability of interference will be higher if the links with a received power less than -75 dBm were considered (20 m will give 96% instead of 83%).

Table 74 provides results of simulations depending on the simulation radius¹⁰ for GS – 10 MHz – 10 dBm.

Table 74: Scenario 1 - Results of simulations depending on the simulation radius – GS – 10 MHz – 10 dBm

Simulation radius	DECT distributed over 10 frequencies		DECT co-channel	
	Probability of interference	Interfering power (mean)	Probability of interference	Interfering power (mean)
5 m	92.7%	-55.3 dBm	99.9%	-45.2 dBm
10 m	88.8%	-61 dBm	99.4%	-51.1 dBm
20 m	82.7%	-66.9 dBm	97.8%	-57.0 dBm
50 m	63.2%	-78.6 dBm	87.1%	-66.1 dBm
100 m	28.3%	-94.2 dBm	42.3%	-84.6 dBm
200 m	6.5%	-111.3 dBm	11.0%	-101.3 dBm
300 m	3.3%	-118.7 dBm	4.5%	-108.8 dBm

It should be noted that in the case of typical outdoor coverage there will be about 250 pairs of DECT links per km² in a given area. This corresponds for each link to an area of about 0.003 km² or a radius of about 36 m. This means that the ground station (GS) is likely to be connected at a distance less than 18 m from a DECT receiver. Therefore, the interference probability is going to range from 77 to 94%.

Scenario 2:

⁹ The simulation radius in SEAMCAT represents the maximum distance between the GS and the DECT victim receiver.

¹⁰ The simulation radius in SEAMCAT represents the maximum distance between the GS and the DECT victim receiver.

Scenario 2 is based on scenario 1, except that to allow maximising the frequency re-use in the DECT deployment, the Tx power is decreased to minimize the size of the DECT cells and to allow an increase of the frequency re-use:

- Power is 12 dBm;
- Sensitivity: -82 dBm;
- The maximum path link is 100 m.

Table 75 provides results of simulations depending on the simulation radius¹¹ for GS – 5 MHz – 10 dBm.

Table 75: Scenarios 2 - Results of simulations depending on the simulation radius – GS – 5 MHz – 10 dBm

Simulation radius	DECT distributed over 10 frequencies		DECT co-channel	
	Probability of interference	Interfering power (mean)	Probability of interference	Interfering power (mean)
5 m	99.7%	-55.3 dBm	100%	-42.2 dBm
10 m	98.6%	-61.2 dBm	100%	-48.0 dBm
20 m	94.4%	-67.2 dBm	100%	-54.0 dBm
50 m	81.6%	-76.2 dBm	99.0%	-63.1 dBm
100 m	42.8%	-94.6 dBm	69.6%	-81.6 dBm
200 m	12.0%	-111.2 dBm	23.1%	-98.4 dBm
300 m	5.2%	-118.8 dBm	10.3%	-105.7 dBm

Table 76 provides results of simulations depending on the simulation radius¹² for GS – 10 MHz – 10 dBm.

Table 76: Scenarios 2 - Results of simulations depending on the simulation radius – GS – 10 MHz – 10 dBm

Simulation radius	DECT distributed over 10 frequencies		DECT co-channel	
	Probability of interference	Interfering power (mean)	Probability of interference	Interfering power (mean)
5 m	98.6%	-55.3 dBm	100%	-45.2 dBm
10 m	94.5%	-61.0 dBm	100%	-51.0 dBm
20 m	90.0%	-67.0 dBm	99.9%	-57.0 dBm
50 m	79.6%	-76.2 dBm	97.9%	-66.2 dBm
100 m	42.8%	-94.6 dBm	63.1%	-84.5 dBm
200 m	12.0%	-111.2 dBm	17.2%	-101.5 dBm
300 m	5.2%	-118.8 dBm	7.6%	-108.8 dBm

A5.3.2 Interferer GS – Tx power 30 dBm – Urban environment

Assumptions on the DECT side:

¹¹ The simulation radius in SEAMCAT represents the maximum distance between the GS and the DECT victim receiver.

¹² The simulation radius in SEAMCAT represents the maximum distance between the GS and the DECT victim receiver.

- Antenna height Tx: 3 m and Rx: 1 m;
- C/(N+I): 21 dB;
- Frequency distribution: same as for scenario 1 and scenario 2.

Assumptions on the ground station (GS) side:

- 5 MHz;
- Gain: 2 dBi;
- Center frequency 1890 MHz
- BS antenna height: 1.5 m;
- Drone antenna height: 25-120 m;
- 30 dBm Tx power;
- 1 km path;
- Unwanted emissions masks for 5 MHz is provided in Figure 33.

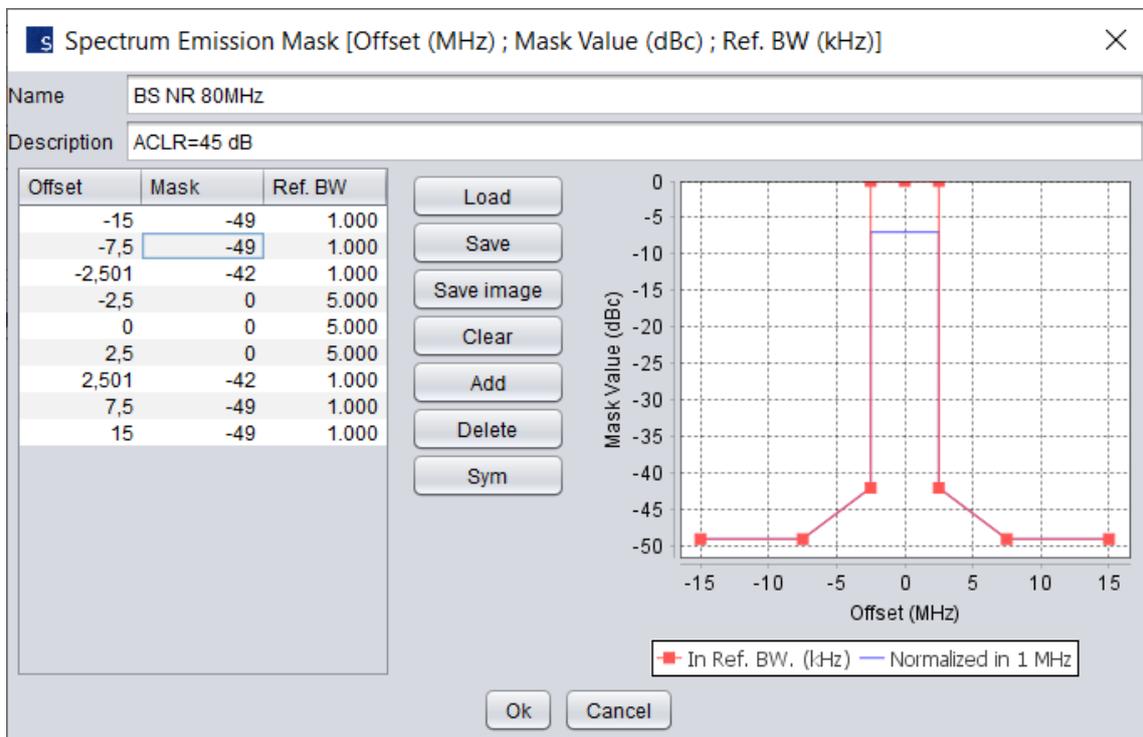


Figure 33: GS unwanted emissions mask – Tx 30 dBm – 5 MHz

Propagation models:

- GS to DECT: Extended Hata SRD – Urban;
- GS to drone: ITU-R P.1546 – Urban;
- DECT path: Extended Hata SRD – Urban.

Scenario 3

Similar as Scenario 1. With Tx power of GS 30 dBm.

DECT assumptions:

- Power is 24 dBm;
- Sensitivity: -75 dBm;
- The maximum DECT path is 200 m.

Table 77 provides results of simulations depending on the simulation radius¹³ for GS – 5 MHz – 30 dBm.

**Table 77: Scenarios 3 - Results of simulations depending on the simulation radius
– GS – 5 MHz – 30 dBm**

Simulation radius	DECT distributed over 10 frequencies		DECT co-channel	
	Probability of interference	Interfering power (mean)	Probability of interference	Interfering power (mean)
5 m	96.5%	-47.5 dBm	100%	-22.1 dBm
10 m	90.5%	-53.4 dBm	100%	-28.1 dBm
20 m	85.7%	-59.4 dBm	100%	-34.0 dBm
50 m	72.5%	-68.4 dBm	99.9%	-44.1 dBm
100 m	42.1%	-86.8 dBm	88.5%	-61.6 dBm
200 m	22.2%	-103.7 dBm	62.4%	-78.4 dBm
300 m	14.1%	-111.1 dBm	42.1%	-85.7 dBm

A5.3.3 Interferer GS – Tx power 30 dBm – Rural environment

Assumptions on the DECT side:

- Antenna height Tx: 3 m and Rx: 1 m;
- Tx power: 24 dBm;
- C/(N+I): 21 dB;
- Frequency distribution: same as for scenario 1 and scenario 2.

Assumptions on the ground station (GS) side:

- 5 MHz;
- Gain: 5 dBi;
- Center frequency 1890 MHz;
- BS antenna height: 1.5 m;
- Drone antenna height 25–120 m;
- 30 dBm Tx power;
- 5.65 km path;
- Unwanted emissions masks for 5 MHz is the same as for scenario 3.

Propagation models:

- GS to DECT: Extended Hata SRD-rural;
- GS to drone: ITU-R P.1546 – rural;
- DECT path: Extended Hata SRD – rural.

Scenario 4

Similar as Scenario 1.

With Tx power of GS 30 dBm, 5 dBi and rural environment.

DECT assumptions:

¹³ The simulation radius in SEAMCAT represents the maximum distance between the GS and the DECT victim receiver.

- Power is 24 dBm;
- Sensitivity: -75 dBm.

Table 78 provides results of simulations depending on the simulation radius¹⁴ for GS – 5 MHz – 30 dBm.

**Table 78: Scenarios 4 - Results of simulations depending on the simulation radius
– GS – 5 MHz – 30 dBm**

Simulation radius	DECT distributed over 10 frequencies		DECT co-channel	
	Probability of interference	Interfering power (mean)	Probability of interference	Interfering power (mean)
10 m	100%	-38.2 dBm	100%	-25.0 dBm
20 m	99.9%	-44.1 dBm	100%	-31.0 dBm
50 m	99.5%	-52 dBm	100%	-39.0 dBm
100 m	97.8%	-58.1 dBm	100%	-45.0 dBm
200 m	91.3%	-64 dBm	99.9%	-51.0 dBm
300 m	80.1%	-67.7 dBm	99.7%	-54.5 dBm

A5.3.4 Interferer Drone – Tx power 28 dBm – Urban environment

Assumptions on the DECT side:

- Antenna height Tx: 3 m and Rx: 1 m;
- C/(N+I): 21 dB.

Assumptions on the drone side:

- 5 MHz;
- Center frequency 1890 MHz;
- BS antenna height: 1.5 m;
- Drone antenna height 30–120 m;
- 28 dBm Tx power;
- 1 km path;
- Power Control on.

For the purpose of the implementation within SEAMCAT and in order to locate the victim relatively to the drone, the drone is modelled as an equipment of 180 kHz. Therefore, the characteristics are recalculated in this band leading to a Tx power of 14 dBm. The drone frequency is distributed over the 5 MHz as shown in Figure 34

¹⁴ The simulation radius in SEAMCAT represents the maximum distance between the GS and the DECT victim receiver.

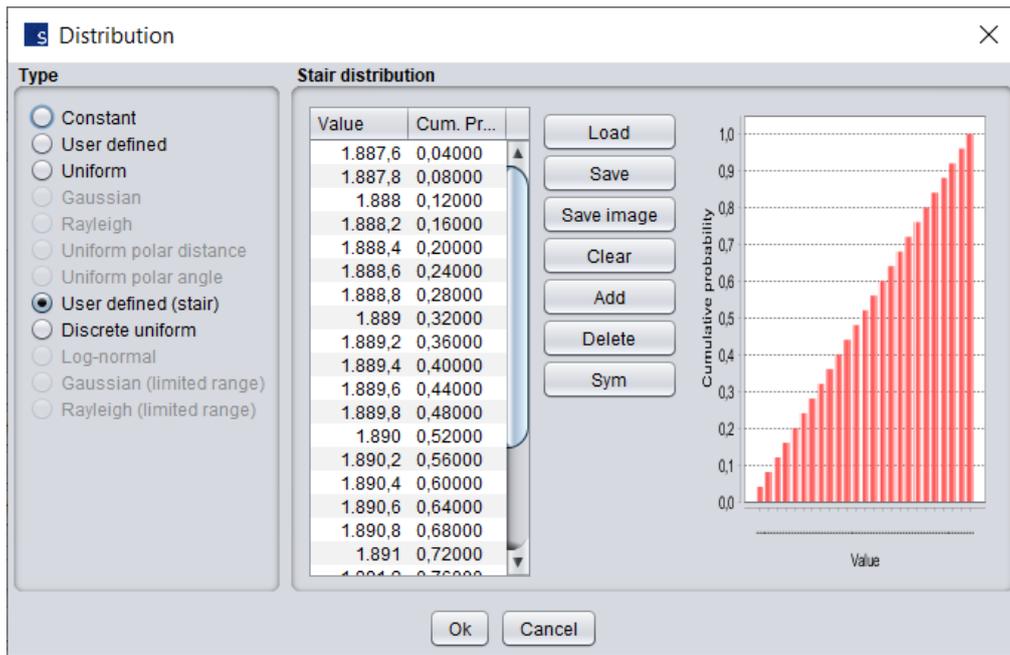


Figure 34: Drone frequency distribution

Unwanted emissions mask is developed based on ETSI TS 136 101 [43] , but applied on a 180 kHz bandwidth as shown in Figure 35.

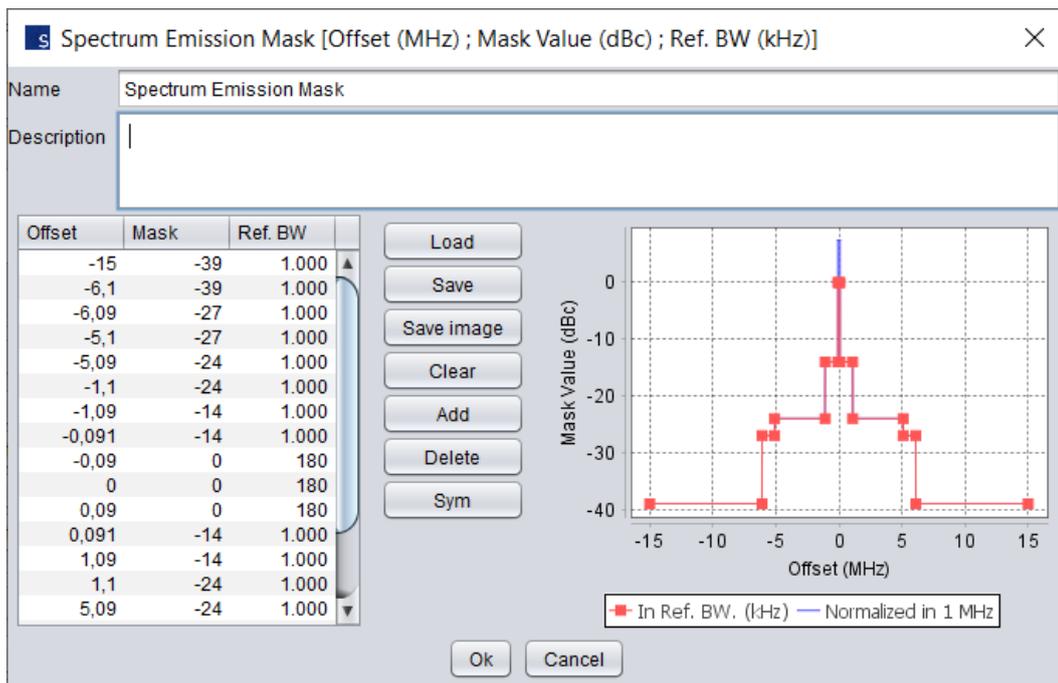


Figure 35: Drone frequency distribution

Propagation models:

- GS to DECT: Extended Hata -urban;
- GS to drone: ITU-R P.1546 – urban;
- DECT path: Extended Hata SRD-urban.

Scenario 5 is similar to Scenario 1.

This scenario corresponds to a situation where the drone is deployed in the same area where an outdoor event is happening.

DECT assumptions:

- Power is 24 dBm;
- Sensitivity: -75 dBm;
- The maximum DECT path is 200 m.

Table 79 provides results of simulations depending on the simulation radius¹⁵ for drone – 5 MHz – 28 dBm (14 dBm in 180 kHz).

Table 79: Scenario 5 - Results of simulations depending on the simulation radius – drone – 5 MHz – 28 dBm

e	DECT distributed over 10 frequencies		DECT co-channel	
	Simulation radius	Probability of interference	Interfering power (mean)	Probability of interference
5 m	41.2%	-87.1 dBm	68.0%	-76.3 dBm
10 m	39.4%	-87.2 dBm	66.6%	-76.3 dBm
20 m	39.3%	-87.3 dBm	67.2%	-76.5 dBm
50 m	35.5%	-89.3 dBm	63.6%	-78.4 dBm
100 m	16.8%	-101.5 dBm	32.2%	-90.9 dBm
200 m	5.1%	-114.5 dBm	11.3%	-103.8 dBm
300 m	1.9%	-120.8 dBm	4.9%	-110.1 dBm

Table 80 provides results of simulations depending on the simulation radius¹⁶ for drone – 5 MHz – 28 dBm (14 dBm in 180 kHz) considering:

- 2 drones: one centered at 1885 MHz and the second is centered 1890 MHz;
- 3 drones: one centered at 1885 MHz and the second is centered 1890 MHz and the third one is centered 1895 MHz.

Table 80: Scenario 5 - Results of simulations depending on the simulation radius – drone – 5 MHz – 28 dBm 2 drones and 3 drones

Simulation radius	2 drones		3 drones	
	Probability of interference	Interfering power (mean)	Probability of interference	Interfering power (mean)
5 m	57.8%	-80.5 dBm	69.4%	-76.0 dBm
10 m	58.0 %	-80.5 dBm	69.1%	-76.0 dBm
20 m	56.6%	-80.8 dBm	69.4%	-76.3 dBm

¹⁵ The simulation radius in SEAMCAT represents the maximum distance between the GS and the DECT victim receiver.

¹⁶ The simulation radius in SEAMCAT represents the maximum distance between the GS and the DECT victim receiver.

50 m	52.7%	-82.8 dBm	64.4%	-78.3 dBm
100 m	24.7%	-93.7 dBm	34.6%	-88.9 dBm
200 m	8.3%	-106.7 dBm	12.5%	-101.6 dBm
300 m	3.9%	-113.4 dBm	5.5%	-108.2 dBm
400 m	1.7%	-117.7 dBm	3.3%	-112.7 dBm

Scenario 6

Scenario 6 is based on scenario 2 using the specific assumptions for the drone:

- DECT power is 12 dBm;
- Sensitivity: -82 dBm;
- The maximum path link is 100 m.

Table 81 provides results of simulations depending on the simulation radius¹⁷ for drone – 5 MHz – 28 dBm.

Table 81: Scenario 6 - Results of simulations depending on the simulation radius – GS – 5 MHz – 28 dBm

Simulation radius	DECT distributed over 10 frequencies		DECT co-channel	
	Probability of interference	Interfering power (mean)	Probability of interference	Interfering power (mean)
5 m	58.4%	-87.0 dBm	81.2%	-76.4 dBm
10 m	58.6%	-87.1 dBm	81.4%	-76.3 dBm
20 m	57.9%	-87.3 dBm	81.0%	-76.6 dBm
50 m	53.3%	-89.2 dBm	81.4%	-76.4 dBm
100 m	24.5%	101.5 dBm	47.3%	-90.8 dBm
200 m	8.6%	-114.5 dBm	20.6%	-103.8 dBm
300 m	4.7%	-120.8 dBm	2.1%	-114.0 dBm

Table 82 provides results of simulations depending on the simulation radius¹⁸ for drone – 5 MHz – 28 dBm (14 dBm in 180 kHz) considering:

- 2 drones: one centered at 1885 MHz and the second is centered 1890 MHz;
- 3 drones: one centered at 1885 MHz and the second is centered 1890 MHz and the third one is centered 1895 MHz.

¹⁷ The simulation radius in SEAMCAT represents the maximum distance between the GS and the DECT victim receiver.

¹⁸ The simulation radius in SEAMCAT represents the maximum distance between the GS and the DECT victim receiver.

Table 82: Scenario 6 - Results of simulations depending on the simulation radius – drone – 5 MHz – 28 dBm 2 drones and 3 drones

Simulation radius	2 drones		3 drones	
	Probability of interference	Interfering power (mean)	Probability of interference	Interfering power (mean)
5 m	73.5%	-80.6 dBm	82.6%	-76.1 dBm
10 m	73.2%	-80.6 dBm	82.8%	-76.1 dBm
20 m	73.0%	-80.9 dBm	82.5%	-76.3 dBm
50 m	68.9%	-82.7 dBm	78.9%	-78.3 dBm
100 m	41.0%	-92.4 dBm	54.2%	-88.7 dBm
200 m	16.9%	-106.4 dBm	23.1%	-101.5 dBm
300 m	9.0%	-113.3 dBm	13.0%	-108.2 dBm
400 m	5.3%	-117.7 dBm	8.1%	-112.7 dBm

A5.3.5 Interferer drone – Tx power 28 dBm – Rural environment

This scenario (Scenario 7) is based on Scenario 4, except that the interferer is a drone. Specific assumptions for the drone are considered (see A5.3.4).

Table 83 provides results of simulations depending on the simulation radius¹⁹ for GS – 5 MHz – 28 dBm.

Table 83: Scenarios 7 - Results of simulations depending on the simulation radius – GS – 5 MHz – 28 dBm

Simulation radius	DECT distributed over 10 frequencies		DECT co-channel	
	Probability of interference	Interfering power (mean)	Probability of interference	Interfering power (mean)
5 m	15.5%	-86.2 dBm	46.5%	-75.6 dBm
10 m	15.5%	-86.1 dBm	46.5%	-75.5 dBm
20 m	14.8%	-86.4 dBm	45.4%	-75.7 dBm
50 m	12.1%	-87.4 dBm	41.1%	-76.7 dBm
100 m	9.8%	-89.3 dBm	34.5%	-78.2 dBm
200 m	7.7%	-92.9 dBm	27.6%	-82.3 dBm
300 m	7.0%	-95.7 dBm	25.3%	-84.8 dBm

¹⁹ The simulation radius in SEAMCAT represents the maximum distance between the GS and the DECT victim receiver.

A5.4 INDOOR SCENARIO

A5.4.1 Interferer GS – Tx power 10 dBm - urban

Scenario 8

This scenario considers the cases where DECT devices are deployed indoor (home, offices and hospitals). The ground station is then deployed outdoor. The scenario investigates the impact of the ground station on DECT devices deployed indoor.

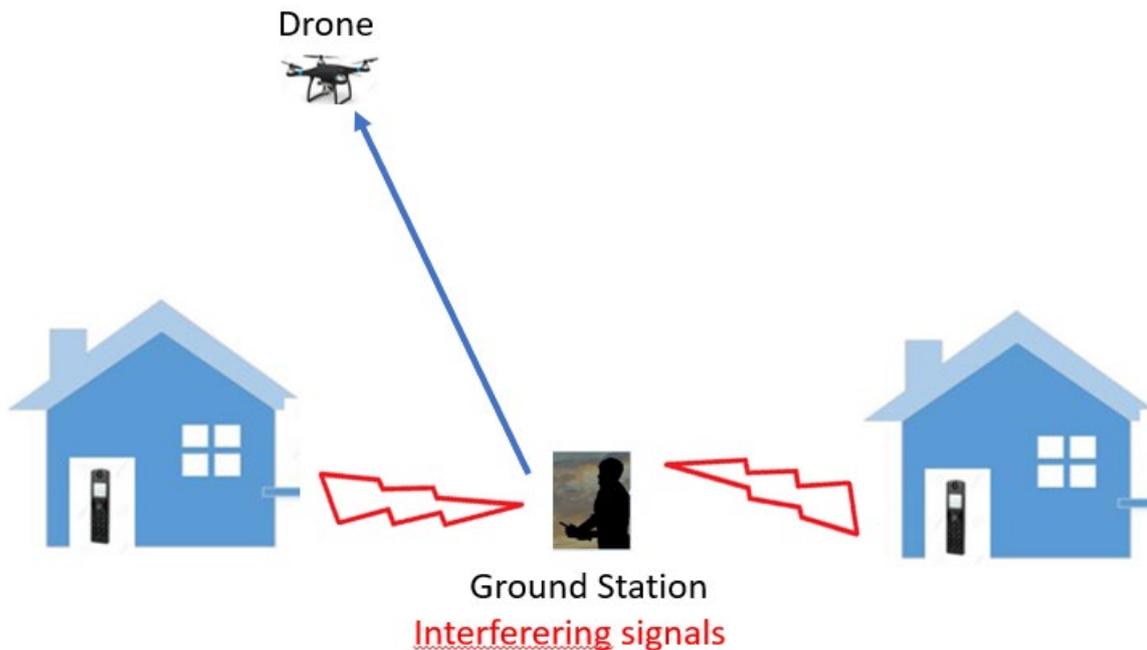


Figure 36: Ground station versus DECT devices deployed indoor

Assumptions on the DECT side:

- DECT antenna height Tx: 2.5 m and Rx: 1 m;
- Power is 4 to 12 dBm;
- Sensitivity: -75 dBm;
- The maximum DECT path is 50 m.

Assumptions on the ground station (GS) side:

- 5 MHz
- BS antenna height: 1.5 m;
- Drone antenna height 25–120 m;
- 10 dBm Tx power;
- 1 km path;
- Unwanted emissions masks for 5 MHz and 10 MHz bandwidths same as before.

Propagation models:

- GS to DECT: Extended Hata SRD – Urban + building loss based on ITU-R P.2109 (50%);
- GS to drone: ITU-R P.1546 – Urban;

- DECT path: IEEE 802.11 rev3 (Model C (break point at 4 m – 20 log d before the breakpoint and 30 log d after the breakpoint)).

Note: in SEAMCAT the building loss is implemented on the GS in order not to impact the DECT path.

Table 84 provides results of simulations depending on the simulation radius for GS – 5 MHz – 10 dBm.

Table 84: Scenario 8- Results of simulations depending on the simulation radius – GS – 5 MHz – 10 dBm

Simulation radius	DECT distributed over 10 frequencies		DECT co-channel	
	Probability of interference	Interfering power (mean)	Probability of interference	Interfering power (mean)
5 m	75.5%	-77.8 dBm	97.4%	-64.7 dBm
10 m	62.0%	-83.8 dBm	93.9%	-70.7 dBm
20 m	48.2%	-89.8 dBm	85.9%	-76.7 dBm
50 m	24.2%	-98.9 dBm	58.7%	-85.9 dBm
100 m	7.0%	-116.6 dBm	18.3%	-103.4 dBm
200 m	1.8%	-132.9 dBm	4.3%	-119.8 dBm
300 m	0.8%	-140.2 dBm	2.2%	-127.9 dBm

A5.4.2 Interferer GS – Tx power 30 dBm - urban

Scenario 9 is similar to scenario 8, except that the GS is operated at 30 dBm and the unwanted emissions mask is changed accordingly.

Table 85 provides results of simulations depending on the simulation radius for GS – 5 MHz – 30 dBm, DECT deployed indoor.

Table 85: Scenarios 9 - Results of simulations depending on the simulation radius – GS – 5 MHz – 30 dBm

Simulation radius	DECT distributed over 10 frequencies		DECT co-channel	
	Probability of interference	Interfering power (mean)	Probability of interference	Interfering power (mean)
5 m	77.0%	-70 dBm	99.9%	-44.7 dBm
10 m	67.2%	-75.9 dBm	99.7%	-50.7 dBm
20 m	56.9%	-82.1 dBm	99.1%	-56.7 dBm
50 m	41.0%	-91.2 dBm	96.2%	-65.8 dBm
100 m	22.1%	-108.8 dBm	61.3%	-83.4 dBm
200 m	6.6%	-125.1 dBm	18.4%	-99.9 dBm
300 m	2.8%	-132.3 dBm	7.9%	-107.1 dBm

A5.4.3 Interferer drone– Tx power 28 dBm - urban

Scenario 10 is similar to scenarios 8 and 9, except that the GS is replaced by a drone.

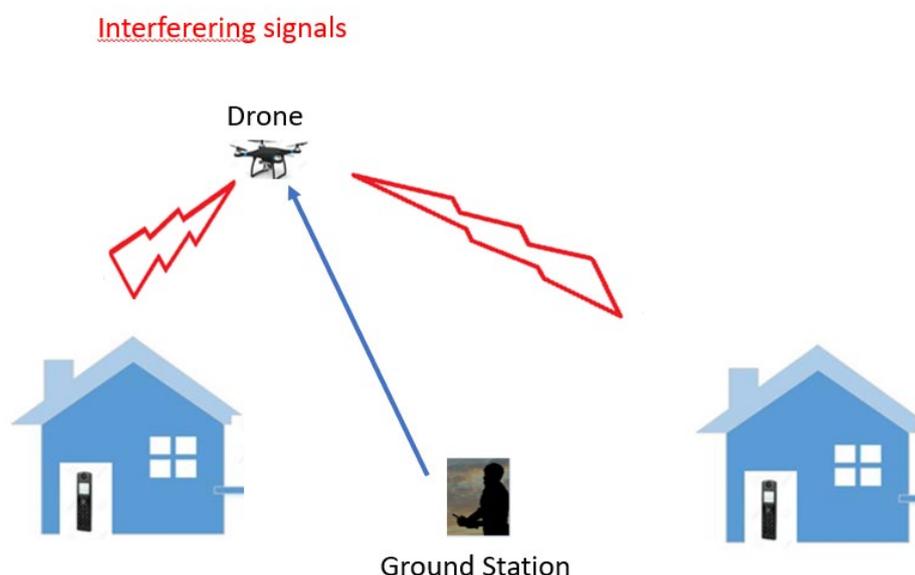


Figure 37: Drone versus DECT devices deployed indoor

In order to account for the building loss, the power of the drone is decreased by 15 dB.

Table 86 provides results of simulations depending on the simulation radius for GS – 5 MHz – 28 dBm, DECT deployed indoor.

Table 86: Scenarios 10 - Results of simulations depending on the simulation radius – GS – 5 MHz – 28 dBm

Simulation radius	DECT distributed over 10 frequencies		DECT co-channel	
	Probability of interference	Interfering power (mean)	Probability of interference	Interfering power (mean)
10 m	6.3%	-108.3 dBm	24.0%	-97.5 dBm
20 m	6.3%	-108.3 dBm	23.0%	-97.7 dBm
50 m	5.7%	-110.3 dBm	19.9%	-99.6 dBm
100 m	1.7%	-121.7 dBm	5.8%	-111 dBm
200 m	0%	-134 dBm	1.3%	-123.7 dBm
300 m	0%	-140.6 dBm	0%	-130 dBm

Table 87 provides results of simulations depending on the simulation radius²⁰ for drone – 5 MHz – 28 dBm (14 dBm in 180 kHz) considering:

- 2 drones: one centered at 1885 MHz and the second is centered 1890 MHz;
- 3 drones: one centered at 1885 MHz and the second is centered 1890 MHz and the third one is centered 1895 MHz

²⁰ The simulation radius in SEAMCAT represents the maximum distance between the GS and the DECT victim receiver.

Table 87: Scenario 10 - Results of simulations depending on the simulation radius – drone – 5 MHz – 28 dBm 2 drones and 3 drones

Simulation radius	2 drones		3 drones	
	Probability of interference	Interfering power (mean)	Probability of interference	Interfering power (mean)
5 m	13.2%	-101.9 dBm	20.3%	-97.4 dBm
10 m	13.6%	-101.9 dBm	19.6%	-97.4 dBm
20 m	12.8%	-102.2 dBm	19.9%	-97.6 dBm
50 m	11.5%	-104.2 dBm	16.8%	-99.6 dBm
100 m	3.6%	-114.6 dBm	5.4%	-109.5 dBm
200 m	0%	-126.8 dBm	1.3%	-121.8 dBm
300 m	0%	-137.6 dBm	0%	-128.3 dBm

ANNEX 6: MONTE CARLO STUDY OF THE POSSIBLE IMPACT OF AN LTE-BASED UAS DEPLOYED IN A CHANNEL CENTERED AT 1890 MHZ TO A DECT DEPLOYMENT IN 1880-1900 MHZ

A6.1 METHODOLOGY

A6.1.1 Space distribution of interferers and victims

The simulation area is centred on the UAS (Unmanned Aircraft System) GS (ground station). For each Monte Carlo run, the UAS UE (User Equipment) is randomly generated within a cylinder whose radius is defined by the range of the UAS system, and whose height is 120 m.

For each Monte Carlo run, DECT devices are deployed by pair. DEC channels are randomly allocated to the generated pairs. 5% of pairs are considered to be located outside. For each pair, a first device is generated within the range of the UAS system. Its altitude is set to 1.5 m in a rural context or for indoor devices, or is distributed as follows in an urban context (devices located inside):

- 25% of devices at ground level (1.5 m);
- 25% of devices on the 1st floor (4.5 m);
- 10% of devices on the 2nd floor (7.5 m);
- 10% of devices on the 3rd floor (10.5 m);
- 10% of devices on the 4th floor (13.5 m);
- 10% of devices on the 5th floor (16.5 m);
- 10% of devices on the 6th floor(19.5 m).

From there, for each pair, a second device is generated at the same altitude, within a circle of radius 100 m for devices located inside, or 350 m for devices located outside.

The density of DECT pairs in the simulation area is derived from the traffic requirements from ETSI TR 101 310, table 5 [34] for residential service type. This gives a traffic load between 25 E/km² and 280 E/km². It was chosen to use 25 E/km² in rural scenarios, and 280 E/km² in urban scenarios. According to ETSI TR 101 310, table 9, residential speech and emerging data services generates between 100 and 140 mE of traffic (the latter value is retained in the following). This gives an overall density of:

- $25 \times 0.14 = 3.5$ DECT pairs per km² in rural simulations;
- $280 \times 0.14 = 39.2$ DECT pairs per km² in urban simulations.

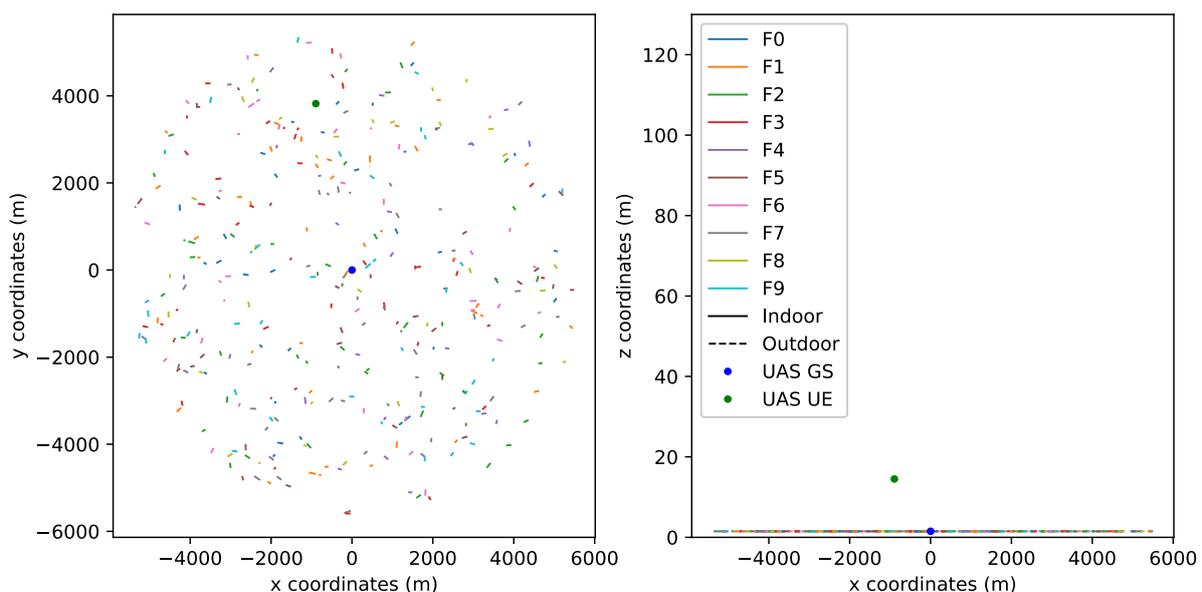


Figure 38: Example of one rural Monte Carlo run (with UAS range of 5650 m)

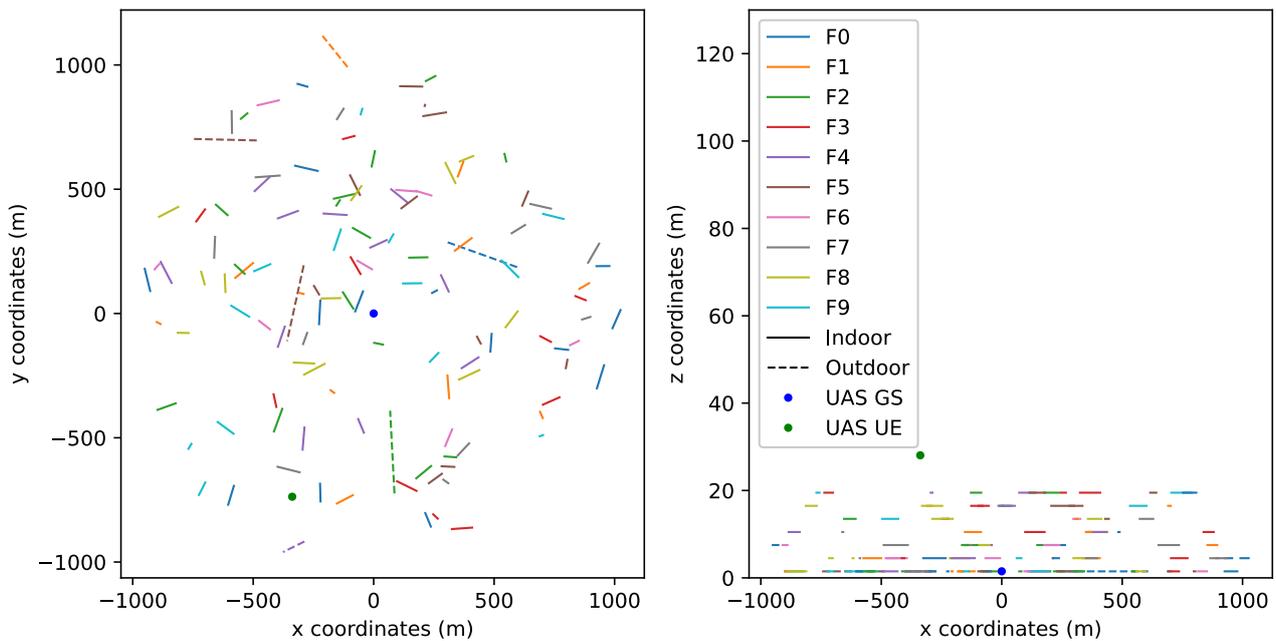


Figure 39: Example of one urban Monte Carlo run (with UAS range of 1000 m)

A6.1.2 Hypothesis

The following hypothesis are considered:

- The UAS transmits and receives on a channel spanning 5 or 10 MHz, and centered at 1890 MHz.
- Because of the Line-of-Sight (LOS) propagation, path loss between UAS GS and UAS UE (used for UE transmit power control – TPC) is computed using FSPL (Free Space Path Loss).
- Path loss between indoor DECT devices of the same pair is given in ETSI TR 103 089, annex B.4²¹.
- Path loss between outdoor DECT devices of the same pair is computed using FSPL.
- Path loss between of different pairs is given by:
 - ETSI TR 103 089, annex B.4 is the two devices are indoor with a distance lower than 250 m.
 - FSPL on top of which building entry loss based on Recommendation ITU-R P.2109-1 is added two times, if the two devices are indoor with a distance higher than 250 m.
 - FSPL on top of which building entry loss based on Recommendation ITU-R P.2109-1 is as well as clutter loss based on ITU-R P.2108-1 (model of Section 3.1.1) is applied, if one device is located indoor, and the second is located outdoor.
 - FSP on top of which clutter loss based on ITU-R P.2108-1 (model of Section 3.1.1) is applied two times, if the two devices are located outdoor.
- Path loss between UAS GS/UE and indoor DECT is computed using FSPL, on top of which Building Entry Loss (BEL) is added, based on Recommendation ITU-R P.2109-1, as well as clutter at the UAS GS/UE side, based on ITU-R P.2108-1 (model of Section 3.1.1)²².
- Path loss between UAS GS/UE and outdoor DECT is computed using FSPL, on top of which clutter is added at the UAS GS side and the DECT Rx side, based on ITU-R P.2108-1 (model of Section 3.1.1).
- The UAS GS Spectrum Emission Mask (SEM) is based on 3GPP 36.104, Table 6.6.3.2C-6 (LTE medium range BS) considering a transmit power of 30 dBm. Portions of this SEM is scaled so that ACLR values of 3GPP 36.104, table 6.6.2.1-2 are respected in the bands concerned. When using a lower transmit power, the SEM is scaled accordingly (see Figure 40);

²¹ When $d \geq 4\text{m}$: $L = 38 + 30 \cdot \log_{10}(d)$, else FSPL at 1890 MHz, with d the distance between the two devices, in m.

²² Note that clutter loss computed using this model decreases with the altitude

- The UAS UE SEM is based on 3GPP 36.101, table 6.6.3.2C-6 considering a transmit power of 30 dBm [17]. Portions of this SEM is scaled so that ACLR values of Section 6.6.2.2 (for power class 1 UEs) are respected in the bands concerned. When using a higher or lower transmit power, the SEM;
- DECT BEM (blocking edge mask) is based on ETSI TR 103 089, table B.2 and ETSI EN 300 172-2, table 5 (see Figure 40);
- DECT SEM is based on ETSI EN 300 175-2, section 5.5.1 [4].

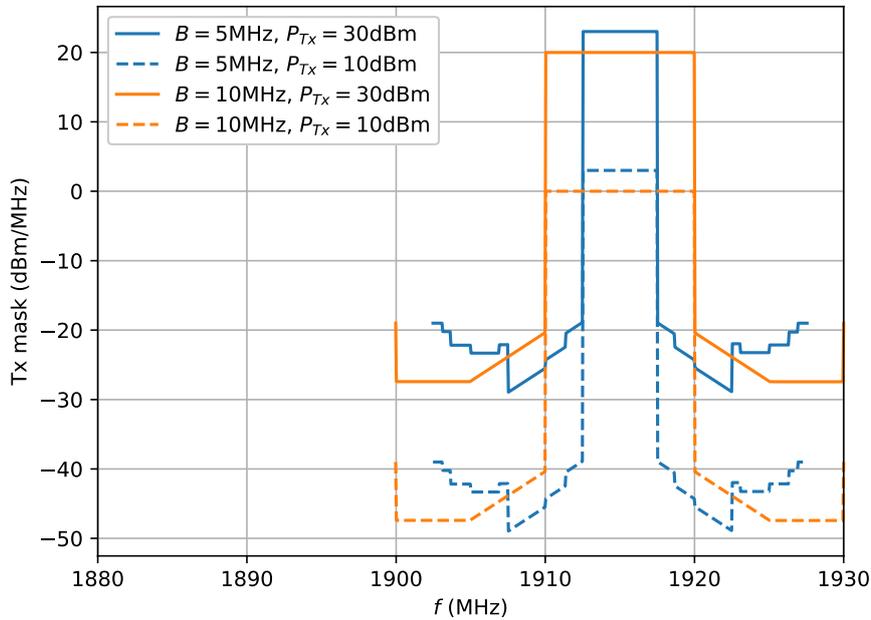


Figure 40: UAS GS SEM, based on 3GPP 36.104, table 6.6.3.2C-6 and table 6.6.2.1-2

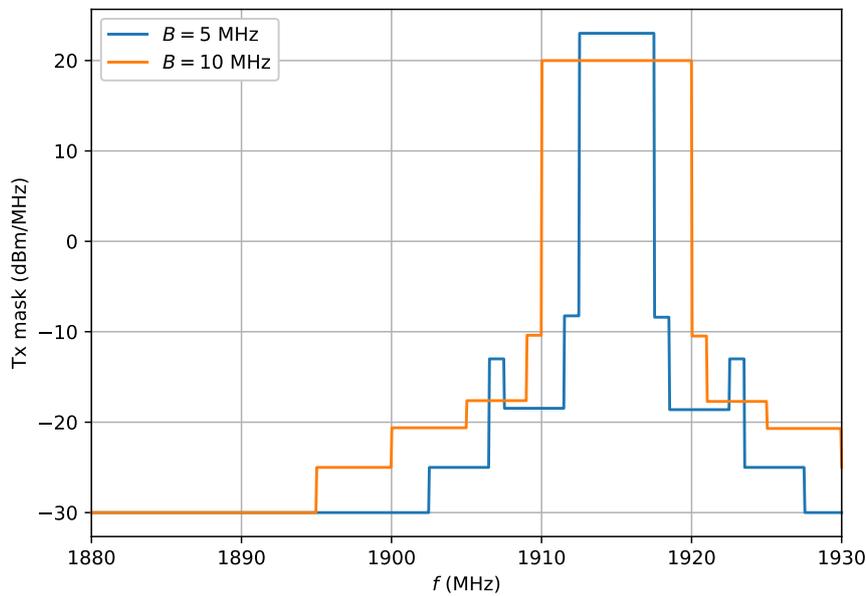


Figure 41: UAS UE SEM based on 3GPP 36.101, table 6.6.2.1.1-1, 1 and section 6.6.2.2 for a transmit power of 30 dBm [17]

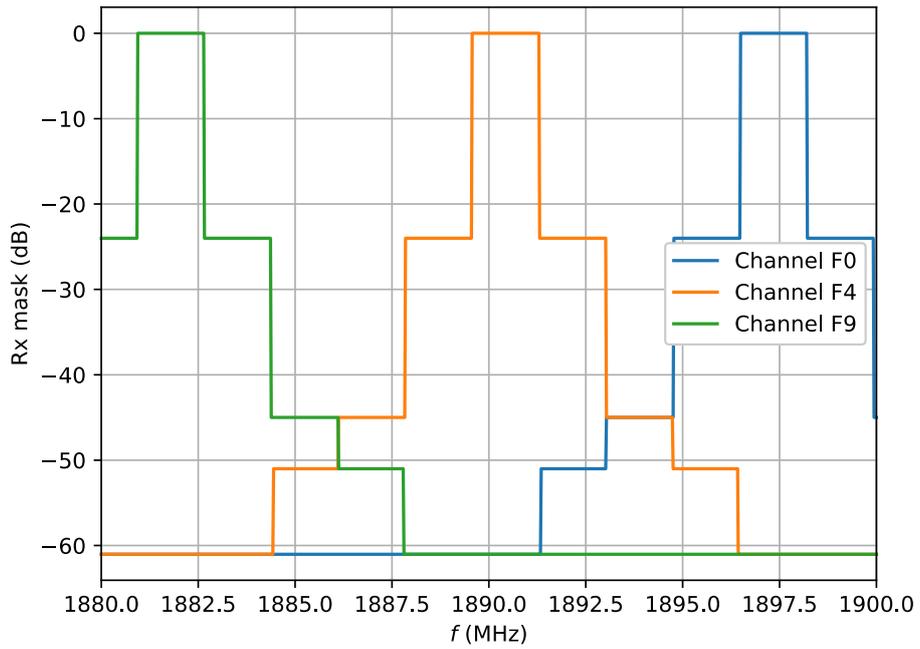


Figure 42: DECT BEM based on ETSI TR 103 089, table B.2 and ETSI EN 300 172-2, table 5

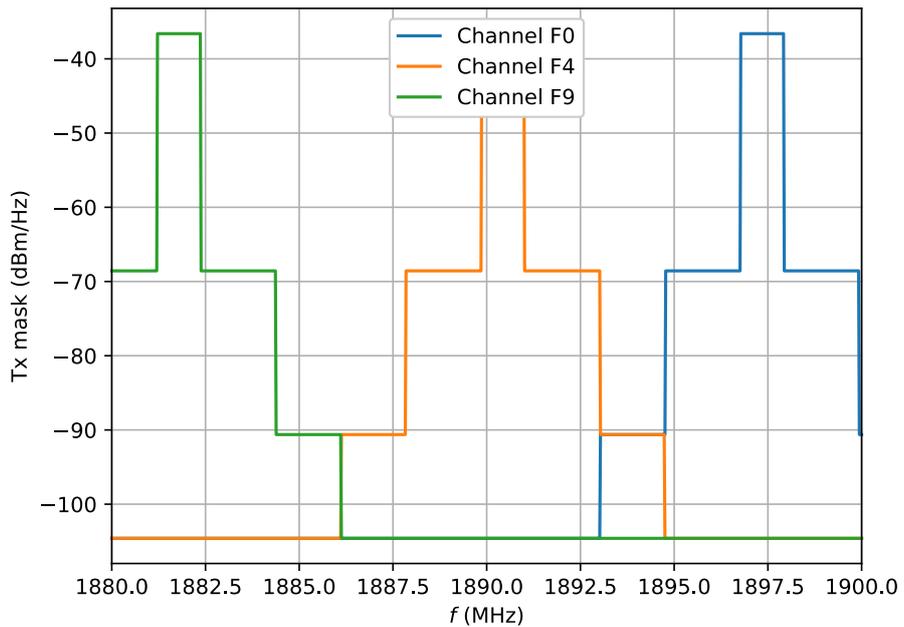


Figure 43: DECT SEM based on ETSI EN 300 175-2, section 5.5.1 [4]

A6.1.3 Model of DECT received interference

A6.1.3.1 UAS GS transmit

For each Monte Carlo run ω , the interference power as experienced from the i th DECT receiver from the UAS GS is given as:

$$\begin{aligned}
 & I_{UAS\ GS \rightarrow DECT\ RX}(\omega, i) \\
 &= P_f(C(i)) + G_{DECT} + G_{UAS\ GS} - PL(\vec{p}_{UAS\ GS}, \vec{p}_{DECT\ RX}(\omega, i)) - CL(\vec{p}_{UAS\ GS}) \\
 & \begin{cases} BEL(\vec{p}_{UAS\ GS}, \vec{p}_{DECT\ RX}(\omega, i)) & \text{if DECT device inside} \\ CL(\vec{p}_{DECT\ RX}(\omega, i)) & \text{if DECT device outside} \end{cases}
 \end{aligned} \tag{12}$$

If the time offset between the beginning of DECT device i TDD frame and the beginning of the UAS GS TDD frame is such that device i receives while the UAS GS transmits (see Figure 44). Else, it is obtained:

$$I_{UAS\ GS \rightarrow DECT\ RX}(\omega, i) = -\infty \text{ [dBm]} \tag{13}$$

Where:

- $P_f(chan) = 10 \cdot \log_{10}(\int_{-\infty}^{+\infty} SEM_{UAS\ GS}(f) \cdot BEM_{DECT\ RX}(f, chan) df)$ is the fraction of the interferer power falling into the receiver's band (in dBm). It depends on the channel on which the DECT pair communicated;
- $SEM_{UAS\ GS}(f)$ is the SEM of the UAS GS, scaled to the UAS GS transmit power (in mW/Hz);
- $BEM_{DECT\ RX}(f, chan)$ is the BEM of the DECT receiver, operating on channel $chan$.
- $C(i)$ is the channel on which the i th DECT pair communicates;
- G_{DECT} is the gain of the DECT antenna (in dBi);
- $G_{UAS\ GS}$ is the gain of the UAS GS (in dBi);
- $PL(\vec{p}_1, \vec{p}_2)$ is the path loss between the two points in space described by vectors \vec{p}_1 and \vec{p}_2 (dB);
- $\vec{p}_{DECT\ RX}(\omega, i)$ vector describing the position in space of the i th DECT receiver, at Monte Carlo run ω ;
- $\vec{p}_{UAS\ GS}$ vector describing the position in space of the UAS GS.

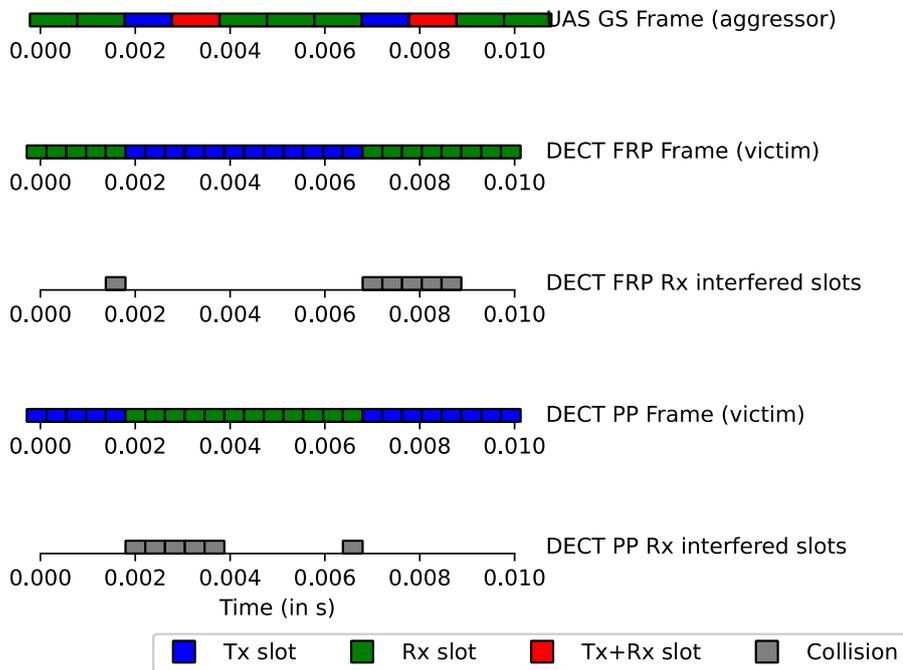


Figure 44: Examples of UAS GS to DECT TDD collision pattern

A6.1.3.2 UAS UE transmit

$$\begin{aligned}
 & I_{UAS\ UE \rightarrow DECT\ RX}(\omega, i) \\
 &= P_f(C(i), \omega) + G_{DECT} + G_{UAS\ UE} - PL(\overrightarrow{p_{UAS\ UE}(\omega)}, \overrightarrow{p_{DECT\ RX}(\omega, i)}) - CL(\overrightarrow{p_{UAS\ UE}(\omega)}) \\
 & - \begin{cases} BEL(\overrightarrow{p_{UAS\ UE}(\omega)}, \overrightarrow{p_{DECT\ RX}(\omega, i)}) & \text{if DECT device inside} \\ CL(\overrightarrow{p_{DECT\ RX}(\omega, i)}) & \text{if DECT device outside} \end{cases}
 \end{aligned} \tag{14}$$

If the time offset between the beginning of DECT device *i* TDD frame and the beginning of the UAS UE TDD frame is such that device *i* receives while the UAS UE transmits (see Figure 45). Else, it is obtained:

$$I_{UAS\ UE \rightarrow DECT\ RX}(\omega, i) = -\infty \text{ [dBm]} \tag{15}$$

Using the same notation as before, and where:

- $P_f(C(i), \omega)$ is the fraction of the interferer power falling into the receiver's band, taking into account UAS UE transmit power control and the channel used by the DECT receiver (in dBm).
- The power control algorithm is taken from Recommendation ITU-R M.2101-0, taking into account that all Resource Blocks are allocated to the same device.
- The power control formula is given then by $P_{UAS\ UE}(\omega) = \min \left\{ P_{UAS\ UE, max}, P_{UAS\ GS, target} + \alpha \cdot PL(\overrightarrow{p_{UAS\ UE}(\omega)}, \overrightarrow{p_{UAS\ GS}(\omega)}) \right\}$
 - $\alpha = 1$
 - $P_{UAS\ GS, target}$ is the target received power at the UAS GS, computed based on the target SNR given in Annex 3, Table 54, plus 3 dB of margin ($P_{UAS\ GS, target} = -80$ dBm for 5 MHz of bandwidth, -85 dBm of 10 MHz of bandwidth).
- $G_{UAS\ UE}$ is the gain of the UAS UE (in dBi).
- $\overrightarrow{p_{UAS\ UE}(\omega)}$ vector describing the position in space of the UAS UE, at Monte Carlo run ω .

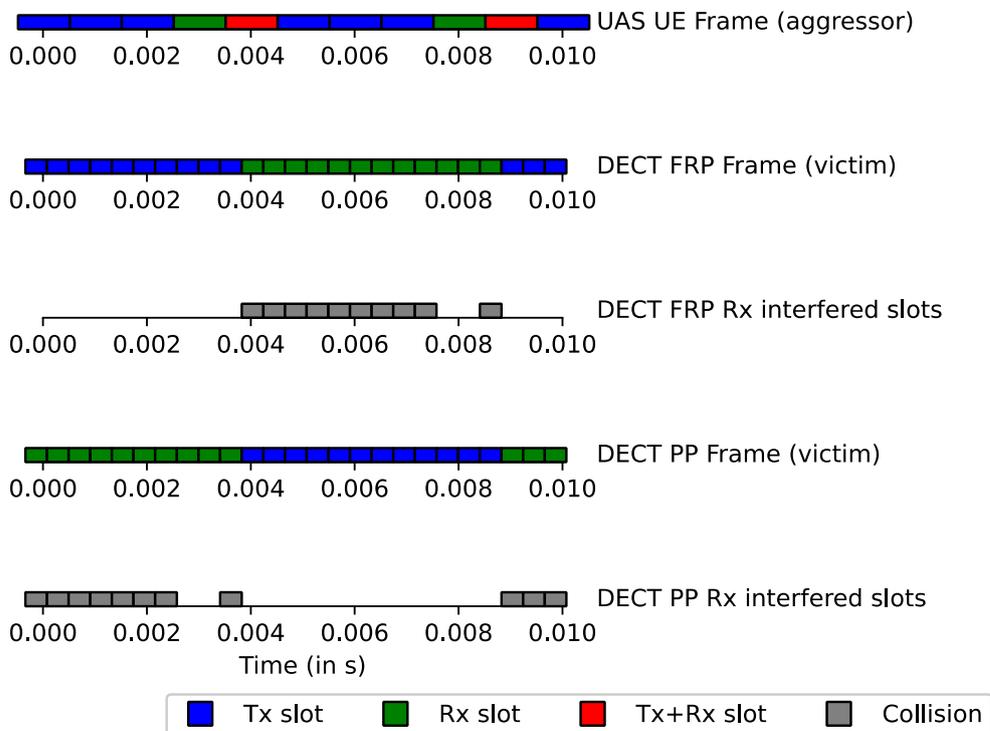


Figure 45: Examples of UAS UE to DECT TDD collision pattern

A6.1.3.3 DECT device from an other pair transmit

$$\begin{aligned}
 & I_{DECT\ TX \rightarrow DECT\ RX}(\omega, i, j) \\
 & = P_f(Ch(i), Ch(j)) + G_{DECT} + D_{DECT} - PL(\overrightarrow{p_{DECT\ TX}(\omega, i)}, \overrightarrow{p_{DECT\ RX}(\omega, j)}) \\
 & - \begin{cases} 0 & \text{if both device inside and } d \leq 250\text{ m} \\ BEL(\overrightarrow{p_{DECT\ TX}(l, \omega)}, \overrightarrow{p_{DECT\ RX}(j, \omega)}) + BEL(\overrightarrow{p_{DECT\ RX}(j, \omega)}, \overrightarrow{p_{DECT\ TX}(l, \omega)}) & \text{if both devices inside and } d > 250\text{ m} \\ BEL(\overrightarrow{p_{DECT\ TX}(l, \omega)}, \overrightarrow{p_{DECT\ RX}(j, \omega)}) + CL(\overrightarrow{p_{DECT\ RX}(j, \omega)}) & \text{if Tx is inside and Rx is outside} \\ CL(\overrightarrow{p_{DECT\ TX}(l, \omega)}) + CL(\overrightarrow{p_{DECT\ RX}(j, \omega)}) & \text{if both devices outside} \end{cases}
 \end{aligned} \tag{16}$$

Using the same notations as before, and where:

- $P_f(Ch(i), Ch(j))$ is the fraction of the interfering DECT device (transmitting on channel $Ch(i)$) power falling into the DECT victim receiver's band (receiving on channel $Ch(j)$) (in dBm).

A6.1.3.4 Aggregate interference from DECT devices from other pairs

$$I_{DECT-DECT,agg}(\omega, j) = 10 \cdot \log_{10} \left(\sum_{i \in I(j)} 10^{\frac{I_{DECT\ TX \rightarrow DECT\ RX}(\omega, i, j)}{10}} \right) \tag{17}$$

Where :

- $I(j)$ is the set of DECT devices indices than interfere with device j (see Figure 46). If $i \in I(j)$, then:
- $i \neq j$;
- DECT device i does not belong to the same pair as DECT device j ;
- The time offset between the beginning of DECT device i TDD frame and the beginning of DECT device j TDD frame is such that device i transmits while device j receives.

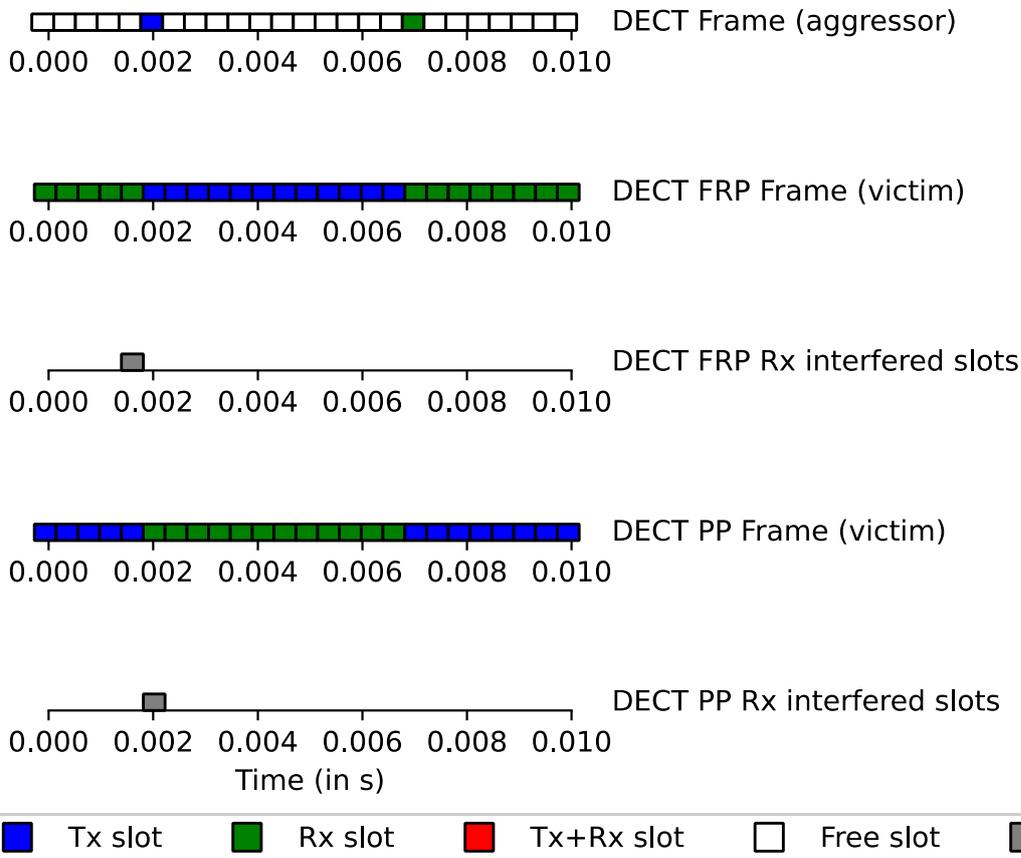


Figure 46: Example DECT to DECT collision example

A6.1.4 Model of UAS received interference

A6.1.4.1 UAS GS receive

$$\begin{aligned}
 & I_{DECT\ TX \rightarrow UAS\ GS}(\omega, i) \\
 & = P_f(Ch(i)) + G_{DECT} + G_{UAS\ GS} - PL(\overrightarrow{p_{UAS\ GS}}, \overrightarrow{p_{DECT\ RX}(\omega, i)}) - CL(\overrightarrow{p_{UAS\ GS}}) \\
 & - \begin{cases} BEL(\overrightarrow{p_{DECT\ RX}(\omega, i)}, \overrightarrow{p_{UAS\ GS}}) & \text{if DECT device inside} \\ CL(\overrightarrow{p_{DECT\ RX}(\omega, i)}) & \text{if DECT device outside} \end{cases}
 \end{aligned} \tag{18}$$

Using the same notation as before, and where:

- $P_f(chan) = 10 \cdot \log_{10}(\int_{-\infty}^{+\infty} BEM_{UAS\ GS}(f) \cdot SEM_{DECT\ TX}(f, chan) df)$ is the fraction of the interferer power falling into the receiver's band (in dBm). It depends on the channel on which the DECT pair communicated.
- $BEM_{UAS\ GS}(f)$ is the BEM of the UAS GS.
- $SEM_{DECT\ RX}(f, chan)$ is the SEM of the DECT receiver, operating on channel $chan$ (in mW/Hz).

A6.1.4.2 UAS UE receive

$$\begin{aligned}
 & I_{DECT\ TX \rightarrow UAS\ UE}(\omega, i) \\
 & = P_f(Ch(i), \omega) + G_{DECT} + G_{UAS\ UE} - PL(\overrightarrow{p_{UAS\ UE}(\omega)}, \overrightarrow{p_{DECT\ RX}(\omega, i)}) \\
 & - \begin{cases} BEL(\overrightarrow{p_{DECT\ RX}(\omega, i)}, \overrightarrow{p_{UAS\ UE}(\omega)}) & \text{if DECT device inside} \\ CL(\overrightarrow{p_{DECT\ RX}(\omega, i)}) & \text{if DECT device outside} \end{cases}
 \end{aligned} \tag{19}$$

Using the same notation as before.

A6.1.4.3 Aggregate interference

$$\begin{aligned}
 I_{UAS\ GS,agg}(\omega) & = 10 \cdot \log_{10} \left(\sum_{i \in I_{UAS\ GS}} 10^{\frac{I_{DECT\ TX \rightarrow UAS\ GS}(\omega, i)}{10}} \right) \\
 I_{UAS\ UE,agg}(\omega) & = 10 \cdot \log_{10} \left(\sum_{i \in I_{UAS\ UE}} 10^{\frac{I_{DECT\ TX \rightarrow UAS\ UE}(\omega, i)}{10}} \right)
 \end{aligned} \tag{20}$$

Where $I_{UAS\ GS}$ (respectively, $I_{UAS\ UE}$) is the set of DECT devices indices that interfere or are interfered with the UAS GS (respectively, UAS UE). If $i \in I_{UAS\ GS}$ (respectively $i \in I_{UAS\ UE}$), then the time offset between the beginning of DECT device i TDD frame and the beginning of the UAS GS (respectively, UAS UE) TDD frame is such that device i transmits while the UAS GS (respectively, UAS UE) receives.

A6.1.5 Model of received signals

A6.1.5.1 Model of DECT received signal

$$C(\omega, i) = P_{TX,DECT} + G_{DECT} + G_{DECT} - PL(\overrightarrow{p_{DECT\ RX}(\omega, i)}, \overrightarrow{p_{DECT\ RX}(\omega, i)}) \tag{21}$$

Using the same notation as before, and where:

- is the DECT transmit power;
- $\overrightarrow{p_{DECT\ TX}(\omega, i)}$ is a vector describing the position in space of the i th DECT transmitter, at Monte Carlo run ω .

A6.1.5.2 UAS GS

$$C_{UAS\ GS}(\omega) = P_{UAS\ UE}(\omega) + G_{UAS\ UE} + G_{UAS\ GS} - PL\left(\overrightarrow{p_{UAS\ UE}(\omega)}, \overrightarrow{p_{UAS\ GS}(\omega)}\right) \quad (22)$$

Using the same notation as before.

A6.1.5.3 UAS UE

$$C_{UAS\ GS}(\omega) = P_{UAS\ BS} + G_{UAS\ UE} + G_{UAS\ GS} - PL\left(\overrightarrow{p_{UAS\ BS}(\omega)}, \overrightarrow{p_{UAS\ UE}(\omega)}\right) \quad (23)$$

A6.1.6 Simulation of DECT DCS

The algorithm to simulate DCS for a Monte Carlo sample ω_0 is as follows:

- `DECT_pair_chosen <- empty_array()` // Will store which pairs have already chosen their channel
- `DECT_chan <- array(N_DECT_chan)` // Will store the channel selected by DECT pairs
- `DECT_slot <- array(N_DECT_slot)` // Will store the channel selected by DECT pairs

For each DECT pair i in the deployment:

// I – Compute heatmap of interference received on each DECT channel and time slot

`HM <- array(2, N_DECT_chan, N_DECT_slot)`

For DECT device j in DECT pair i : // 2 devices per pair

For each DECT channel k :

For each DECT time slot l :

`I_UAS_GS <- IUAS GS→DECT RX(ω_0 , j)`

`I_UAS_UE <- IUAS UE→DECT RX(ω_0 , j)`

`I_DECT_DECT <- IDECT-DECT,agg(ω , j)` // Exclude DECT interference for pairs not yet in `DECT_pair_chosen`

`HM[j,k,l] <- 10.log10 $\left(10^{\frac{I_{UAS_GS} + I_{UAS_UE} + I_{DECT_DECT}}{10}}\right)$`

// II – Compute aggregate heatmap of the two DECT devices in the pair

`HM_sum <- array(N_DECT_chan, N_DECT_slot)`

For each DECT channel k :

For each DECT time slot l :

`HM_sum[k,l] = 10.log10 $\left(10^{\frac{HM[0,j,k] + HM[1,j,k]}{10}}\right)$`

// III – Choose channel experiencing the least interference

`DECT_chan[i], DECT_slot[i] <- arg mink∈[0;N_DECT_chan], l∈[0;N_DECT_slot] HM_sum[k, l]`

`DECT_pair_chosen.append(i)`

A6.1.7 Gathered statistics

A6.1.7.1 DECT interfered by UAS

In order to assess the probability for any MFCN BS to be interfered with either the UAS BS or the UAS UE, we compute the SINR ratio of the most interfered MFCN BS at each Monte Carlo run:

$$\begin{aligned} SINR_{DECT|_{worst}}(\omega) &= \min_i SINR_{DECT}(\omega, i) \\ &= \min_i \left\{ C_{DECT}(\omega, i) - 10 \log_{10} \left(10^{\frac{I_{UAS GS \rightarrow DECT RX}(\omega, i) + I_{UAS UE \rightarrow DECT RX}(\omega, i) + I_{DECT-DECT,agg}(\omega, i) + P_{N,DECT}}{10}} \right) \right\} \end{aligned} \quad (24)$$

Where:

- $P_{N,DECT}$ is the noise floor of the DECT receiver (in dBm).

A6.1.7.2 UAS interfered by DECT

$$\begin{aligned} SINR_{UAS BS}(\omega) &= C_{UAS BS} - 10 \cdot \log_{10} \left(10^{\frac{I_{UAS GS,agg}(\omega) + P_{N,UAS BS}}{10}} \right) \\ SINR_{UAS UE}(\omega) &= C_{UAS UE} - 10 \cdot \log_{10} \left(10^{\frac{I_{UAS UE,agg}(\omega) + P_{N,UAS UE}}{10}} \right) \end{aligned} \quad (25)$$

Where:

- $P_{N,UAS BS}$ and $P_{N,UAS UE}$ is the noise floor of the UAS BS receiver and UAS UE receiver, respectively (in dBm).

A6.2 STUDY

Figure 47-Figure 52 gives the Cumulative Distribution Function (CDF) of $SINR_{DECT|_{worst}}(\omega)$, $SINR_{UAS BS}(\omega)$ and $SINR_{UAS UE}(\omega)$ for different configurations of bandwidth, transmit power and range.

A6.2.1 Rural scenario

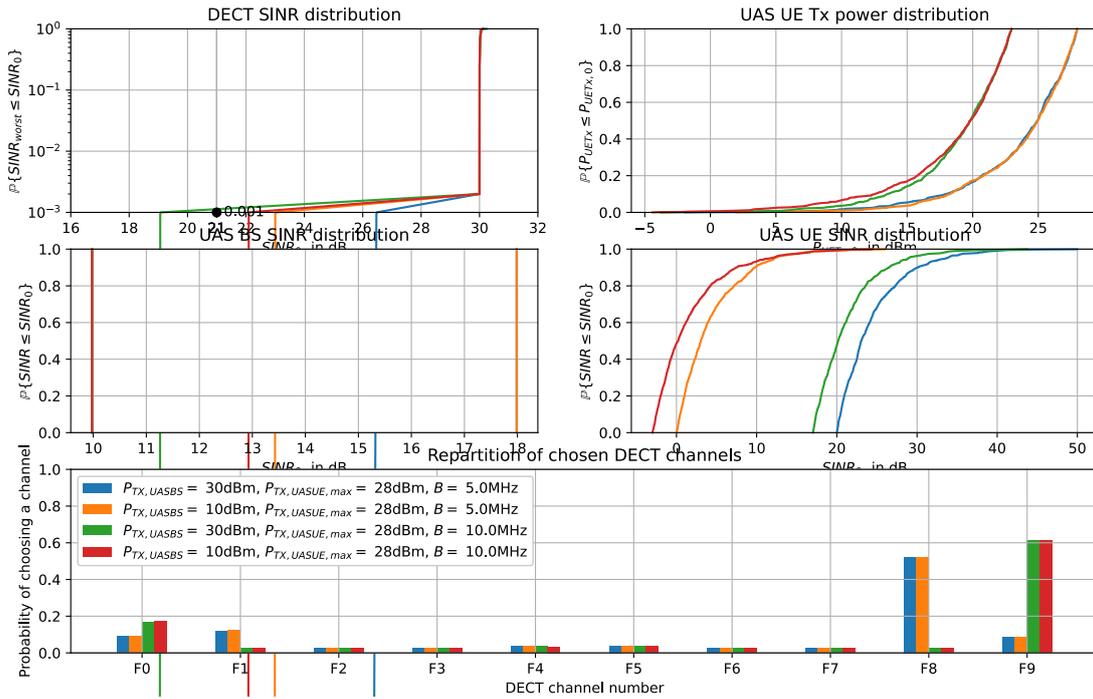


Figure 47: Rural scenario: interference to DECT in 1880-1900 MHz, range of 5650 m

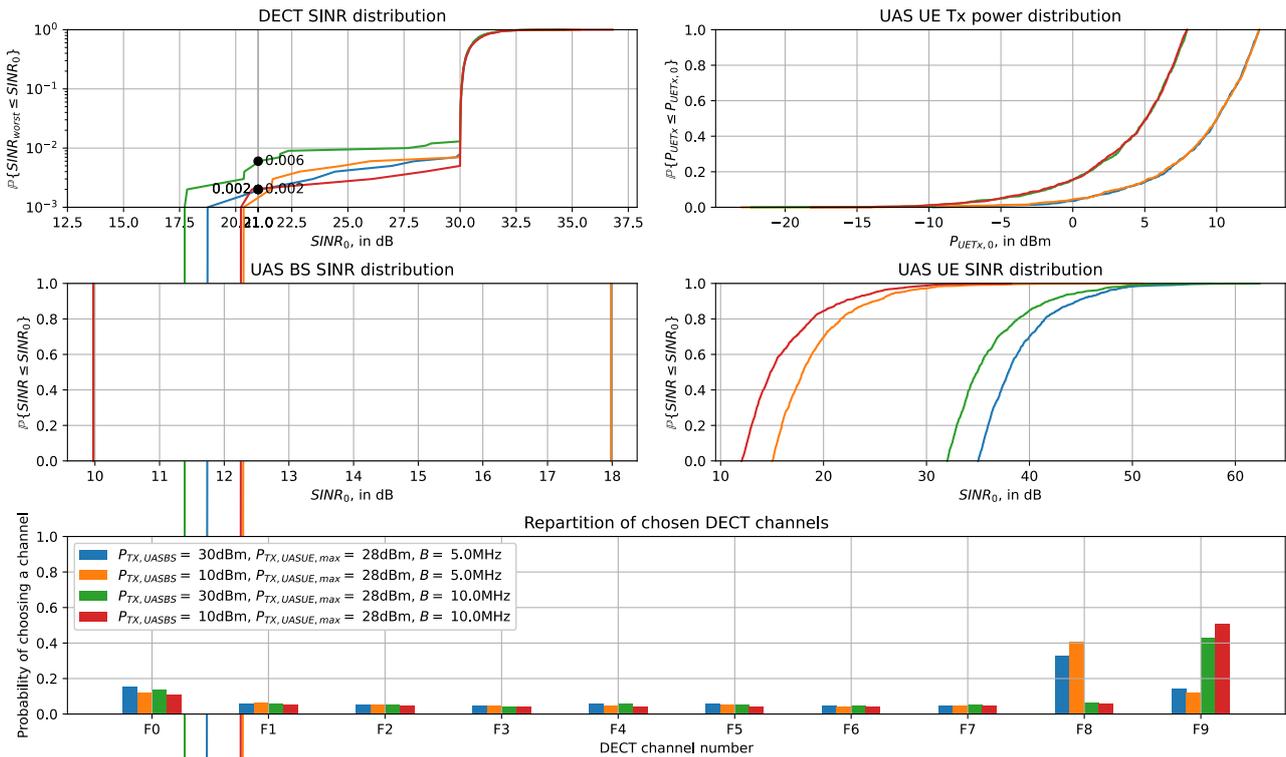


Figure 48: Rural scenario: interference to DECT in 1880-1900 MHz, range of 1000 m

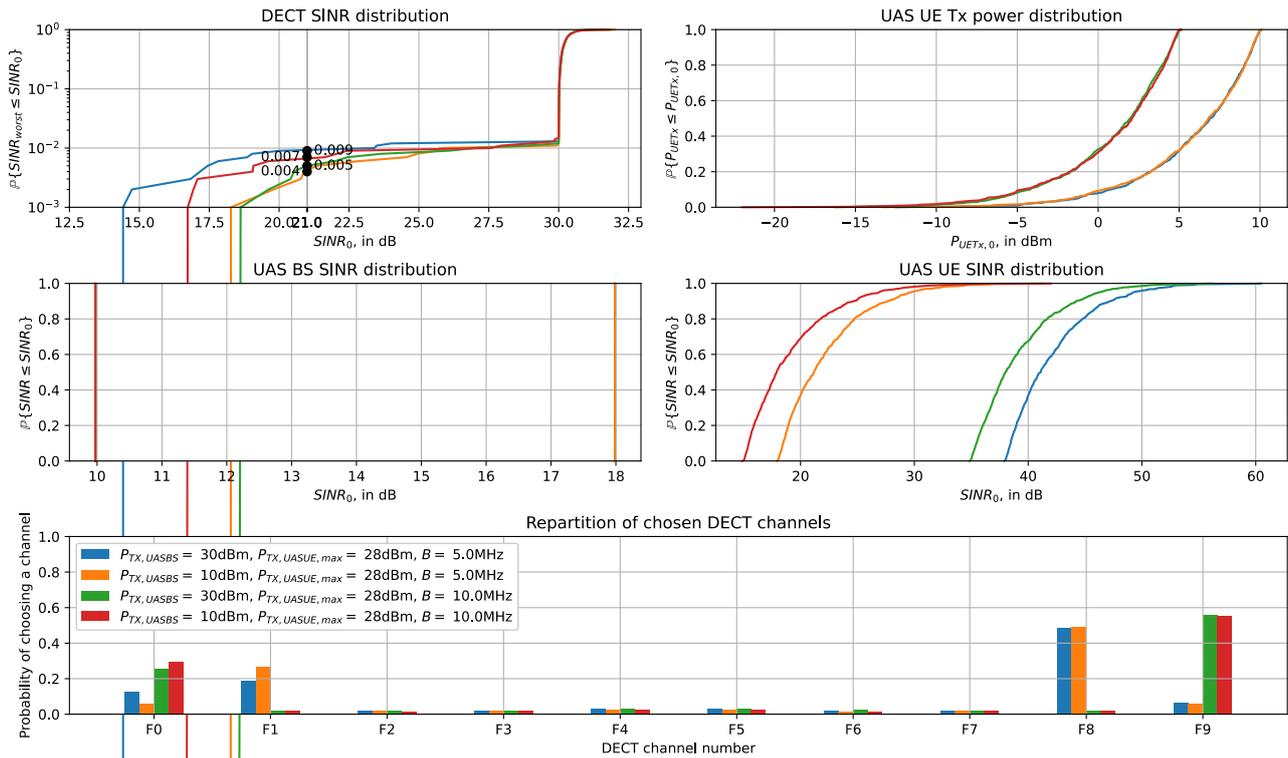


Figure 49: Rural scenario: interference to DECT in 1880-1900 MHz, range of 500 m

A6.2.2 Urban scenario

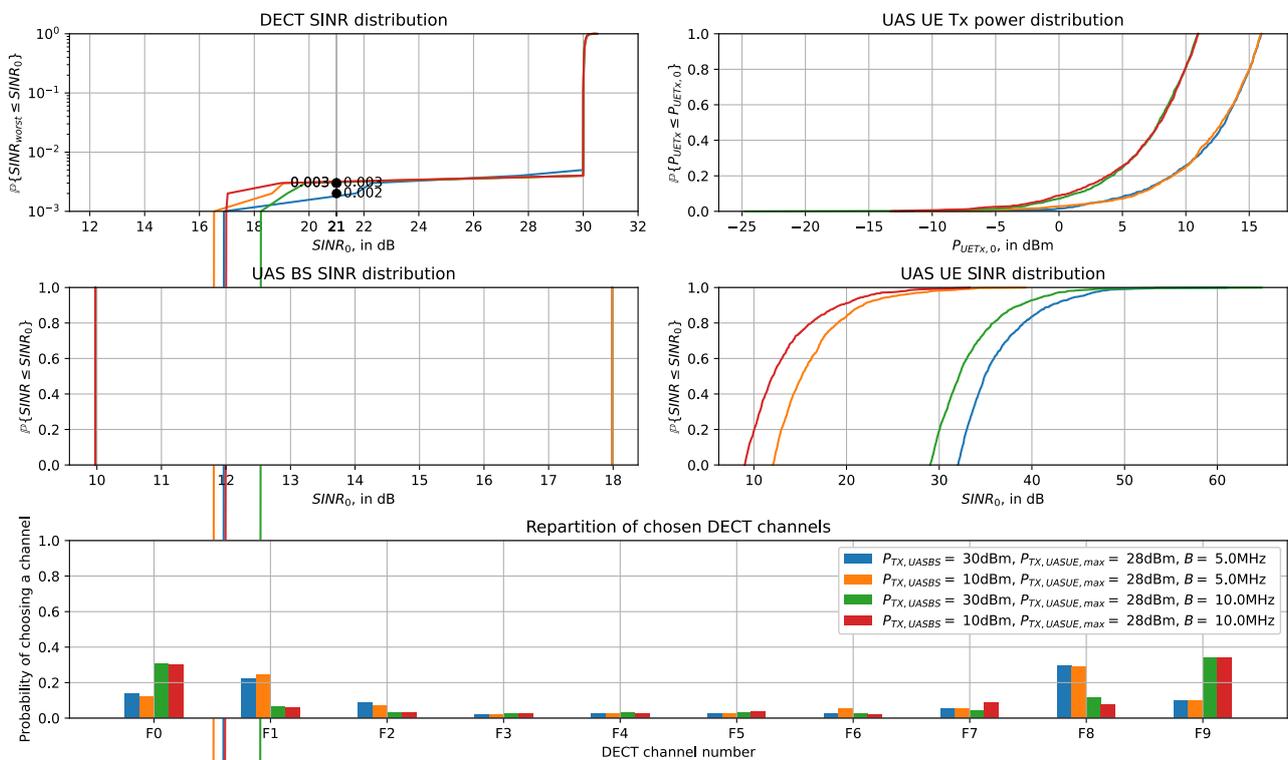


Figure 50: Urban scenario: interference to DECT in 1880-1900 MHz, range of 1000 m

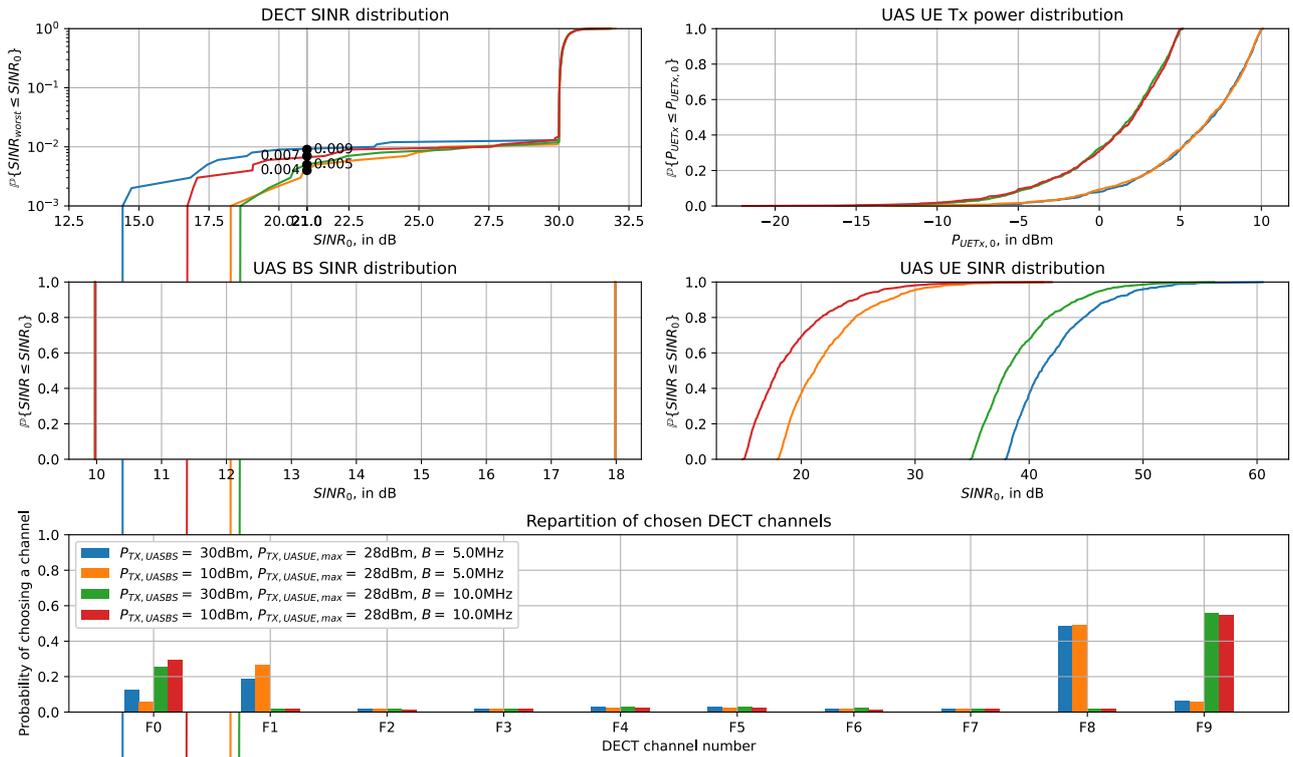


Figure 51: Urban scenario: interference to DECT in 1880-1900 MHz, range of 500 m

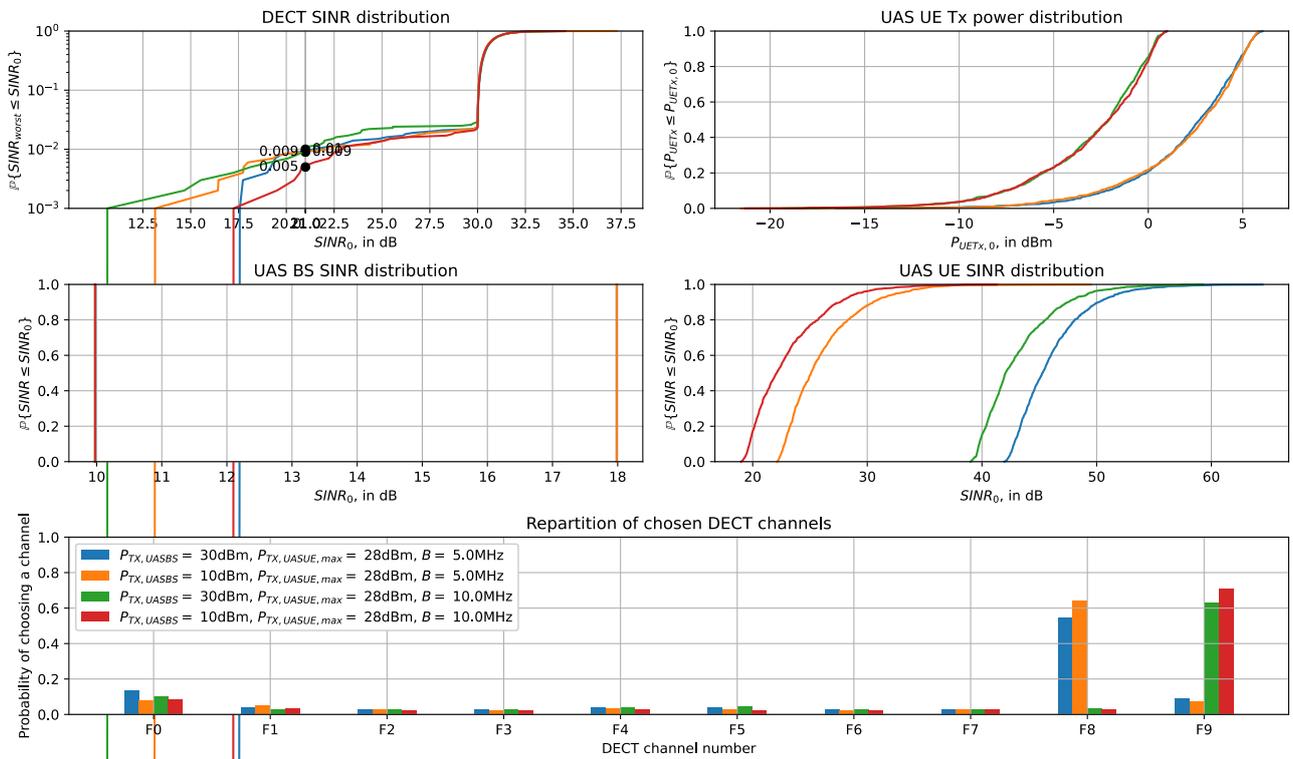


Figure 52: Urban scenario: interference to DECT in 1880-1900 MHz, range of 300 m

A6.3 SUMMARY

A6.3.1 DECT interfered by UAS

Considering an SINR protection criterion of 21 dB for DECT receivers, Table 88 and Table 89 summarise the results of the study. Results are given as the probability of interference of the DECT device receiving the highest level of interference.

The probability of interference of the worst interfered DECT device is comprised between 0.1% and 2.3%. In all scenarios, a closer look at the simulation outputs suggest that all cases DECT interference is due to interference with other DECT devices, ie the probability of interference will be even lower if there is not a high density of DECT device in operation. This self interference is certainly worsen by the fact that the presence of the UAS channel at the center of the DECT band tends to push the DECT devices in channels at the edges of the DECT band. Even when DECT devices chose channels that are in-band with the UAS channel, they tend to chose time slots that avoird interference from UAS BS or UE, whichever is closer. In these cases, less range for the UAS means less opportunities for the in-band DECT devices to avoid interference, which explains why interference probability is higher when the UAS range is reduced.

Table 88: Summary of UAS 1890 MHz interference probability to DECT in 1880-1900 MHz

Environment	Range (m)	Bandwidth (MHz)	UAS BS Tx power (dBm)	Max UAS UE Tx power (dBm)	Probability for the worst impacted DECT device to be interfered (%)
Rural	5650	5	30	28	0.1
			10		0.1
		10	30		0.2
			10		0.1
	1000	5	30		0.2
			10		0.2
		10	30		0.6
			10		0.3
	500	5	30		1.3
			10		1.2
		10	30		2.3
			10		1.2
Urban	1000	5	30	0.2	
			10	0.4	
		10	30	0.4	
			10	0.4	
	300	5	30	1	
			10	0.5	
		10	30	0.6	
			10	0.7	
	250	5	30	1	

Environment	Range (m)	Bandwidth (MHz)	UAS BS Tx power (dBm)	Max UAS UE Tx power (dBm)	Probability for the worst impacted DECT device to be interfered (%)
			10		1
		10	30		1.1
			10		0.6

A6.3.2 UAS interfered by DECT

Considering an SINR protection criterion of:

- 16 dB for UAS GS operating at 5 MHz;
- 8 dB for UAS GS operating at 10 MHz;
- -2 dB for UAS UE operating at 5 MHz
- -6 dB for UAS UE operating at 10 MHz

The simulations shows no interference from DECT to UAS GS and UAS UE. This is thanks to DECT DCS allowing DECT devices to select channels and time slots that does not interfere with nearby UAS GS and UE, resulting in negligible SINR degradation of the latters.

Table 89: Summary of interference probability of DECT in 1880-1900 MHz to UAS at 1890 MHz

Environment	Range (m)	BW (MHz)	UAS BS Tx power (dBm)	UAS UE max Tx power (dBm)	Probability of DECT devices interfering UAS BS (%)	Probability of DECT devices interfering UAS UE (%)
rural	5650	5	30	28	0	0
			10		0	0
		10	30		0	0
			10		0	0
	1000	5	30		0	0
			10		0	0
		10	30		0	0
			10		0	0
	500	5	30		0	0
			10		0	0
		10	30		0	0
			10		0	0
urban	1000	5	30	0	0	
			10	0	0	
		10	30	0	0	
			10	0	0	
	500	5	30	0	0	
			10	0	0	

Environment	Range (m)	BW (MHz)	UAS BS Tx power (dBm)	UAS UE max Tx power (dBm)	Probability of DECT devices interfering UAS BS (%)	Probability of DECT devices interfering UAS UE (%)
		10	30		0	0
			10		0	0
	300	5	30		0	0
			10		0	0
		10	30		0	0
			10		0	0

ANNEX 7: MONTE CARLO STUDY OF THE POSSIBLE IMPACT OF A TWO LTE-BASED UAS DEPLOYED IN CHANNELS CENTERED AT 1885 MHZ AND 1895 MHZ TO A DECT DEPLOYMENT IN 1880-1900 MHZ

A7.1 METHODOLOGY

A7.1.1 Space distribution of interferers and victims

The space distribution of interferers and victims is identical to Annex 6, taking into account that two UAS systems are deployed in the area, instead of one. The UAS GS of the second UAS deployment is put within a circle centred at the center of the simulation area, with radius 10 m.

A7.1.2 Hypothesis

Same as the Monte Carlo compatibility study between one UAS and DECT in Annex 6.

A7.1.3 Model of DECT received interference

The model of DECT received interference is similar as the one described in the Monte Carlo compatibility study between one UAS and DECT in Annex 6. The only differences are that $I_{UAS\ GS \rightarrow DECT\ RX}(\omega, i)$ and $I_{UAS\ UE \rightarrow DECT\ RX}(\omega, i)$ are aggregate interference of the two UAS GS and the two UAS UE, respectively:

$$\begin{aligned} I_{UAS\ GS \rightarrow DECT\ RX}(\omega, i) &= 10 \cdot \log_{10} \left(10^{\frac{I_{UAS\ GS1 \rightarrow DECT\ RX}(\omega, i)}{10}} + 10^{\frac{I_{UAS\ GS2 \rightarrow DECT\ RX}(\omega, i)}{10}} \right) \\ I_{UAS\ UE \rightarrow DECT\ RX}(\omega, i) &= 10 \cdot \log_{10} \left(10^{\frac{I_{UAS\ UE1 \rightarrow DECT\ RX}(\omega, i)}{10}} + 10^{\frac{I_{UAS\ UE2 \rightarrow DECT\ RX}(\omega, i)}{10}} \right) \end{aligned} \quad (26)$$

A7.1.4 Model of UAS received interference

Similar as the Monte Carlo compatibility study between one UAS and DECT in Annex 6. Note that interference of coming from one UAS to the other has not been taken into account. Hence, the interference for the two UAS GS and UAS UE are given as:

$$\begin{aligned} I_{UAS\ GS1,agg}(\omega) &= 10 \cdot \log_{10} \left(\sum_{i \in I_{UAS\ GS}} 10^{\frac{I_{DECT\ TX \rightarrow UAS\ GS1}(\omega, i)}{10}} \right) \\ I_{UAS\ UE1,agg}(\omega) &= 10 \cdot \log_{10} \left(\sum_{i \in I_{UAS\ UE}} 10^{\frac{I_{DECT\ TX \rightarrow UAS\ UE1}(\omega, i)}{10}} \right) \\ I_{UAS\ GS2,agg}(\omega) &= 10 \cdot \log_{10} \left(\sum_{i \in I_{UAS\ GS}} 10^{\frac{I_{DECT\ TX \rightarrow UAS\ GS2}(\omega, i)}{10}} \right) \\ I_{UAS\ UE2,agg}(\omega) &= 10 \cdot \log_{10} \left(\sum_{i \in I_{UAS\ UE}} 10^{\frac{I_{DECT\ TX \rightarrow UAS\ UE2}(\omega, i)}{10}} \right) \end{aligned} \quad (27)$$

A7.1.5 Model of received signals

Same as the Monte Carlo compatibility study between one UAS and DECT in Annex 6.

A7.1.6 Simulation of DECT DCS

Same as the Monte Carlo compatibility study between one UAS and DECT in Annex 6.

A7.1.7 Gathered statistics

A7.1.7.1 DECT interfered by UAS

Same as the Monte Carlo compatibility study between one UAS and DECT in Annex 6.

A7.2 UAS INTERFERED BY DECT

Similarly to the Monte Carlo compatibility study between one UAS and DECT in Annex 6, we have:

$$\begin{aligned}
 SINR_{UAS\ BS1}(\omega) &= C_{UAS\ BS1} - 10 \cdot \log_{10} \left(10^{\frac{I_{UAS\ GS1,agg}(\omega) + P_{N,UAS\ BS}}{10}} \right) \\
 SINR_{UAS\ UE1}(\omega) &= C_{UAS\ UE1} - 10 \cdot \log_{10} \left(10^{\frac{I_{UAS\ UE1,agg}(\omega) + P_{N,UAS\ UE}}{10}} \right) \\
 SINR_{UAS\ BS2}(\omega) &= C_{UAS\ BS2} - 10 \cdot \log_{10} \left(10^{\frac{I_{UAS\ GS2,agg}(\omega) + P_{N,UAS\ BS}}{10}} \right) \\
 SINR_{UAS\ UE2}(\omega) &= C_{UAS\ UE2} - 10 \cdot \log_{10} \left(10^{\frac{I_{UAS\ UE2,agg}(\omega) + P_{N,UAS\ UE}}{10}} \right)
 \end{aligned}
 \tag{28}$$

We gather the worst SINR between the two UAS:

$$SINR_{UAS\ BS|worst}(\omega) = \min\{SINR_{UAS\ BS1}(\omega), SINR_{UAS\ BS2}(\omega)\}
 \tag{29}$$

$$SINR_{UAS\ UE|worst}(\omega) = \min\{SINR_{UAS\ UE1}(\omega), SINR_{UAS\ UE2}(\omega)\}
 \tag{30}$$

A7.3 STUDY

A7.3.1 Rural scenario

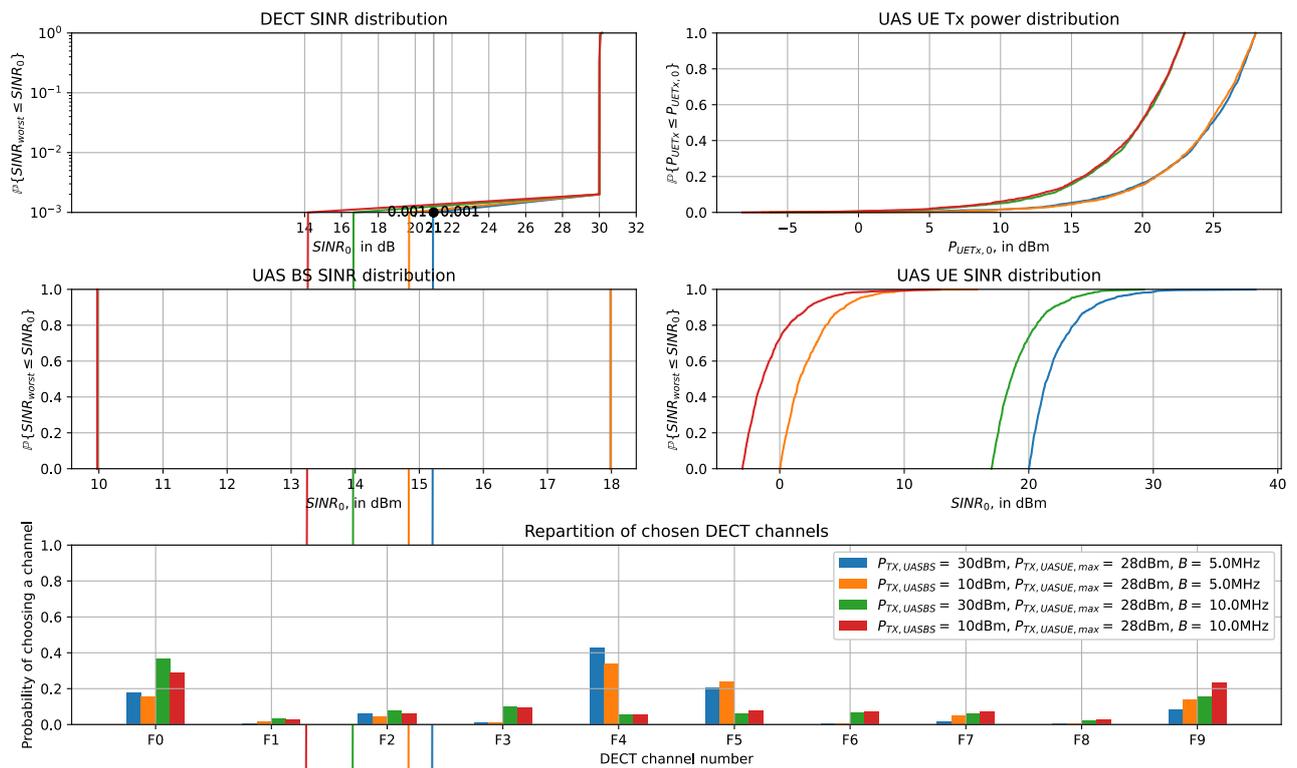


Figure 53: Rural scenario: interference to DECT in 1880-1900 MHz, range of 5650 m

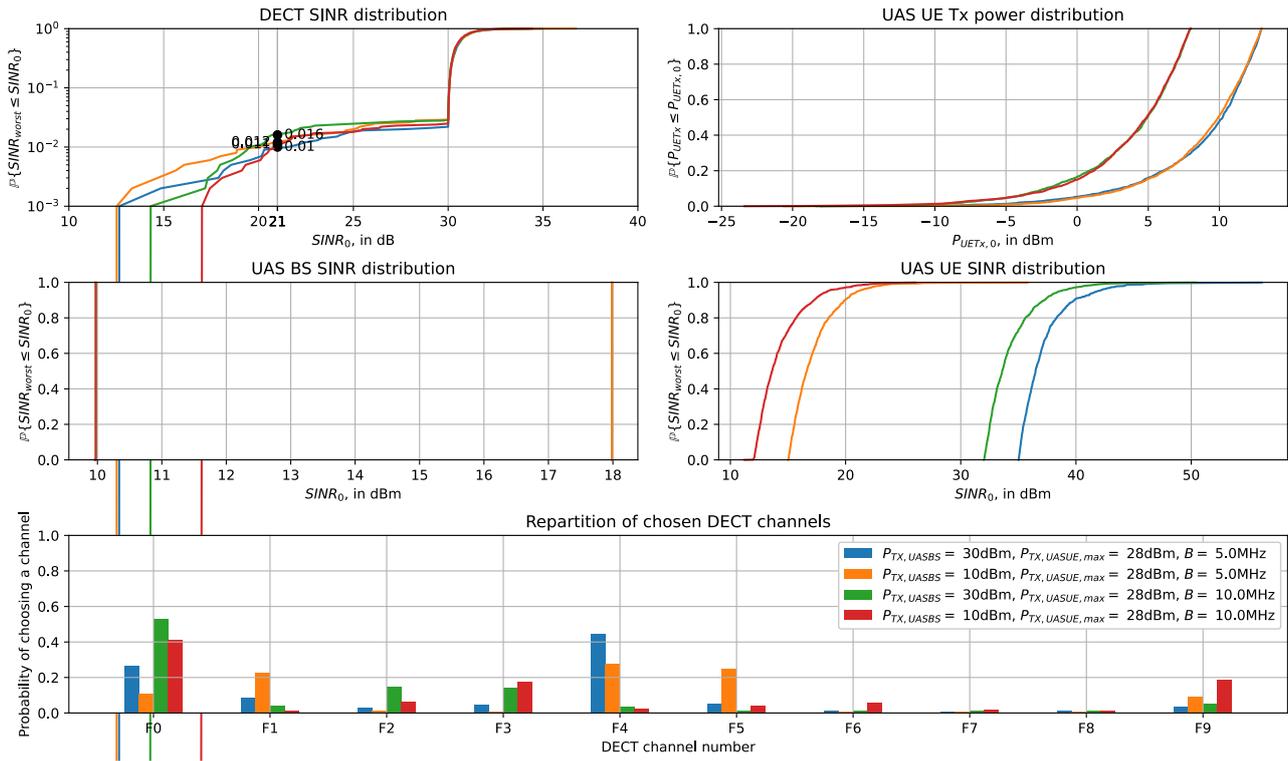


Figure 54: Rural scenario: interference to DECT in 1880-1900 MHz, range of 1000 m

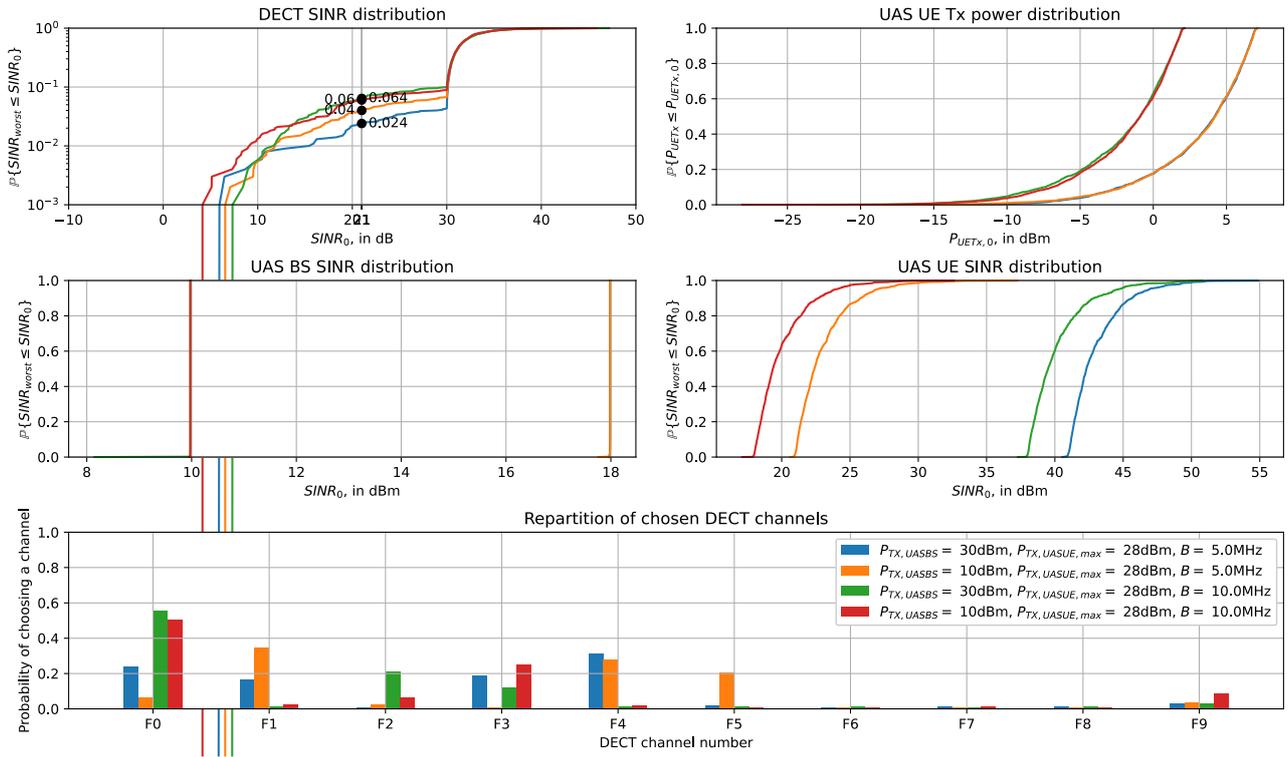


Figure 55: Rural scenario: interference to DECT in 1880-1900 MHz, range of 500 m

A7.3.2 Urban scenario

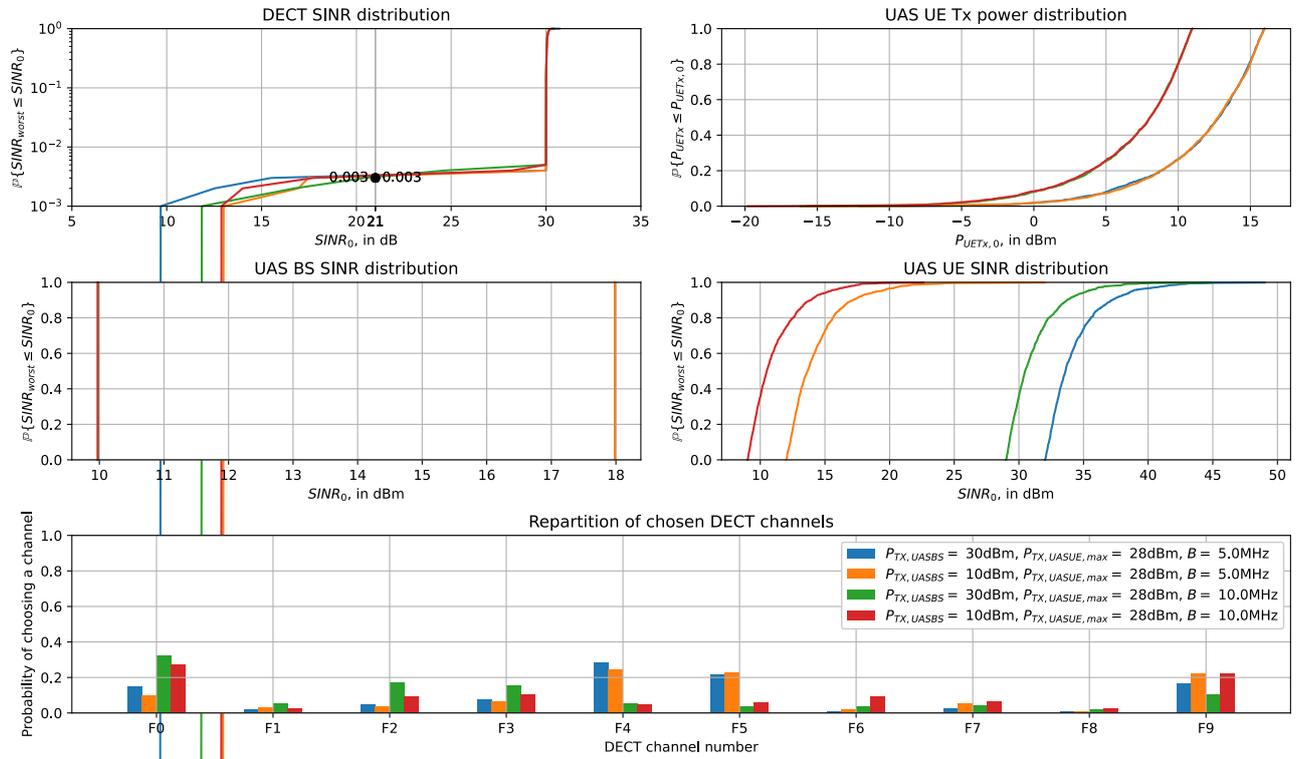


Figure 56: Urban scenario: interference to DECT in 1880-1900 MHz, range of 1000 m

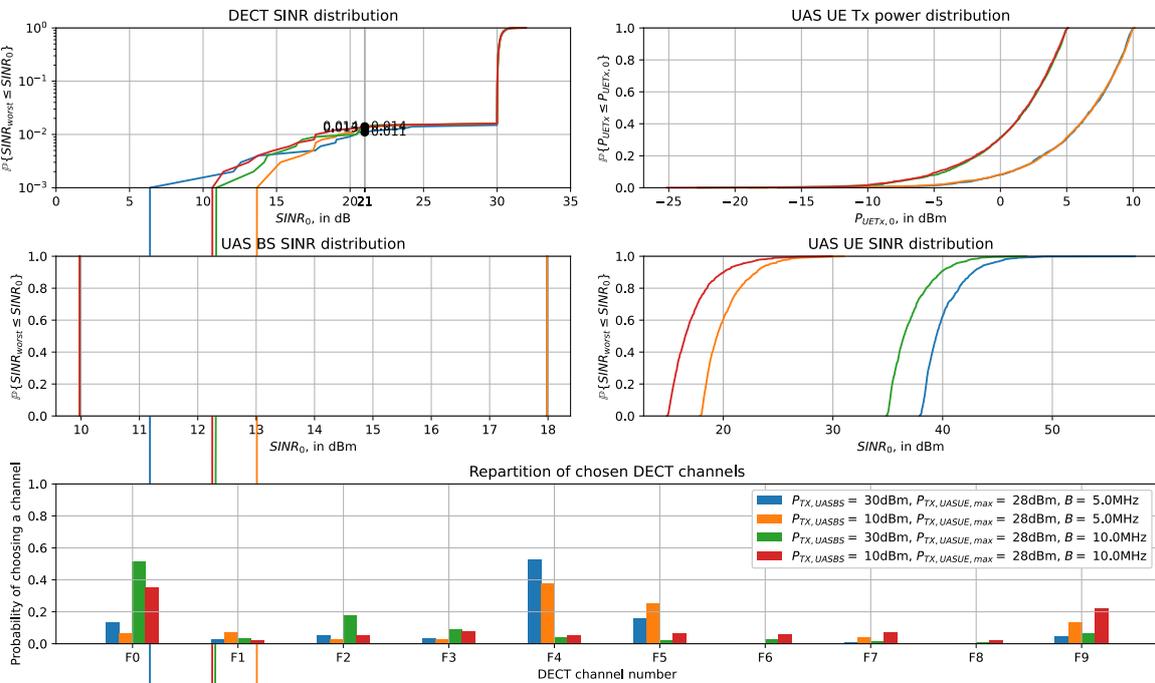


Figure 57: Urban scenario: interference to DECT in 1880-1900 MHz, range of 500 m

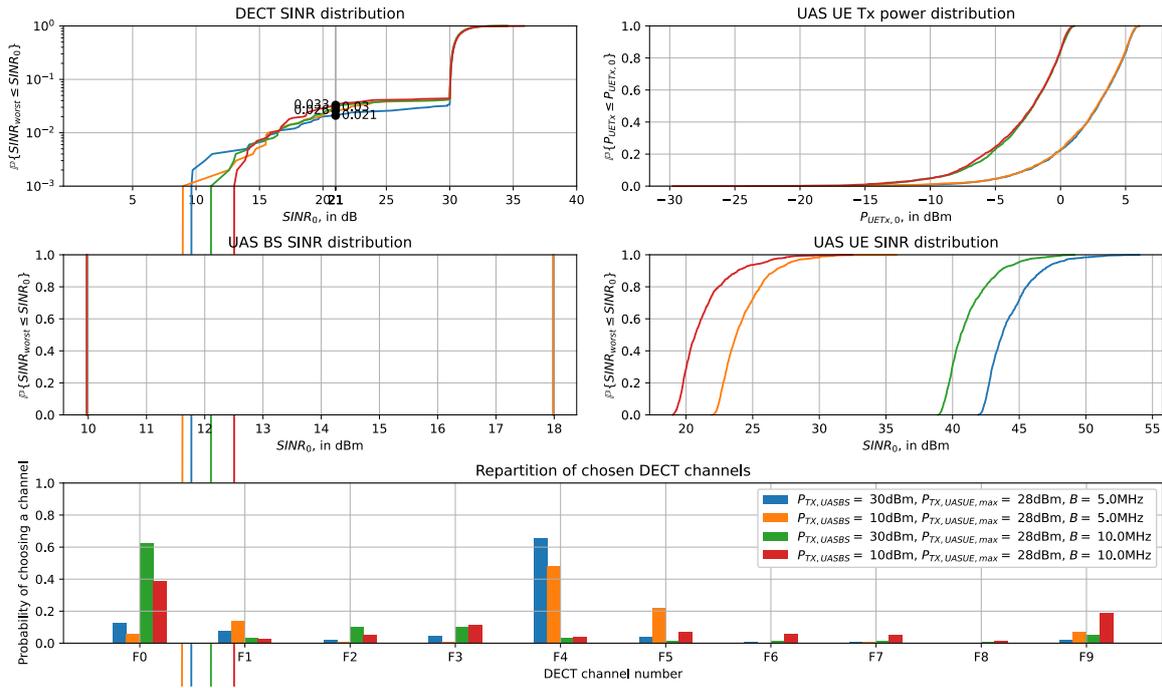


Figure 58: Urban scenario: interference to DECT in 1880-1900 MHz, range of 300 m

A7.4 SUMMARY

A7.4.1 DECT interfered by UAS

Considering an SINR protection criterion of 21 dB for DECT receivers, Table 90 and Table 91 summarise the results of the study. Results are given as the probability of interference of the DECT device receiving the highest level of interference.

The probability of interference of the worst interfered DECT device comprised between 0.2% and 6.5%. Similarly to the study with only one UAS, the DECT DCS mechanism allows to avoid direct interference from UAS for the DECT devices nearby UAS GS and UAS UE. As a result, the interference is mainly due to DECT self-interference. Note that this self interference is certainly worsen by the fact that UAS presence tends to occupy DECT channels in their vicinity. Also similar to the one UAS scenario is that less range for the UAS means less opportunities for the in-band DECT devices to avoid UAS interference, which explains why interference probability is higher when the UAS range is reduced.

Table 90: Summary of two UAS at 1885 MHz and 1895 MHz interference probability to DECT in 1880-1900 MHz

Environment	Range (m)	Bandwidth (MHz)	UAS BS Tx power (dBm)	Max UAS UE Tx power (dBm)	Probability for the worst impacted DECT device to be interfered (%)
Rural	5650	5	30	28	0.2
			10		0.2
		10	30		0.2
			10		0.2
	1000	5	30		1

Environment	Range (m)	Bandwidth (MHz)	UAS BS Tx power (dBm)	Max UAS UE Tx power (dBm)	Probability for the worst impacted DECT device to be interfered (%)
		10	10		1.3
			30		1.7
		10	10		1.1
		30	10		1.1
	500	5	30		2.5
			10		4
		10	30		6.5
			10		6
Urban	1000	5	30	0.4	
			10	0.4	
		10	30	0.4	
			10	0.4	
	300	5	30	1.2	
			10	1.4	
		10	30	1.5	
			10	1.4	
	250	5	30	2.2	
			10	2.7	
		10	30	3	
			10	3.3	

A7.4.2 UAS interfered by DECT

Considering an SINR protection criterion of:

- 16 dB for UAS GS operating at 5 MHz;
- 8 dB for UAS GS operating at 10 MHz;
- -2 dB for UAS UE operating at 5 MHz;
- -6 dB for UAS UE operating at 10 MHz-

The simulations shows no interference from DECT to UAS GS and UAS UE. This is thanks to DECT DCS allowing DECT devices to select channels and time slots that does not interfere with nearby UAS GS and UE, resulting in negligible SINR degradation of the latters.

Table 91: Summary of interference probability of DECT in 1880-1900 MHz to two UAS at 1885 MHz and 1895 MHz

Environment	Range (m)	BW(MHz)	UAS BS Tx power (dBm)	UAS UE max Tx power (dBm)	Probability of DECT devices interfering UAS BS (%)	Probability of DECT devices interfering UAS UE (%)
rural	5650	5	30	28	0	0
			10		0	0
		10	30		0	0
			10		0	0
	1000	5	30		0	0
			10		0	0
		10	30		0	0
			10		0	0
	500	5	30		0	0
			10		0	0
		10	30		0	0
			10		0	0
urban	1000	5	30	0	0	
			10	0	0	
		10	30	0	0	
			10	0	0	
	500	5	30	0	0	
			10	0	0	
		10	30	0	0	
			10	0	0	
	300	5	30	0	0	
			10	0	0	
		10	30	0	0	
			10	0	0	

ANNEX 8: MONTE CARLO STUDY OF THE POSSIBLE IMPACT OF AN MFCN BS DEPLOYMENT IN 1805-1880 MHZ TO AN LTE-BASED UAS DEPLOYED AT 1885 MHZ

A8.1 METHODOLOGY

A8.1.1 Space distribution of interferers and victims

Same as Annex 6.

A8.2 HYPOTHESIS

The following hypothesis are considered:

- All MFCN BS transmit on the same channel spanning 20 MHz and centered at 1870 MHz.
- MFCN BS have an average activity factor of 50% (see Report ITU-R M.2292).
- The UAS transmits and receives on a channel spanning 5 or 10 MHz, and centered at 1885 MHz.
- The UAS uses TDD, so the interference either impacts the UAS BS or the UAS UE, but not both at the same time.
- Path loss between UAS GS and MFCN BS is computed using the Extended Hata propagation model.
- Path loss between UAS UE and MFCN BS is computed using Extended Hata when the UAS UE altitude is in [1.5; 10[m, or using Free Space Path Loss (FSPL) when the altitude is above 10 m.
- Path loss between UAS GS and UAS UE (used for UE transmit power control – TPC) is computed using the drone propagation model described in Annex 6.
- The UAS GS Blocking Edge Mask (BEM) is based on 3GPP 36.104:
 - Table 7.2.1-2 (reference sensitivity levels),
 - Table 7.5.1-6 (adjacent channel selectivity – ACS),
 - Table 7.6.1.1-c and 7.6.1.1-2 (CW blocking).
- The UAS UE BEM is based on 3GPP 36.101:
 - Table 7.5.1-1 (ACS),
 - Table 7.6.2.1-1 (out-of-band blocking),
 - Table 7.2.3.1-1 (narrowband blocking).
- The MFCN BS SEM is based on 3GPP 37.104:
 - Sections 6.6.2.1 and 6.6.2.2 (general requirements),
 - Table 6.6.1.1.2 (spurious emissions),
 - Section 6.6.4.1 (adjacent channel leakage ratio – ACLR).

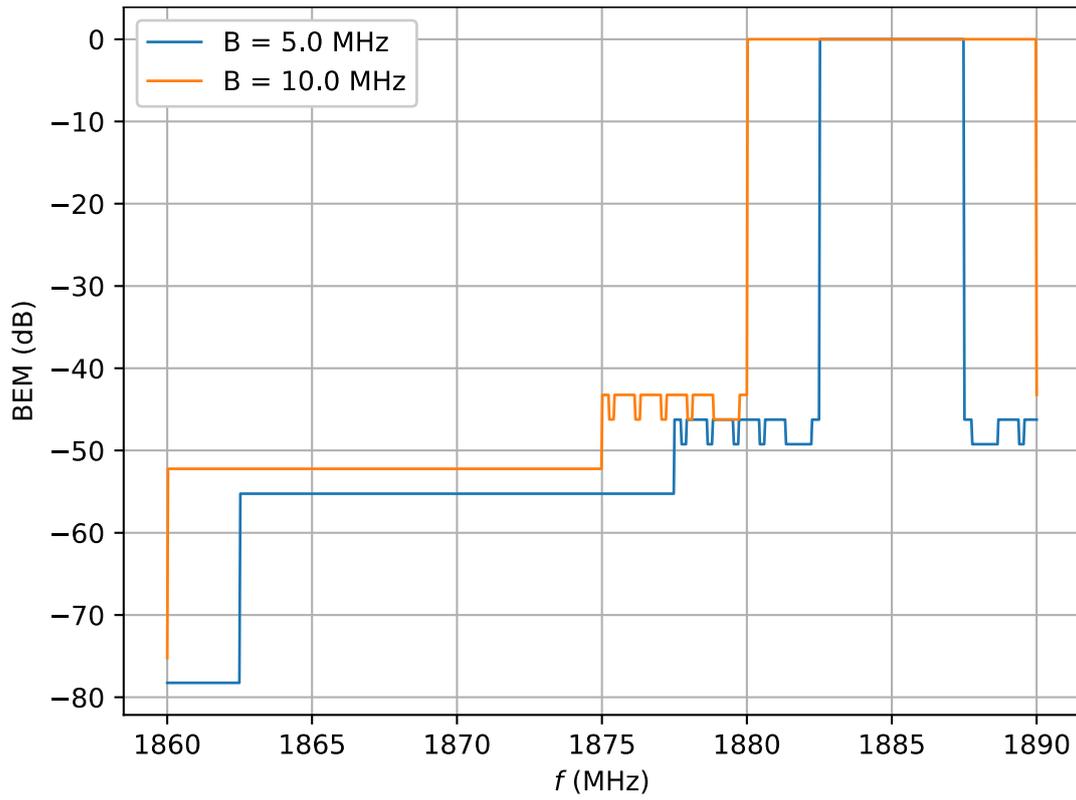


Figure 59: UAS GS BEM, based on 3GPP 36.104

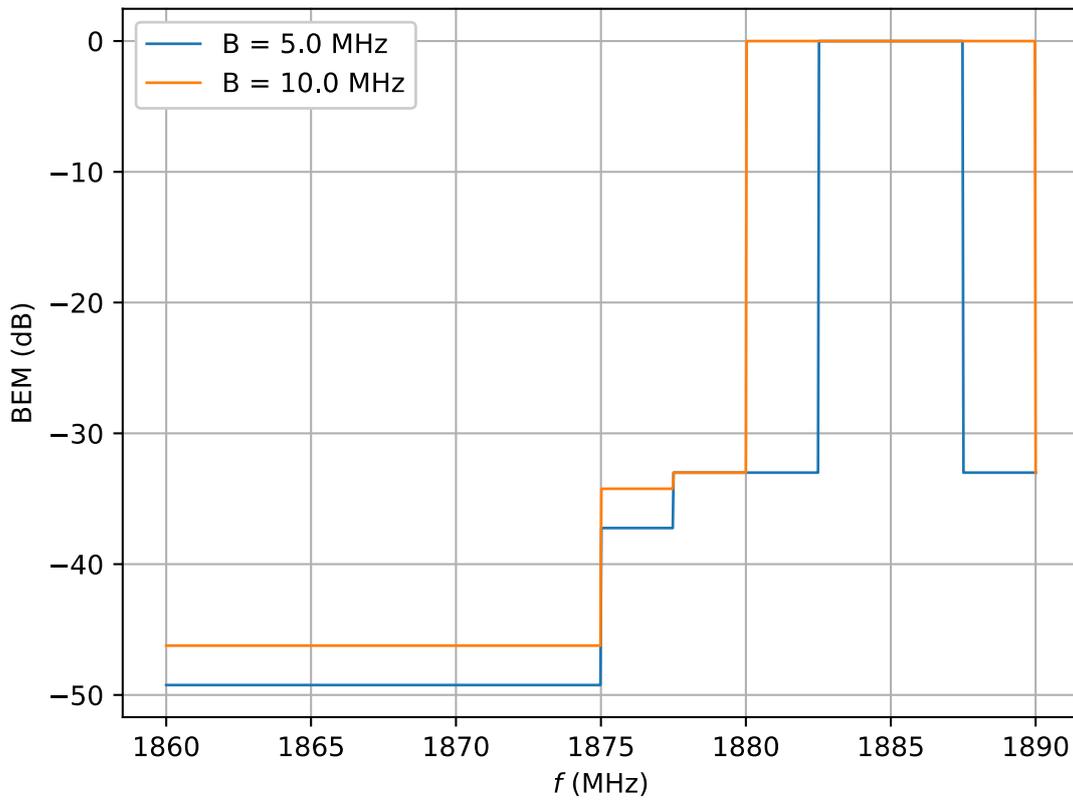


Figure 60: UAS UE BEM based on 3GPP 36.101 [17]

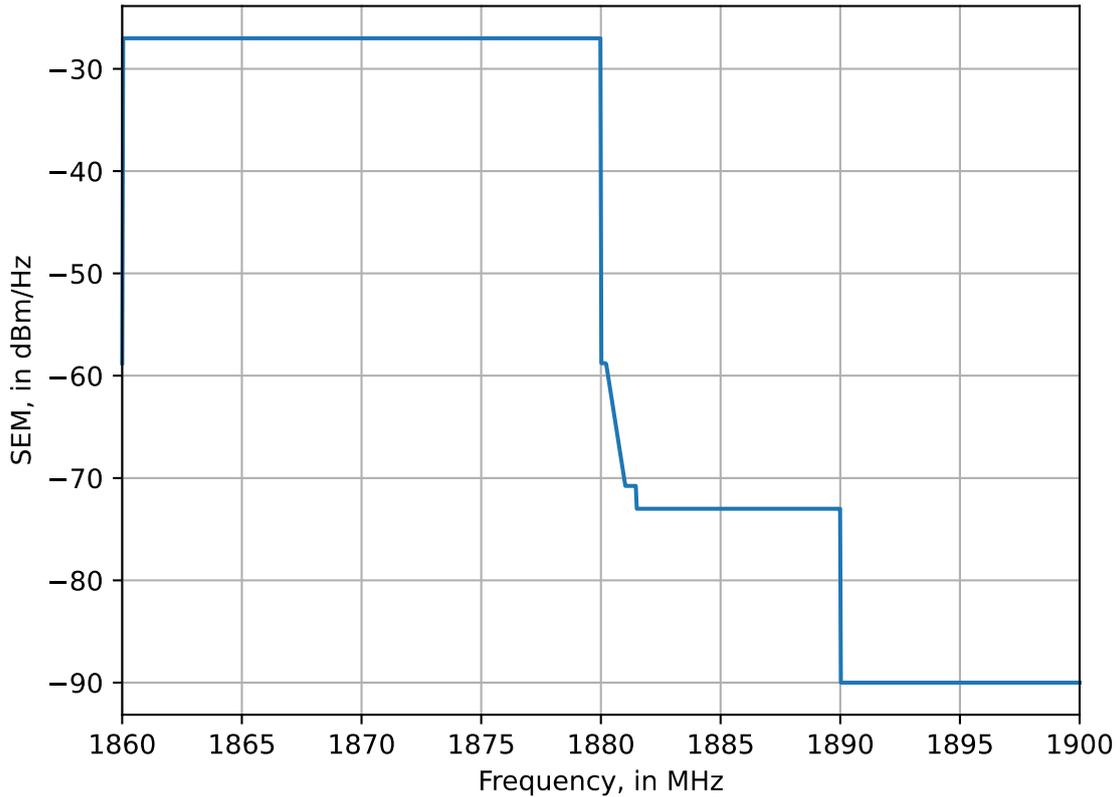


Figure 61: MFCN BS SEM based on 3GPP 37.104

A8.3 MODEL OF UAS RECEIVED INTERFERENCE AND SIGNAL

A8.3.1 UAS GS received interference

For each Monte Carlo run ω , the interference power as experienced from the i th MFCN BS from the UAS GS is given as:

$$I_{MFCN\ BS \rightarrow UAS\ GS}(\omega, i) = P_f + G_{MFCN\ BS, i}(\vec{p}_{UAS\ GS}(i)) + G_{UAS\ GS}(\omega, \vec{p}_{MFCN\ BS}(i)) - FL_{MFCN\ BS} - PL(\vec{p}_{MFCN\ BS}(i), \vec{p}_{UAS\ GS}(\omega)) \quad (31)$$

If the i -th MFCN BS is active, otherwise: $I_{MFCN\ BS \rightarrow UAS\ GS}(\omega, i) = -\infty$ [dBm]

Where:

- $P_f = 10 \cdot \log_{10}(\int_{-\infty}^{+\infty} SEM_{MFCN\ BS}(f) \cdot BEM_{UAS\ GS}(f) df)$ is the fraction of the interferer power falling into the receiver's band (in dBm);
- $SEM_{MFCN\ BS}(f)$ is the SEM of the MFCN BS (in mW/Hz);
- $BEM_{UAS\ GS}(f)$ is the BEM of the UAS GS;
- $G_{MFCN\ BS, i}(\vec{p})$ is the i th MFCN BS antenna gain toward the point in space described by vector \vec{p} (in dBi);
- $G_{UAS\ GS}(\omega, \vec{p})$ is the gain of the UAS GS antenna toward the point in space described by vector \vec{p} (in dBi);
- $FL_{MFCN\ BS}$ is the feeder loss of the MFCN BS (in dB);
- $PL(\vec{p}_1, \vec{p}_2)$ is the path loss between the two points in space described by vectors \vec{p}_1 and \vec{p}_2 (dB);
- $\vec{p}_{MFCN\ BS}(i)$ vector describing the position in space of the i th MFCN BS;
- $\vec{p}_{UAS\ GS}(\omega)$ vector describing the position in space of the UAS GS, at Monte Carlo run ω .

The UAS GS receives the aggregate of interference coming from all MFCN BS in the simulation area. Hence, the total interference at the UAS GS receiver is given by:

$$I_{MFCN\ BS \rightarrow UAS\ GS}(\omega) = 10 \cdot \log_{10} \left(\sum_i 10^{\frac{I_{MFCN\ BS \rightarrow UAS\ GS}(\omega, i)}{10}} \right) \quad (32)$$

A8.3.2 UAS UE received interference

$$= P_f + G_{MFCN\ BS, i} \left(\overrightarrow{p_{UAS\ UE}(\omega)} \right) + G_{UAS\ UE} - FL_{MFCN\ BS} - PL \left(\overrightarrow{p_{UAS\ UE}(\omega)}, \overrightarrow{p_{MFCN\ BS}(l)} \right) \quad (33)$$

Using the same notation as before, and where:

- $\overrightarrow{p_{UAS\ UE}(\omega)}$ vector describing the position in space of the UAS UE, at Monte Carlo run ω .

The UAS UE receives the aggregate of interference coming from all MFCN BS in the simulation area. Hence, the total interference at the UAS UE receiver is given by:

$$I_{MFCN\ BS \rightarrow UAS\ UE}(\omega) = 10 \cdot \log_{10} \left(\sum_i 10^{\frac{I_{MFCN\ BS \rightarrow UAS\ UE}(\omega, i)}{10}} \right) \quad (34)$$

A8.3.3 UAS GS received signal

$$C_{UAS\ GS}(\omega) = P_{UAS\ UE}(\omega) + G_{UAS\ UE} + G_{UAS\ GS} \left(\overrightarrow{p_{UAS\ UE}(\omega)} \right) - PL \left(\overrightarrow{p_{UAS\ UE}(\omega)}, \overrightarrow{p_{UAS\ GS}(\omega)} \right) \quad (35)$$

Using the same notation as before, and where:

- $P_{UAS\ UE}(\omega)$ is the power transmitter by the UAS UE, which depends on transmit power control (TPC).
 - The power control algorithm is taken from Recommendation ITU-R M.2101-0, taking into account that all Ressource Blocks are allocated to the same device.
 - The power control formula is given then by $P_{UAS\ UE}(\omega) = \max \left\{ \min \left\{ P_{UAS\ UE, max}, P_{UAS\ GS, target} + \alpha \cdot PL \left(\overrightarrow{p_{UAS\ UE}(\omega)}, \overrightarrow{p_{UAS\ GS}(\omega)} \right) \right\}, -40 \right\}$
 - $\alpha = 1$
 - $P_{UAS\ GS, target}$ is the target received power at the UAS GS, computed based on the target SNR given in Annex 3, Table 54, plus 3 dB of margin ($P_{UAS\ GS, target} = -80$ dBm for 5 MHz of bandwidth, -85 dBm of 10 MHz of bandwidth).

A8.3.4 UAS UE received signal

$$C_{UAS\ GS}(\omega) = P_{UAS\ BS} + G_{UAS\ UE} + G_{UAS\ GS} \left(\overrightarrow{p_{UAS\ UE}(\omega)} \right) - PL \left(\overrightarrow{p_{UAS\ BS}(\omega)}, \overrightarrow{p_{UAS\ UE}(\omega)} \right) \quad (36)$$

Using the same notation as before, and where $P_{UAS\ BS}$ is the power transmitter by the UAS GS.

A8.4 GATHERED STATISTICS

In order to assess the probability for an UAS GS or UE to be interfered with a deployment of MFCN BS, we compute the SINR ratio of UAS UE and GS at each Monte Carlo run:

$$INR_{UAS\ GS}(\omega) = C_{UAS\ GS}(\omega) - 10 \cdot \log_{10} \left(10^{\frac{I_{MFCN\ BS \rightarrow UAS\ GS}(\omega) + P_{N, UAS\ GS}}{10}} \right) \quad (37)$$

$$SINR_{UAS\ UE}(\omega) = C_{UAS\ UE}(\omega) - 10 \cdot \log_{10} \left(10^{\frac{I_{MFCN\ BS \rightarrow UAS\ UE}(\omega) + P_{N, UAS\ UE}}{10}} \right)$$

Where:

- $P_{N,UAS\ GS}$ is the noise floor of the UAS GS.
- $P_{N,UAS\ UE}$ is the noise floor of the UAS UE.

The SNR is also computed in order to better assess the degradation due to MFCN interference:

Because TPC is involved, and in order to better understand the results when the UAS UE is the interferer, the values of $P_{UAS\ UE}(\omega)$ and $P_f(\omega)$ are gathered.

A8.5 STUDY

Figure 62 gives the Cumulative Distribution Function (CDF) of $SINR_{UAS\ GS}(\omega)$ and $SINR_{UAS\ UE}(\omega)$ for different configurations of bandwidth, transmit power and range.

A8.5.1 Rural scenario

A8.5.1.1 Interference to UAS GS

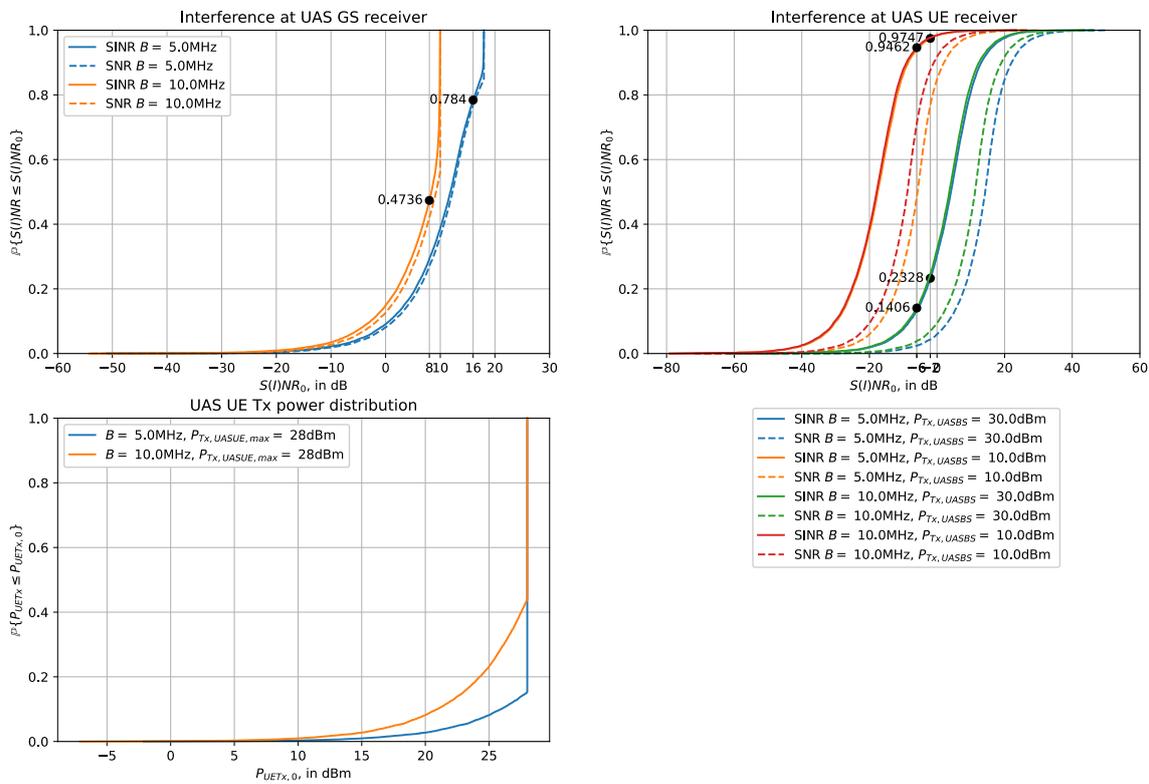


Figure 62: Rural scenario: interference from MFCN BS to UAS in 1805-1880 MHz, range of 5650 m

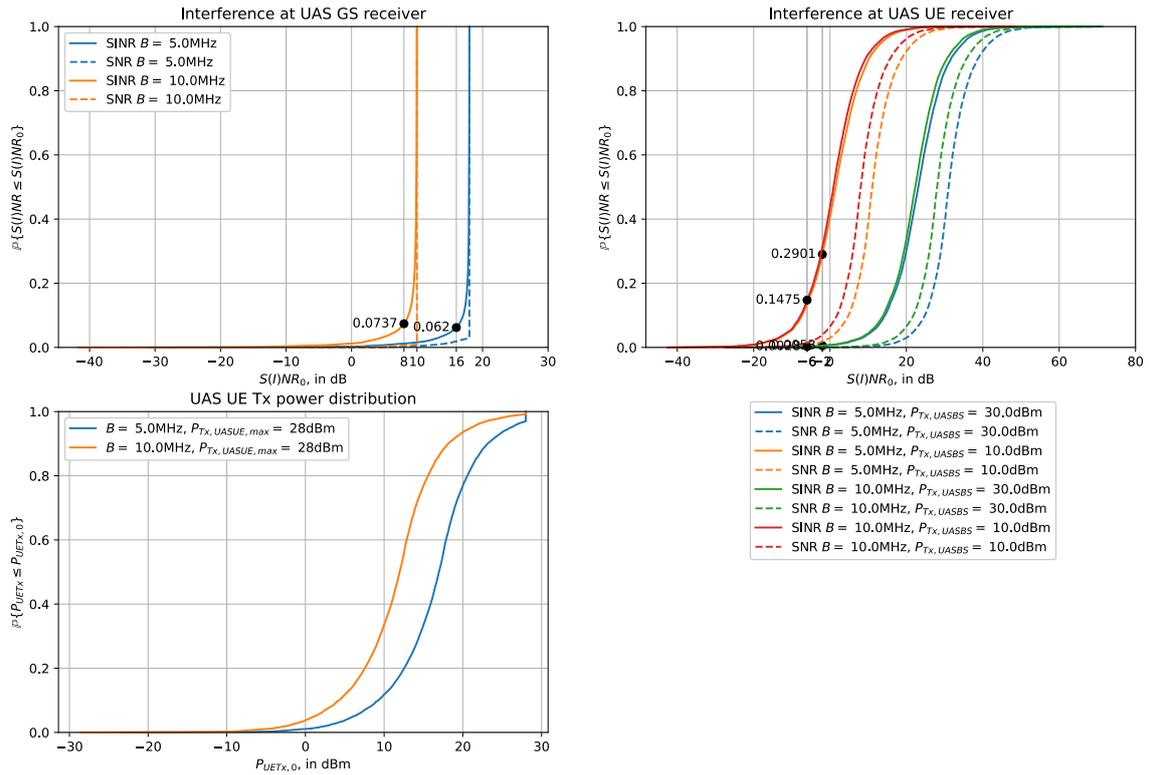


Figure 63: Rural scenario: interference from MFCN BS to UAS in 1805-1880 MHz, range of 1000 m

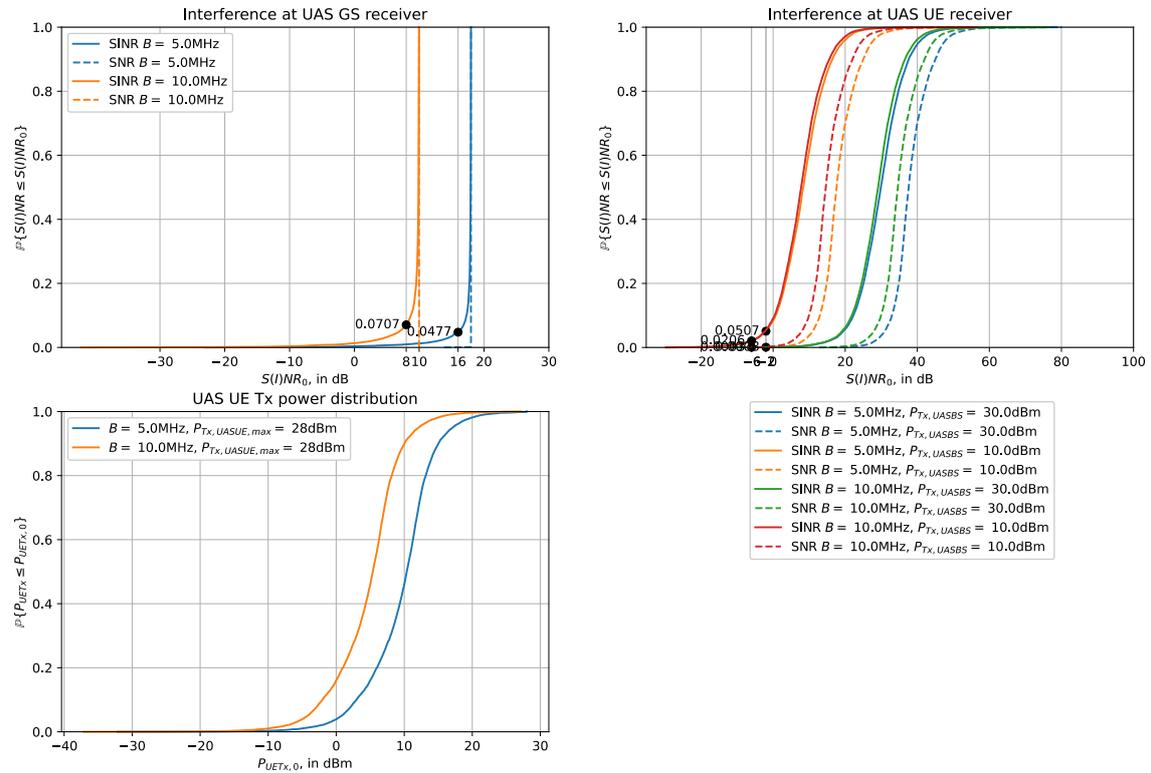


Figure 64: Rural scenario: interference from MFCN BS to UAS in 1805-1880 MHz, range of 500 m

A8.6 URBAN SCENARIO

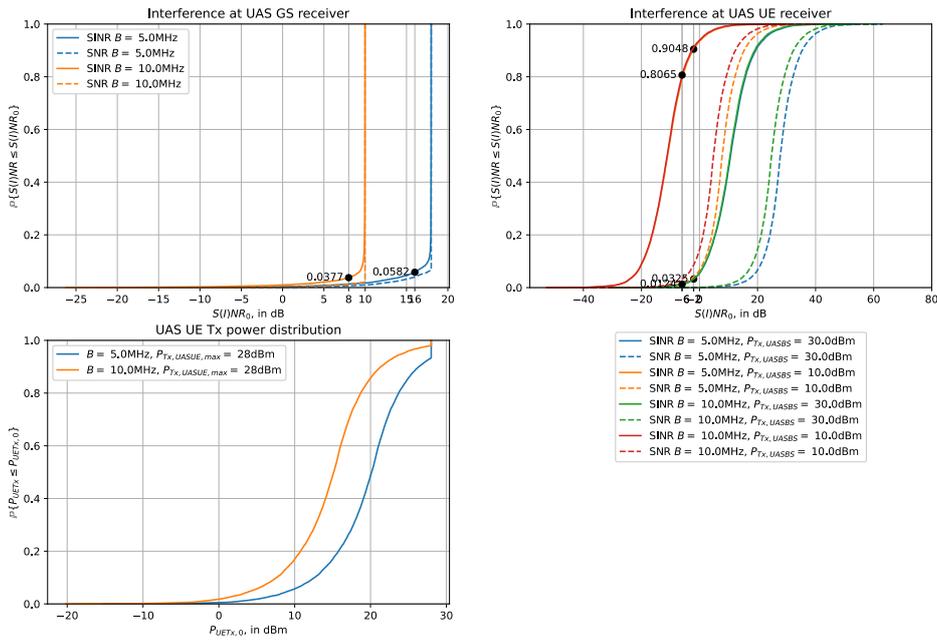


Figure 65: Urban scenario: interference from MFCN BS to UAS in 1805-1880 MHz, range of 1000 m

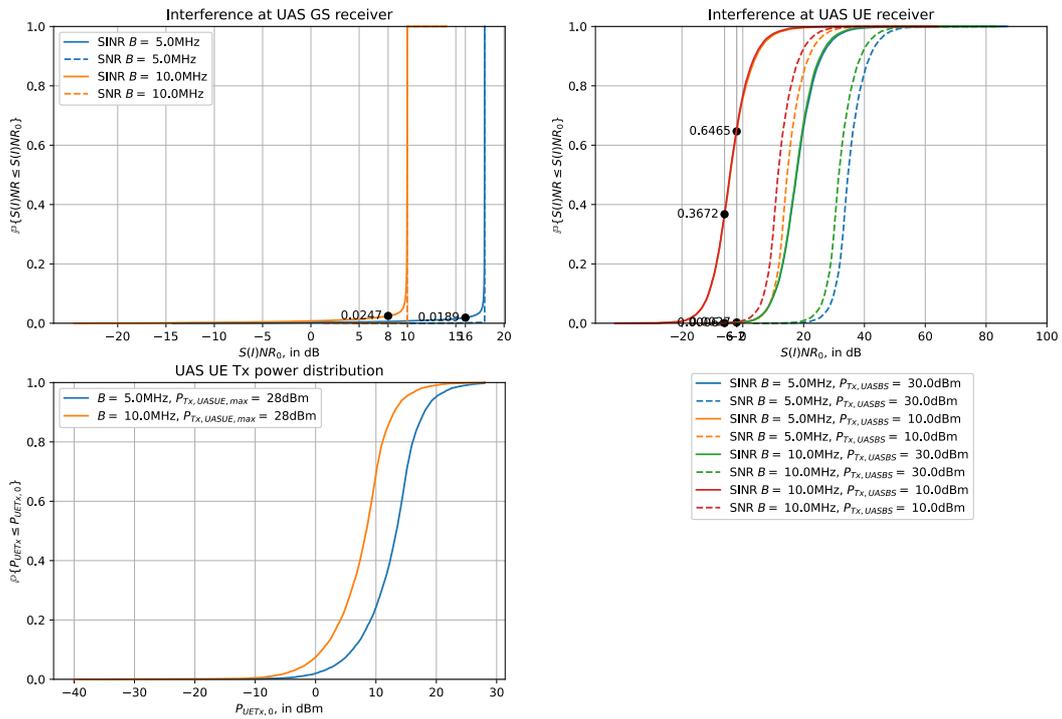


Figure 66: Urban scenario: interference from MFCN BS to UAS in 1805-1880 MHz, range of 500 m

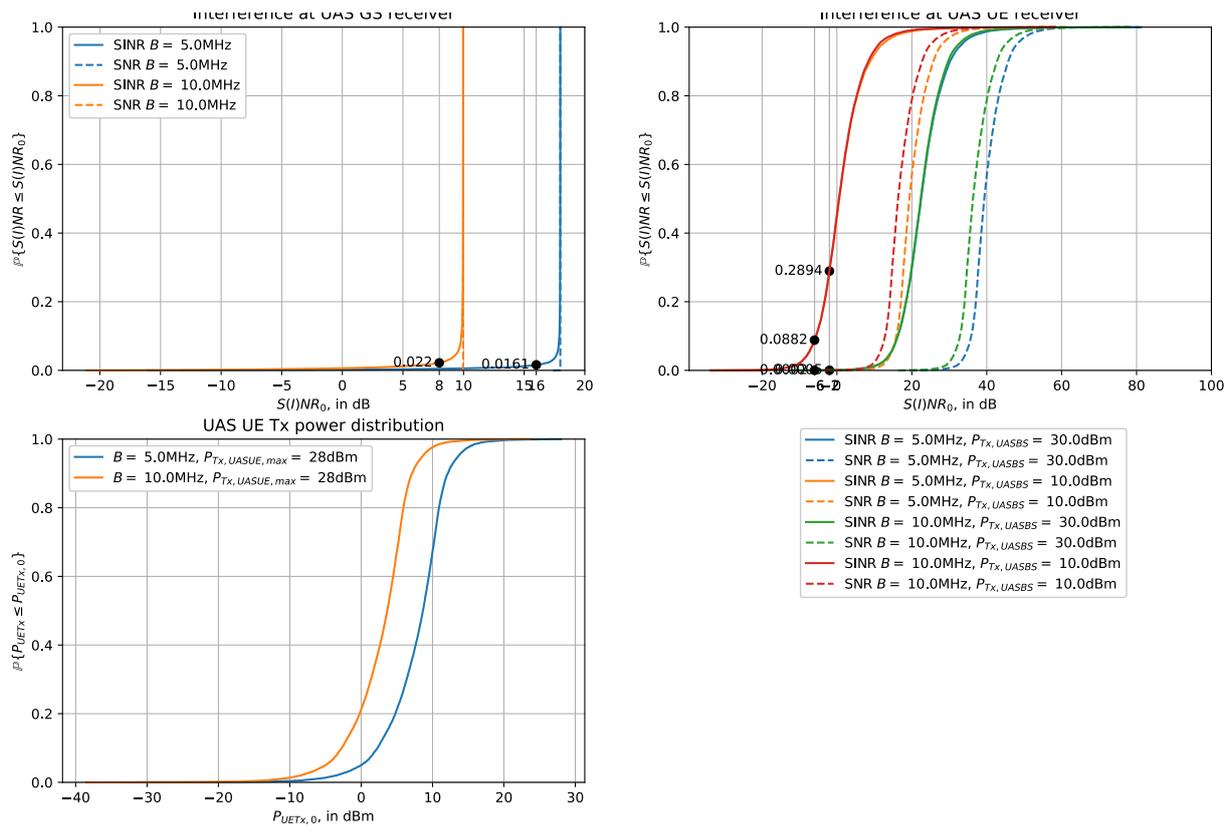


Figure 67: Urban scenario: interference from MFCN BS to UAS in 1805-1880 MHz, range of 300 m

A8.7 SUMMARY

Considering an SINR protection criterion of:

- 16 dB for UAS GS operating at 5 MHz;
- 8 dB for UAS GS operating at 10 MHz;
- -2 dB for UAS UE operating at 5 MHz;
- -6 dB for UAS UE operating at 10 MHz.

Results summarised in Table 92 and Table 93 show a high probability of interference to UAS GS with a range of 5650 m (more than 45% and up to 79%). In any other scenario, the probability of interference is between 1.5% and 8%. In this regard, it is likely that the drone operator will maintain a certain margin in its operation, (through limiting the distance, ensure field of view, etc.) to ensure the quality of the transmission so that worst case interference will not materialize. Note also that the UAS GS receives a video flux from the UAS UE. This means that interference on this link would result in the loss of video frames. Furthermore, there exist several ways to dynamically adapt the video compression ratio (which impact the video quality) to the channel state, such as MPEG-DASH²³ or RTSP [41] along with RTP [42] and RTCP [42].

Regarding interference to UAS UE, the rural scenario with a range of 5650 m also exhibits a high probability of interference (between 14 and 98%). In other scenarios, a lower UAS GS transmit power of 10 dBm also leads to significant probabilities of interference (between 2 and 90%). Keeping an UAS GS transmit power of 30 dBm yields an interference probability between 0.03 to 4% (excluding scenarios with a range of 5650 m).

²³ MPEG Dynamic Adaptive Streaming over HTTP.

Table 92: Summary of MFCN BS in 1805-1880 MHz interference probability to UAS GS at 1885 MHz

Environment	Range	Bandwidth (MHz)	UAS UE max. Tx power (dBm)	Probability of interference (%)
Rural	5650	5	28	78.4
		10		47.36
	1000	5		6.21
		10		7.37
	500	5		4.78
		10		7.08
Urban	1000	5		5.82
		10		3.78
	500	5		1.9
		10		2.48
	300	5		1.61
		10		2.21

Table 93: Summary of MFCN BS in 1805-1880 MHz interference probability to UAS UE at 1885 MHz

Environment	Range (m)	Bandwidth (MHz)	UAS BS Tx power (dBm)	Probability of interference (%)
Rural	5650	5	30	23.29
			10	97.47
		10	30	14.07
			10	94.62
	1000	5	30	0.54
			10	29.01
		10	30	0.29
			10	14.75
	500	5	30	0.08
			10	5.08
		10	30	0.03
			10	2.07
Urban	1000	5	30	3.26
			10	90.49
		10	30	1.25
			10	80.66

Environment	Range (m)	Bandwidth (MHz)	UAS BS Tx power (dBm)	Probability of interference (%)
	300	5	30	0.28
			10	64.66
		10	30	0.06
			10	36.73
	250	5	30	0.05
			10	28.94
		10	30	0.03
			10	8.82

ANNEX 9: MONTE CARLO STUDY OF THE POSSIBLE IMPACT OF AN LTE-BASED UAS DEPLOYED IN 1910-1920 MHZ TO AN MFCN BS DEPLOYMENT IN 1920-1980 MHZ

A9.1 METHODOLOGY

A9.1.1 Space distribution of interferers and victims

The simulation area is centered on one MFCN BS tri-sectorial antenna. UAS GS (Stationsground stations) are randomly placed in a circle whose radius corresponds to the double of one MFCN sector radius, at an altitude of 1.5 m. For each UAS GS deployed, a UAS UE is randomly positioned within a cylinder centered on the UAS GS, with radius the range of the UAS in the considered scenario, and an altitude randomly distributed between 1.5 m and 120 m. The UAS GS azimuth points to the UAS UE. Finally, MFCN cells as added as necessary so that all UAS UE and GS are within one MFCN sector. Each MFCN antenna is placed at 30 m (rural) or 25 m (urban) The result of this process is illustrated in Figure 68 and Figure 69.

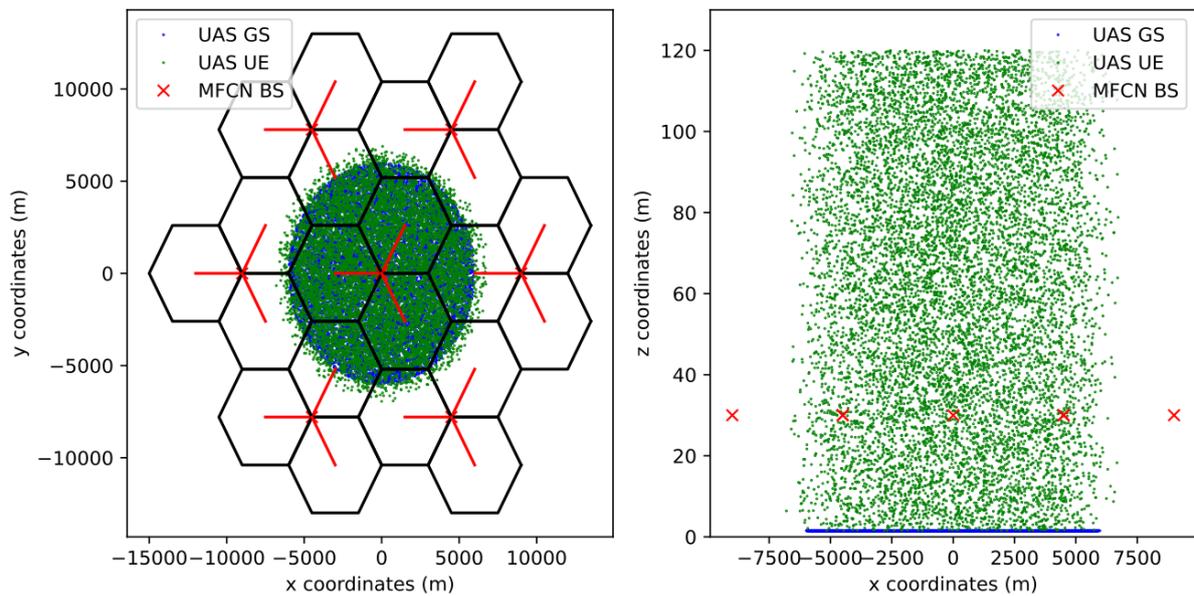


Figure 68: Example of a rural distribution (with UAS range of 1000 m). Each pair of green and blue point correspond to one Monte Carlo run

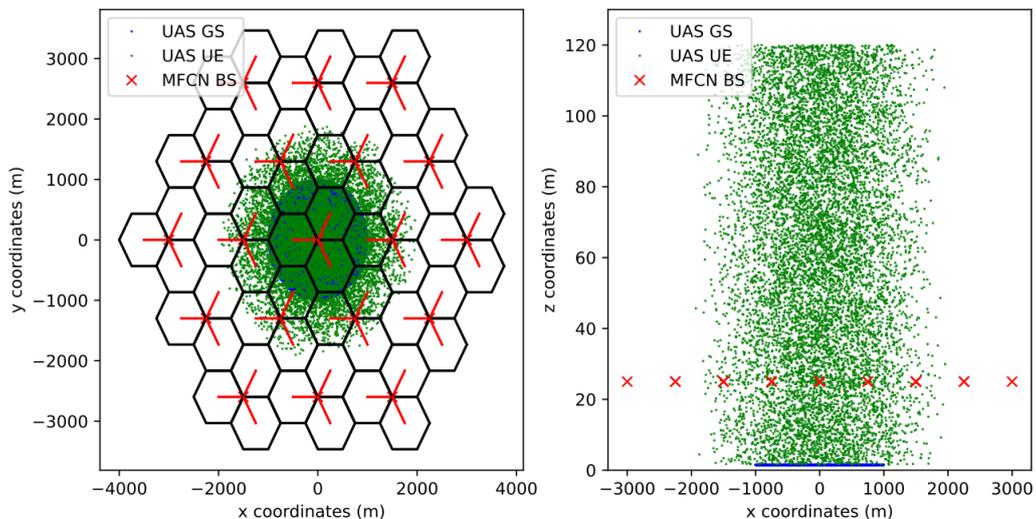


Figure 69: Example of an urban distribution (with UAS range of 1000 m). Each pair of green and blue point correspond to one Monte Carlo run

A9.1.2 Hypothesis

The following hypothesis are considered:

- All MFCN BS receive on the same channel spanning 10 MHz and centered at 1925 MHz;
- The UAS transmits and receives on a channel spanning 5 or 10 MHz, and centered at 1915 MHz;
- The UAS uses TDD, so the interference comes from either the UAS BS or the UAS UE, but not both at the same time;
- Path loss between UAS GS and MFCN BS is computed using the Extended Hata propagation model;
- Path loss between UAS UE and MFCN BS is computed using Extended Hata when the UAS UE altitude is in $[1.5; 10[$ m, or using Free Space Path Loss (FSPL) when the altitude is above 10 m;
- Path loss between UAS GS and UAS UE (used for UE transmit power control – TPC) is computed using a dedicated propagation model (see next subsection);
- The UAS GS Spectrum Emission Mask (SEM) is based on 3GPP 36.104, Table 6.6.3.2C-6 (LTE medium range BS) considering a transmit power of 30 dBm. Portions of this SEM is scaled so that ACLR values of 3GPP 36.104, table 6.6.2.1-2 are respected in the bands concerned. When using a lower transmit power, the SEM is scaled accordingly (see Figure 70);
- The UAS UE SEM is based on 3GPP 36.101, Figure 71);
- The MFCN BS Blocking Edge Mask (BEM) is based on 3GPP 37.104, Sections 7.4-1, 7.4.2-1, 7.4.5-1, 7.5.1-1 and 36.104 7.5.1-1.

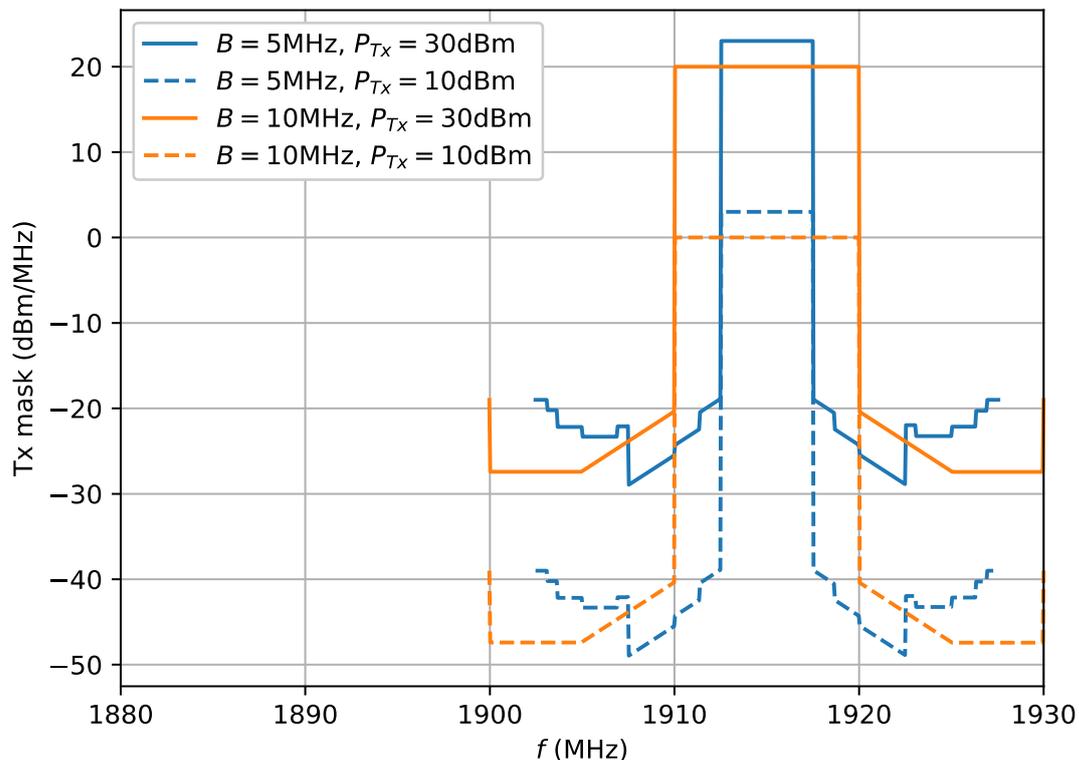


Figure 70: UAS GS SEM, based on 3GPP 36.104, Table 6.6.3.2C-1 and Table 6.6.2.1-2

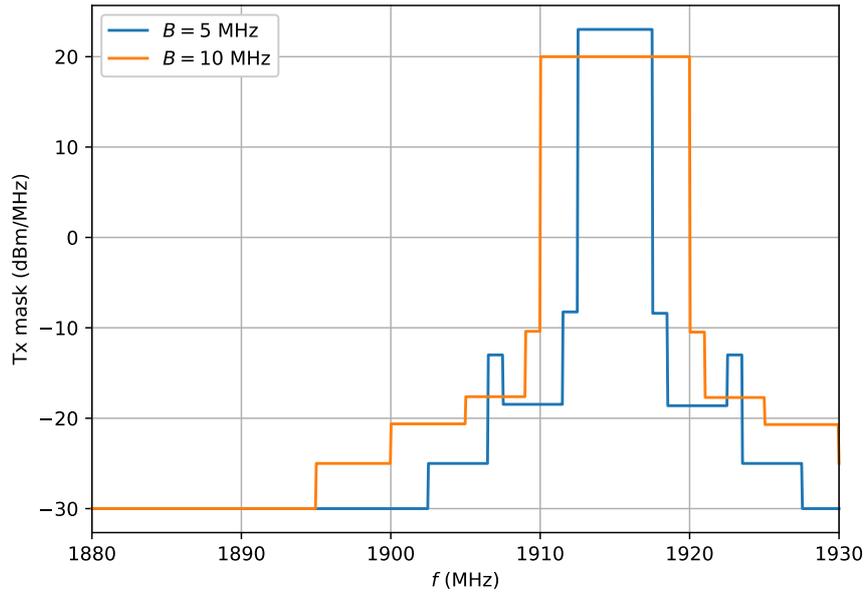


Figure 71: UAS UE SEM based on 3GPP 36.101, Table 6.6.2.1.1-1 and Section 6.6.2.2, for a transmit power of 30 dBm

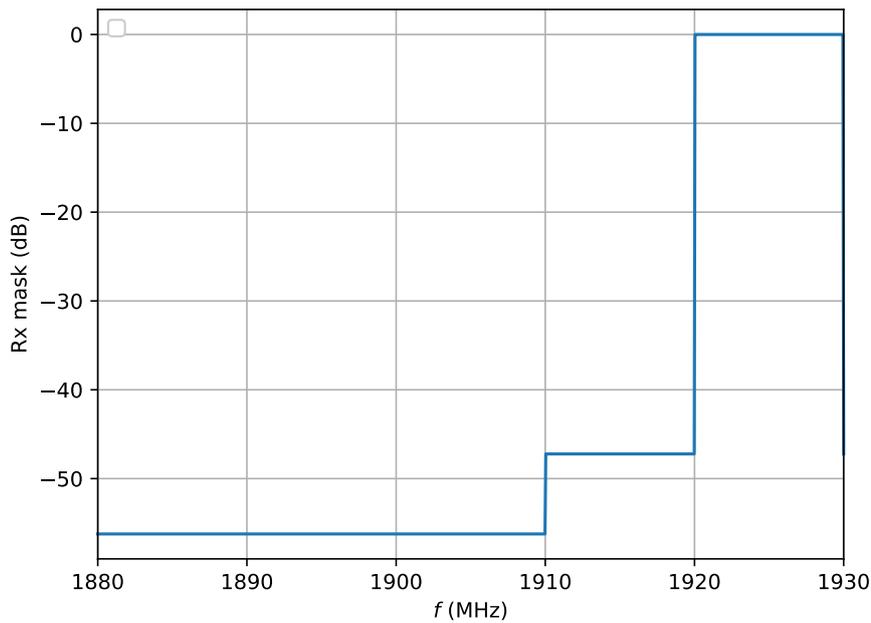


Figure 72: MFCN BS BEM based on 3GPP 37.104, Sections 7.4-1, 7.4.2-1, 7.4.5-1, 7.5.1-1 and 36.104 7.5.1-1

A9.1.3 Propagation model between UAS UE and GS

Even though the UAS UE is required to be in visual line of sight (VLOS), propagation between UAS UE and GS is not purely FSPL unless the drone flies at high altitude, since the ground (and, potentially, buildings in urban areas) mask part of the Fresnel ellipsoid.

A review of the literature [1][2][3] on drone propagation models involving VLOS and low altitude of the GS concludes that approaches using clutter defined in Recommendation ITU-R P.2108, or propagation models applicable to IMT such as Recommendation ITU-R P.1546, tends to overestimate the propagation losses between UAS UE and GS in rural scenarios, especially when the drone is flying at a high altitude. Inversely,

when the drone is flying close to the ground, the path loss seems underestimated by these models (see Figure 73)

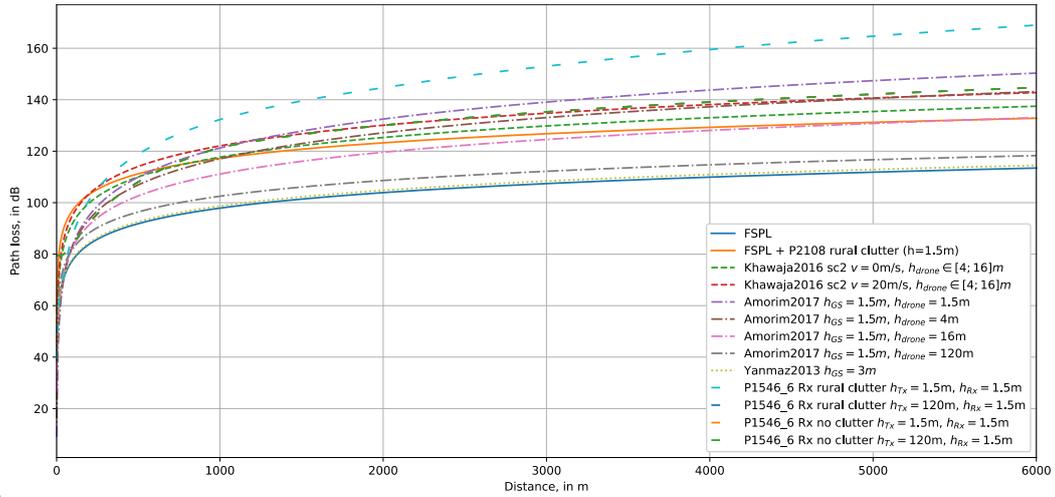


Figure 73: Comparison of drone rural propagation models [1][2][3]

In urban environment, propagation models found in the [1][2][3] focus on UAS GS located at high altitude. However, it has to be noted that prediction of clutter loss in Recommendation ITU-R P.2108 for urban environment covers propagation masked by several buildings. Urban scenarios involving VLOS implies street-canyon type of propagation, for which Recommendation ITU-R P.1411 predicts propagation losses similar to FSPL (see Figure 74), which suggest that clutter losses predicted by Recommendation ITU-R P.2108 in urban environments overestimate propagation losses. Similarly, [1][2][3] approaches based on models applicables for IMT (extended Hata, Recommendation ITU-R P.1546, etc.) consider a propagation potentially masked by other buildings. Unfortunately, Recommendation ITU-R P.1411 can only be used for short propagation paths.

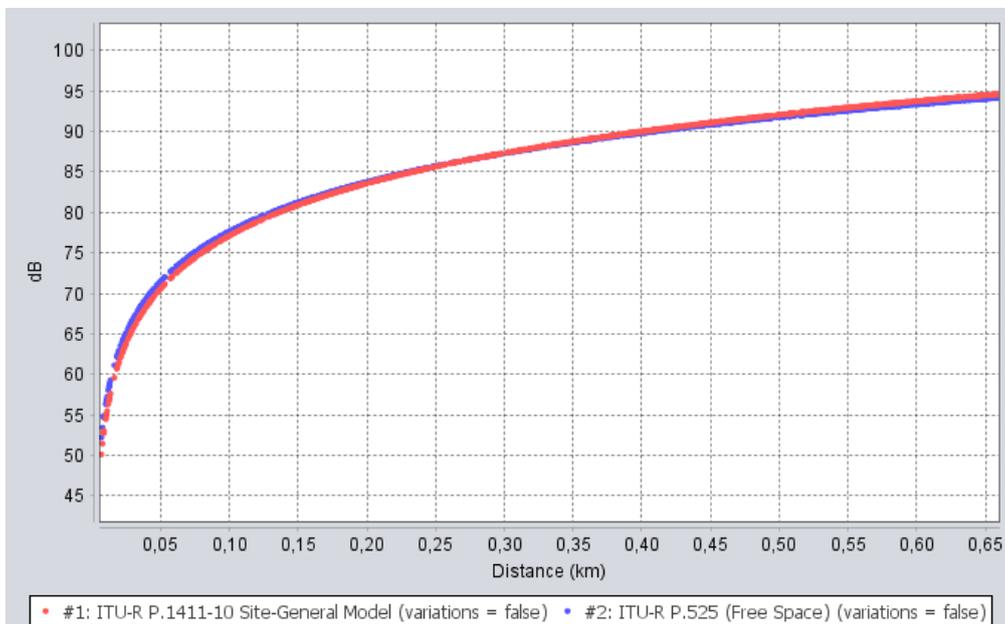


Figure 74: Comparison of FSPS and Recommendation ITU-R P.1411 street canyon model

As this propagation model has been derived for a carrier frequency of 800 MHz, it has to be adapted to predict path loss in the bands considered in this Report. This is done as follows: the propagation model takes the following form:

$$PL = \alpha \cdot 10 \cdot \log_{10}(d) + \beta \tag{38}$$

With d the distance in m, and α and β two real constants, that can be found in Equations (4) and (5) of [4] . It can be converted to the following form:

$$PL = \alpha \cdot 10 \cdot \log_{10}(d) + \beta \tag{39}$$

Where:

- $PL_0 = 20 \cdot \log_{10} \left(4\pi \cdot d_0 \cdot \frac{f}{c_0} \right)$
- f is the frequency, in Hz.
- c_0 is the speed of light in a vacuum, in m/s.

Resolving for γ and PL_0 gives:

$$\gamma = \alpha \tag{40}$$

$$PL_0 = \frac{1}{1 - \frac{\alpha}{2}} \left(\beta + \alpha \cdot 10 \cdot \log_{10} \left(\frac{c_0}{4\pi f_m} \right) \right) \tag{41}$$

Where $f_m = 800$ MHz is the frequency at which the model has been derived. Finally, d_0 is derived from PL_0 using the relation $PL_0 = 20 \cdot \log_{10} \left(4\pi \cdot d_0 \cdot \frac{f}{c_0} \right)$. This allows to transpose the model to any carrier frequency.

A graphical description of the model is given in Figure 75.

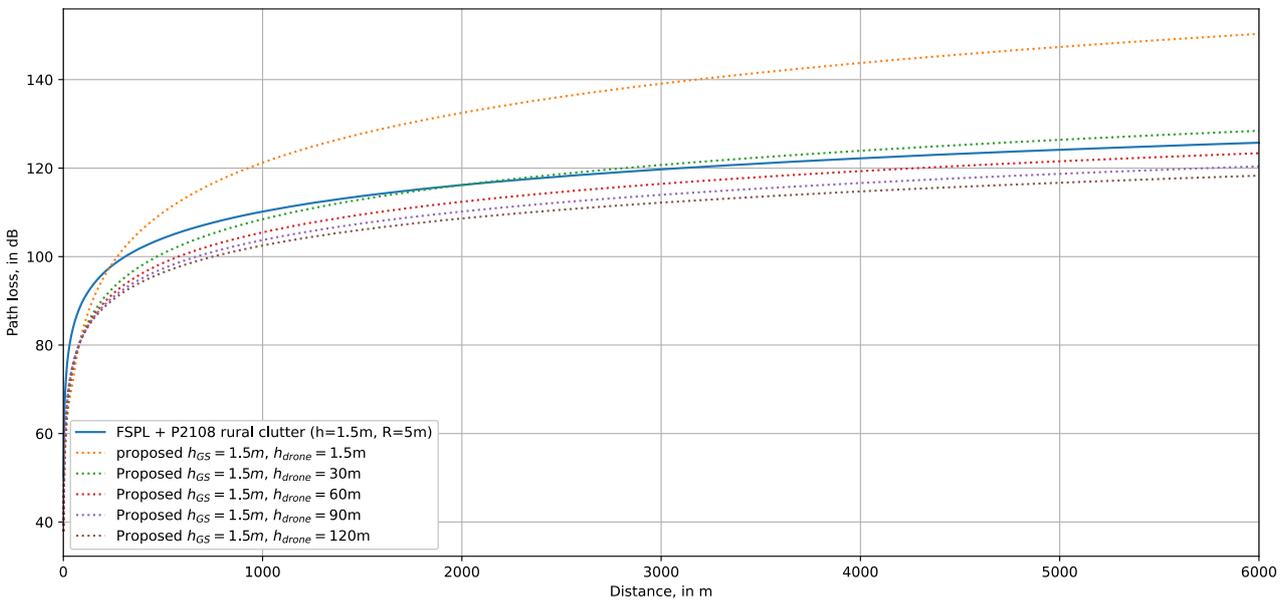


Figure 75: Proposed propagation model between UAS UE and UAS GS

A9.2 MODEL OF MFCN BS RECEIVED INTERFERENCE

A9.2.1 UAS GS transmit

For each Monte Carlo run ω , the interference power as experienced from the i th MFCN BS from the UAS GS is given as:

$$= P_f + G_{MFCN\ BS,i}(\overrightarrow{p_{UAS\ GS}(l)}) + G_{UAS\ GS}(\omega, \overrightarrow{p_{MFCN\ BS}(l)}) - FL_{MFCN\ BS} - PL(\overrightarrow{p_{UAS\ GS}(\omega)}, \overrightarrow{p_{MFCN\ BS}(l)}) \quad (42)$$

Where:

- $P_f = 10 \cdot \log_{10}(\int_{-\infty}^{+\infty} SEM_{UAS\ GS}(f) \cdot BEM_{MFCN\ BS}(f) df)$ is the fraction of the interferer power falling into the receiver's band (in dBm).
- $SEM_{UAS\ GS}(f)$ is the SEM of the UAS GS, scaled to the UAS GS transmit power (in mW/Hz).
- $BEM_{MFCN\ BS}(f)$ is the BEM of the MFCN BS.
- $G_{MFCN\ BS,i}(\vec{p})$ is the i th MFCN BS antenna gain toward the point in space described by vector \vec{p} (in dBi).
- $G_{UAS\ GS}(\omega, \vec{p})$ is the gain of the UAS GS toward the point in space described by vector \vec{p} (in dBi).
- $FL_{MFCN\ BS}$ is the feeder loss of the MFCN BS (in dB).
- $PL(\vec{p}_1, \vec{p}_2)$ is the path loss between the two points in space described by vectors \vec{p}_1 and \vec{p}_2 (dB).
- $\overrightarrow{p_{MFCN\ BS}(l)}$ vector describing the position in space of the i th MFCN BS.
- $\overrightarrow{p_{UAS\ GS}(\omega)}$ vector describing the position in space of the UAS GS, at Monte Carlo run ω .

A9.2.2 UAS UE transmit

$$I_{UAS\ UE \rightarrow MFCN\ BS}(\omega, i) = P_f(\omega) + G_{MFCN\ BS,i}(\overrightarrow{p_{UAS\ UE}(l)}) + G_{UAS\ UE} - FL_{MFCN\ BS} - PL(\overrightarrow{p_{UAS\ UE}(\omega)}, \overrightarrow{p_{MFCN\ BS}(l)})$$

Using the same notation as before, and where:

$P_f(\omega)$ is the fraction of the interferer power falling into the receiver's band, taking into account UAS UE transmit power control (in dBm).

The power control algorithm is taken from Recommendation ITU-R M.2101-0, taking into account that all Resource Blocks are allocated to the same device.

The power control formula is given then by $P_{UAS\ UE}(\omega) = \max\{\min\{P_{UAS\ UE,max}, P_{UAS\ GS,target} + \alpha \cdot PL(\overrightarrow{p_{UAS\ UE}(\omega)}, \overrightarrow{p_{UAS\ GS}(\omega)})\}, -40\}$

$$\alpha = 1$$

$P_{UAS\ GS,target}$ is the target received power at the UAS GS, computed based on the target SNR given in Table 54 plus 3 dB of margin ($P_{UAS\ GS,target} = -80$ dBm for 5 MHz of bandwidth, -85 dBm of 10 MHz of bandwidth).

$\overrightarrow{p_{UAS\ UE}(\omega)}$ vector describing the position in space of the UAS UE, at Monte Carlo run ω .

A9.3 GATHERED STATISTICS

In order to assess the probability for any MFCN BS to be interfered with either the UAS BS or the UAS UE, the I/N ratio of the most interfered MFCN BS at each Monte Carlo run is computed:

$$I/N|_{worst}(\omega) = \max_i I(\omega, i) - P_{N,MFCN BS} \tag{43}$$

Where:

- $I(\omega, i)$ is either $I_{UAS GS \rightarrow MFCN BS}(\omega, i)$ or $I_{UAS UE \rightarrow MFCN BS}(\omega, i)$;
- $P_{N,MFCN BS}$ is the noise floor of the MFCN BS.

Because TPC is involved, and in order to better understand the results when the UAS UE is the interferer, the values of $P_{UAS UE}(\omega)$ and $P_f(\omega)$ are also gathered.

A9.4 STUDY

Figure 76 gives the Cumulative Distribution Function (CDF) of $I/N|_{worst}(\omega)$ for different configurations of bandwidth, transmit power and range.

A9.5 RURAL SCENARIO

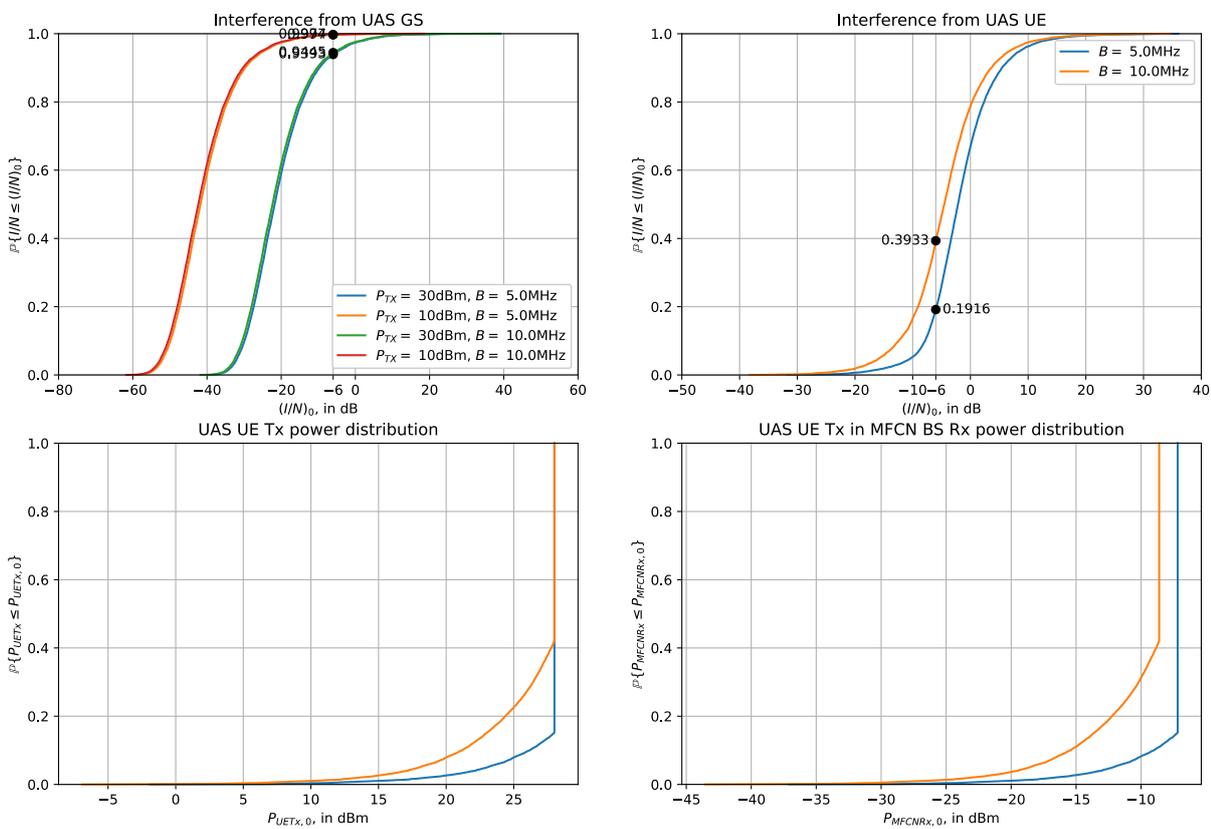


Figure 76: Rural scenario: interference to MFCN BS in 1920-1980 MHz, range of 5650 m

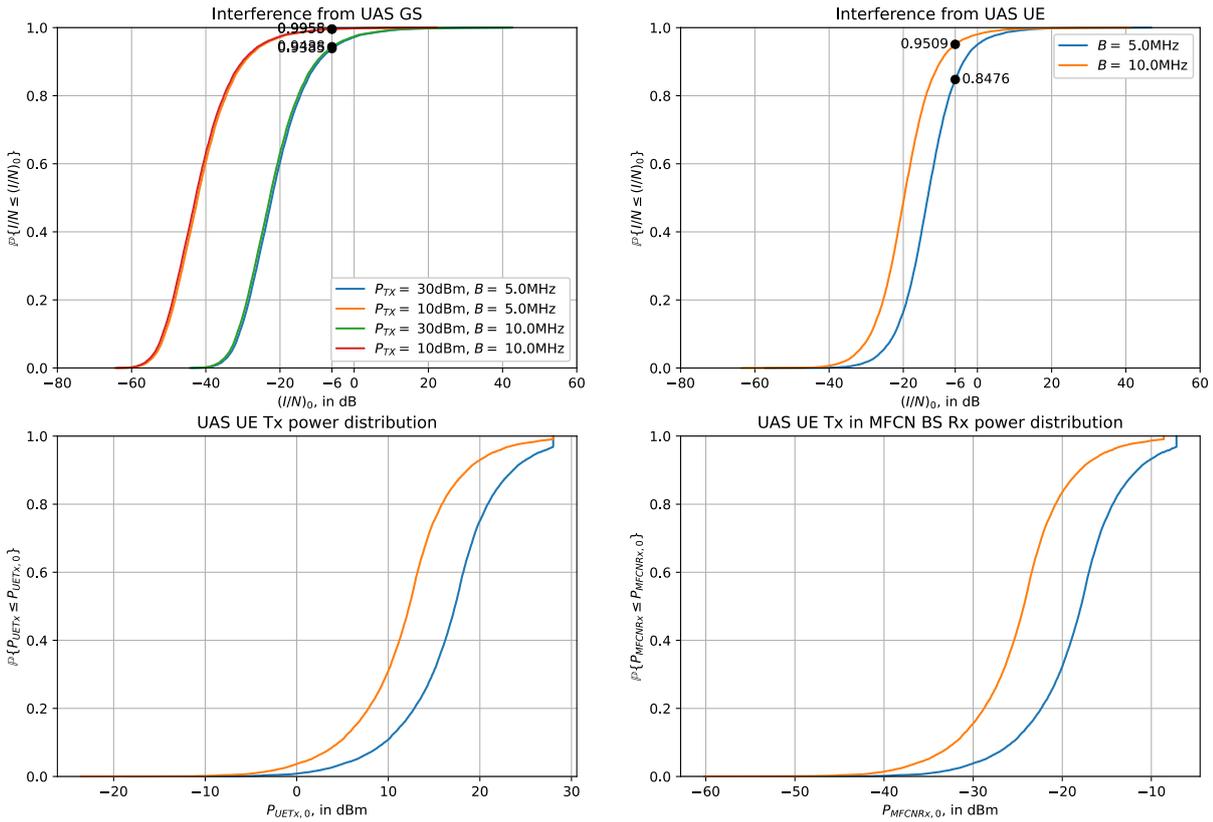


Figure 77: Rural scenario: interference to MFCN BS in 1920-1980 MHz, range of 1000 m

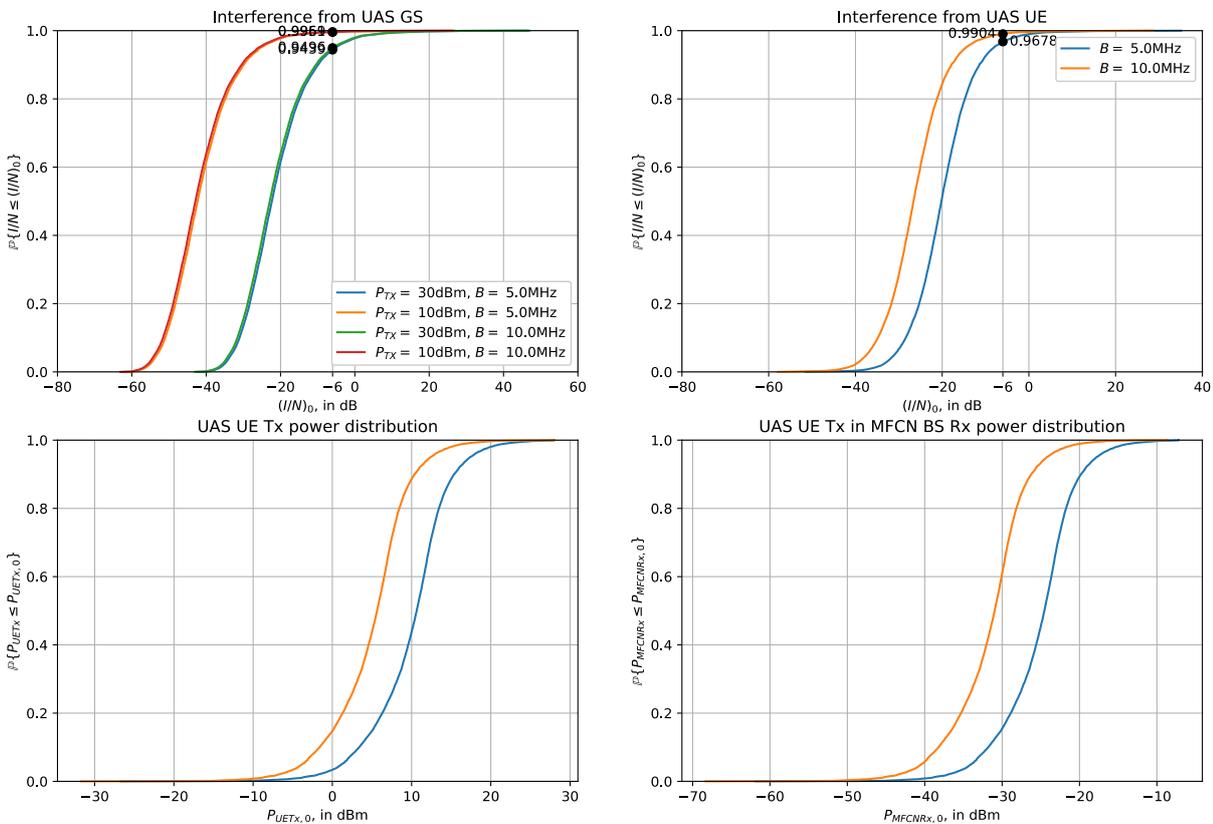


Figure 78: Rural scenario: interference to MFCN BS in 1920-1980 MHz, range of 500 m

A9.5.1 Urban scenario

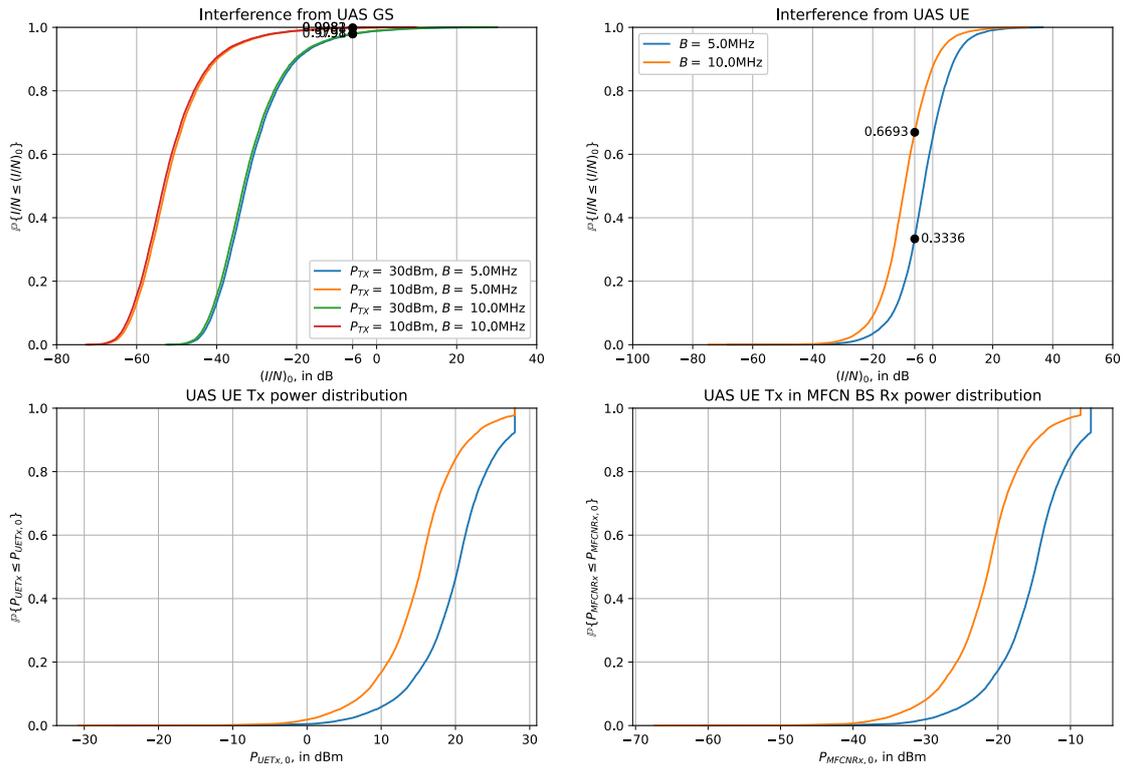


Figure 79: Urban scenario: interference to MFCN BS in 1920-1980 MHz, range of 1000 m

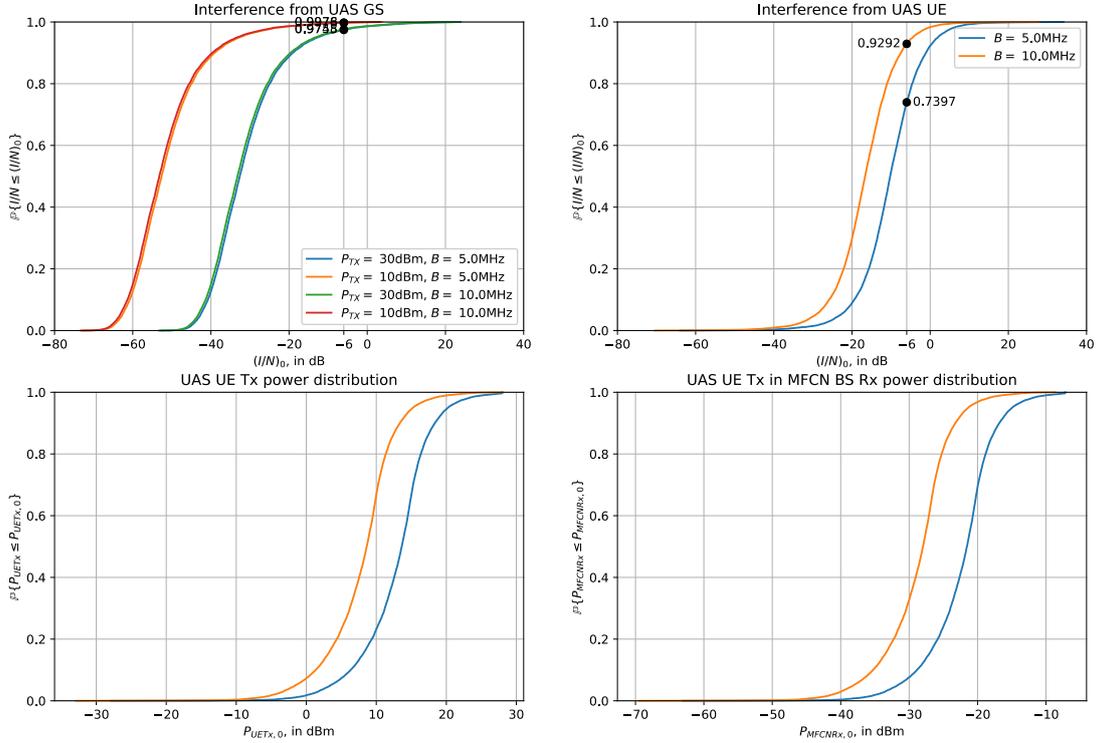


Figure 80: Urban scenario: interference to MFCN BS in 1920-1980 MHz, range of 500 m

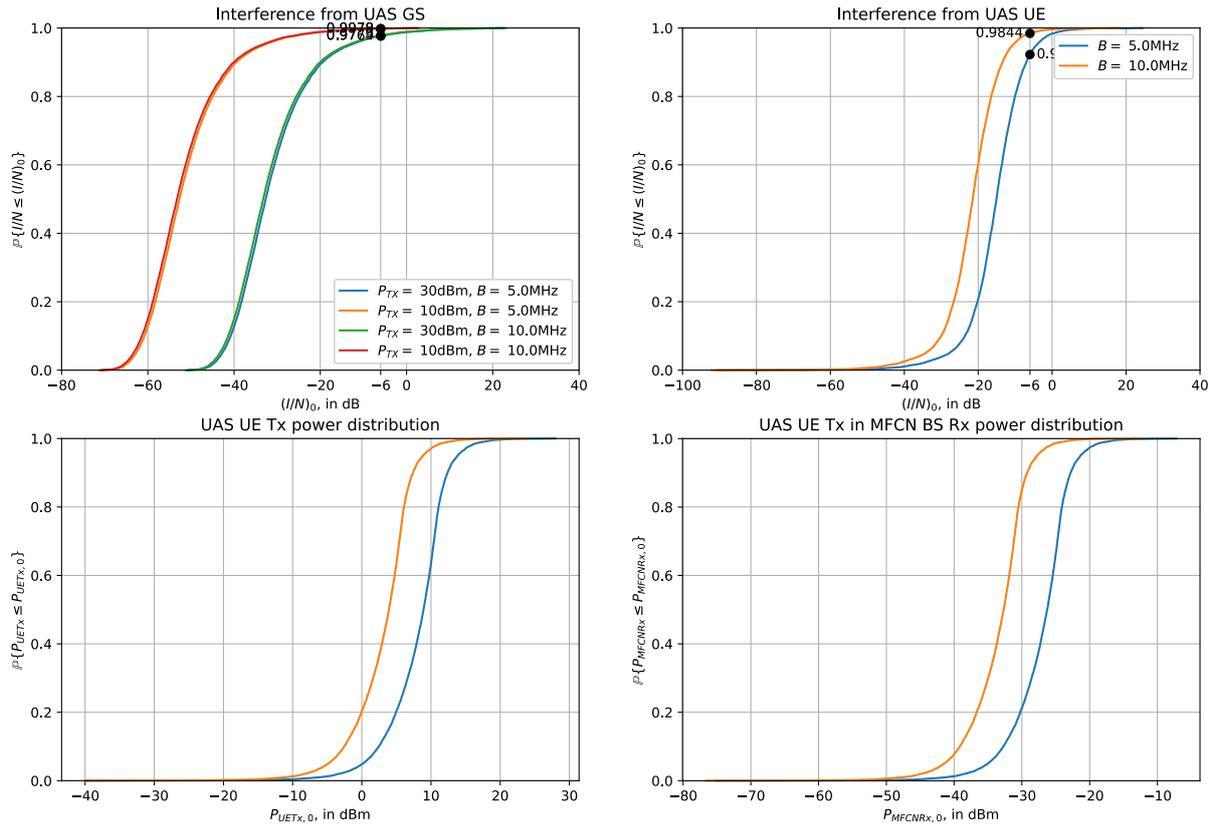


Figure 81: Urban scenario: interference to MFCN BS in 1920-1980 MHz, range of 300 m

A9.6 SUMMARY

Considering an I/N protection criterion of -6 dB for MFCN BS, Table 95 and Table 96 summarise the results of the study. Results are given as the probability of interference of the MFCN BS receiving the highest level of interference.

For the interference coming from UAS GS, the probability for the closest MFCN BS to be interfered remains limited (2 to 5.6% for transmit power of 30 dBm and less than 0.2% for the transmit power of 10 dBm). It is noted that, using the drone propagation model of [4], the reduction of transmit power to 10 dBm would not allow the link from the UAS BS to the UAS GS to reach the target bitrate with a range of 5650 m (see Figure 76). UAS bandwidth of 5 MHz instead of 10 MHz has little impact on the co-existence of the two system.

When UAS UE is the interferer, thanks to TPC, the worst case interference happens when the UAS UE is at its maximum range. Hence, reducing the maximum range facilitate the co-existence between UAS UE and MFCN BS. In this regard, it is likely that the drone operator will maintain a certain margin in its operation, (through limiting the distance, ensure field of view, etc.) to ensure the quality of the transmission so that worst case interference will not materialize. Also, because of the difference of the target SNR for TPC depending on the UAS bandwidth, setting it to 5 MHz instead of 10 MHz only marginally ease the co-existence. Note that because the UAS UE is meant to move in its range, the worst interfered MFCN BS will likely be different at different instant in time.

Table 94: Summary of UAS GS in 1910-1920 MHz interference probability to MFCN BS in 1920-1980 MHz

Environment	Bandwidth (MHz)	Tx power (dBm)	Probability for the worst impacted MFCN BS to be interfered (%)
Rural	5	30	5.6
		10	0.4
	10	30	5.04
		10	0.38
Urban	5	30	2.08
		10	0.19
	10	30	1.99
		10	0.17

Table 95: Summary of UAS UE in 1910-1920 MHz interference probability to MFCN BS in 1920-1980 MHz

Environment	Range (m)	Bandwidth (MHz)	Max Tx power (dBm)	Probability for the worst impacted MFCN BS to be interfered (%)
Rural	5650	5	28	80.84
		10		60.66
	1000	5		15.24
		10		4.9
	500	5		3.21
		10		0.95
Urban	1000	5		66.63
		10		33.07
	500	5		26.03
		10		7.08
	300	5		7.77
		10		1.56

ANNEX 10: MONTE CARLO STUDY OF THE POSSIBLE IMPACT OF AN LTE-BASED UAS DEPLOYED IN 1910-1920 MHZ TO AN FRMCS DEPLOYMENT IN 1900-1910 MHZ

A10.1 METHODOLOGY

A10.1.1 Space distribution of interferers and victims

The simulation area is centered on the center of the rail tracks covered by FRMCS system. Rail tracks covered by FRMCS system are picked up from a database that is an extract of Openstreetmap data in the european zone. This allowed to get real track data for high-speed, low-density and high-density train tracks. As the diameter of a rural UAS deployment zone goes up to 12 km, and 2 km in urban, railways are split into sections of 12 km in rural environment (low-density or high-speed) and into sections of 2 km in urban environments.

Once a track section is selected, FRMCS BS are positioned at a distance between 5 and 50 m from the tracks, and spaced using an inter-site distance of:

- 8 km in low-density or high-speed areas;
- Between 2 km and 4 km in urban areas.

Each FRMCS BS sites comprises two antennas. They are orientated towards the point on the track that is equidistant from two the next or previous FRMCS BS site (or track limits, for the first and last BS in the simulation area). Their down tilt is set to 2°. The altitude of the FRMCS BS is distributed as follows, based on an analysis of the French radioelectrical sites database (altitudes of BS close to or within tunnels was ignored, altitudes with low probabilities of occurrence were also ignored):

- 20 m with probability 35%;
- 25 m with probability 36%;
- 30 m with probability 29%.

FRMCS UE (trains) are regularly positionned on the train tracks based on the following train densities:

- 0.33 train/km for low-density tracks;
- 0.67 train/km for high-density tracks;
- 0.50 train/km for high-speed tracks.

And on the following minimum separation distance between two trains:

- 1500 m for conventional speeds;
- 4000 m for high-speed.

The antenna of the FRMCS UE is not tilted. It follows the orientation of the train track, and is positionned with an altitude of 4 m.

The UAS BS is randomly positionned at a maximum distance of 1 km from the tracks. The UAS UE is then randomly positionned within a circle centered on the UAS BS, and with a radius corresponding to the UAS range. The altitude of the UAS BS is 1.5 m, while the altitude of the UAS UE is uniformly distributed between 1.5 m and 120 m. The UAS GS points its azimuth to the position of the UAS UE.

Examples of FRMCS deployments can be found in Figure 82, Figure 83 and Figure 84.

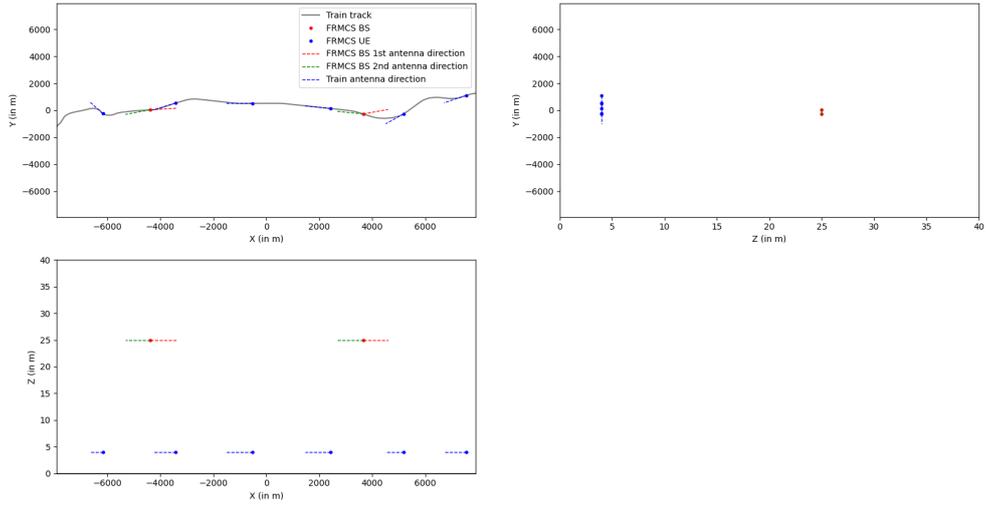


Figure 82: Low density FRMCS deployment example

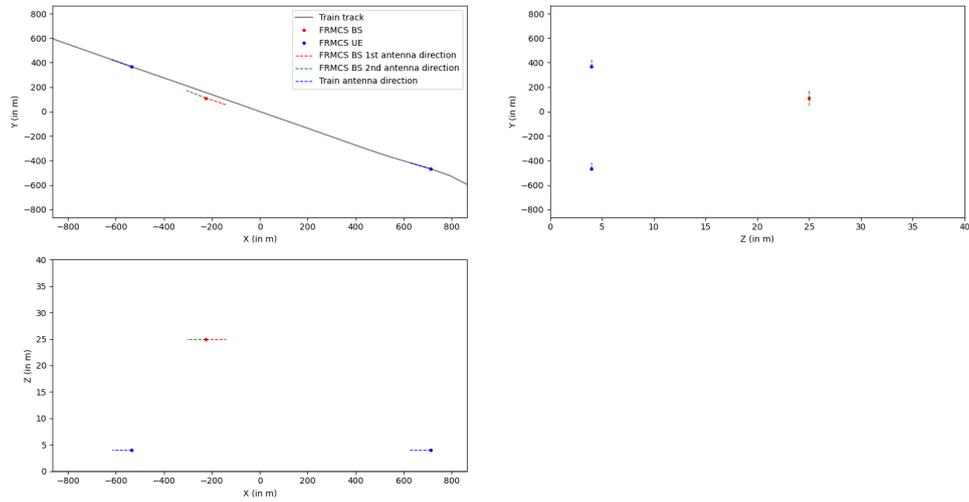


Figure 83: High density FRMCS deployment example

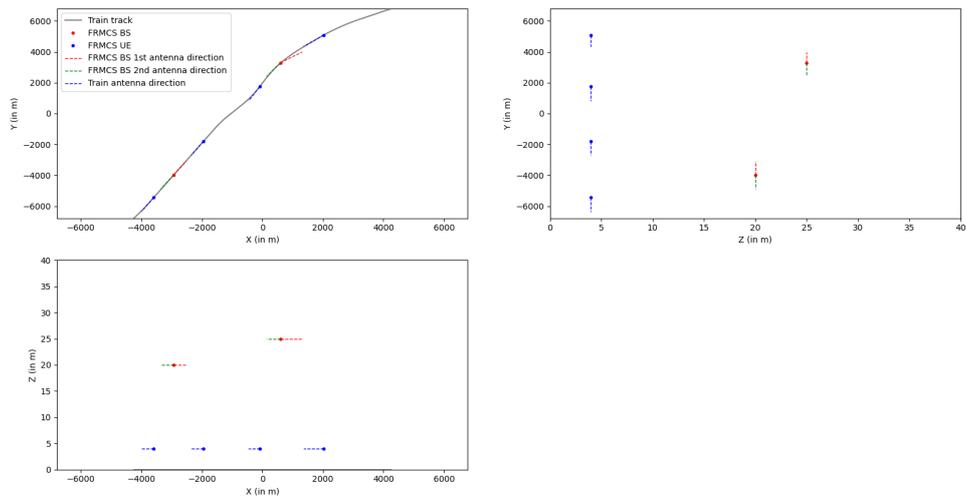


Figure 84: High-speed FRMCS deployment example

A10.1.2 Hypothesis

The following hypothesis are considered:

- The UAS transmits and receives on a channel spanning 5 or 10 MHz, and centered at 1915 MHz;
- The UAS uses TDD, so the interference comes from either the UAS BS or the UAS UE, but not both at the same time;
- Path loss between UAS GS and FRMCS BS is computed using the Extended Hata propagation model;
- Path loss between UAS UE and FRMCS BS is computed using Extended Hata when the UAS UE altitude is in [1.5; 10] m, or using Free Space Path Loss (FSPL) when the altitude is above 10 m;
- Path loss between UAS GS and FRMCS UE is computed using FSPL, on top of which clutter is added both at the UAS GS end and the FRMCS UE end, based on Recommendation ITU-R P.2108; Path loss between UAS UE and FRMCS UE is computed using FSPL, on top of which clutter is added at the FRMCS UE end, based on Recommendation ITU-R P.2108;
- Path loss between UAS GS and UAS UE (used for UE transmit power control – TPC) is computed using FSPL;
- The UAS GS Spectrum Emission Mask (SEM) is based on 3GPP 36.104, Table 6.6.3.2C-6 (LTE medium range BS) considering a transmit power of 30 dBm. Portions of this SEM is scaled so that ACLR values of 3GPP 36.104, table 6.6.2.1-2 are respected in the bands concerned. When using a lower transmit power, the SEM is scaled accordingly (see Figure 85);
- The UAS UE SEM is based on 3GPP 36.101, table 6.6.3.2C-6 considering a transmit power of 30 dBm. Portions of this SEM is scaled so that ACLR values of Section 6.6.2.2 (for power class 1 UEs) are respected in the bands concerned. When using a higher or lower transmit power, the SEM is scaled accordingly (see Figure 86);
- The FRMCS BS Blocking Edge Mask (BEM) is based on ETSI 3GPP 36.104, Sections 7.5 and 7.6 for medium range BS;
 - Table 7.2.1-1 for reference sensitivity levels,
 - Table 7.5.1-1 for narrowband blocking,
 - Table 7.5.1-3 for ACS,
 - Tables 7.6.1.1 and 7.6.1.1-2 for CW blocking,
 - and ECC Report 314, table 2 for additional requirements.
- The FRMCS UE BEM is based on ETSI 3GPP 36.101, Sections 7.5 and 7.6 for medium range BS:
 - Table 7.5.1-1 for ACS,
 - Tables 7.6.2.1-2 for out-of-band blocking.
 - Table 7.2.3.1-1 for narrowband blocking,
 - and in ECC Report 314, table 1 for additional requirements.

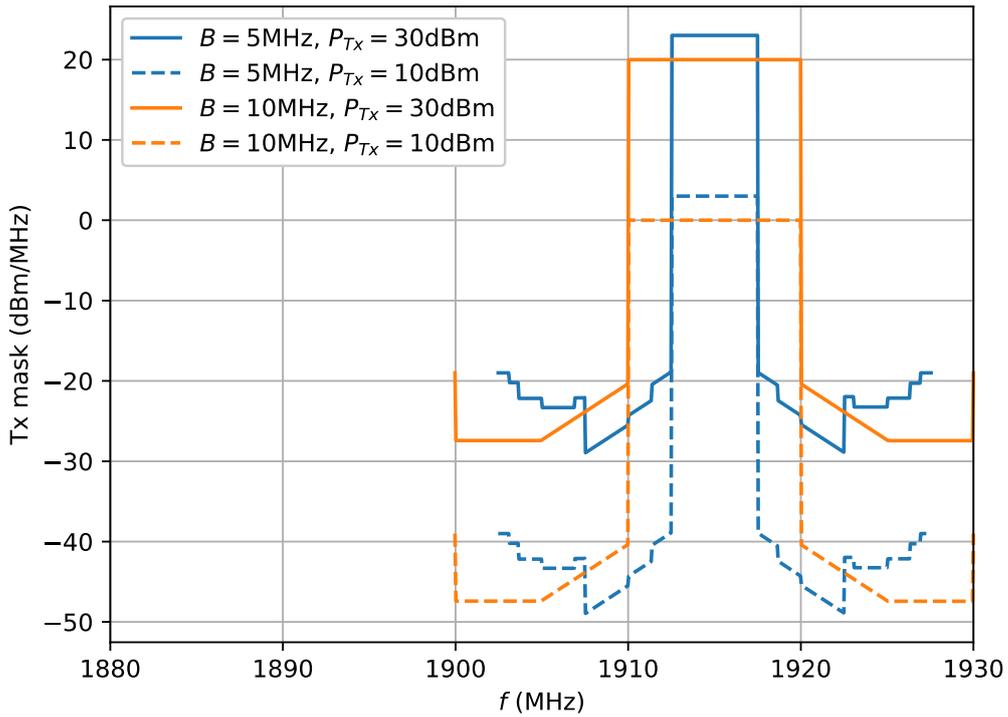


Figure 85: UAS GS SEM, based on 3GPP 36.104, tble 6.6.3.2C-1 and table 6.6.2.1-2

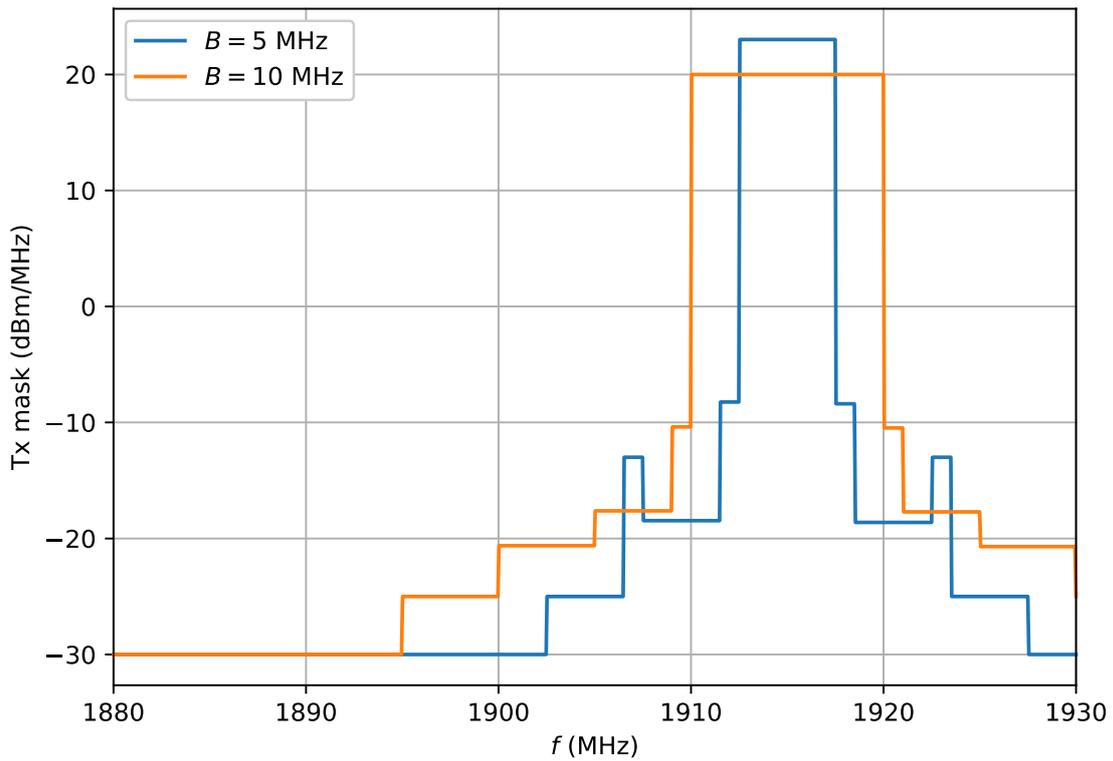


Figure 86: UAS UE SEM based on 3GPP 36.101, table 6.6.2.1.1-1 and section 6.6.2.2, for a transmit power of 30 dBm

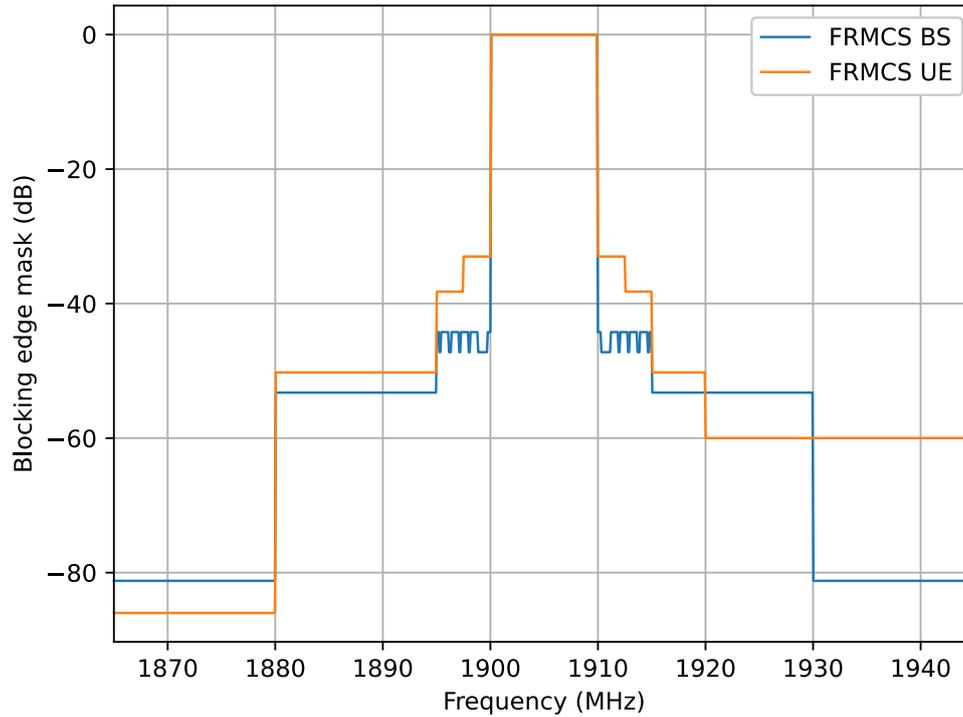


Figure 87: FRMCS BS and FRMCS BEM based on 3GPP 36.104, 3GPP 36.101 and ECC Report 314

A10.1.3 Model of FRMCS received interference

A10.1.3.1 UAS GS transmit FRMCS BS receive

For each Monte Carlo run ω , the interference power as experienced from the i th MFCN BS from the UAS GS is given as:

$$I_{UAS\ GS \rightarrow FRMCS\ BS}(\omega, i) = P_f + G_{FRMCS\ BS, i}(\vec{p}_{UAS\ GS}(\omega)) + G_{UAS\ GS}(\omega, \vec{p}_{FRMCS\ BS}(\omega, i)) - FL_{FRMCS\ BS} - PL(\vec{p}_{UAS\ GS}(\omega), \vec{p}_{FRMCS\ BS}(\omega, i))$$

Where:

- $P_f = 10 \cdot \log_{10}(\int_{-\infty}^{+\infty} SEM_{UAS\ GS}(f) \cdot BEM_{FRMCS\ BS}(f) df)$ is the fraction of the interferer power falling into the receiver's band (in dBm);
- $SEM_{UAS\ GS}(f)$ is the SEM of the UAS GS, scaled to the UAS GS transmit power (in mW/Hz).
- $BEM_{FRMCS\ BS}(f)$ is the BEM of the FRMCS BS.
- $G_{FRMCS\ BS, i}(\vec{p})$ is the i th FRMCS BS antenna gain toward the point in space described by vector \vec{p} (in dBi);
- $G_{UAS\ GS}(\omega, \vec{p})$ is the gain of the UAS GS toward the point in space described by vector \vec{p} (in dBi);
- $FL_{FRMCS\ BS}$ is the feeder loss of the FRMCS BS (in dB);
- $PL(\vec{p}_1, \vec{p}_2)$ is the path loss between the two points in space described by vectors \vec{p}_1 and \vec{p}_2 (dB);
- $\vec{p}_{FRMCS\ BS}(\omega, i)$ vector describing the position in space of the i th FRMCS BS, at Monte Carlo run ω ;
- $\vec{p}_{UAS\ GS}(\omega)$ vector describing the position in space of the UAS GS, at Monte Carlo run ω .

A10.1.3.2 UAS UE transmit FRMCS BS receive

$$I_{UAS\ UE \rightarrow FRMCS\ BS}(\omega, i) = P_f(\omega) + G_{FRMCS\ BS, i}(\vec{p}_{UAS\ UE}(\omega)) + G_{UAS\ UE} - FL_{MFCN\ BS} - PL(\vec{p}_{UAS\ UE}(\omega), \vec{p}_{FRMCS\ BS}(\omega, i))$$

Using the same notation as before, and where:

- $P_f(\omega)$ is the fraction of the interferer power falling into the receiver's band, taking into account UAS UE transmit power control (in dBm)
 - The power control algorithm is taken from Recommendation ITU-R M.2101-0, taking into account that all Resource Blocks are allocated to the same device.
 - The power control formula is given then by $P_{UAS UE}(\omega) = \max\left\{\min\left\{P_{UAS UE,max}, P_{UAS GS,target} + \alpha \cdot PL(\overrightarrow{p_{UAS UE}(\omega)}, \overrightarrow{p_{UAS GS}(\omega)})\right\}, -40\right\}$
 - $\alpha = 1$
- $P_{UAS GS,target}$ is the target received power at the UAS GS, computed based on the target SNR given in Annex 3, Table 54, plus 3 dB of margin ($P_{UAS GS,target} = -80$ dBm for 5 MHz of bandwidth, -85 dBm of 10 MHz of bandwidth);
- $\overrightarrow{p_{UAS UE}(\omega)}$ vector describing the position in space of the UAS UE, at Monte Carlo run ω .

A10.1.3.3 UAS BS transmit FRMCS UE receive

$$= P_f + G_{FRMCS UE,i}(\overrightarrow{p_{UAS GS}(\omega)}) + G_{UAS GS}(\omega, \overrightarrow{p_{MFCN UE}(\omega, i)}) - HL_{FRMCS UE} - PL(\overrightarrow{p_{UAS GS}(\omega)}, \overrightarrow{p_{FRMCS UE}(\omega, i)}) \quad (44)$$

Using the same notation as before, and where:

- $G_{MFCN UE,i}(\vec{p})$ is the gain of the i-th FRMCS UE antenna towards the point in space described by vector \vec{p} .
- $\overrightarrow{p_{FRMCS UE}(\omega, i)}$ vector describing the position in space of the i-th FRMCS UE, at Monte Carlo run ω .
- $HL_{FRMCS UE}$ are hardware losses in the FRMCS cab-receiver (dB).

A10.1.3.4 UAS UE transmit FRMCS UE receive

$$= P_f(\omega) + G_{FRMCS UE,i}(\overrightarrow{p_{UAS UE}(\omega)}) + G_{UAS UE} - HL_{MFCN UE} - PL(\overrightarrow{p_{UAS UE}(\omega)}, \overrightarrow{p_{FRMCS UE}(\omega, i)}) \quad (45)$$

A10.1.4 Gathered statistics

In order to assess the probability for any MFCN BS to be interfered with either the UAS BS or the UAS UE, the I/N ratio of the most interfered MFCN BS at each Monte Carlo run is computed:

$$I/N|_{worst}(\omega) = \max_i I(\omega, i) - P_{N,FRMCS} \quad (46)$$

Where:

- $I(\omega, i)$ can be $I_{UAS GS \rightarrow FRMCS BS}(\omega, i)$, $I_{UAS UE \rightarrow FRMCS BS}(\omega, i)$, $I_{UAS GS \rightarrow FRMCS UE}(\omega, i)$, $I_{UAS UE \rightarrow FRMCS UE}(\omega, i)$;
- $P_{N,FRMCS}$ is the noise floor of the FRMCS BS or the noise floor of the FRMCS UE.

Because TPC is involved, and in order to better understand the results when the UAS UE is the interferer, the values of $P_{UAS UE}(\omega)$ and $P_f(\omega)$ are also gathered.

A10.2 STUDY

Figure 88 gives the Cumulative Distribution Function (CDF) of $I/N|_{worst}(\omega)$ for different configurations of bandwidth, transmit power and range.

A10.2.1 Rural/low-density scenario

A10.2.1.1 Interference from UAS BS to FRMCS BS

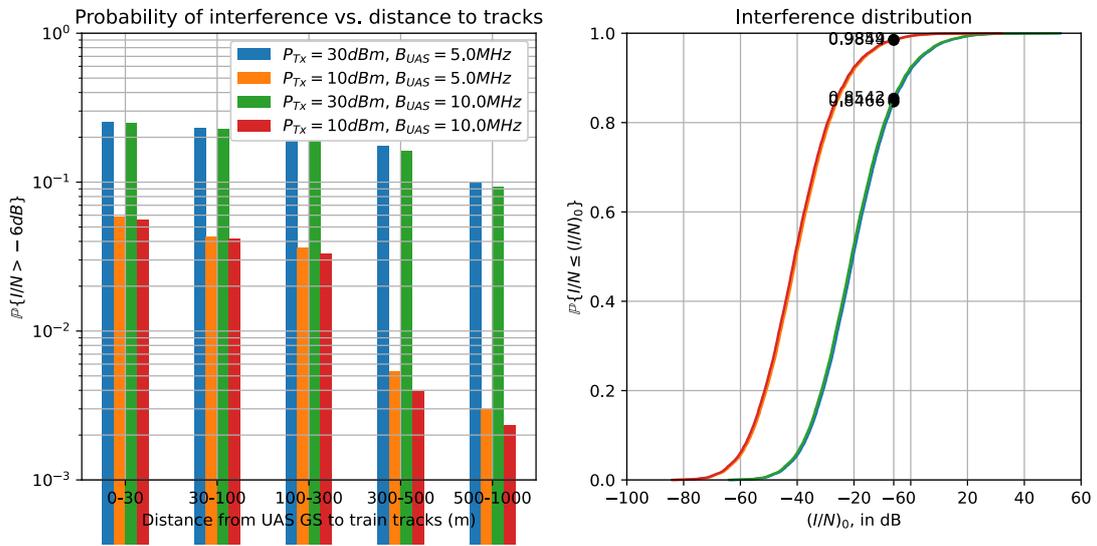


Figure 88: Rural scenario: interference from UAS BS at 1915 MHz to low-density FRMCS BS in 1900-1910 MHz, range of 5650 m

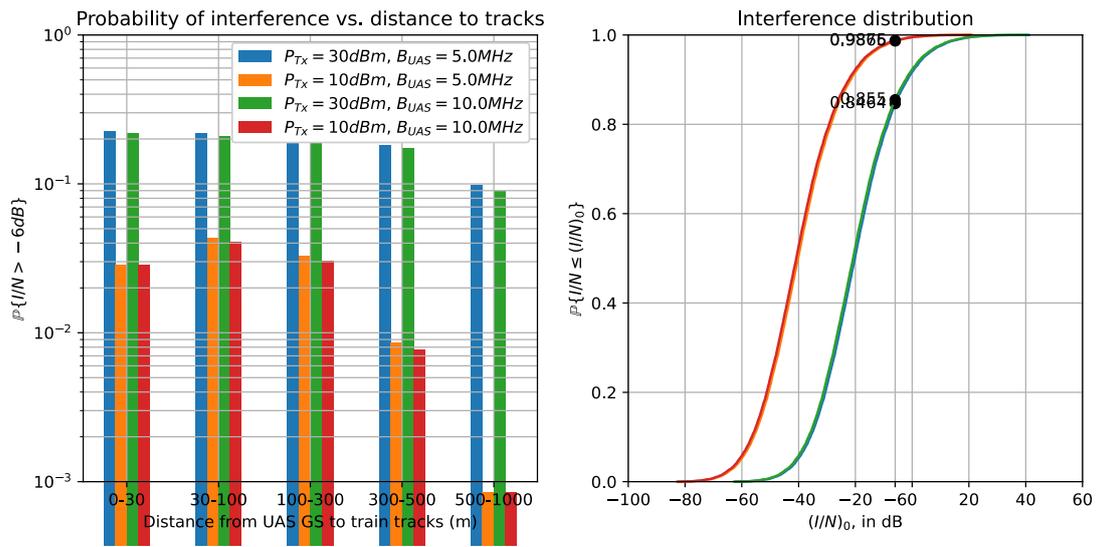


Figure 89: Rural scenario: interference from UAS BS at 1915 MHz to low-density FRMCS BS in 1900-1910 MHz, range of 1000 m

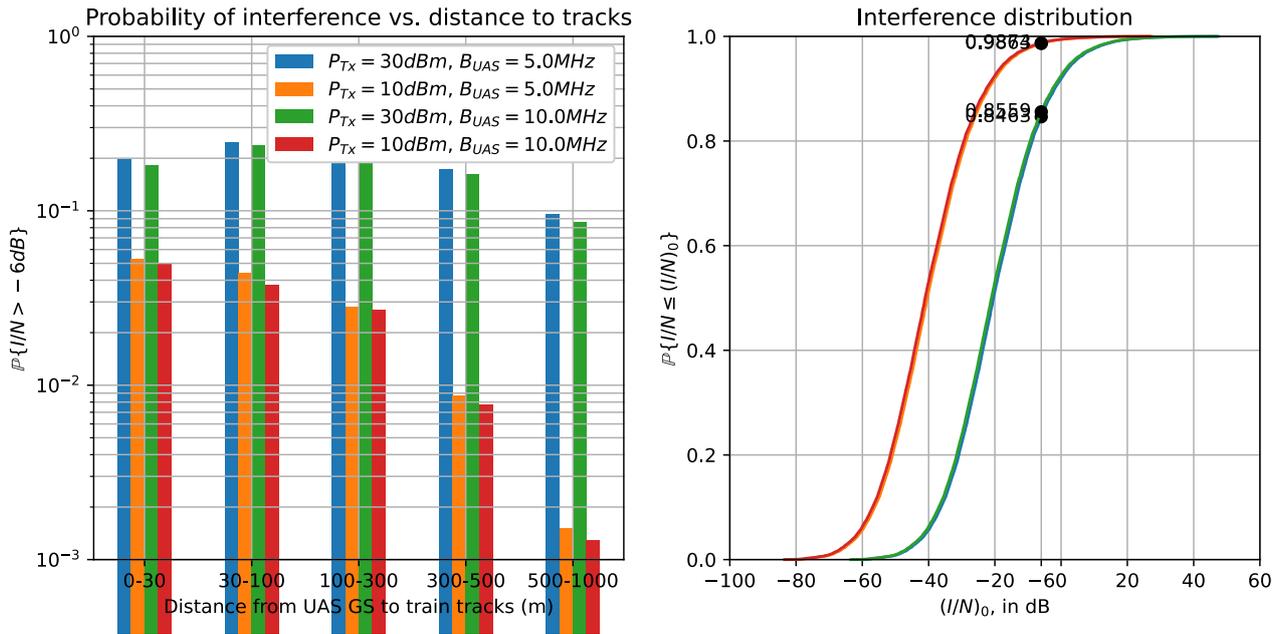


Figure 90: Rural scenario interference from UAS BS at 1915 MHz to low-density FRMCS BS in 1900-1910 MHz, range of 500 m

A10.2.1 Interference from UAS UE to FRMCS BS

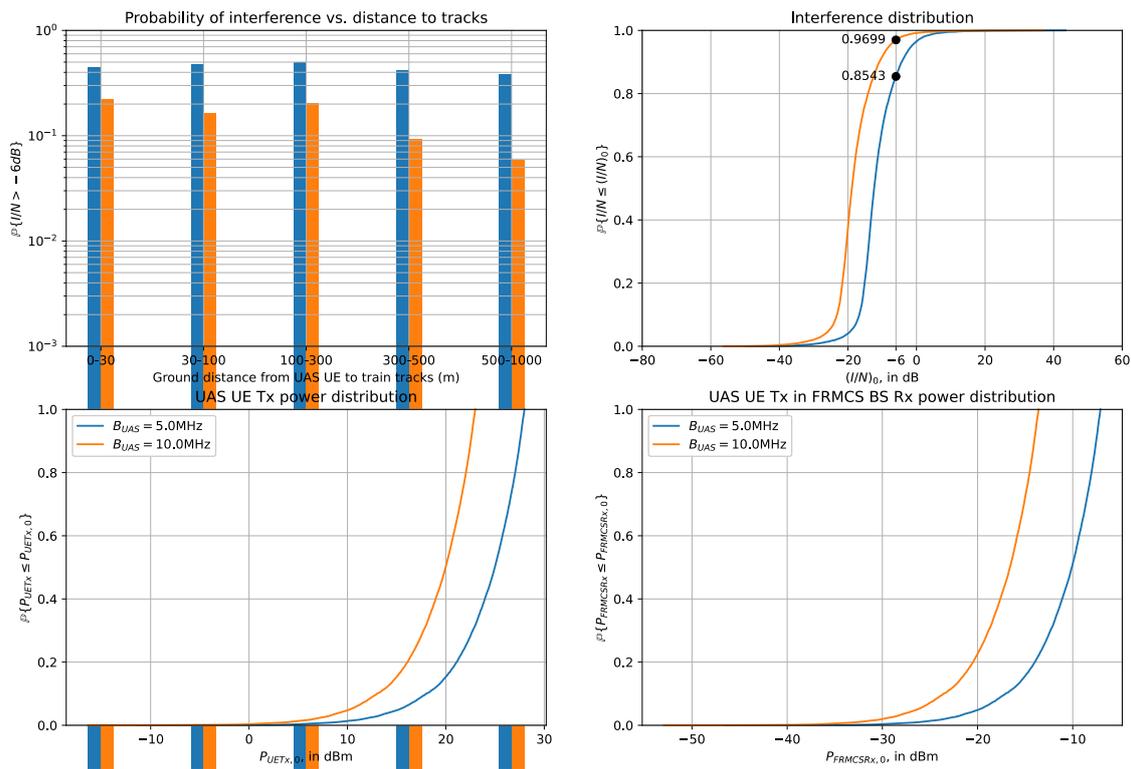


Figure 91: Rural scenario: interference from UAS UE at 1915 MHz to low-density FRMCS BS in 1900-1910 MHz, range of 5650 m

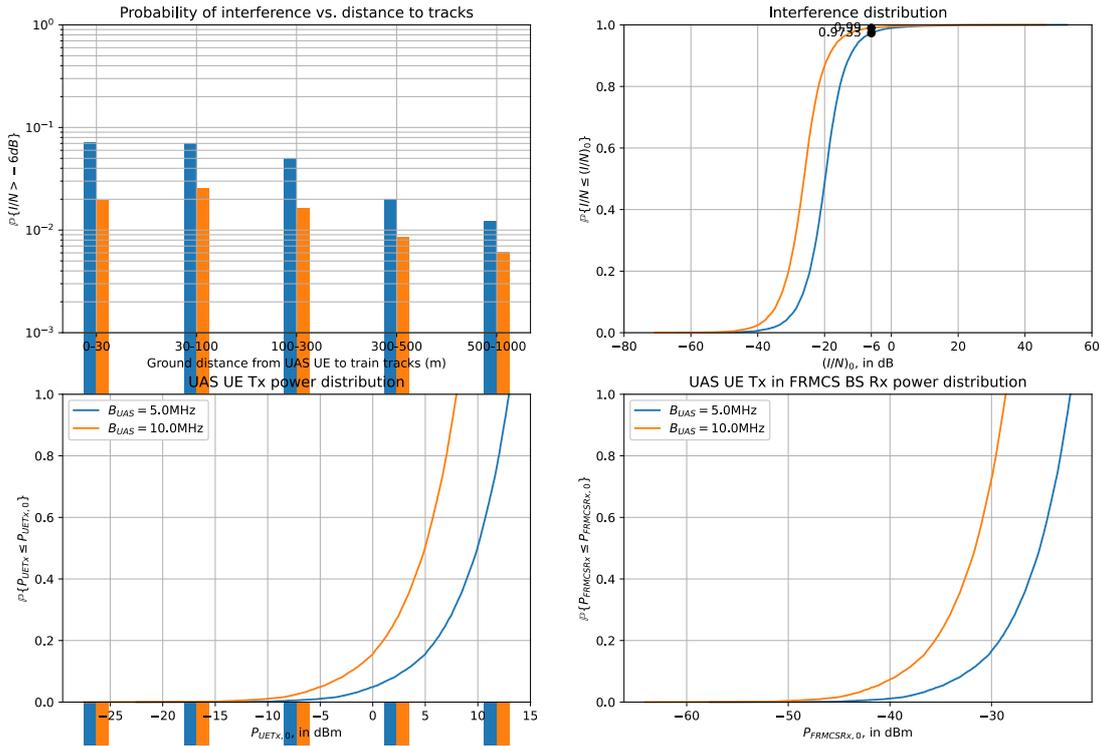


Figure 92: Rural scenario: interference from UAS UE at 1915 MHz to low-density FRMCS BS in 1900-1910 MHz, range of 1000 m

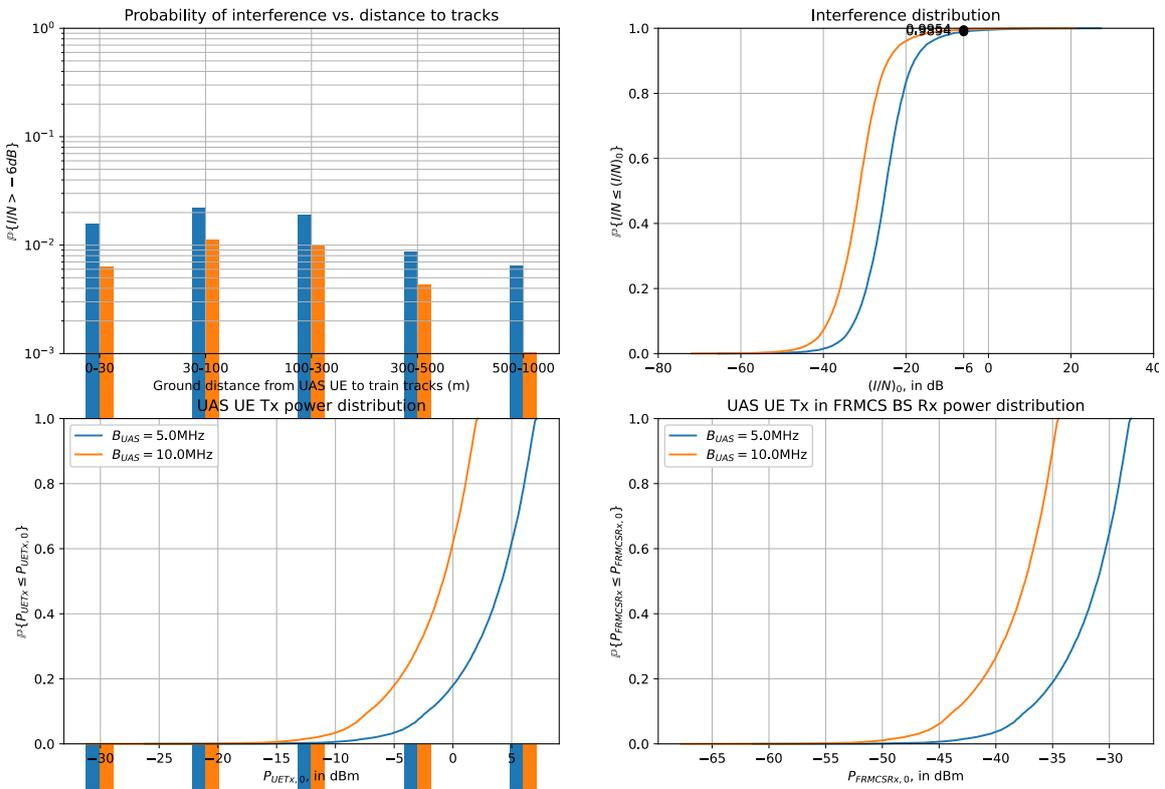


Figure 93: Rural scenario interference from UAS UE at 1915 MHz to low-density FRMCS BS in 1900-1910 MHz, range of 500 m

A10.2.2 Interference from UAS BS to FRMCS UE

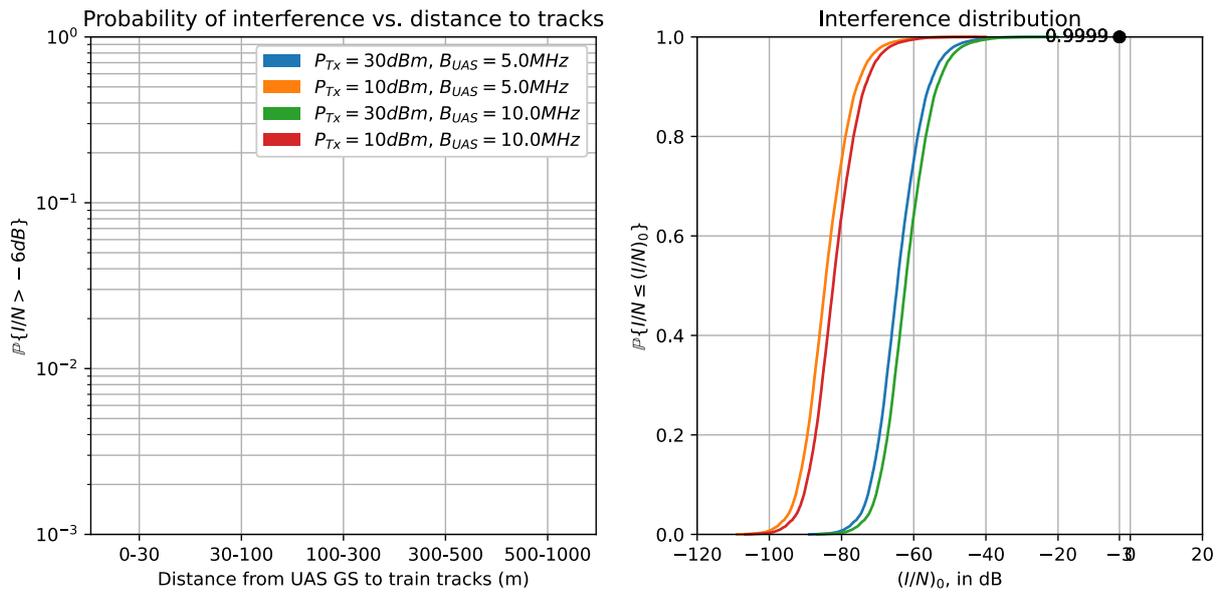


Figure 94: Rural scenario: interference from UAS BS at 1915 MHz to low-density FRMCS UE in 1900-1910 MHz, range of 5650 m

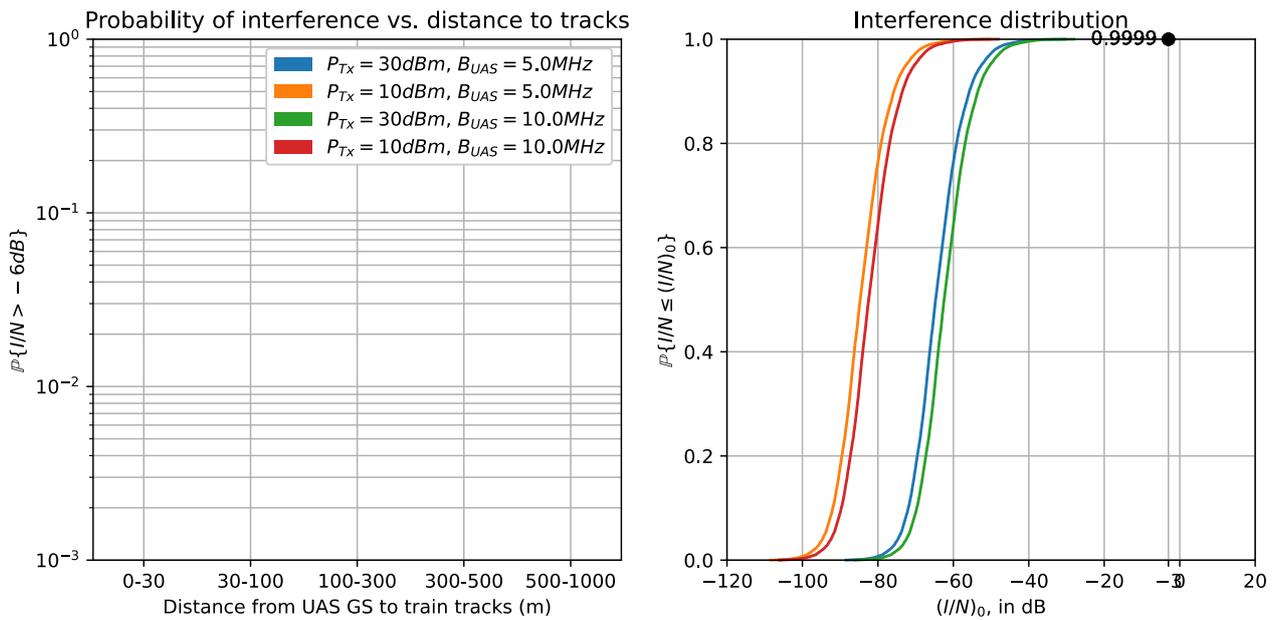


Figure 95: Rural scenario: interference from UAS BS at 1915 MHz to low-density FRMCS UE in 1900-1910 MHz, range of 1000 m

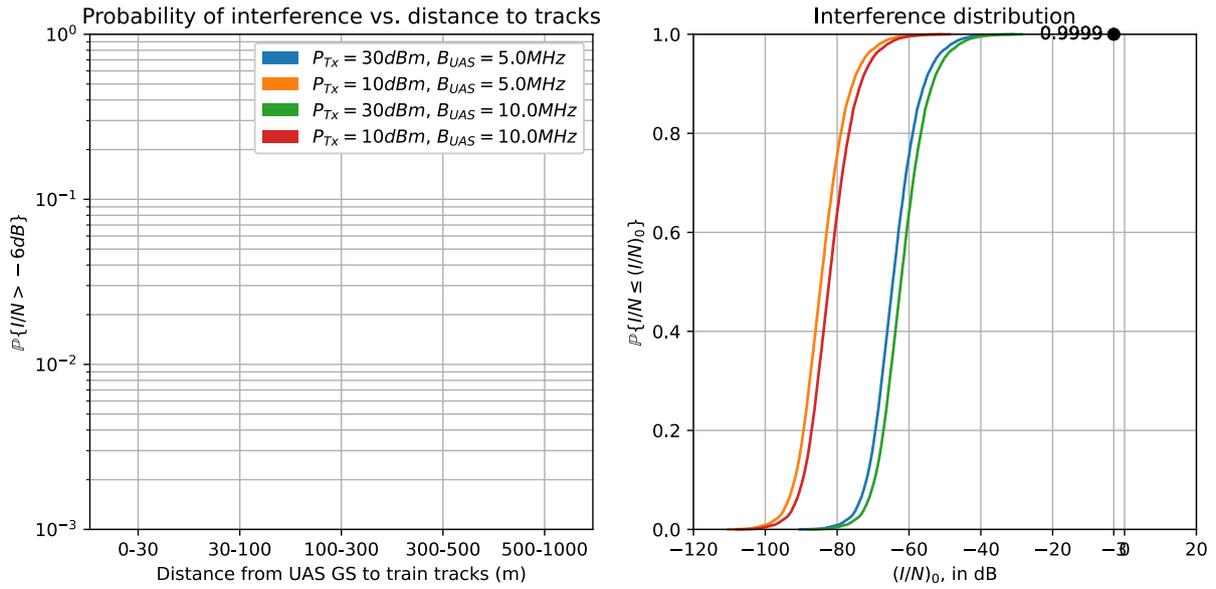


Figure 96: Rural scenario interference from UAS BS at 1915 MHz to low-density FRMCS UE in 1900-1910 MHz, range of 500 m

A10.2.2.1 Interference from UAS UE to FRMCS UE

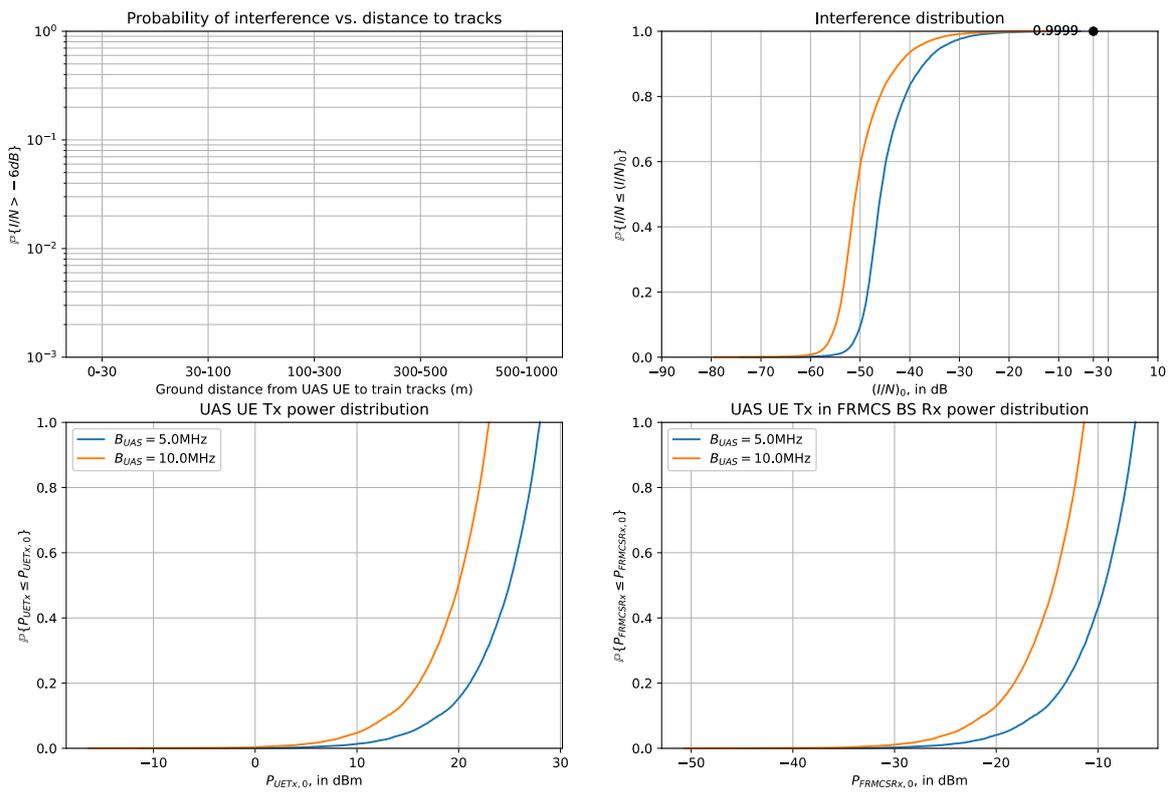


Figure 97: Rural scenario: interference from UAS UE at 1915 MHz to low-density FRMCS UE in 1900-1910 MHz, range of 5650 m

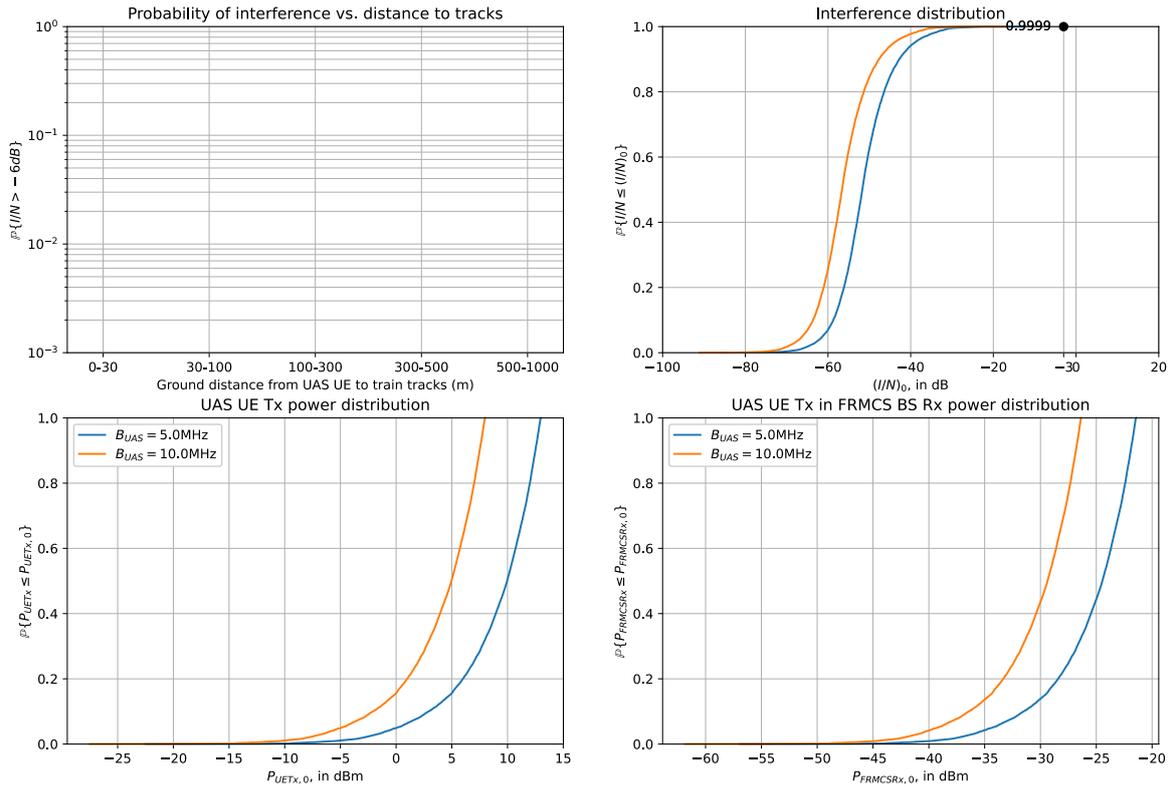


Figure 98: Rural scenario: interference from UAS UE at 1915 MHz to low-density FRMCS UE in 1900-1910 MHz, range of 1000 m

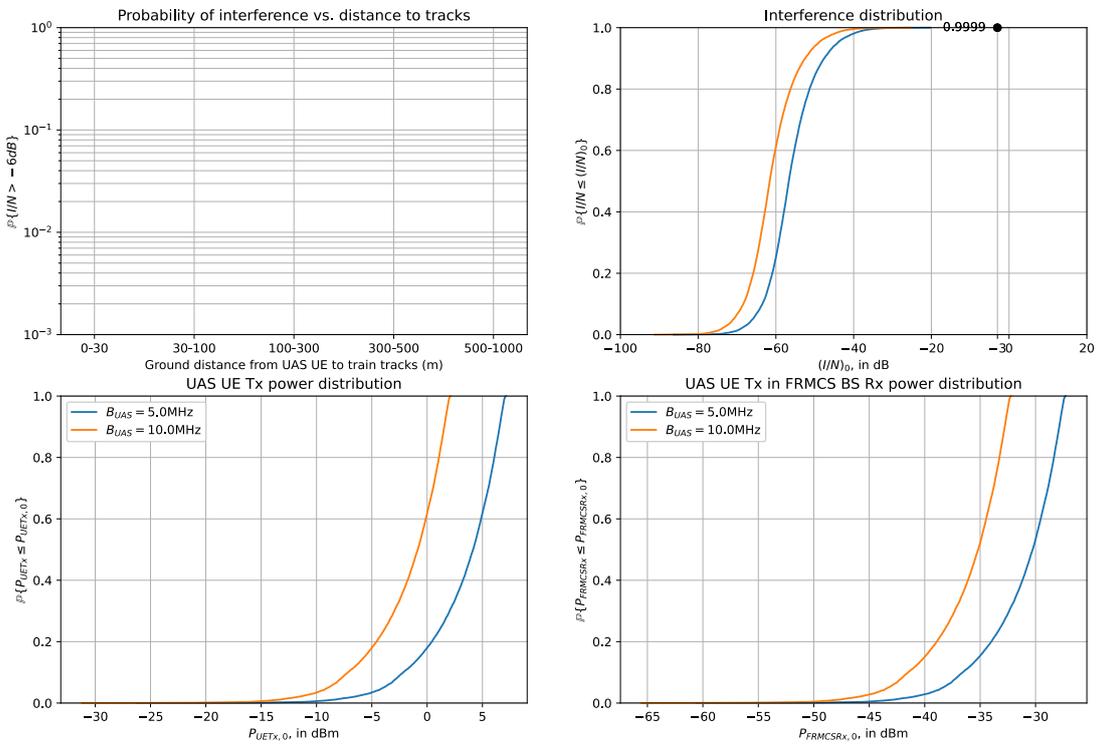


Figure 99: Rural scenario interference from UAS UE at 1915 MHz to low-density FRMCS UE in 1900-1910 MHz, range of 500 m

A10.3 RURAL/HIGH-SPEED SCENARIO

A10.3.1 Interference from UAS BS to FRMCS BS

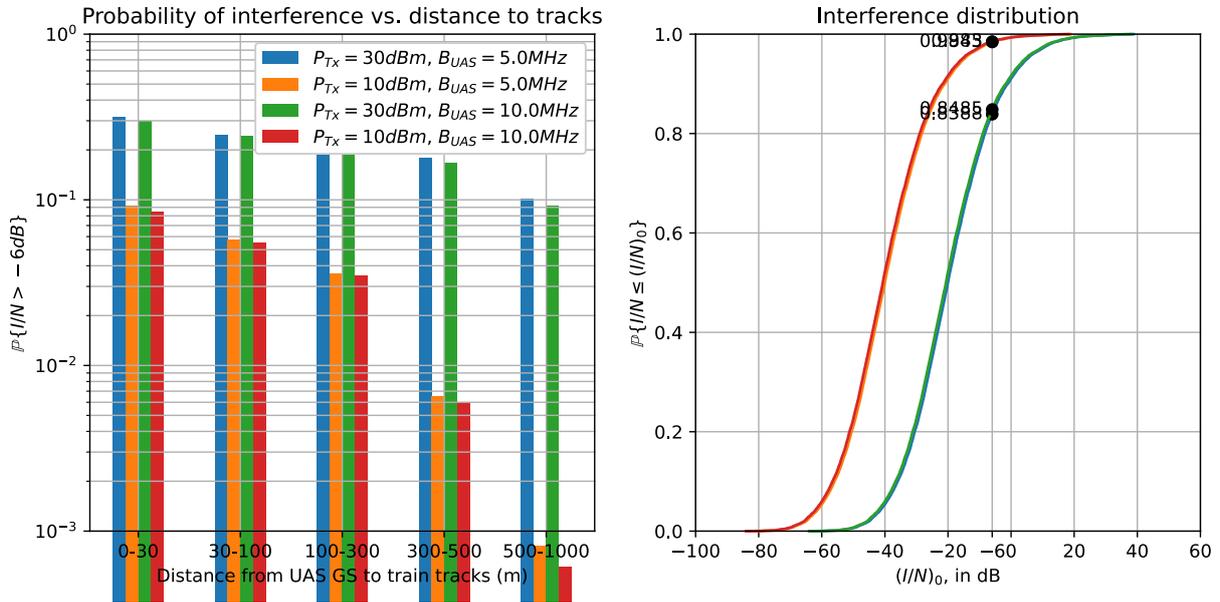


Figure 100: Rural scenario: interference from UAS BS at 1915 MHz to high-speed FRMCS BS in 1900-1910 MHz, range of 5650 m

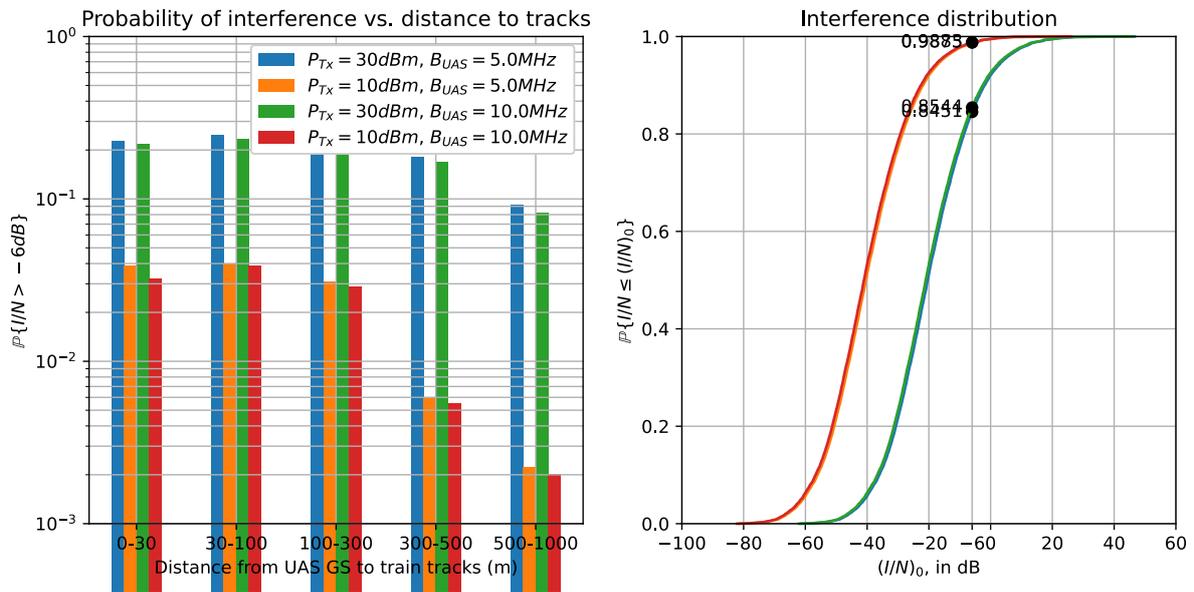


Figure 101: Rural scenario: interference from UAS BS at 1915 MHz to high-speed FRMCS BS in 1900-1910 MHz, range of 1000 m

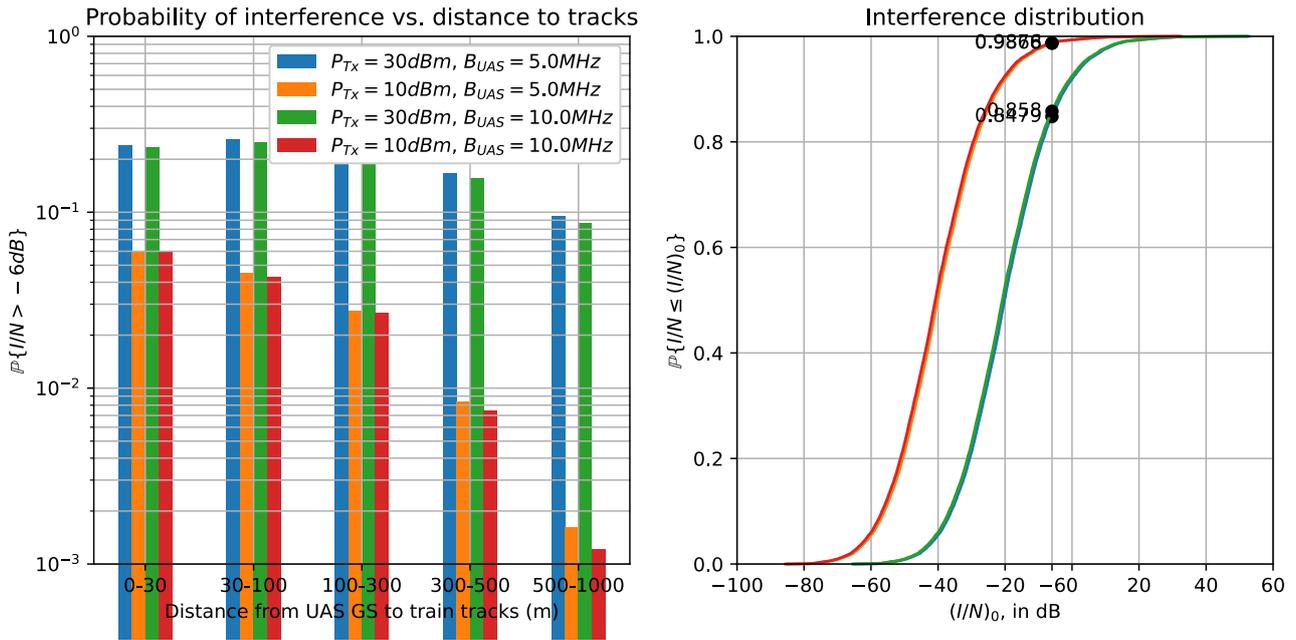


Figure 102: Rural scenario interference from UAS BS at 1915 MHz to high-speed FRMCS BS in 1900-1910 MHz, range of 500 m

A10.3.1.1 Interference from UAS UE to FRMCS BS

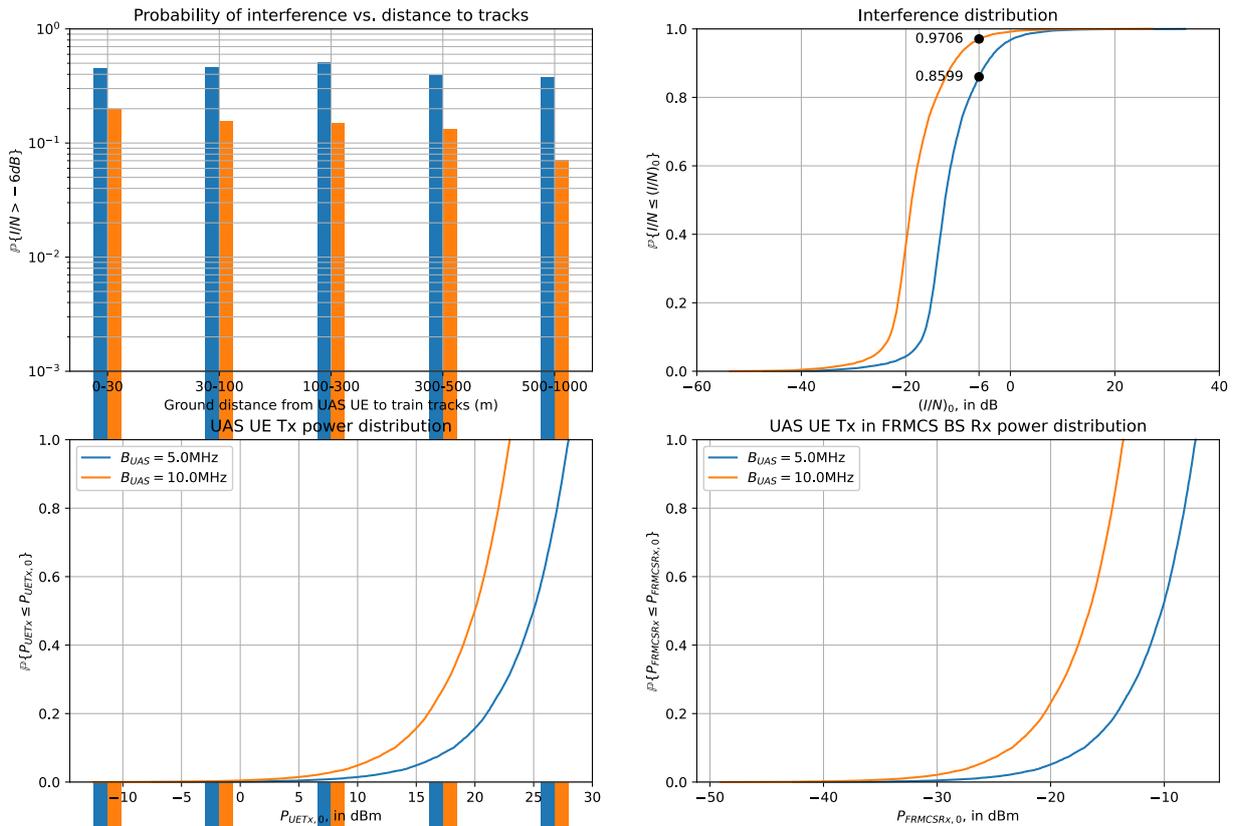


Figure 103: Rural scenario: interference from UAS UE at 1915 MHz to high-speed FRMCS BS in 1900-1910 MHz, range of 5650 m

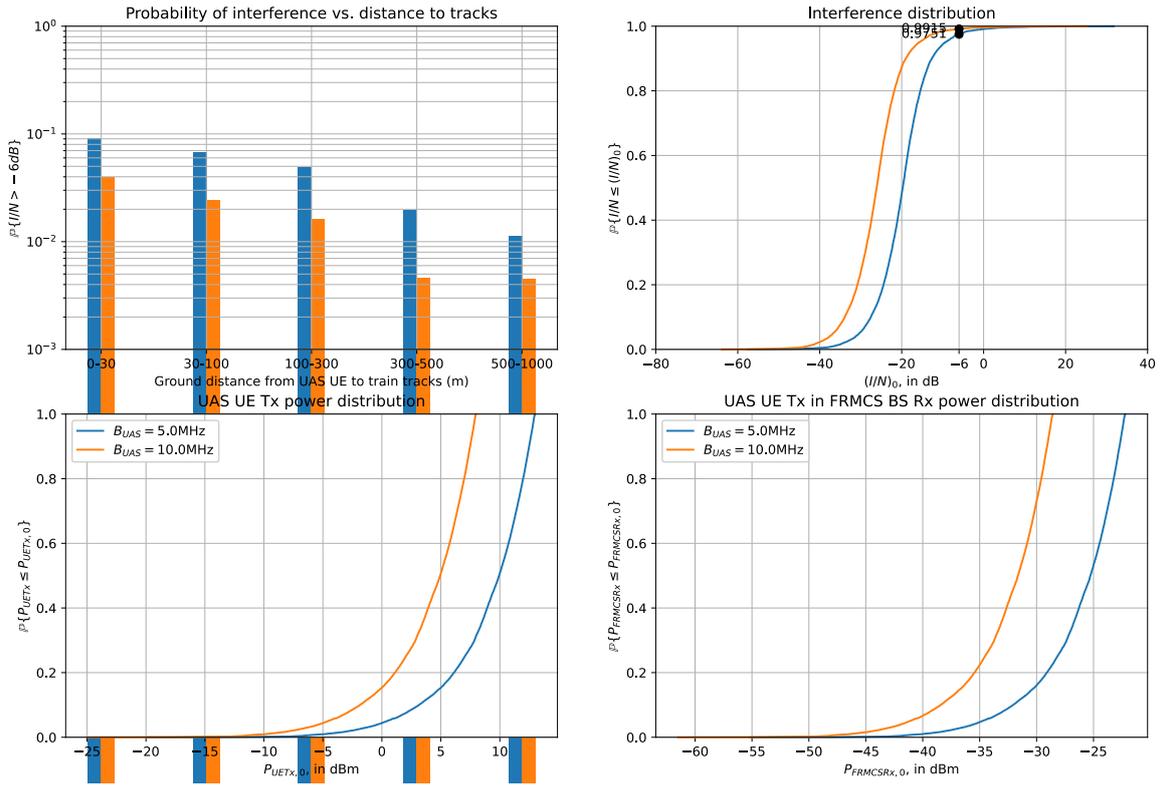


Figure 104: Rural scenario: interference from UAS UE at 1915 MHz to high-speed FRMCS BS in 1900-1910 MHz, range of 1000 m

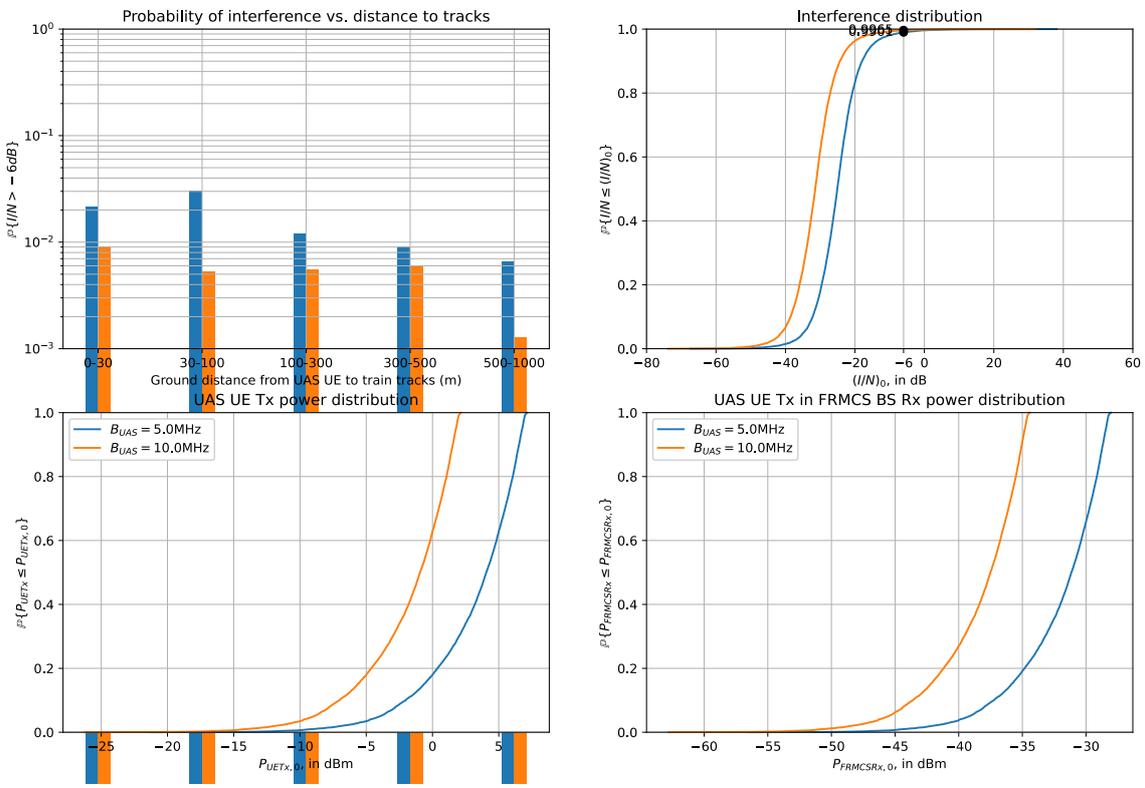


Figure 105: Rural scenario interference from UAS UE at 1915 MHz to high-speed FRMCS BS in 1900-1910 MHz, range of 500 m

A10.3.1.2 Interference from UAS BS to FRMCS UE

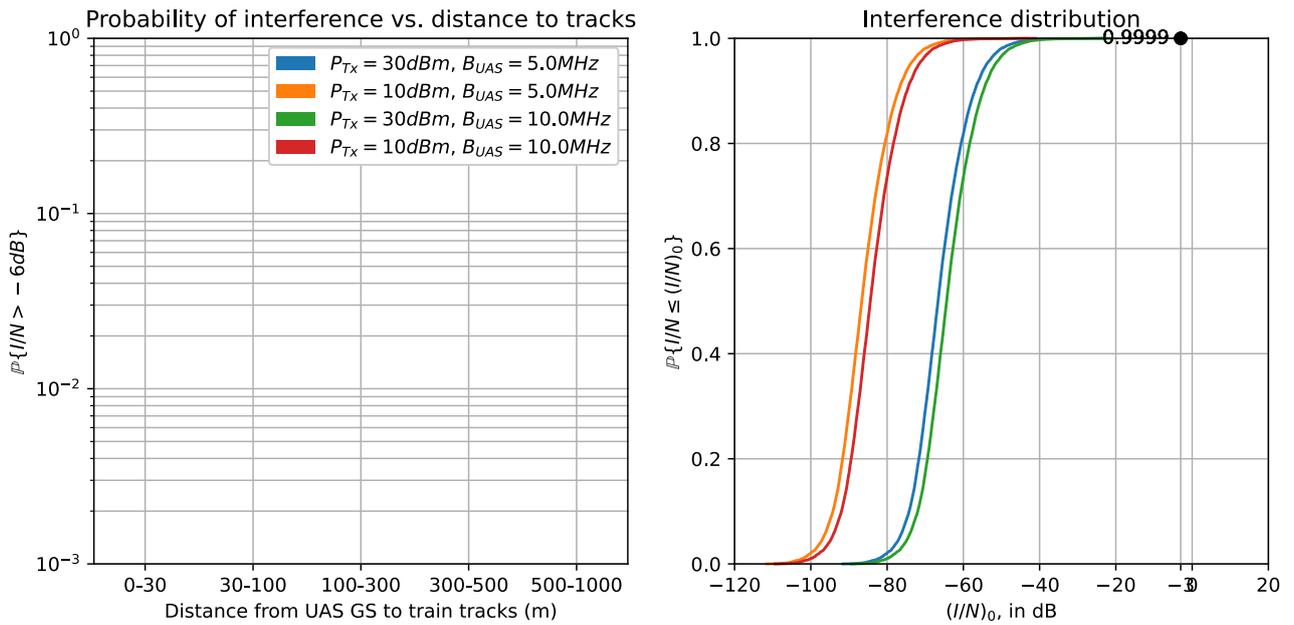


Figure 106: Rural scenario: interference from UAS BS at 1915 MHz to high-speed FRMCS UE in 1900-1910 MHz, range of 5650 m

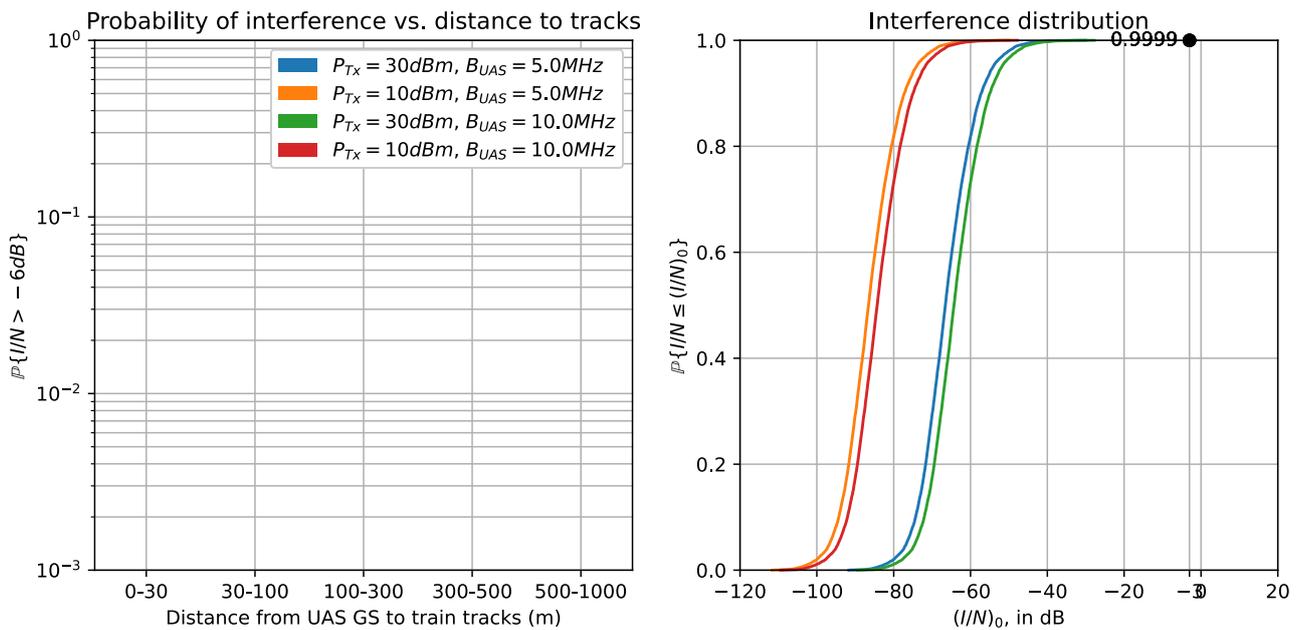


Figure 107: Rural scenario: interference from UAS BS at 1915 MHz to high-speed FRMCS UE in 1900-1910 MHz, range of 1000 m

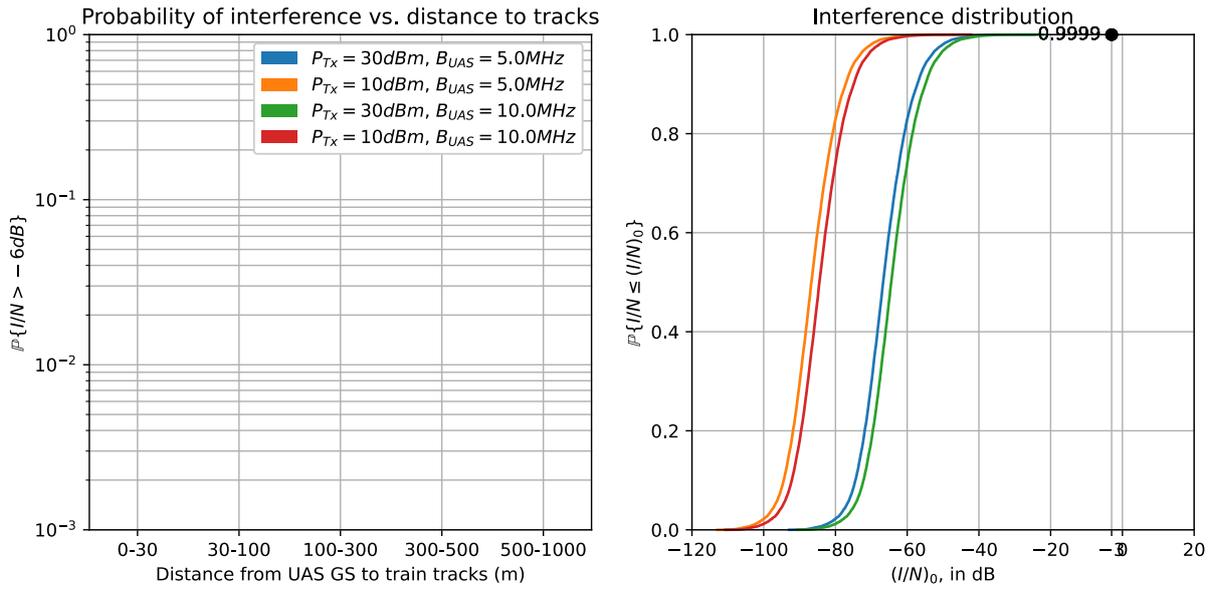


Figure 108: Rural scenario interference from UAS BS at 1915 MHz to high-speed FRMCS UE in 1900-1910 MHz, range of 500 m

A10.3.1.3 Interference from UAS UE to FRMCS UE

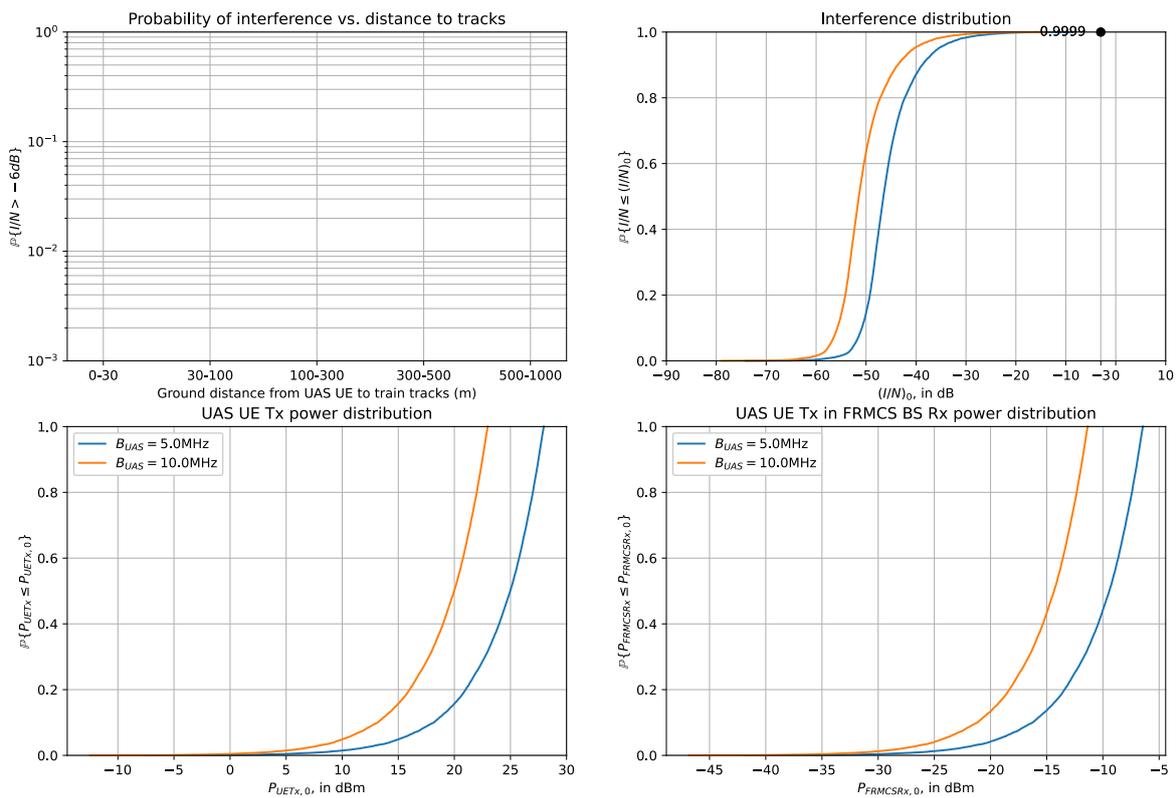


Figure 109: Rural scenario: interference from UAS UE at 1915 MHz to high-speed FRMCS UE in 1900-1910 MHz, range of 5650 m

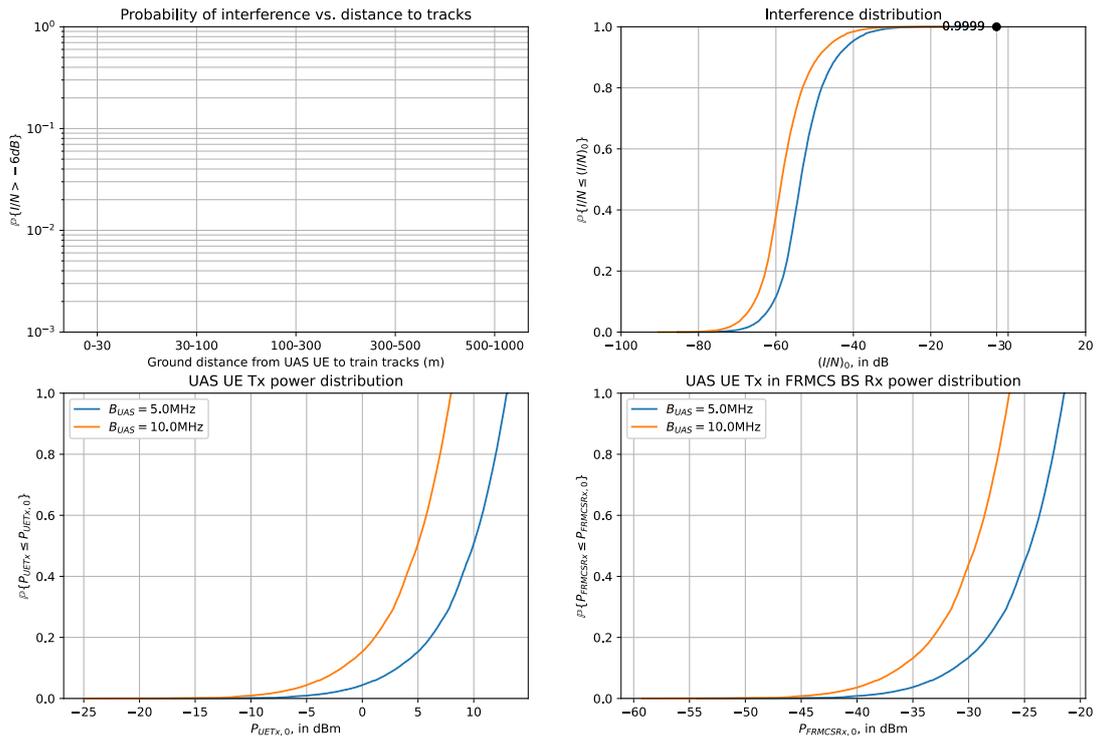


Figure 110: Rural scenario: interference from UAS UE at 1915 MHz to high-speed FRMCS UE in 1900-1910 MHz, range of 1000 m

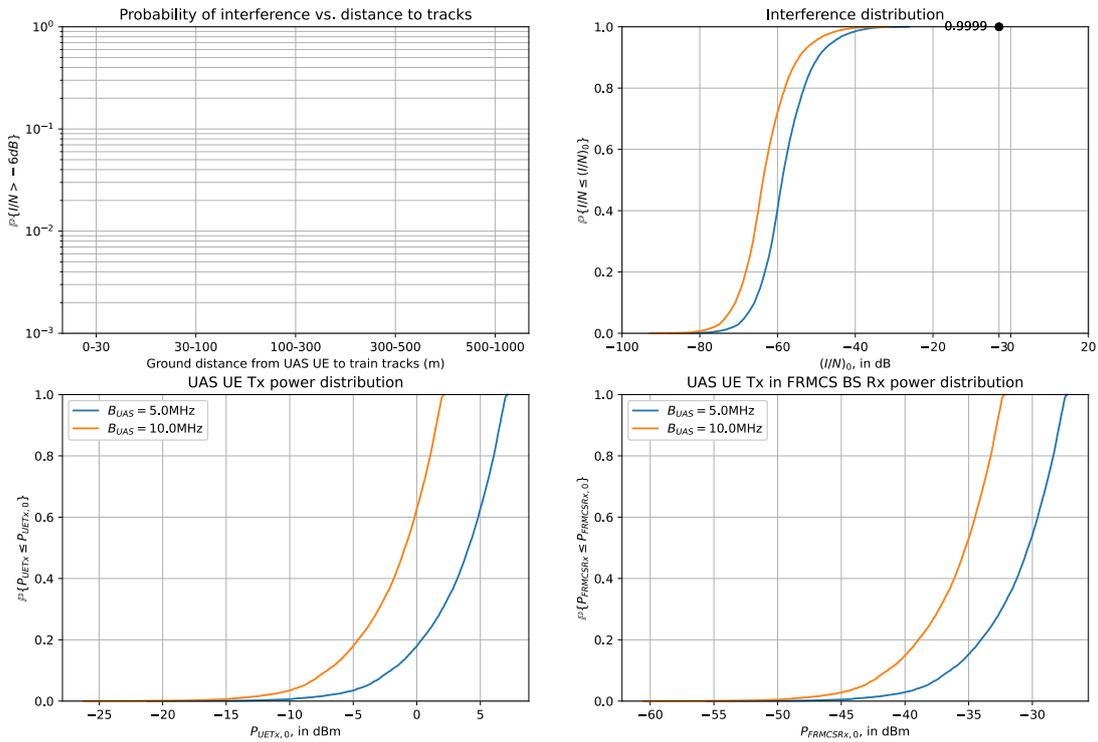


Figure 111: Rural scenario interference from UAS UE at 1915 MHz to high-speed FRMCS UE in 1900-1910 MHz, range of 500 m

A10.3.2 Urban/High-density scenario

A10.3.2.1 Interference from UAS BS to FRMCS BS

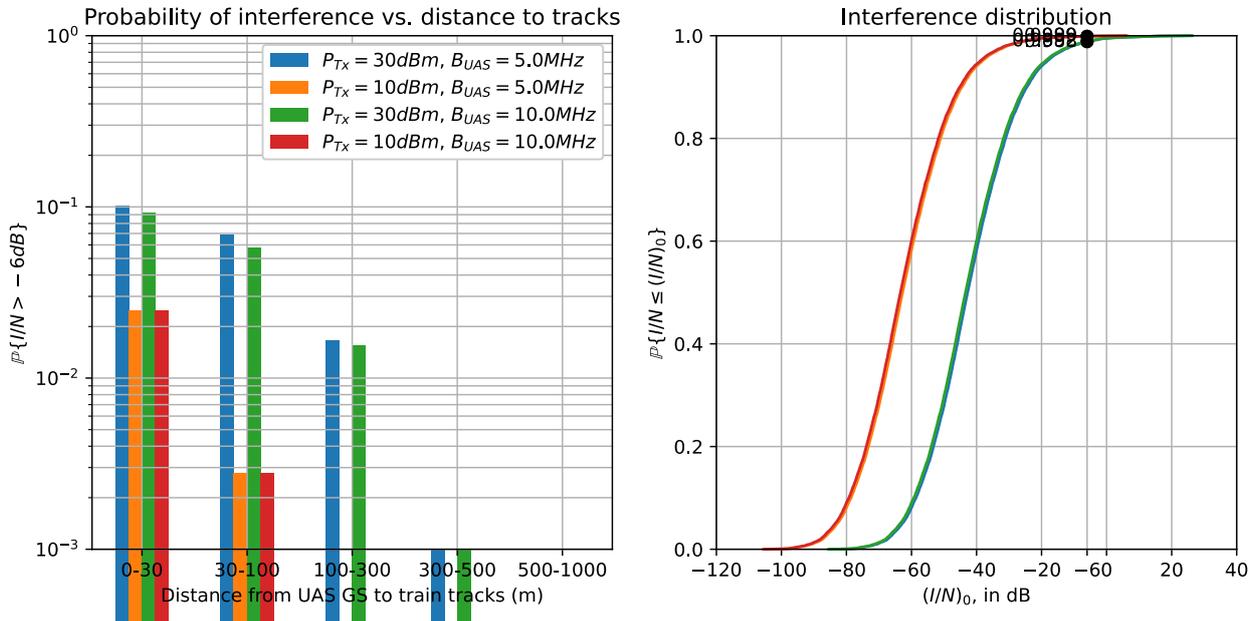


Figure 112: Urban scenario: interference from UAS BS at 1915 MHz to high-density FRMCS BS in 1900-1910 MHz, range of 1000 m

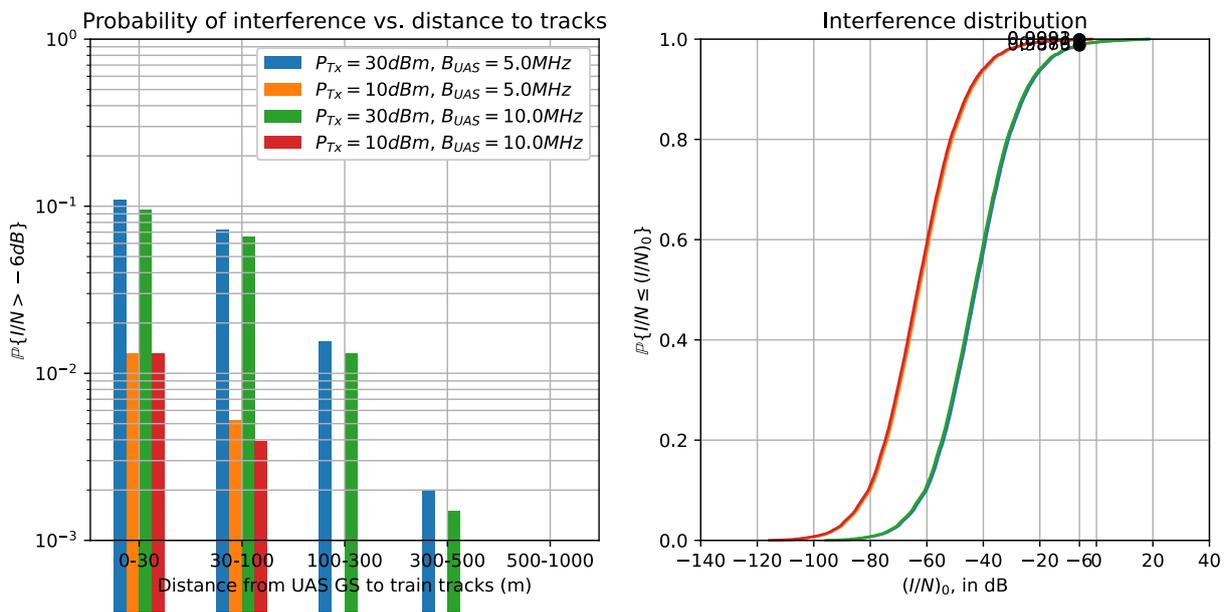


Figure 113: Urban scenario: interference from UAS BS at 1915 MHz to high-density FRMCS BS in 1900-1910 MHz, range of 500 m

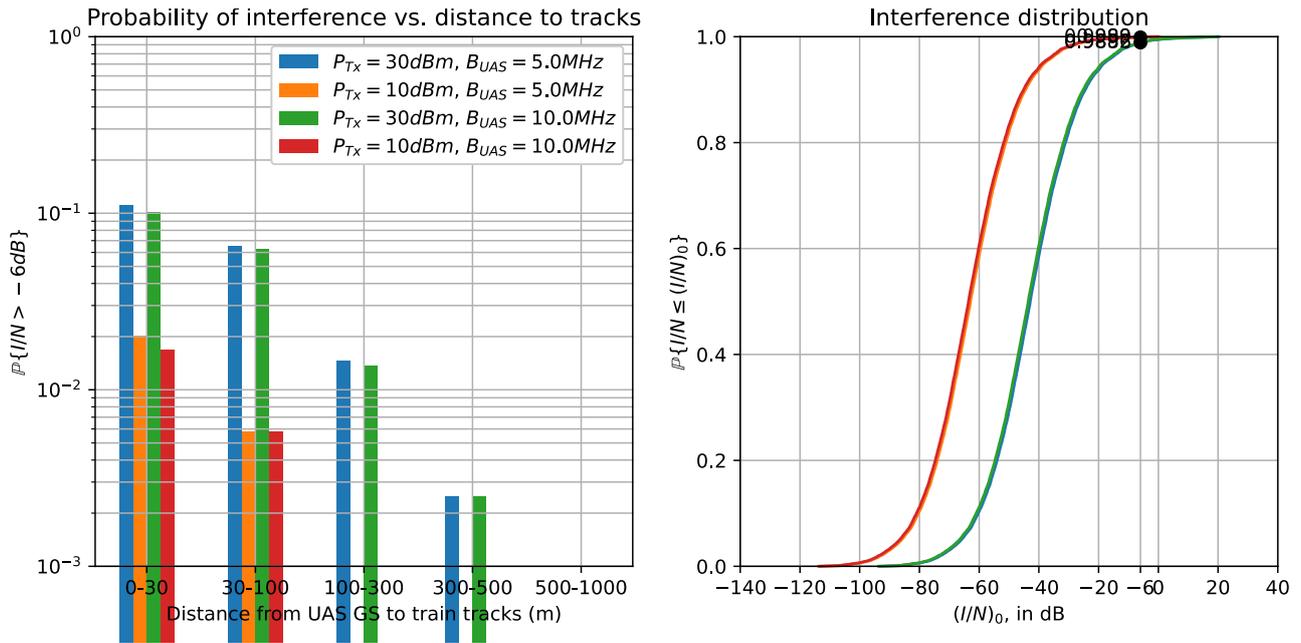


Figure 114: Urban scenario interference from UAS BS at 1915 MHz to high-density FRMCS BS in 1900-1910 MHz, range of 300 m

A10.3.2 Interference from UAS UE to FRMCS BS

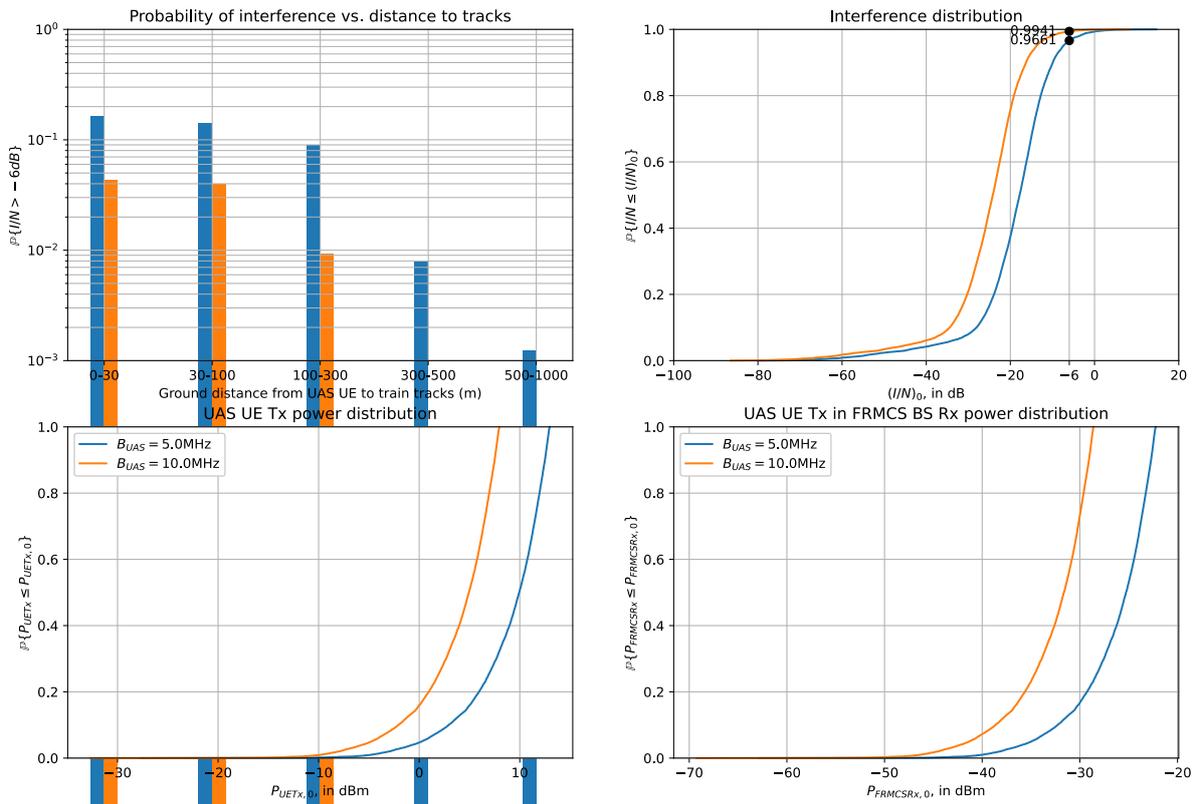


Figure 115: Urban scenario: interference from UAS UE at 1915 MHz to high-density FRMCS BS in 1900-1910 MHz, range of 1000 m

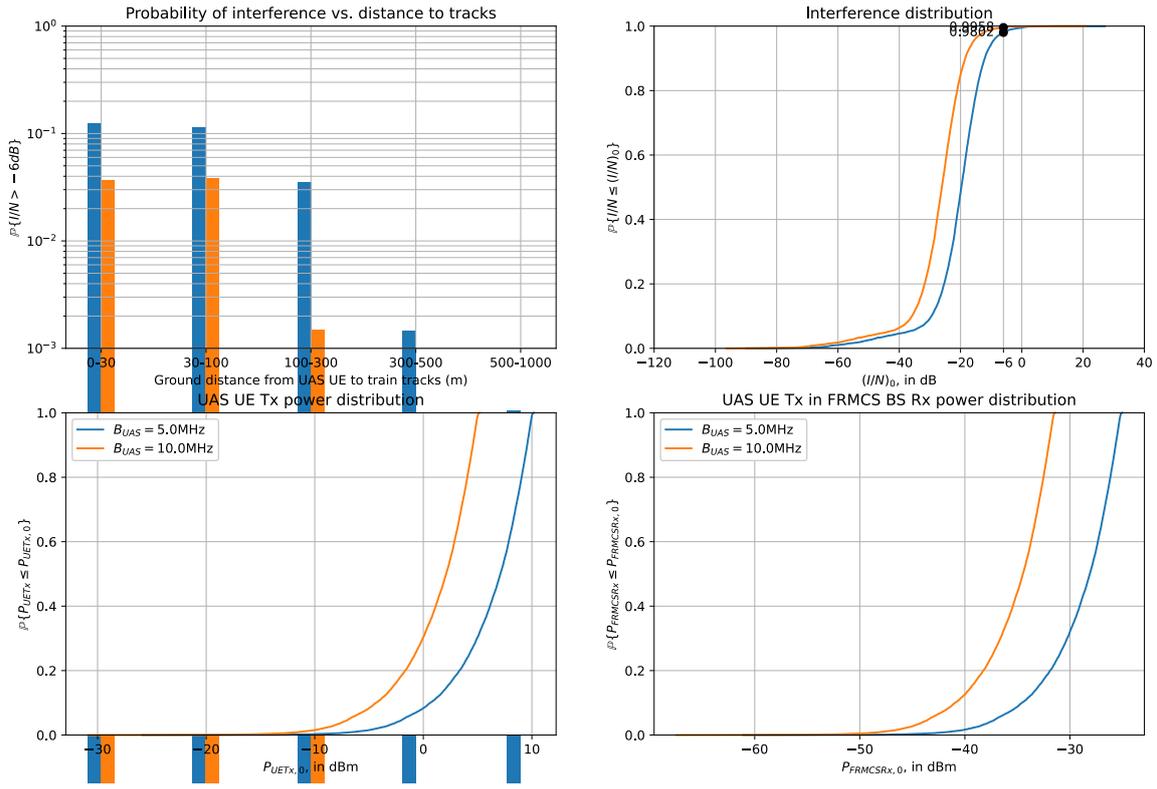


Figure 116: Urban scenario: interference from UAS UE at 1915 MHz to high-density FRMCS BS in 1900-1910 MHz, range of 500 m

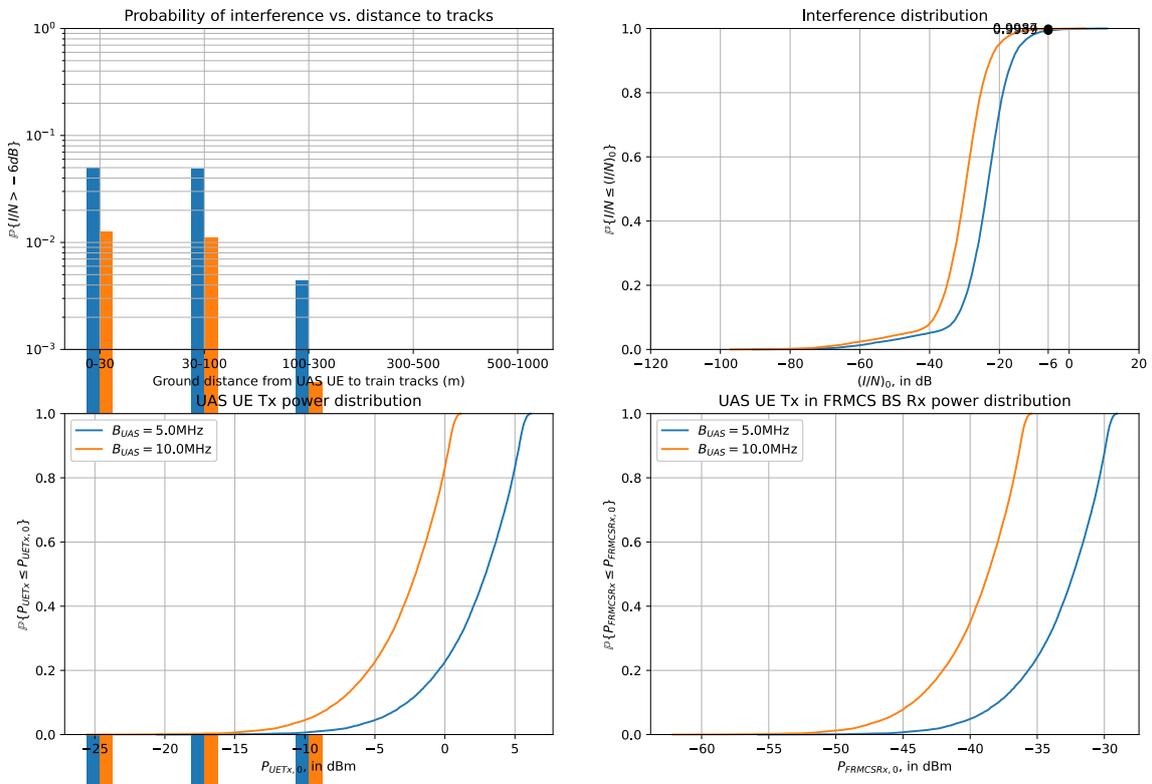


Figure 117: Urban scenario interference from UAS UE at 1915 MHz to high-density FRMCS BS in 1900-1910 MHz, range of 300 m

A10.3.3 Interference from UAS BS to FRMCS UE

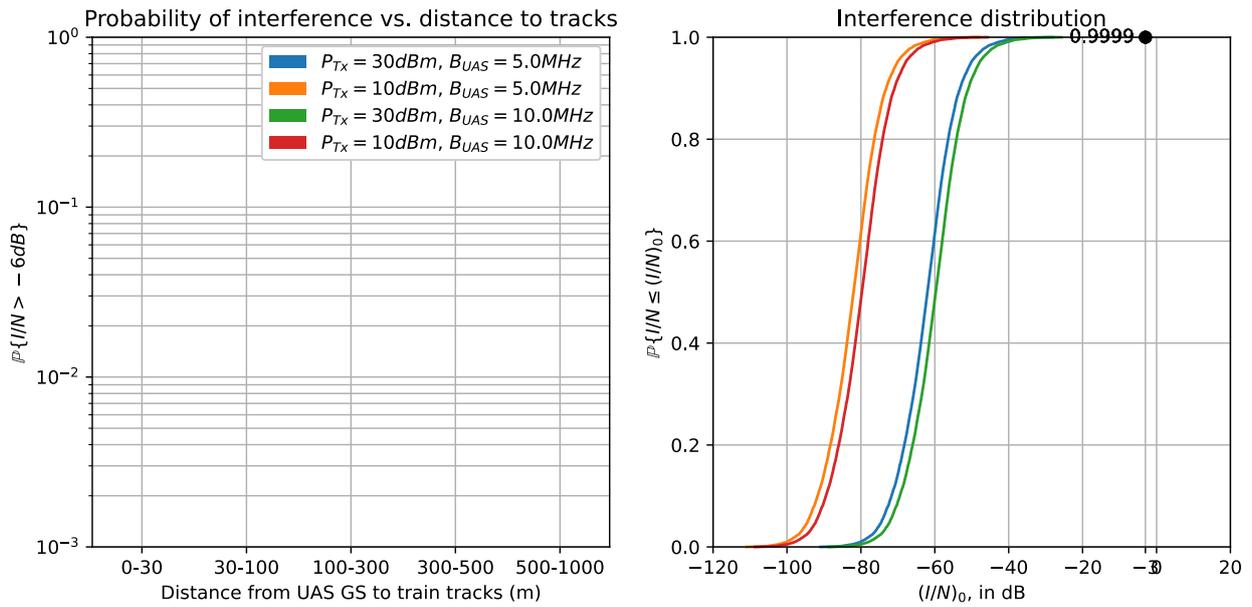


Figure 118: Urban scenario: interference from UAS BS at 1915 MHz to high-density FRMCS UE in 1900-1910 MHz, range of 1000 m

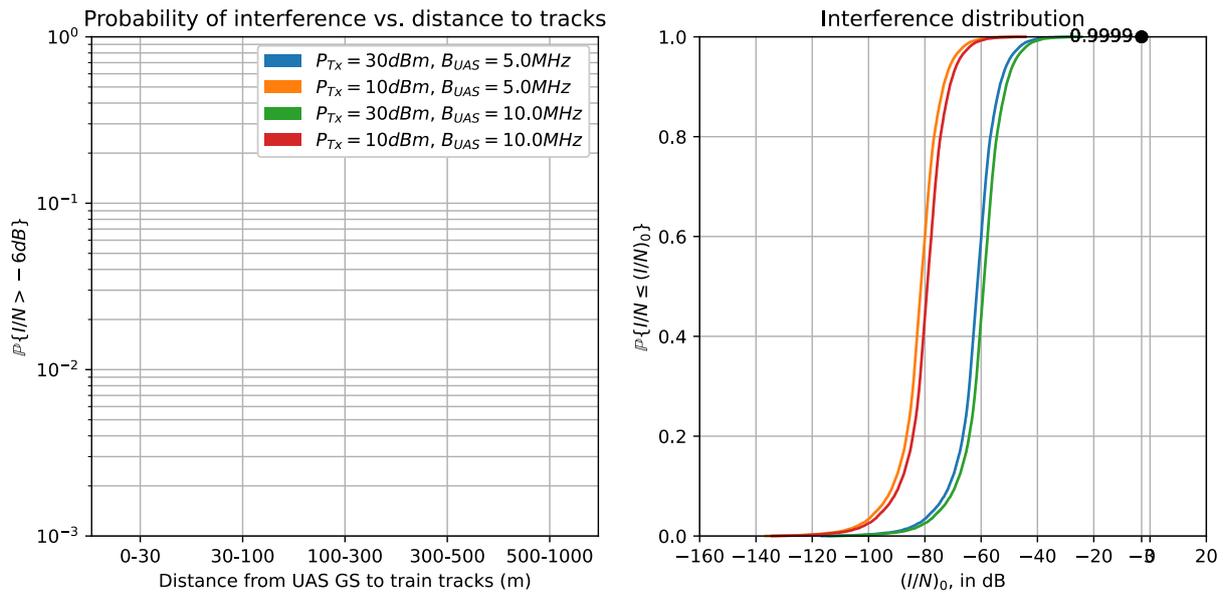


Figure 119: Urban scenario: interference from UAS BS at 1915 MHz to high-density FRMCS UE in 1900-1910 MHz, range of 500 m

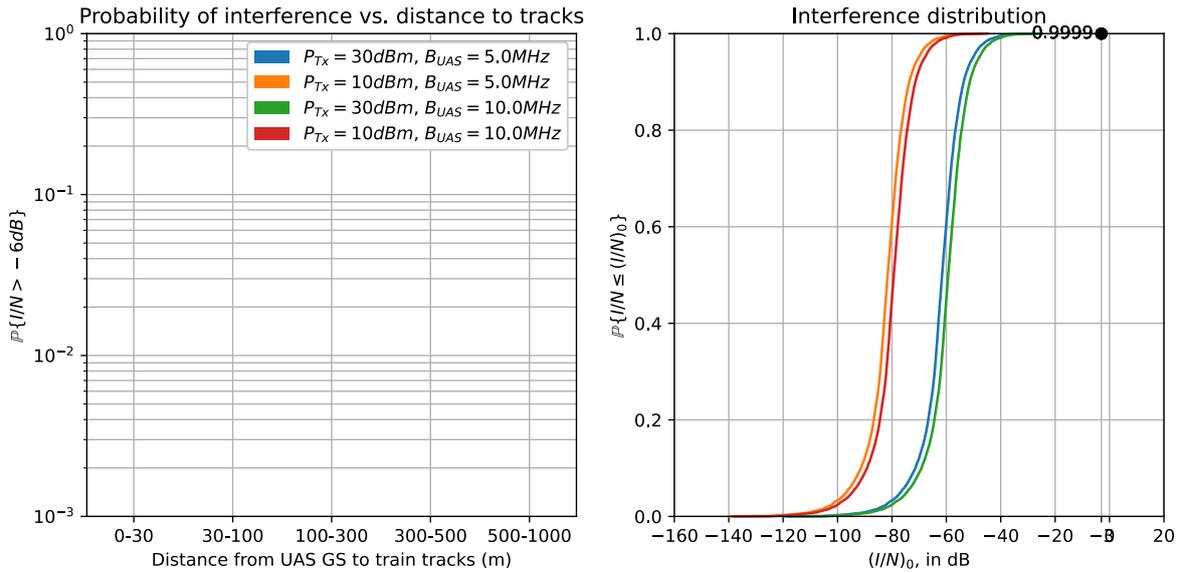


Figure 120: Urban scenario interference from UAS BS at 1915 MHz to high-density FRMCS UE in 1900-1910 MHz, range of 300 m

A10.3.3.1 Interference from UAS UE to FRMCS UE

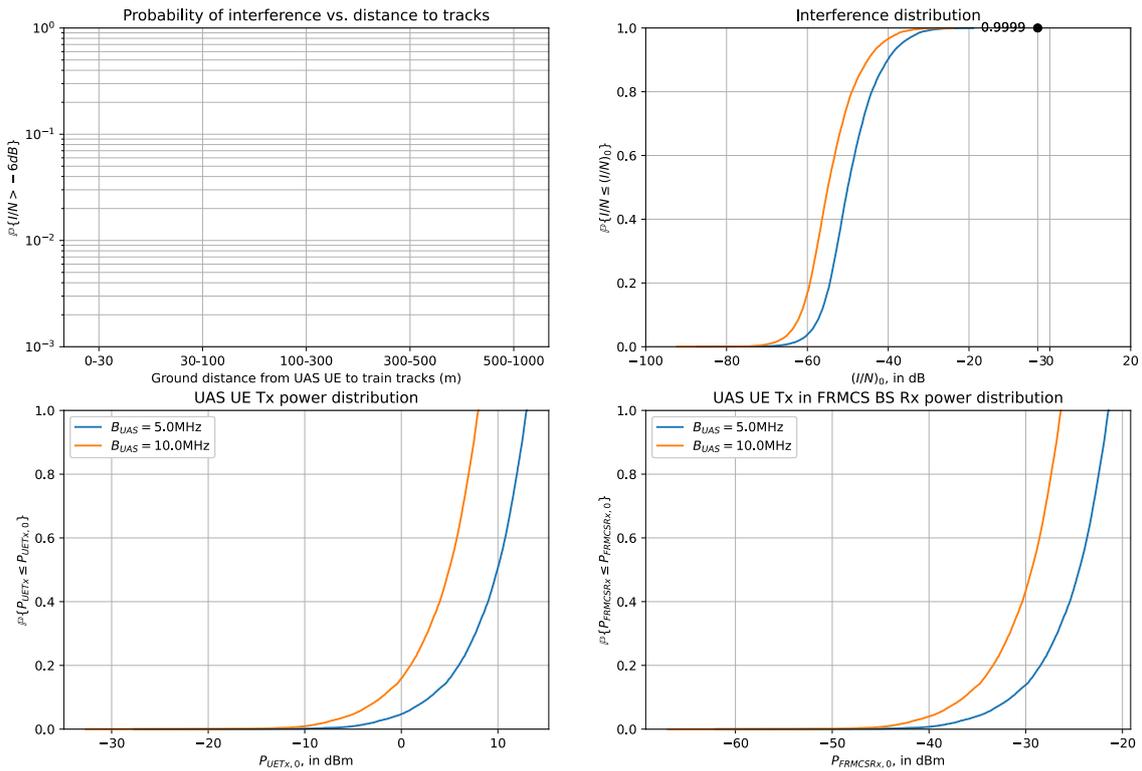


Figure 121: Urban scenario: interference from UAS UE at 1915 MHz to high-density FRMCS UE in 1900-1910 MHz, range of 1000 m

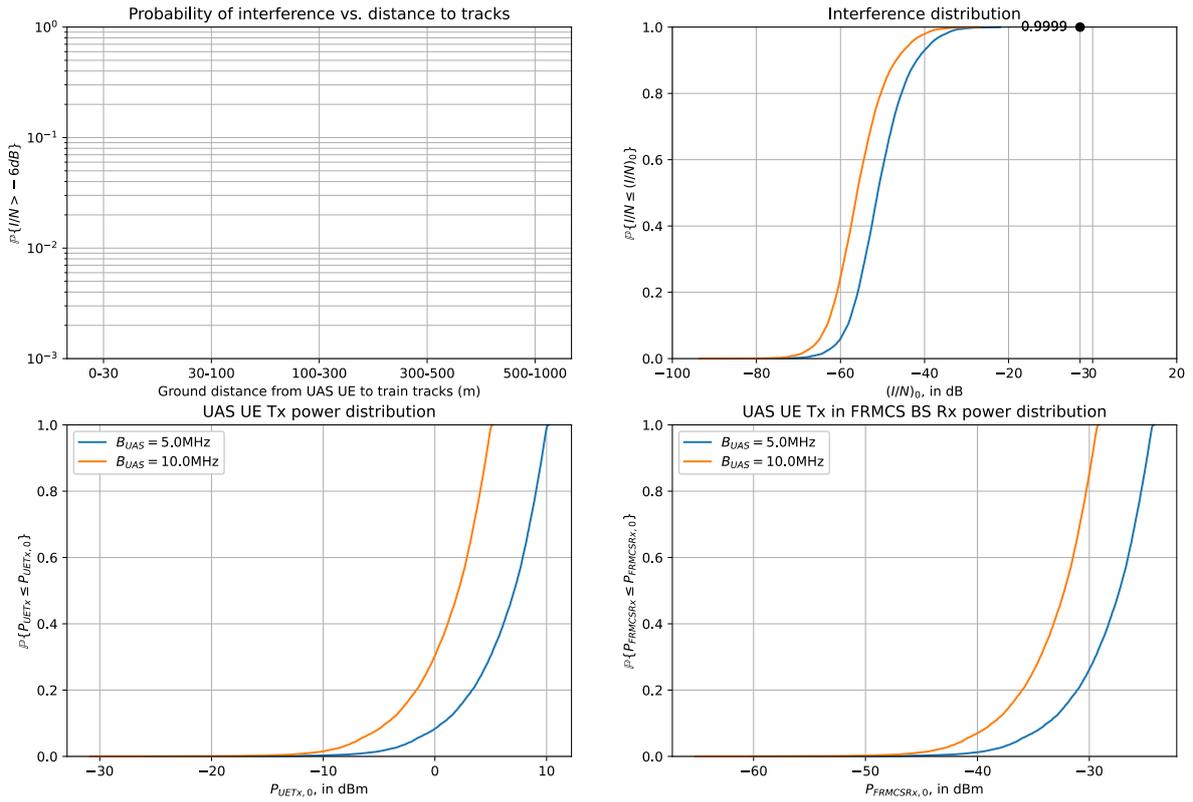


Figure 122: Urban scenario: interference from UAS UE at 1915 MHz to high-density FRMCS UE in 1900-1910 MHz, range of 500 m

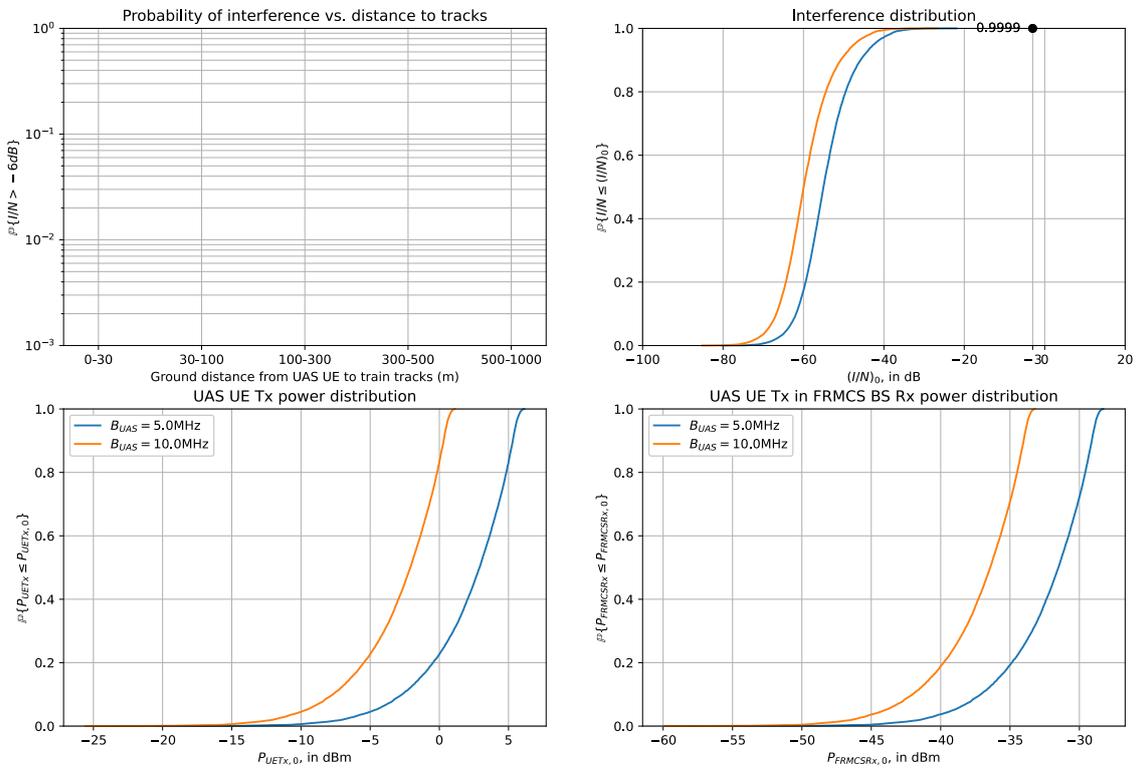


Figure 123: Urban scenario interference from UAS UE at 1915 MHz to high-density FRMCS UE in 1900-1910 MHz, range of 300 m

A10.4 MCL COMPUTATION OF UAS SEM AND FRMCS BS BEM LIMITS

The previous section shows that interference to the FRMCS BS is the most problematic. In this section, conditions on the UAS UE and BS SEM is derived, and on FRMCS BEM in order to prevent interference to FRMCS BS.

A10.4.1 UAS SEM

In order to prevent interference to the FRMCS BS, the out-of-band emissions of UAS GS in 1900-1910 MHz must satisfy:

$$P_{UAS\ GS,0oB} + G_{UAS\ GS,max} + G_{FRMCS\ BS,max} - FL_{FRMCS\ BS} - PL(d) - P_{N,FRMCS\ BS} = I/N_{thres} \quad (47)$$

Assuming, for the sake of simplicity, FSPL propagation between UAS GS and FRMCS BS, the UAS GS out-of-band emission limits are given in Table 96.

Table 96: UAS GS out-of-band emissions limits based on MCL

d (m)	$P_{UAS\ GS,0oB}$ (dBm/MHz)	$P_{UAS\ GS,0oB}$ (dBm/Hz)	I/N_{thres} (dB)	$P_{N,FRMCS\ BS}$ (dBm)	$G_{UAS\ GS,max}$ (dB)	$G_{FRMCS\ BS,max}$ (dB)	PL(d) (dB)	FL (dB)
30	-68.3	-128.3	-6	-100.98	5	18	67.63	4
100	-57.9	-117.9	-6	-100.98	5	18	78.09	4
300	-48.3	-108.3	-6	-100.98	5	18	87.63	4
500	-43.9	-103.9	-6	-100.98	5	18	92.07	4
700	-41.0	-101.0	-6	-100.98	5	18	94.99	4

Similarly, out-of-band emissions from UAS UE in 1900-1910 MHz must satisfy:

$$P_{UAS\ UE,0oB} + G_{UAS\ UE,max} + G_{FRMCS\ BS,max} - FL_{FRMCS\ BS} - PL(d) - P_{N,FRMCS\ BS} = I/N_{thres} \quad (48)$$

Assuming, FSPL propagation between UAS GS and FRMCS BS, the UAS GS out-of-band emission limits are given in Table 97.

Table 97: UAS UE out-of-band emissions limits based on MCL

d (m)	$P_{UAS\ GS,0oB}$ (dBm/MHz)	$P_{UAS\ GS,0oB}$ (dBm/Hz)	I/N_{thres} (dB)	$P_{N,FRMCS\ BS}$ (dBm)	$G_{UAS\ UE,max}$ (dB)	$G_{FRMCS\ BS,max}$ (dB)	PL(d) (dB)	FL (dB)
30	-63.3	-123.3	-6	-100.98	2	18	67.63	4
100	-52.9	-112.9	-6	-100.98	2	18	78.09	4
300	-43.3	-103.3	-6	-100.98	2	18	87.63	4
500	-38.9	-98.9	-6	-100.98	2	18	92.07	4
700	-36.0	-96.0	-6	-100.98	2	18	94.99	4

A10.4.2 FRMCS BEM

In order to prevent interference to the FRMCS BS, the 1dB desentization (corresponding to an I/N of -6dB) blocking requirement to UAS GS signals in 1910-1920 MHz and 1880-1900 MHz must satisfy:

$$I_{\text{blocking,1dB}} = P_{\text{UAS}} + G_{\text{UAS,max}} + G_{\text{FRMCS BS,max}} - FL_{\text{FRMCS BS}} - PL(d) \tag{49}$$

Taking $P_{\text{UAS,BS}} = P_{\text{UAS,UE}} = 30$ dBm for the sake of simplicity, then blocking requirements to the UAS GS (that has a higher antenna gain) are more stringent than blocking requirements to UAS UE. Hence, blocking requirements in Table 98 are computed using UAS GS characteristics.

Table 98: FRMCS BS blocking requirements in 1880-1900 MHz and 1910-1920 MHz

D (m)	$I_{\text{blocking,1dB}}$ (dBm)	P_{UAS} (dBm)	$G_{\text{UAS,max}}$ (dB)	$G_{\text{FRMCS BS,max}}$ (dB)	PL (dB)	FL (dB)
30	-18.63358388	30	5	18	67.6335839	4
100	-29.09115879	30	5	18	78.0911588	4
300	-38.63358388	30	5	18	87.6335839	4
500	-43.07055887	30	5	18	92.0705589	4
700	-45.99311959	30	5	18	94.9931196	4

A10.5 SUMMARY OF MONTE CARLO STUDY

An I/N protection criterion of -6 dB for FRMCS BS, and of -3 dB for the FRMCS UE has been considered in this study. Because of the symmetry of the FRMCS BEM and UAS SEM, these results also apply for interference from an UAS deployed at 1895 MHz.

The simulation show that interference from UAS (GS and UE UAS) to FRMCS UE is negligible. On the contrary, interference to the FRMCS BS is more likely.

When using a UAS GS transmit power of 10 dBm, the probability of interfering the FRMCS BS is less than 1% when the distance to the tracks is between 100 and 300 m in urban areas. In rural areas, this figure is reached when the distance to the tracks is between 300 and 500 m.

When using a UAS GS transmit power of 30 dBm, the probability of interfering the FRMCS BS is also less than 1% when the distance to the tracks is between 100 and 300 m in urban areas. However, at a distance between 500 and 1000 m, the interference probability is still around 10% in rural areas.

Considering the impact of the UAS UE, the interference probability is lower than 1% when the UAS UE is between 500 and 1000 m from the tracks (horizontal distance) if the range is limited to 500 m in rural areas (1000 m is only 10 MHz channel is used). In urban areas, the probability of interference is less than 1% when the UAS UE is between 300 and 500 m from the tracks (horizontal distance).

In order to mitigate interference from UAS GS or UE to FRMCS BS, the UAS out-of-band requirements of Table 96 and Table 97 could be implemented.

ANNEX 11: STUDY OF CO-CHANNEL FRMCS OPERATION WITH LTE-BASED UAS IN BAND 1900 MHZ TO 1910 MHZ

A11.1 INTRODUCTION

When considering the characteristics of UAS and the various corresponding use cases it can be envisaged that UAS will be operated in the vicinity of RMR BS and railway tracks. The worst-case arises for RMR BS when UAS is situated inside of the main beam range in the azimuth plane and operates in a co-channel situation in the 1900-1910 MHz band. The worst-case compares the interference generated by UAS operating in co-channel to RMR BS and UE operating in 1900-1910 MHz band.

The interference situation will be improved accordingly in cases, where the UAS is located in a side-lobe region and operate in an adjacent channel including a guard band between the FRMCS operational band and the UAS bands.

Especially for the border areas, where UAS operated at one side of the border and RMR is operated on the other side of the border, interference between UAS and RMR is expected. From the railway perspective, it is unclear how the impact on railway operation of this co-channel usage across country borders will be handled.

In this annex, it is assumed that the UAS is operating in a co-channel situation to FRMCS thus in the 1900-1910 MHz band. It is assumed that the UAS is in a LoS condition towards the FRMCS-BS and the FRMCS cab-radio.

A11.2 FRMCS PARAMETER

Table 99 and Table 100 give system and deployment-related parameters to be used in Co-existence studies involving FRMCS, as extracted from ECC Report 314, section 2.4. They assume that FRMCS uses 4G LTE E-UTRA.

Note: These figures are already partly included in this Report.

Table 99: FRMCS system parameters.

Parameter	Value
Operating band	E-UTRA TDD operating band n°33
Carrier centre frequency	1905 MHz
Channel bandwidth	10 MHz
TDD configuration	frame configuration 0 special subframe configuration 6
Maximum number of Resource Blocks	50
Occupied bandwidth	9 MHz
FRMCS BS receiver	
Noise Figure (NF)	5 dB (3GPP TR 36.824 or Report ITU-R M.2292-0)
Noise floor in 5 MHz	-102 dBm

I/N protection criterion	0 dB
FRMCS on-board receiver	
Noise Figure (NF)	5 dB (Data from cab-radio manufacturer)
Noise floor	-102 dBm/5 MHz
I/N protection criterion	0 dB

Table 100: FRMCS deployment-related parameters.

Parameter	Value
Parameters of FRMCS BS	
Feeder loss	4 dB
Antenna height, azimuth and tilt	Two antennas per FRMCS site 2° downtilt antenna Height not relevant for MCL calculation
Antenna type	Passive sectoral panel antennas
Antenna pattern	Recommendation ITU-R F.1336-5, section 3.1.1 or 3.1.2 with improved side-lobe efficiency: $k_p = 0.7$; $k_a = 0.7$; $k_h = 0.7$; $k_v = 0.3$
Antenna pattern parameters	Peak gain = 18 dBi / Horizontal Half-Power Beamwidth (HPBW) = 65° / Vertical HPBW = 8.5°
Antenna Discrimination	-2 dBi
Maximum allowed interfering level at BS connector	-102 dBm/5 MHz
Parameters of on-board equipment	
Hardware losses	3 dB
Antenna pattern	HUBER+SUHNER 1399.99.0121
Antenna Peak Gain	0 dBi (omni antenna)
Antenna discrimination	0 dB
Antenna height above the rail track	4 m

A11.3 UAS PARAMETERS FROM ECC REPORT 314

Table 101: Governmental UAS characteristics

Parameter	Value	Comment
Bandwidth	5 or 10 MHz	
Maximum output power	30 dBm	long range (~ 10 km)
Antenna gain	5 dBi	
TX power e.i.r..p	35 dBm	

For UAS usage, the 1880-1920 MHz band will be split in channels of 5 MHz or 10 MHz. Up to 3 UAS may be used at the same time in the same geographical area.

In this Report it is assumed that only 1 UAS flies in the vicinity of the rail tracks operating in a co-channel situation.

A11.4 CO-CHANNEL INTERFERENCE SITUATION

In a co-channel situation, a 5 MHz UAS system would be operate in the 1900-1910 MHz band and thus a full overlap of the UAS operational band with the FRMCS channel. In a worst-case scenario, a 5 MHz UAS channel would cover a 5 MHz FRMCS channel.

Table 102: Path-loss calculation for UAS UE towards FRMCS BS and Cab radio in LoS conditions

Parameter	Value	Comment
Bandwidth	5 MHz	Full overlap of UAs band and FRMCS band
Maximum output power UAS UE	30 dBm	long range (~ 10 km)
Antenna gain UAS UE	5 dBi	
TX power e.i.r..p UAS UE	35 dBm	
FRMCS BS		
Maximum allowed inferring level at BS connector	-102 dBm/5 MHz	
Antenna gain FRMCS BS towards UAS	15 dBi	Max Antenna Gain – Antenna discrimination
Minimum Path loss required	149 dB	UAS e.i.r.p.+ Max Antenna Gain – Antenna discrimination – feeder Loss – Maximum interring Level
Required separation distance	354 km	Free Space Loss
FRMCS Cab-radio		
Maximum allowed inferring level at Cab-Radio connector	-102 dBm/5 MHz	
Antenna gain FRMCS cab radio towards UAS	0 dBi	Max Antenna Gain – Antenna discrimination

Minimum Path loss required	134 dB	UAS e.i.r.p. + Max Antenna Gain – Antenna discrimination – feeder Loss – Maximum interfering Level
Required separation distance	63 km	Free Space Loss

A11.5 CONCLUSION

The studies show that a co-channel operation of UAS in the FRMCS band is not feasible and will lead to a significant interference risk towards the FRMCS operation. Under a free space loss model, all UAS in distances up to 354 km to a FRMCS BS will lead to a desensitization of at least 3 dB. In practice, the radio horizon would limit the separation distance but that does not change the conclusion. For the cab radio the separation distance is 63 km.

ANNEX 12: MONTE CARLO STUDY OF THE POSSIBLE IMPACT OF AN UAS DEPLOYMENT IN 1880-1900 MHZ TO A PROFESSIONAL DECT DEPLOYMENT.

A12.1 METHODOLOGY

A12.1.1 Space distribution of interferers and victims

This study considers a call-center deployment of DECT devices within a building. The building is randomly placed within the range of the deployed UAS (1000 m). Such deployment is illustrated in the Figures below. Within the call-center, DECT Fixed Radio Parts (FRP) are placed on a grid with 2m of separation, at an altitude of 2 m (supposed to be placed on a desk). DECT Portable Parts (PP) are randomly distributed within a rectangle of 2 m x 1 m in front of the associated FRP, at an altitude of 1.2 m (seated person). An urban environment is assumed. There are 100 DECT devices and the building is 20 m x 20 m, yielding a density of 0.25 pairs/m² (250000 pairs/km²).

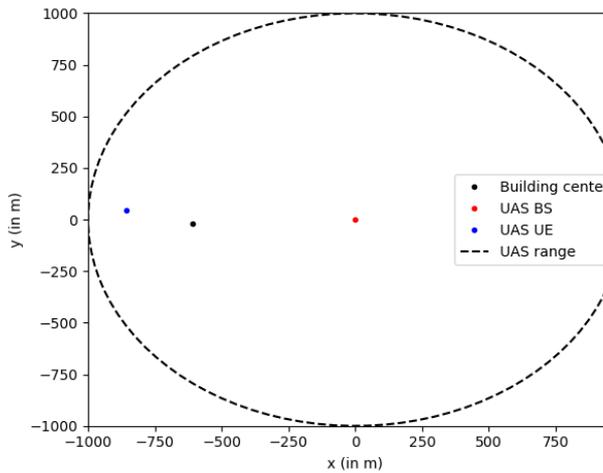


Figure 124:-Example of distribution with one UAS

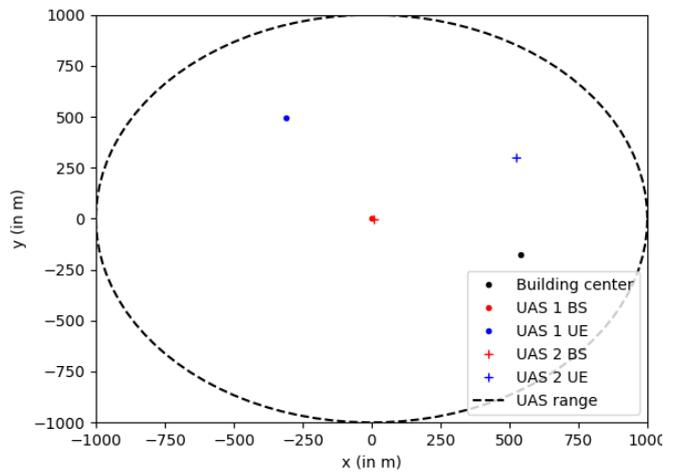


Figure 125: Example of distribution with two UAS

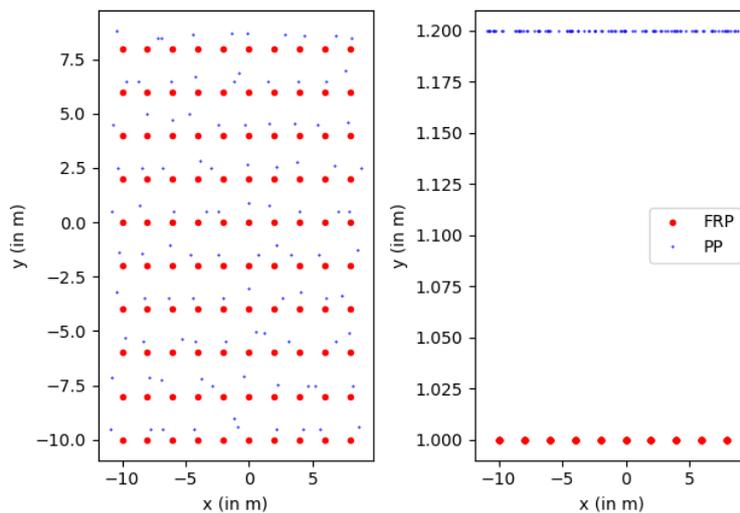


Figure 126: Example of DECT distribution within the building

A12.1.2 Hypothesis

The following hypothesis are considered:

- The UAS transmits and receives on a channel spanning 5 or 10 MHz, and centered at 1890 MHz for single drone deployment, and centered at 1885 MHz and 1895 MHz for two-drones deployments;
- Path loss between UAS GS and UAS UE (used for UE transmit power control – TPC) is computed using FSPL (street canyon like propagation of urban LoS UAS deployment);
- Path loss between DECT devices (used to compute SINR) is given in ETSI TR 103 089, annex B.4²⁴;
- Path loss between UAS GS/UE and indoor DECT is computed using FSPL, on top of which Building Entry Loss (BEL) is added, based on Recommendation ITU-R P.2109-1, as well as clutter at the UAS GS side only if the distance between the GS and the center of the building is higher than 300 m (based on ITU-R P.2108-1, model of section 3.1.1);
- Path loss between UAS GS/UE and outdoor DECT is computed using FSPL, on top of which clutter is added at the UAS GS side and the DECT Rx side, based on ITU-R P.2108-1 (model of section 3.1.1);
- The UAS GS Spectrum Emission Mask (SEM) is based on 3GPP 36.104, Table 6.6.3.2C-6 (LTE medium range BS) considering a transmit power of 30 dBm. Portions of this SEM is scaled so that ACLR values of 3GPP 36.104 Table 6.6.2.1-2 are respected in the bands concerned. When using a lower transmit power, the SEM is scaled accordingly (see Figure 127);
- The UAS UE SEM is based on 3GPP 36.101, table 6.6.3.2C-6 considering a transmit power of 30dBm. Portions of this SEM is scaled so that ACLR values of section 6.6.2.2 (for power class 1 UEs) are respected in the bands concerned. DECT transmit power of 4 dBm;
- DECT devices are supposed to form an isochronous network (all time slots begin and end at the same instant);
- DECT Dynamic Channel Selection (DCS) is unable to detect the presence of the UAS 10% of the time;
- DECT BEM (blocking edge mask) is based on ETSI TR 103 089, table B.2 and ETSI EN 300 172-2, table 5 (see Figure 127);
- DECT SEM is based on ETSI EN 300 175-2, section 5.5.1.

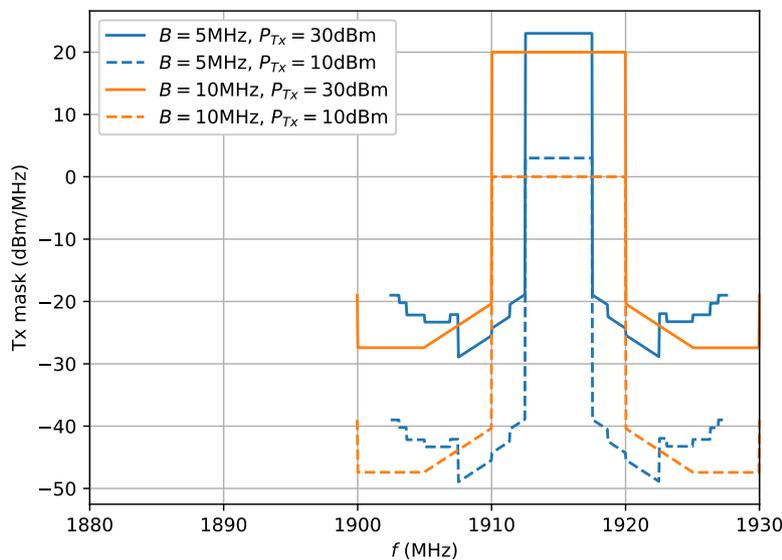


Figure 127: UAS GS SEM, based on 3GPP 36.104, Table 6.6.3.2C-6 and Table 6.6.2.1-2

²⁴ When $d \geq 4m$: $L = 38 + 30 \cdot \log_{10}(d)$, else FSPL at 1890 MHz, with d the distance between the two devices, in m.

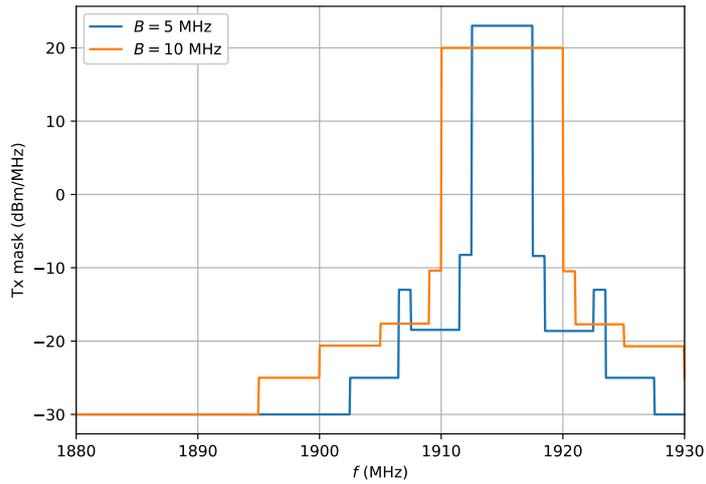


Figure 128: UAS UE SEM based on 3GPP 36.101, table 6.6.2.1.1-1, 1 and section 6.6.2.2 for a transmit power of 30 dBm [17]

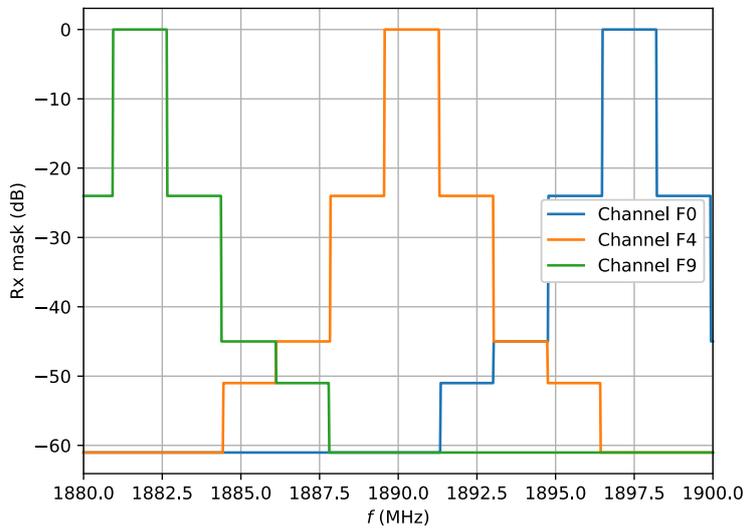


Figure 129: DECT BEM based on ETSI TR 103 089, table B.2 and ETSI EN 300 172-2, table 5

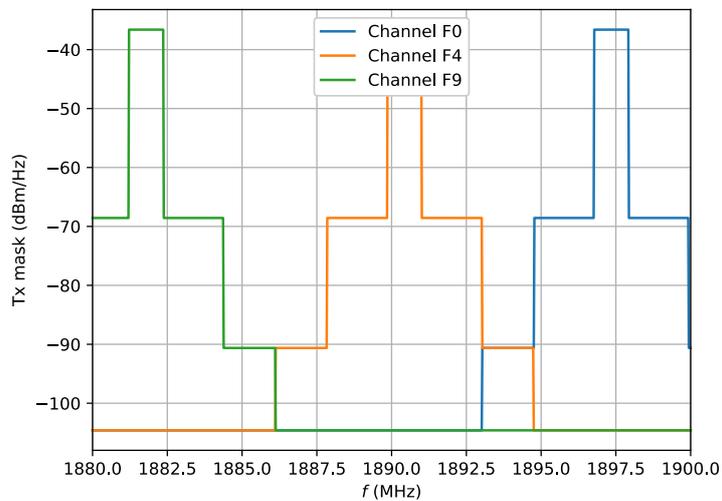


Figure 130: DECT SEM based on ETSI EN 300 175-2, section 5.5.1

A12.1.3 Model of DECT received interference

A12.1.3.1 UAS GS transmit

For each Monte Carlo run ω , the interference power as experienced from the i th DECT receiver from the UAS GS is given as:

$$I_{UAS\ GS \rightarrow DECT\ RX}(\omega, i) = P_f(Ch(i)) + G_{DECT} + G_{UAS\ GS} - PL(\vec{p}_{UAS\ GS}, \vec{p}_{DECT\ RX}(\omega, i)) - CL(\vec{p}_{UAS\ GS})$$

$$- \begin{cases} BEL(\vec{p}_{UAS\ GS}, \vec{p}_{DECT\ RX}(\omega, i)) & \text{if DECT device inside} \\ CL(\vec{p}_{DECT\ RX}(\omega, i)) & \text{if DECT device outside} \end{cases}$$

If the time offset between the beginning of DECT device i TDD frame and the beginning of the UAS GS TDD frame is such that device i receives while the UAS GS transmits (see figure below). Else, it is obtained:

$$I_{UAS\ GS \rightarrow DECT\ RX}(\omega, i) = -\infty \text{ [dBm]}$$

Where:

- $P_f(chan) = 10 \cdot \log_{10}(\int_{-\infty}^{+\infty} SEM_{UAS\ GS}(f) \cdot BEM_{DECT\ RX}(f, chan) df)$ is the fraction of the interferer power falling into the receiver's band (in dBm). It depends on the channel on which the DECT pair communicated.
 - $SEM_{UAS\ GS}(f)$ is the SEM of the UAS GS, scaled to the UAS GS transmit power (in mW/Hz).
 - $BEM_{DECT\ RX}(f, chan)$ is the BEM of the DECT receiver, operating on channel $chan$.
- i denoted the i -th DECT device deployed.
- $Ch(i)$ is the channel on which the i th DECT device communicates.
- G_{DECT} is the gain of the DECT antenna (in dBi)
- $G_{UAS\ GS}$ is the gain of the UAS GS (in dBi).
- $PL(\vec{p}_1, \vec{p}_2)$ is the path loss between the two points in space described by vectors \vec{p}_1 and \vec{p}_2 (dB).
- $\vec{p}_{DECT\ RX}(\omega, i)$ vector describing the position in space of the i th DECT receiver, at Monte Carlo run ω .
- $\vec{p}_{UAS\ GS}$ vector describing the position in space of the UAS GS.

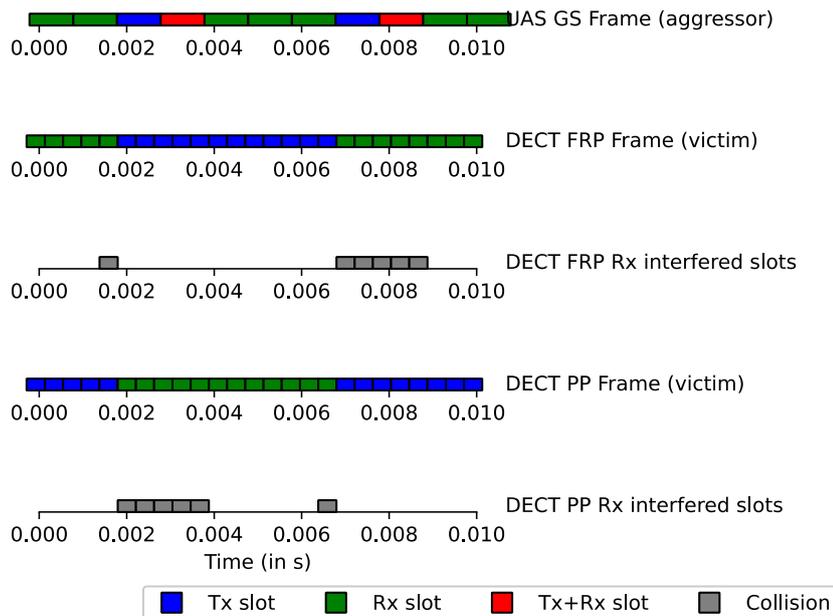


Figure 131: Examples of UAS GS to DECT TDD collision pattern

A12.1.3.2 UAS UE transmit

$$I_{UAS\ UE \rightarrow DECT\ RX}(\omega, i) = P_f(Ch(i), \omega) + G_{DECT} + G_{UAS\ UE} - PL(\overrightarrow{p_{UAS\ UE}(\omega)}, \overrightarrow{p_{DECT\ RX}(\omega, i)}) - BEL(\overrightarrow{p_{UAS\ UE}(\omega)}, \overrightarrow{p_{DECT\ RX}(l, \omega)})$$

If the time offset between the beginning of DECT device i TDD frame and the beginning of the UAS UE TDD frame is such that device i receives while the UAS UE transmits (see Figure 132). Else, it is obtained:

$$I_{UAS\ UE \rightarrow DECT\ RX}(\omega, i) = -\infty \text{ [dBm]}$$

Using the same notation as before, and where:

- $P_f(Ch(i), \omega)$ is the fraction of the interferer power falling into the receiver's band, taking into account UAS UE transmit power control and the channel used by the DECT receiver (in dBm).
 - The power control algorithm is taken from Recommendation ITU-R M.2101-0, taking into account that all Ressource Blocks are allocated to the same device.
 - The power control formula is given then by $P_{UAS\ UE}(\omega) = \max\left\{\min\left\{P_{UAS\ UE,max}, P_{UAS\ GS,target} + \alpha \cdot PL(\overrightarrow{p_{UAS\ UE}(\omega)}, \overrightarrow{p_{UAS\ GS}(\omega)})\right\}, -40\right\}$
 - $\alpha = 1$
 - $P_{UAS\ GS,target}$ is the target received power at the UAS GS, computed based on the target SNR given in Annex 3, Table 18, plus 3 dB of margin ($P_{UAS\ GS,target} = -80\text{dBm}$ for 5 MHz of bandwidth, -85dBm of 10 MHz of bandwidth).
- $G_{UAS\ UE}$ is the gain of the UAS UE (in dBi).
- $\overrightarrow{p_{UAS\ UE}(\omega)}$ vector describing the position in space of the UAS UE, at Monte Carlo run ω .

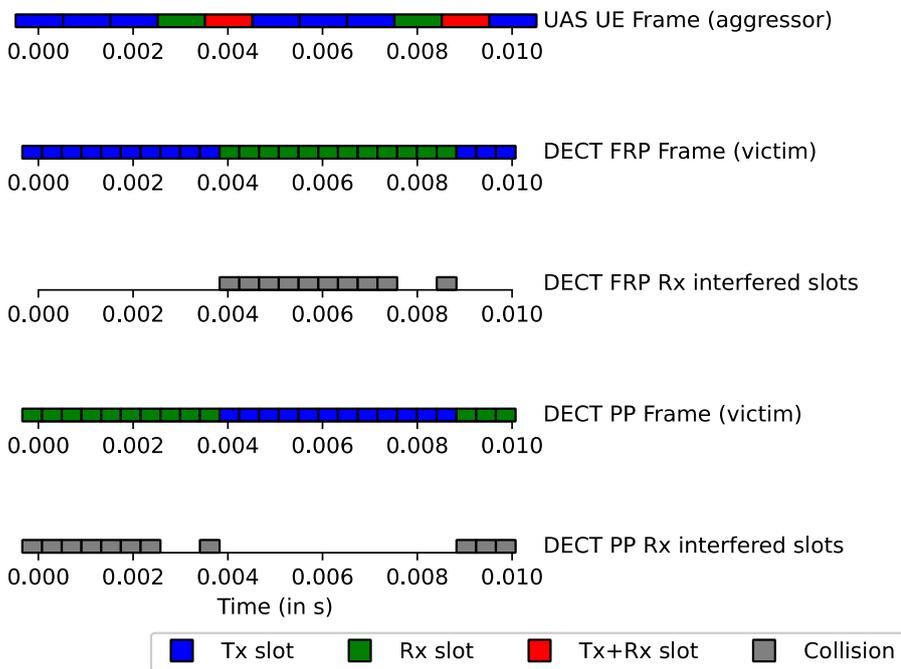


Figure 132: Examples of UAS UE to DECT TDD collision pattern

A12.1.3.3 DECT device from an other pair transmit

$$I_{DECT\ TX \rightarrow DECT\ RX}(\omega, i, j) = P_f(Ch(i), Ch(j)) + G_{DECT} + G_{DECT} - PL(\overrightarrow{p_{DECT\ TX}(\omega, i)}, \overrightarrow{p_{DECT\ RX}(\omega, j)})$$

Using the same notations as before, and where:

- $P_f(Ch(i), Ch(j))$ is the fraction of the interfering DECT device (transmitting on channel $Ch(i)$) power falling into the DECT victim receiver's band (receiving on channel $Ch(j)$) (in dBm).

A12.1.3.4 Aggregate interference from DECT devices from other pairs

$$I_{DECT-DECT,agg}(\omega, j) = 10 \cdot \log_{10} \left(\sum_{i \in I(j)} 10^{\frac{I_{DECT TX \rightarrow DECT RX}(\omega, i, j)}{10}} \right)$$

Where $I(j)$ is the set of DECT devices indices than interfere with device j (see Figure below). If $i \in I(j)$, then:

- $i \neq j$;
- DECT device i does not belong to the same pair as DECT device j ;
- Devices i and j use the same time slot (but not necessarily the same frequency channel), but one use it for transmission and the other for reception.

A12.1.4 Model of UAS received interference

A12.1.4.1 UAS GS receive

$$I_{DECT TX \rightarrow UAS GS}(\omega, i) = P_f(Ch(i)) + G_{DECT} + G_{UAS GS} - PL(\overrightarrow{p_{UAS GS}}, \overrightarrow{p_{DECT RX}(\omega, i)}) - CL(\overrightarrow{p_{UAS GS}}) - BEL(\overrightarrow{p_{DECT RX}(\omega, i)}, \overrightarrow{p_{UAS GS}})$$

Using the same notation as before, and where:

- $P_f(chan) = 10 \cdot \log_{10} \left(\int_{-\infty}^{+\infty} BEM_{UAS GS}(f) \cdot SEM_{DECT TX}(f, chan) df \right)$ is the fraction of the interferer power falling into the receiver's band (in dBm). It depends on the channel on which the DECT pair communicated.
 - $BEM_{UAS GS}(f)$ is the BEM of the UAS GS.
 - $SEM_{DECT RX}(f, chan)$ is the SEM of the DECT receiver, operating on channel $chan$ (in mW/Hz).

A12.1.4.2 UAS UE receive

$$I_{DECT TX \rightarrow UAS UE}(\omega, i) = P_f(Ch(i), \omega) + G_{DECT} + G_{UAS UE} - PL(\overrightarrow{p_{UAS UE}(\omega)}, \overrightarrow{p_{DECT RX}(\omega, i)}) - BEL(\overrightarrow{p_{DECT RX}(\omega, i)}, \overrightarrow{p_{UAS UE}(\omega)})$$

Using the same notation as before.

A12.1.4.3 Aggregate interference

$$I_{UAS GS,agg}(\omega) = 10 \cdot \log_{10} \left(\sum_{i \in I_{UAS GS}} 10^{\frac{I_{DECT TX \rightarrow UAS GS}(\omega, i)}{10}} \right)$$

$$I_{UAS UE,agg}(\omega) = 10 \cdot \log_{10} \left(\sum_{i \in I_{UAS UE}} 10^{\frac{I_{DECT TX \rightarrow UAS UE}(\omega, i)}{10}} \right)$$

Where $I_{UAS GS}$ (respectively, $I_{UAS UE}$) is the set of DECT devices indices that interfere or are interfered with the UAS GS (respectively, UAS UE). If $i \in I_{UAS GS}$ (respectively $i \in I_{UAS UE}$), then the time offset between the beginning of DECT device i TDD frame and the beginning of the UAS GS (respectively, UAS UE) TDD frame is such that device i transmits while the UAS GS (respectively, UAS UE) receives.

A12.1.5 Model of received signals

A12.1.5.1 DECT

$$C_{DECT}(\omega, i) = P_{TX,DECT} + G_{DECT} + G_{DECT} - PL\left(\overrightarrow{p_{DECT\ RX}(\omega, i)}, \overrightarrow{p_{DECT\ RX}(\omega, i)}\right)$$

Using the same notation as before, and where:

- $P_{TX,DECT}$ is the DECT transmit power.
- $\overrightarrow{p_{DECT\ TX}(\omega, i)}$ is a vector describing the position in space of the i th DECT transmitter, at Monte Carlo run ω .

A12.1.5.2 UAS GS

$$C_{UAS\ GS}(\omega) = P_{UAS\ UE}(\omega) + G_{UAS\ UE} + G_{UAS\ GS} - PL\left(\overrightarrow{p_{UAS\ UE}(\omega)}, \overrightarrow{p_{UAS\ GS}(\omega)}\right)$$

Using the same notation as before.

A12.1.5.3 UAS UE

$$C_{UAS\ GS}(\omega) = P_{UAS\ BS} + G_{UAS\ UE} + G_{UAS\ GS} - PL\left(\overrightarrow{p_{UAS\ BS}(\omega)}, \overrightarrow{p_{UAS\ UE}(\omega)}\right)$$

A12.1.6 Simulation of DECT DCS

The algorithm to simulate DCS for a Monte Carlo sample ω_0 is as follows:

```
DECT_pair_chosen <- empty_array() // Will store which pairs have already chosen their channel
```

```
DECT_chan <- array(N_DECT_chan) // Will store the channel selected by DECT pairs
```

```
DECT_slot <- array(N_DECT_slot) // Will store the channel selected by DECT pairs
```

For each DECT pair i in the deployment:

```
    // I - Compute heatmap of interference received on each DECT channel and time slot
```

```
    HM <- array(2, N_DECT_chan, N_DECT_slot)
```

```
    j <- index of DECT PP belonging to DECT pair i
```

```
    For each DECT channel k:
```

```
        For each DECT time slot l:
```

```
            I_UAS_GS <-  $I_{UAS\ GS \rightarrow DECT\ RX}(\omega_0, j)$ 
```

```
            I_UAS_UE <-  $I_{UAS\ UE \rightarrow DECT\ RX}(\omega_0, j)$ 
```

```
            I_DECT_DECT <-  $I_{DECT-DECT,agg}(\omega, j)$  // Exclude DECT interference for pairs not yet in DECT_pair_chosen
```

```
            If 10% of times
```

```

HM[k,l] <- I_DECT_DECT
Else
HM[k,l] <- 10.log10  $\left(10^{\frac{I_{UAS\_GS} + I_{UAS\_UE} + I_{DECT\_DECT}}{10}}\right)$ 
// III - Choose channel experiencing the least interference
DECT_chan[i], DECT_slot[i] <- arg mink∈[0;N_DECT_chan[,l∈[0;N_DECT_slot[ HM[k,l]
DECT_pair_chosen.append(i)

```

A12.1.7 Gathered statistics

A12.1.7.1 DECT interfered by UAS

In order to assess the probability for any MFCN BS to be interfered with either the UAS BS or the UAS UE, the SINR ratio of each DECT device is computed at each Monte Carlo run:

$$SINR_{DECT}(\omega, i) = C_{DECT}(\omega, i) - 10 \log_{10} \left(10^{\frac{I_{UAS\ GS \rightarrow DECT\ RX}(\omega, i) + I_{UAS\ UE \rightarrow DECT\ RX}(\omega, i) + I_{DECT-DECT,agg}(\omega, i) + P_{N,DECT}}{10}} \right)$$

Where $P_{N,DECT}$ is the noise floor of the DECT receiver (in dBm). A DECT pair is declared interfered if either the link between the FRP and the PP or between the PP and the FRP has an SINR lower than 21 dB.

A12.2 STUDY

The following figure gives results of the study for various combination of UAS transmit power, ranges and deployments. Raw results of simulations are filtered according to the distance between the center of the DECT building and the position of the (closest, in the case of 2 UAS deployments) UAS GS or UE.

A12.2.1 One UAS in 1880-1900 MHz

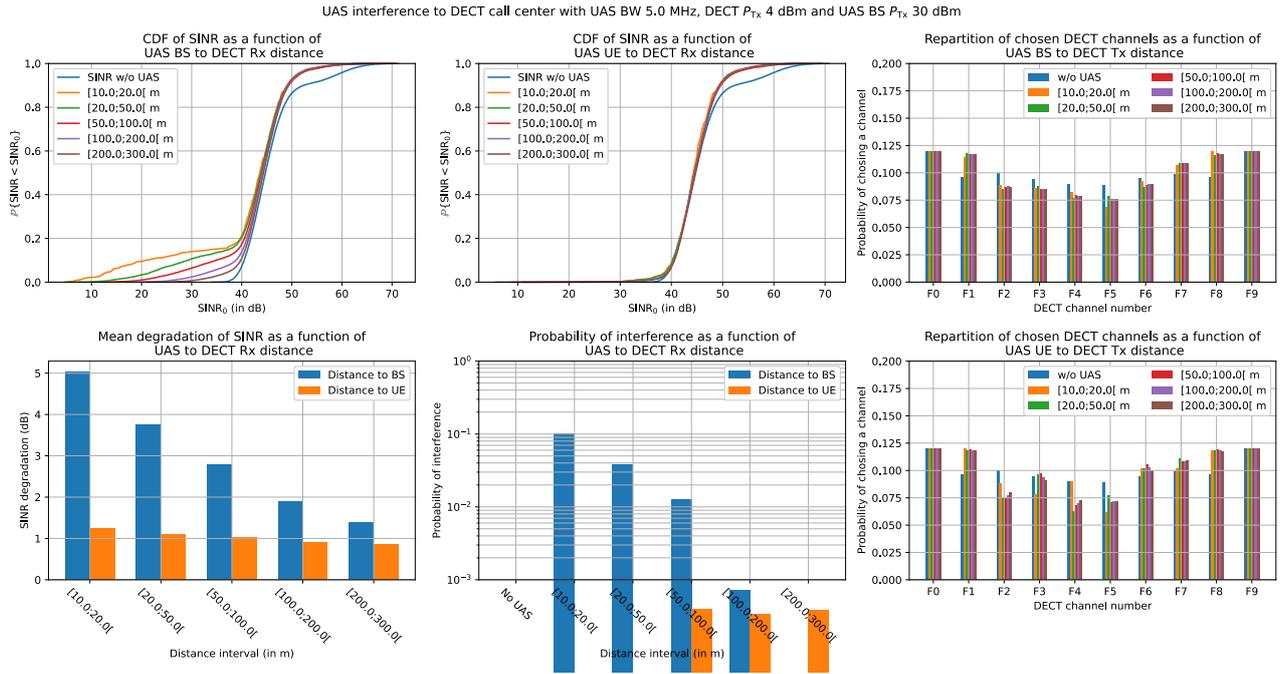


Figure 133: Single UAS (10 MHz bandwidth, 30 dBm GS Tx power) interference to DECT call center

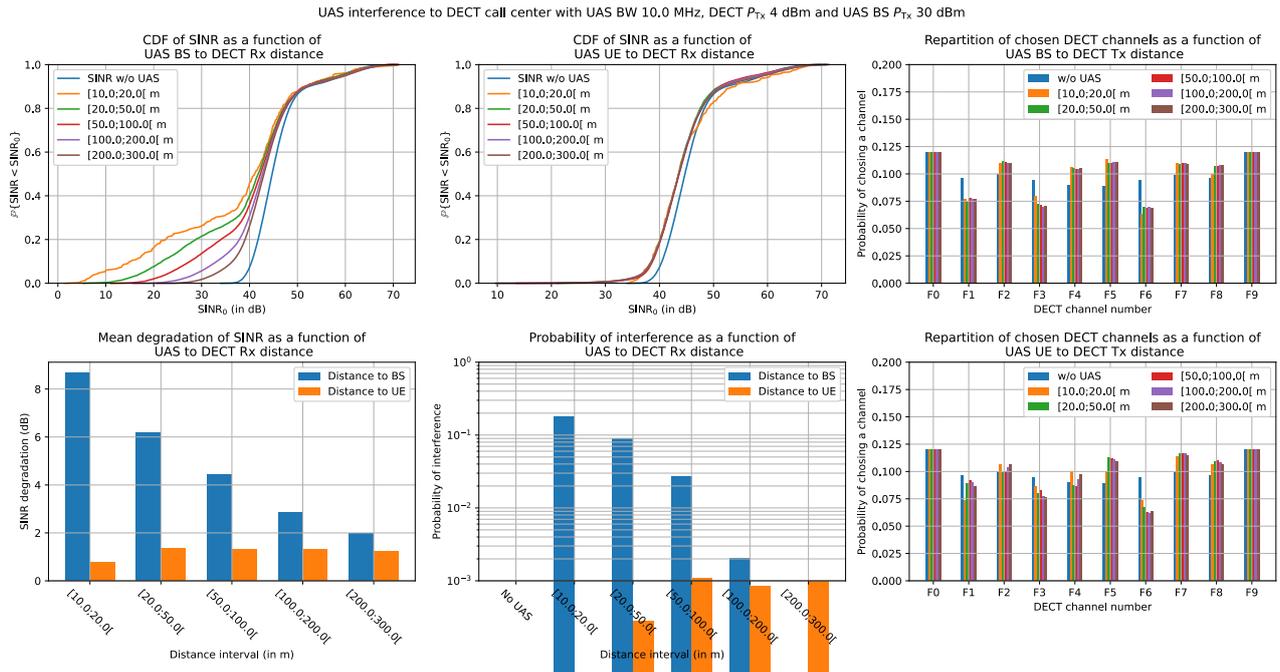


Figure 134: Single UAS (5 MHz bandwidth, 30 dBm GS Tx power) interference to DECT call center

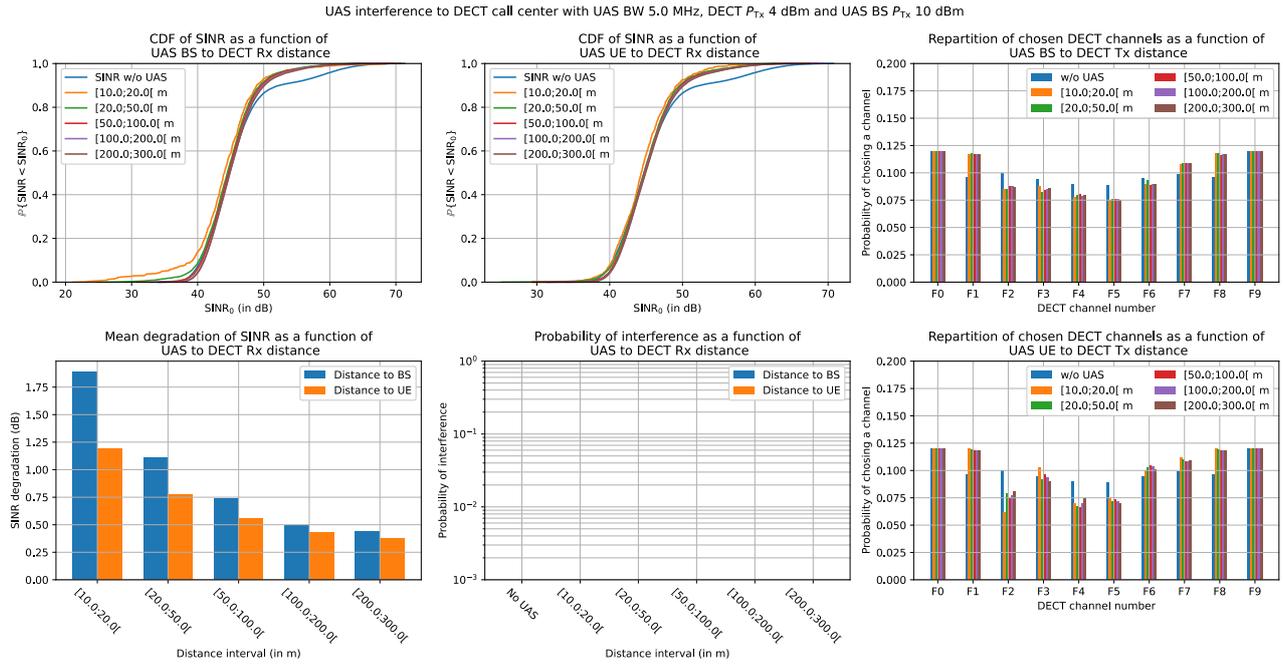


Figure 135: Single UAS (10 MHz bandwidth, 10 dBm GS Tx power) interference to DECT call center

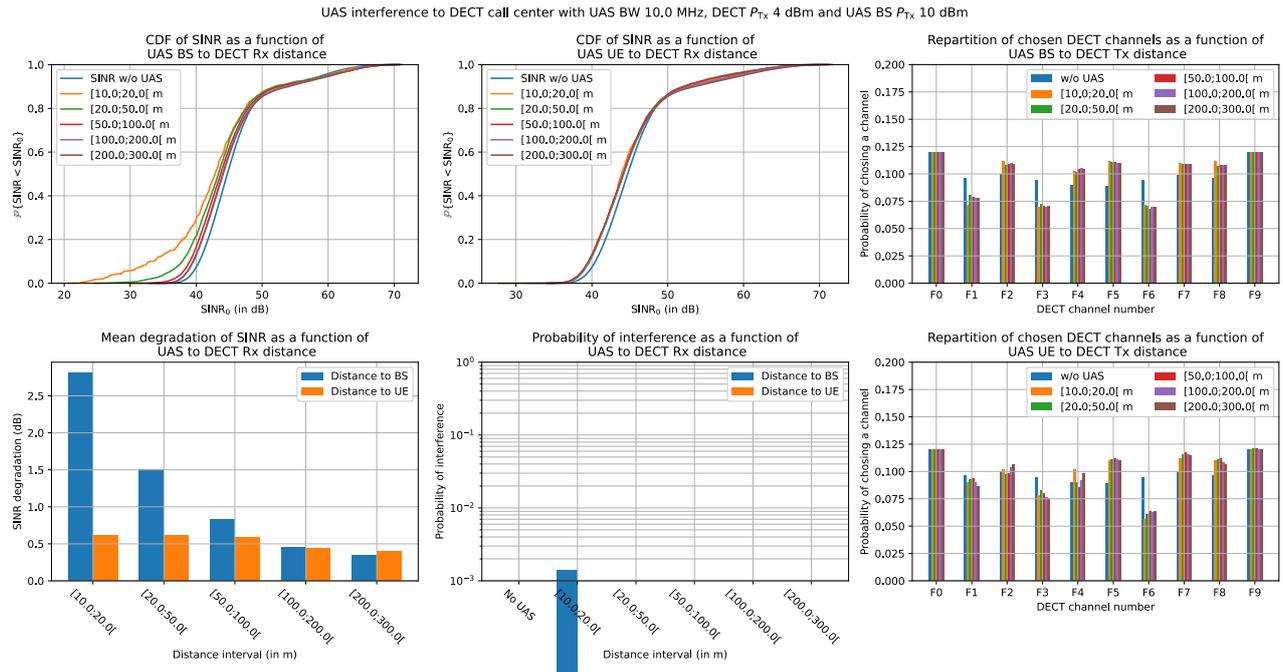


Figure 136: Single UAS (5 MHz bandwidth, 10 dBm GS Tx power) interference to DECT call center

A12.2.2 Two UAS in 1880-1900 MHz

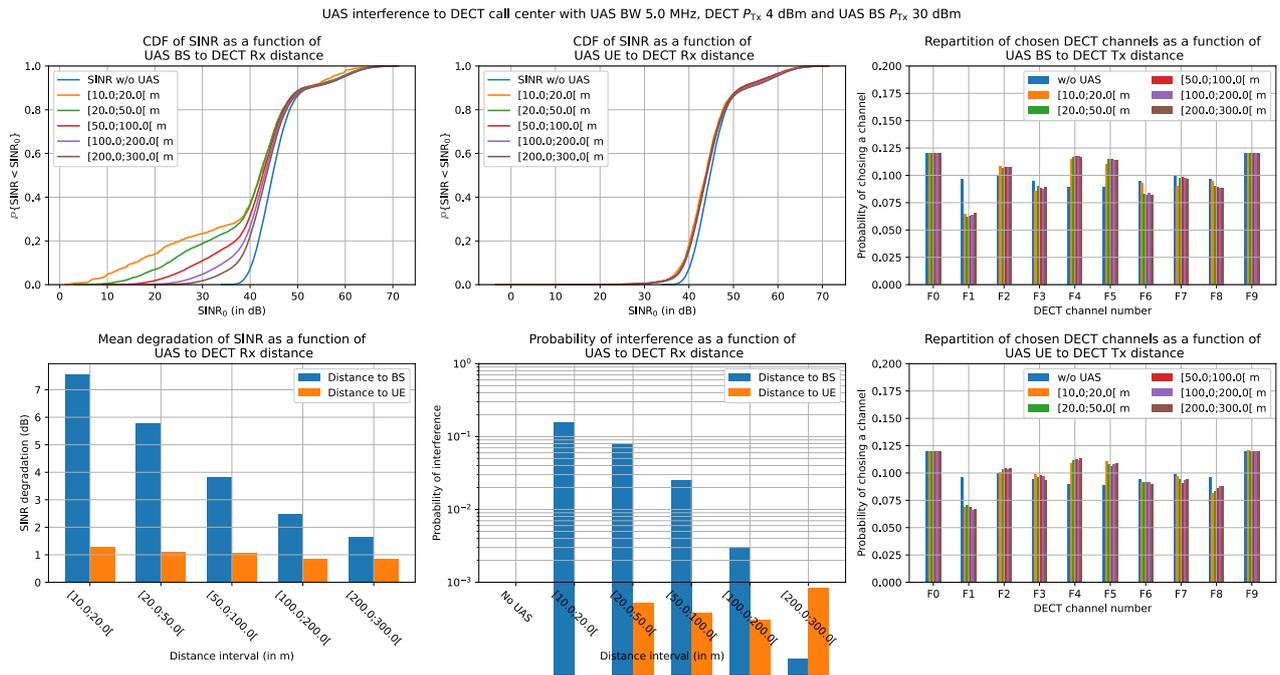


Figure 137: Two UAS (10 MHz bandwidth, 30 dBm GS Tx power) interference to DECT call center

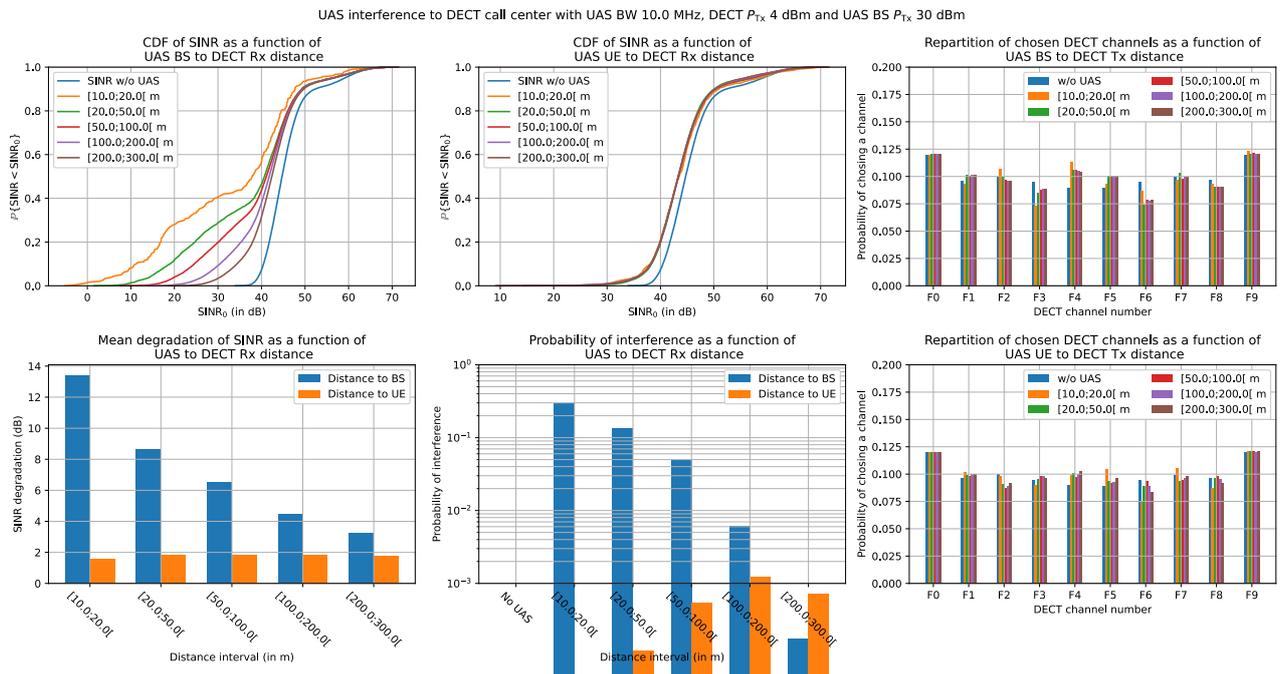


Figure 138: Two UAS (5 MHz bandwidth, 30 dBm GS Tx power) interference to DECT call center

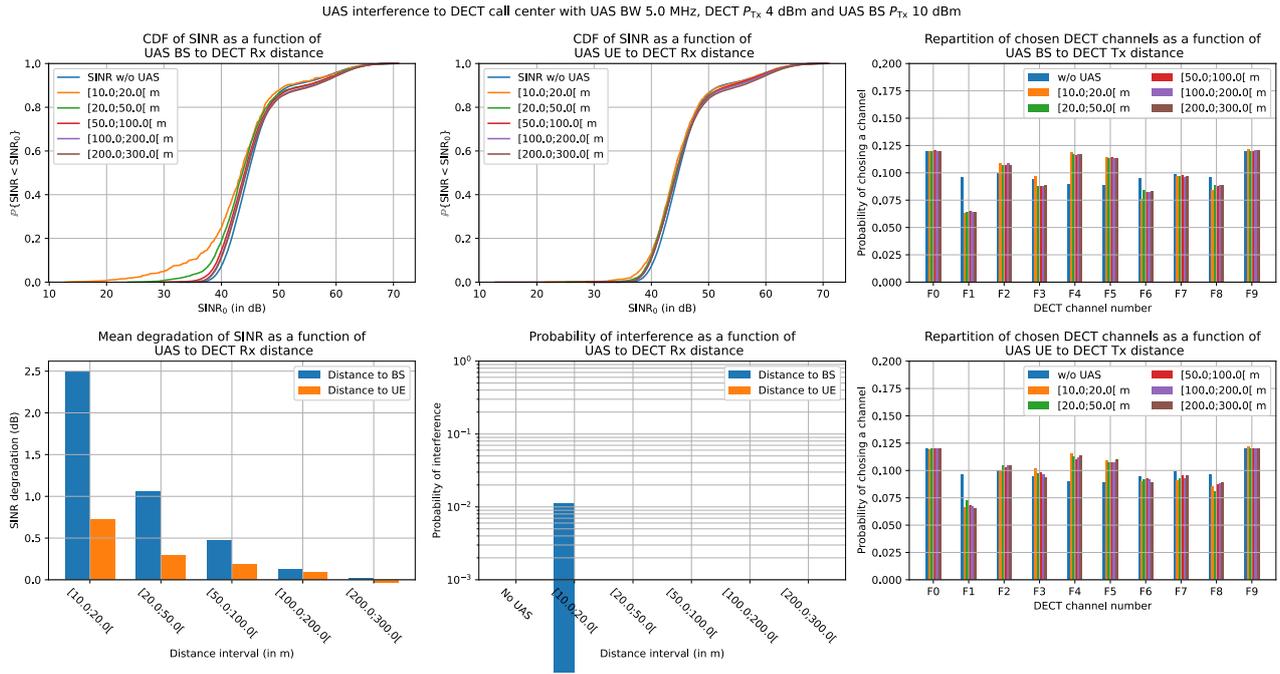


Figure 139: Two UAS (10 MHz bandwidth, 10 dBm GS Tx power) interference to DECT call center

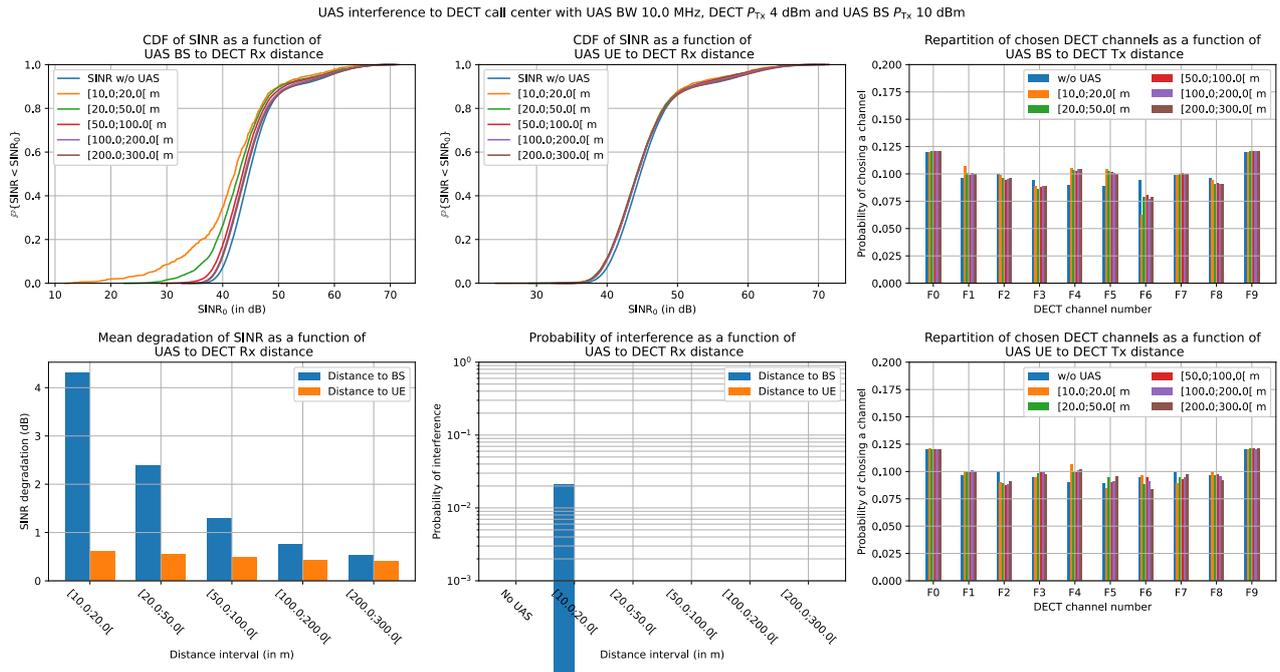


Figure 140: Two UAS (5 MHz bandwidth, 10 dBm GS Tx power) interference to DECT call center

A12.3 SUMMARY

Results of the studies are summarised in the two tables below. They show that the UAS UE as a low impact on DECT devices (interference lower than 1% in all scenarios), due to its power control algorithm. UAS GS very close to the building can affect several communications within the DECT building. Using 30 dBm of transmit power, and assuming LoS between UAS GS and the DECT building, a separation distance of 100 m (around 90 m from the walls) between the UAS GS and the center of the DECT building allows the interference

probability to be under 1%. Using 10 dBm of transmit power, this distance drops to 20 m (around 10 m from the walls).

Table 103: Summary of Single UAS GS in 1880-1900 MHz interference probability to professional DECT

UAS BS Tx power (dBm)	Bandwidth (MHz)	Max UAS UE Tx power (dBm)	UAS to center of DECT building distance (m)	Mean percentage of interfered DECT devices (%) – Distance to UAS GS	Mean percentage of interfered DECT devices (%) – Distance to UAS UE
30	5	28	10-20	10.1	0
			20-50	3.8	0
			50-100	1.3	0
			100-200	0.1	0
			200-300	0	0
	10		10-20	18.3	0
			20-50	8.9	0
			50-100	2.7	0
			100-200	0.2	0
			200-300	0	0
10	5		10-20	0	0
			20-50	0	0
			50-100	0	0
			100-200	0	0
			200-300	0	0
	10		10-20	0.1	0
			20-50	0	0
			50-100	0	0
			100-200	0	0
			200-300	0	0

Table 104: Summary of Two UAS GS in 1880-1900 MHz interference probability to professional DECT

UAS BS Tx power (dBm)	Bandwidth (MHz)	Max UAS UE Tx power (dBm)	UAS to center of DECT building distance (m)	Mean percentage of interfered DECT devices (%) – Distance to closest UAS GS	Mean percentage of interfered DECT devices (%) – Distance to closest UAS UE
30	5	28	10-20	15.6	0
			20-50	7.7	0.1

UAS BS Tx power (dBm)	Bandwidth (MHz)	Max UAS UE Tx power (dBm)	UAS to center of DECT building distance (m)	Mean percentage of interfered DECT devices (%) – Distance to closest UAS GS	Mean percentage of interfered DECT devices (%) – Distance to closest UAS UE	
			50-100	2.5	0	
			100-200	0.3	0	
			200-300	0	0.1	
			10-20	29.3	0	
			20-50	13.6	0	
			50-100	4.9	0.1	
	10			100-200	0.6	0.1
				200-300	0	0.1
				10-20	1.1	0
				20-50	0	0
				50-100	0	0
				100-200	0	0
10	5	200-300	0	0		
		10-20	2.1	0		
		20-50	0	0		
		50-100	0	0		
		100-200	0	0		
		200-300	0	0		
	10		10-20	2.1	0	
			20-50	0	0	
			50-100	0	0	
			100-200	0	0	
			200-300	0	0	
			200-300	0	0	

ANNEX 13: MCL STUDY OF THE POSSIBLE IMPACT OF DECT-2020-BASED UAS DEPLOYMENT IN 1880-1900 MHZ AND 1910-1920 MHZ TO ADJACENT SERVICES

A13.1 DECT-2020 UAS TECHNICAL PARAMETERS

DECT-2020 is an evolution of DECT. It allows for higher bitrates and more flexible resource allocation. Its physical layer shares similarities with 5G and LTE (turbo-coded CP-OFDM). However, it has multiple mechanisms allowing operation within interfered environments: dynamic channel selection (time slot and carrier frequency selection based on channel sensing), transmit power control and other-the-air time-synchronisation (allowing several DECT devices to operate isochronously, and thus minimize intra interference). Technical characteristics of UAS using DECT-2020 are given in Table 105.

Table 105: Technical parameters to be considered in compatibility studies (DECT-2020 based)

Parameter	Ground station		Aerial vehicle	
	Long range	Medium range	Long range	Medium range
Environment	Long range	Medium range	Long range	Medium range
Maximum transmitted power	24 dBm with TPC		24 dBm with TPC	
Frequency band (MHz)	1880-1920 (note 6)			
Antenna gain (dBi)	5 (note 2, 4)	2 (note 3, 4)	0	
Maximum radiated power e.i.r.p. (dBm)	29	26	24	
Bandwidth (MHz)	3.456			
Noise figure (dB)	7			
Target bitrate	300 kbps for C2, 5 Mbps for payload (note 1)			
SINR protection criteria (dB)	10 (note 5)		4 (note 5)	
Spectrum emission mask	ETSI TS 103 636-2, section 6.5.3, table 6.5.3-2 [11]			
Blocking mask	ETSI TS 103 636-2, section 7.4, table 7.4-1 [11] ETSI TS 103 636-2, section 7.5.3, tables 7.5.3-1, 7.5.3-2 and 7.5.3-3 [11]			
<p>Note 1: 5 Mbps is considered sufficient for 30 fps full HD (1080p) video streaming using ITU-T H.264 [28] (see, for instance, https://stream.twitch.tv/encoding/). 5 Mbps is also considered sufficient for compressed video links (also using ITU-T H.264) involving racing drones (see section 9.2 of Theolin, H., « Video compression optimized for racing drones », Luleå University of Technology, 2018).</p> <p>Note 2: Corresponds to the peak gain of quarter wavelength monopole antenna above a ground plate. Antenna diagrams taking into account non-finite ground plates can be found in "Radiation pattern and impedance of a quarter wavelength monopole antenna above a finite ground plane" [39]</p> <p>Note 3: Corresponds to the peak gain of a half wavelength dipole antenna. Antenna patterns can be found in the classical literature, for instance, "Analysis and Design", section 4.6 [40]</p> <p>Note 4: As it is much easier for an operator to follow a drone in the azimuth plane than in the elevation plane, the antenna is rotated so that the plane of the radiation pattern having a quasi-constant gain coincide with the elevation plane.</p> <p>Note 5: These SINR are based on results of ETSI MSGEVAL(21)002004, showing SNR requirements under a Rician channel, and assuming 2x2 MIMO, MCS-2 over 5 subslots for C2, and MCS-4 over 6 subslots for payload. Lower SNR can achieve same or higher bitrates under different channel conditions, time slot allocation and MIMO configuration.</p> <p>Note 6: Channelization is defined in ETSI TS 103 636-2, section 5.4.2 [11]. In 1880-1900 MHz, 3 MHz DECT-2020 carrier frequencies are chosen in the center between two (non-2020) DECT channels.</p>				

A13.2 COMPATIBILITY STUDY WITH MFCN IN 1805-1880 MHZ

A13.2.1 Computation of minimum distance

A13.2.1.1 Victim is MFCN

Interference power is computed as follows.

$$I_{UAS\ GS \rightarrow MFCN\ UE}(d) = Pf_{UAS\ GS \rightarrow MFCN\ UE} - (PL_{FSPL}(d) + CL(h_{UAS\ BS}) + CL(h_{MFCN\ UE}) - G_{UAS\ GS} - G_{MFCN\ UE})$$

$$I_{UAS\ UE \rightarrow MFCN\ UE}(d) = Pf_{UAS\ UE \rightarrow MFCN\ UE} - (PL_{FSPL}(d) + CL(h_{MFCN\ UE}) - G_{UAS\ UE} - G_{MFCN\ UE})$$

Where:

- d is the ground distance between the UAS (GS or UE) and the MFCN UE, in m.
- $I_{UAS\ GS \rightarrow MFCN\ UE}(d)$ is the interference received by the MFCN UE from the UAS GS, in dBm.
- $I_{UAS\ UE \rightarrow MFCN\ UE}(d)$ is the interference received by the MFCN UE from the UAS UE, in dBm.
- $Pf_{UAS\ GS \rightarrow MFCN\ UE} = 10 \cdot \log_{10} \left(\int_{-\infty}^{+\infty} SEM_{UAS\ GS}(f) \cdot BEM_{MFCN\ UE}(f) df \right)$ is the fraction of the UAS GS transmit power falling into the MFCN UE receiver (in dBm).
- $Pf_{UAS\ UE \rightarrow MFCN\ UE} = 10 \cdot \log_{10} \left(\int_{-\infty}^{+\infty} SEM_{UAS\ UE}(f) \cdot BEM_{MFCN\ UE}(f) df \right)$ is the fraction of the UAS UE power falling into the MFCN UE receiver (in dBm).
- $PL_{FSPL}(d)$ is the path loss using free space path loss on a distance of d meters, in dB..
- $CL(h)$ represent clutter losses (in dB) for a transmitter or receiver at an altitude of h (in m). It is based on ITU-R P.2108-1, model of Section 3.1.1
- $G_{MFCN\ UE}$ is the antenna gain of the MFCN UE, in dBi.
- $G_{UAS\ GS}$ is the antenna gain of the UAS GS, in dBi.
- $G_{UAS\ UE}$ is the antenna gain of the UAS UE, in dBi.

The minimum separation distance is the highest value of d_{min} satisfying:

$$I(d_{min}) - N_{MFCN\ UE} = \frac{I}{N} \Big|_{th,dB}$$

Where:

- d_{min} is the MCL minimum separation distance between the MFCN UE and the UAS GS/UE, in m.
- $I(d_{min})$ is the interference power received by the MFCN UE from the UAS GS/UE, in dBm.
- $N_{MFCN\ UE}$ is the noise floor of the MFCN UE, in dBm.
- $\frac{I}{N} \Big|_{th,dB}$ is the I/N protection criterion of the MFCN UE, in dB.

When several values of d_{min} satisfy the equation above, the highest one is retained.

A13.2.1.2 Victim is UAS

Interference power is computed as follows.

$$I_{MFCN\ BS \rightarrow UAS\ GS}(d) = Pf_{MFCN\ BS \rightarrow UAS\ GS} - (PL_{ehata}(d, h_{UAS\ GS}, h_{MFCN\ BS}) - G_{UAS\ GS} - G_{MFCN\ BS}(\theta) + FL)$$

$$I_{MFCN\ BS \rightarrow UAS\ UE}(d) = Pf_{MFCN\ BS \rightarrow UAS\ UE} - (PL_{FSPL}(d) - G_{UAS\ UE} - G_{MFCN\ BS}(\theta) + FL)$$

Using the same notations as above, and where:

- θ is the elevation angle of the MFCN BS antenna towards the UAS GS/UE, in radians. It is a function of d .
- $G_{MFCN\ BS}(\theta)$ is the gain of the MFCN BS antenna at an elevation angle of θ .
- $PL_{ehata}(d, h_1, h_2)$ is the path loss using Extended Hata on a distance of d meters, assuming a that the heights, in m, at each end of the link are given by h_1 and h_2 , in dB .
- FL is the feeder loss of the MFCN BS, in dB.

Useful signal power is computed as follows.

$$S = UAS_{PTx} - (PL_{FSPL}(r) - G_{UAS\ GS} - G_{UAS\ UE} + CL(h_{UAS\ BS})) \text{ in rural environment (assuming ground clutter)}$$

$S = UAS_{PTX} - (PL_{FSPL}(r) - G_{UAS\ GS} - G_{UAS\ UE} + CL(h_{UAS\ BS}))$ in urban environment (assuming street canyon-like, LoS propagation)

Where:

- r is the range of the UAS, in m.
- UAS_{PTX} is the UAS transmit power, in dBm.

The minimum separation distance is the highest value of d_{min} satisfying:

$$S - 10 \cdot \log_{10} \left(10^{\frac{I(d_{min})}{10}} + 10^{\frac{N_{UAS}}{10}} \right) = SINR_{th}$$

Using similar notations as above, and where $SINR_{th}$ is the SINR protection of the UAS GS/UE, in dB.

A13.2.2 Results

urban scenario, range of 1000m

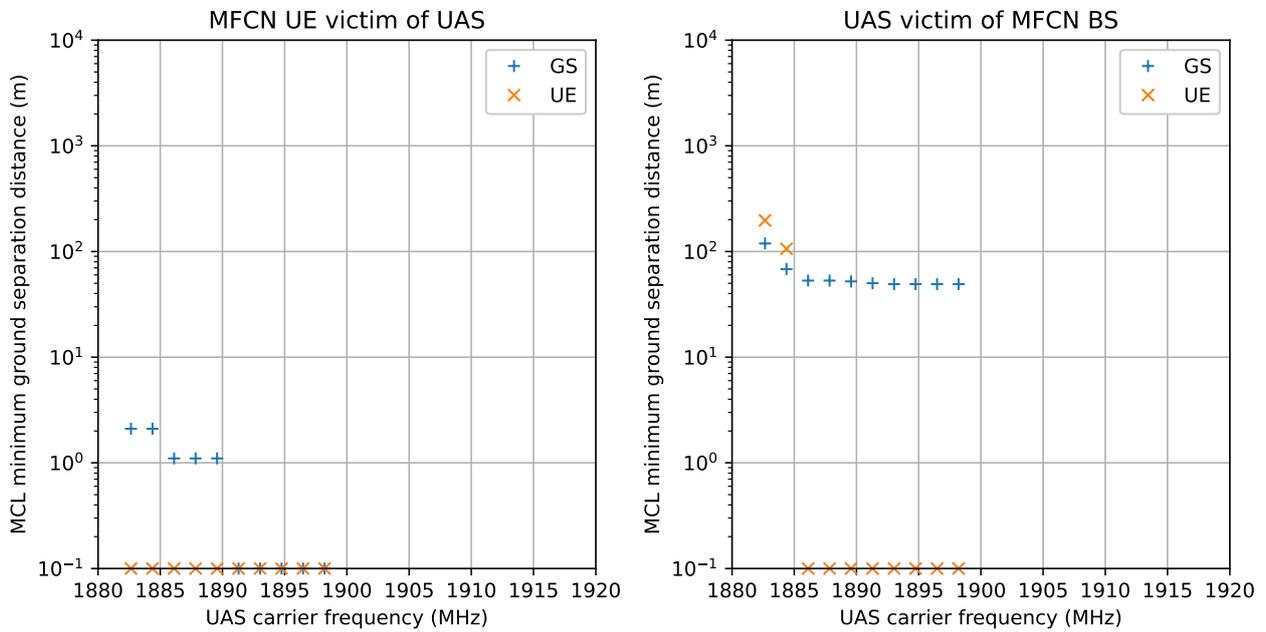


Figure 141: MCL compatibility between MFCN at 1805-1880 MHz and DECT-2020 UAS. Urban scenario, range of 1000 m, UAS UE altitude of 50 m

rural scenario, range of 5650m

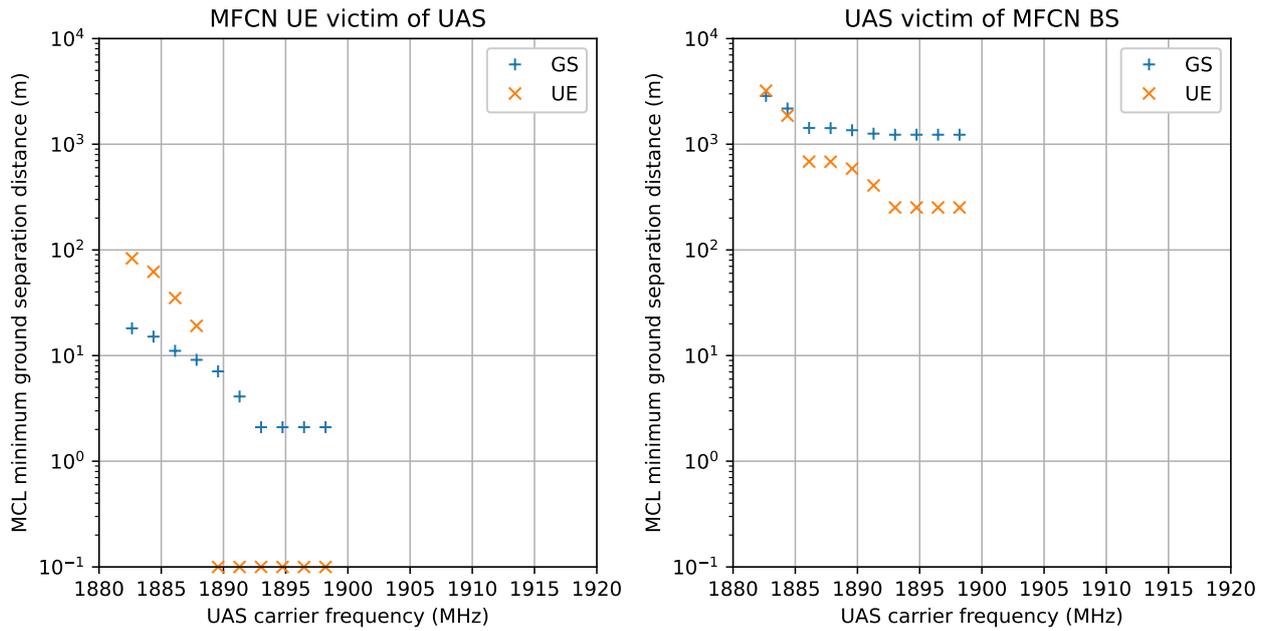


Figure 142: MCL compatibility between MFCN at 1805-1880 MHz and DECT-2020 UAS. Rural scenario, range of 5650 m, UAS UE altitude of 50 m

rural scenario, range of 1000m

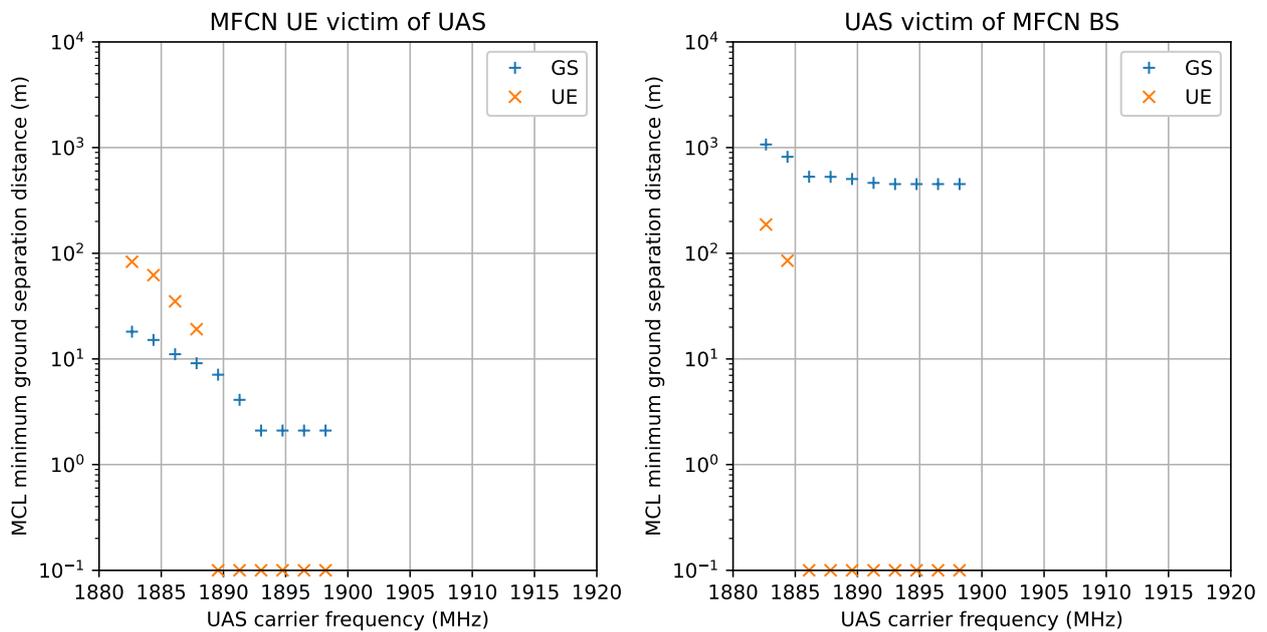


Figure 143: MCL compatibility between MFCN at 1805-1880 MHz and DECT-2020 UAS. Rural scenario, range of 1000 m, UAS UE altitude of 50 m

A13.2.3 Summary

The interference from DECT-2020 UAS operating on channels in 1880-1900 MHz to MFCN UE in 1805-1880 MHz leads to maximum separation distances of 2 m in an urban context, and 85 m in a rural environment. These separation distances gets lower when using DECT-2020 channels farther away from 1880 MHz.

The interference from MFCN BS in 1805-1880 MHz to UAS using DECT-2020 in 1880-1900 MHz leads to a maximum separation distance of 200 m in urban scenarios, and around 3 km in rural scenarios. The separation distance between MFCN BS and UAS GS never goes under 1250 m, no matter the DECT channel chosed in 1880-1900 MHz. Separation distance in rural scenarios can be reduced by reducing the UAS range. For instance, reducing the UAS range to 1 km in rural areas leads to maximum separation distances of around 500 m for all carriers higher than 1886.112 MHz (included).

A13.3 COMPATIBILITY STUDY WITH FRMCS IN 1900-1910 MHZ

A13.3.1 Computation of minimum distance

A13.3.1.1 Victim is FRMCS

Interference power is computed as follows.

$$I_{UAS\ GS \rightarrow FRMCS\ BS}(d) = Pf_{UAS\ GS \rightarrow FRMCS\ BS} - (PL_{ehata}(d, h_{UAS\ GS}, h_{FRMCS\ BS}) - G_{UAS\ GS} - G_{FRMCS\ BS}(\theta) + FL)$$

$$I_{UAS\ UE \rightarrow FRMCS\ BS}(d) = Pf_{UAS\ UE \rightarrow FRMCS\ BS} - (PL_{FSPL}(d) - G_{UAS\ UE} - G_{FRMCS\ BS}(\theta) + FL)$$

$$I_{UAS\ GS \rightarrow FRMCS\ UE}(d) = Pf_{UAS\ GS \rightarrow FRMCS\ UE} - (PL_{FSPL}(d) + CL(h_{UAS\ BS}) + CL(h_{FRMCS\ UE}) - G_{UAS\ GS} - G_{FRMCS\ UE} + HL)$$

$$I_{UAS\ UE \rightarrow FRMCS\ UE}(d) = Pf_{UAS\ UE \rightarrow FRMCS\ UE} - (PL_{FSPL}(d) + CL(h_{FRMCS\ UE}) - G_{UAS\ UE} - G_{FRMCS\ UE} + HL)$$

Using similar notations as previous sections, and where HL are the hardware losses in the FRMCS UE (cab radio). The minimum separation distance is the highest value of d_{min} satisfying:

$$I(d_{min}) - N_{FRMCS} = \frac{I}{N} \Big|_{th, dB}$$

Using similar notations as previous sections.

A13.3.1.2 Victim is UAS

Interference power is computed as follows.

$$I_{FRMCS\ BS \rightarrow UAS\ GS}(d) = Pf_{FRMCS\ BS \rightarrow UAS\ GS} - (PL_{ehata}(d, h_{UAS\ GS}, h_{FRMCS\ BS}) - G_{UAS\ GS} - G_{FRMCS\ BS}(\theta) + FL)$$

$$I_{FRMCS\ UE \rightarrow UAS\ GS}(d) = Pf_{FRMCS\ UE \rightarrow UAS\ GS} - (PL_{FSPL}(d) + CL(h_{UAS\ BS}) + CL(h_{FRMCS\ UE}) - G_{UAS\ GS} - G_{FRMCS\ UE} + HL)$$

$$I_{FRMCS\ BS \rightarrow UAS\ UE}(d) = Pf_{FRMCS\ BS \rightarrow UAS\ UE} - (PL_{FSPL}(d) - G_{UAS\ UE} - G_{FRMCS\ BS}(\theta) + FL)$$

$$I_{FRMCS\ UE \rightarrow UAS\ UE}(d) = Pf_{FRMCS\ UE \rightarrow UAS\ UE} - (PL_{FSPL}(d) + CL(h_{FRMCS\ UE}) - G_{UAS\ UE} - G_{FRMCS\ UE})$$

A13.3.2 Results

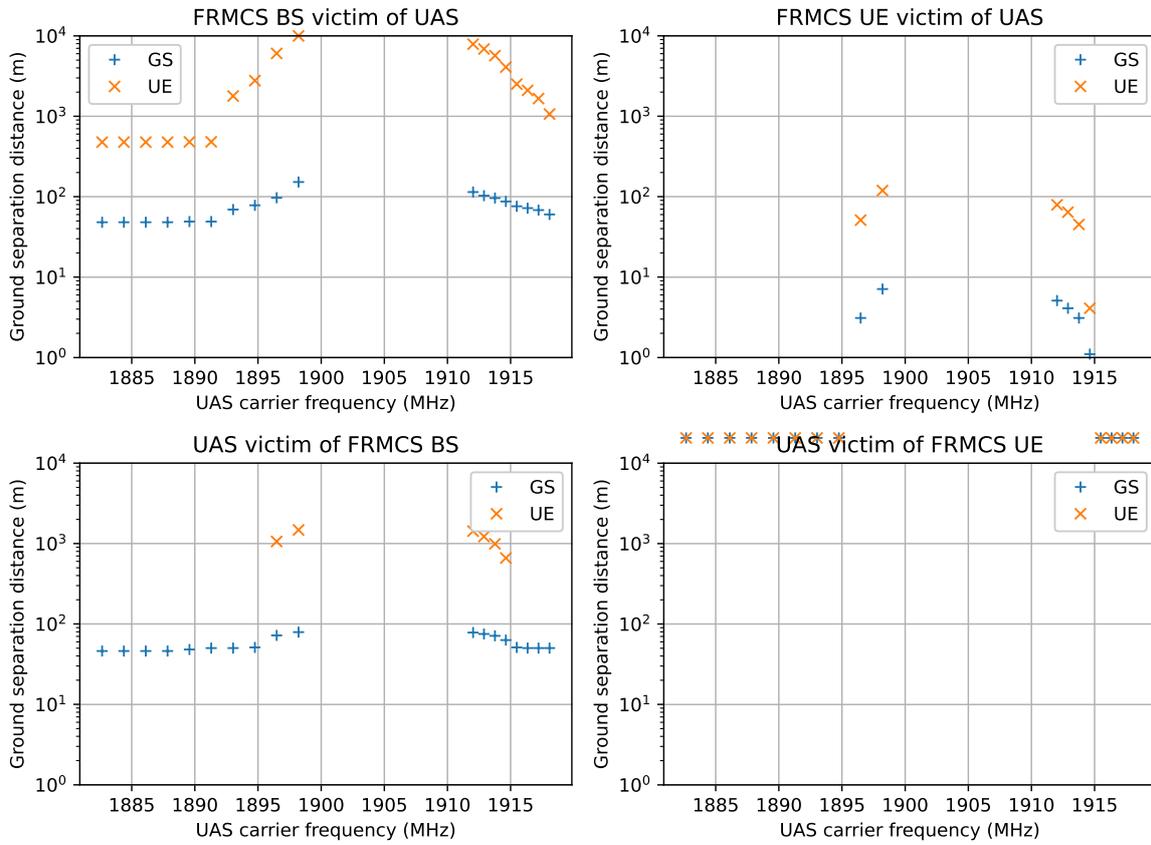


Figure 144: MCL compatibility between FRMCS at 1900-1910 MHz and DECT-2020 UAS. Urban scenario, range of 1000 m, UAS UE altitude of 50 m

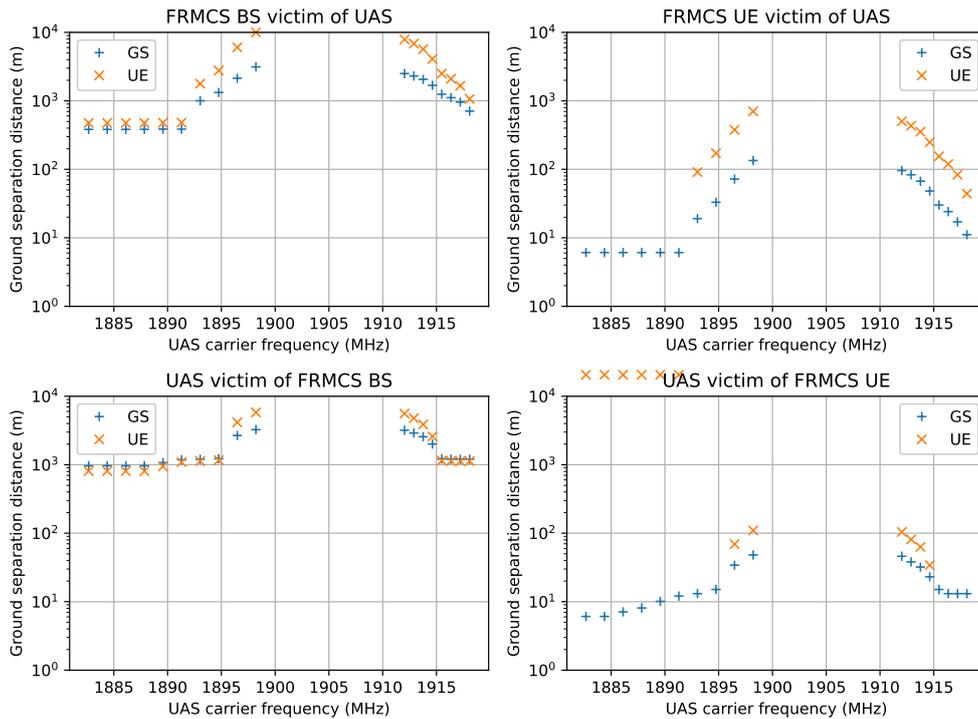


Figure 145: MCL compatibility between FRMCS at 1900-1910 MHz and DECT-2020 UAS. Rural scenario, range of 5650 m, UAS UE altitude of 50 m

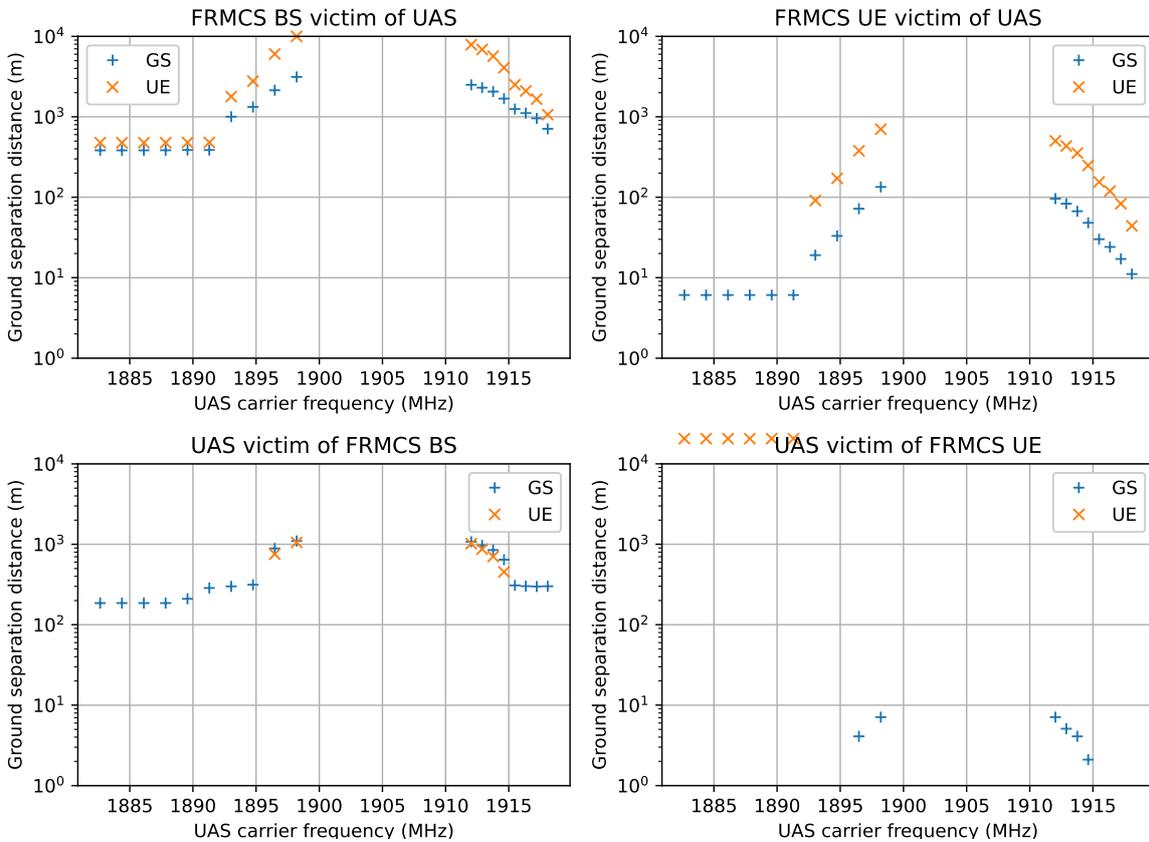


Figure 146: MCL compatibility between FRMCS at 1900-1910 MHz and DECT-2020 UAS. Rural scenario, range of 1000 m, UAS UE altitude of 50 m

A13.3.3 Summary

Co-existence between FRMCS in 1900-1910 MHz band UAS using DECT-2020 in 1880-1900 MHz and 1910-1920 MHz shows that the UAS UE (drone) has higher impact on the co-existence as it is more susceptible to interference (in particular, the FRMCS BS), and more susceptible from interference (in particular, from FRMCS BS).

In urban areas, separation distances between UAS GS and FRMCS BS/UE are always lower than 200 m.

Regarding UAS UE in urban areas, and both UAS GS and UE in rural areas, the following applies:

- On DECT-2020 carriers between 1896.46 MHz and 1914.624 MHz, the interference received by either UAS GS or UAS UE (or both) is high enough that they are unlikely to be selected by DECT-2020 dynamic channel selection (DCS), unless the UAS operates very far away from the railways (up to 10 km).
- Using channels at 1893.024 MHz, 1894.752 MHz, and above 1915.488 MHz (included) leads to a MCL separation distance lower than 3 km to protect the FRMCS BS (it also protects FRMCS UE, and UAS GS/UE).
- Using channels between 1882.656 MHz and 1891.296 MHz (included), separation distances of 500 m protects the FRMCS BS and UE. However, MCL computations in a rural context suggest that a range of 5650 m cannot be attained when the UAS GS/UE are 1000 m or closer from an FRMCS BS. A range of 1000 m in rural areas allows for separation distances less than 500 m.

A13.4 COMPATIBILITY STUDY WITH MFCN IN 1920-1980 MHZ

A13.4.1 Computation of minimum distance

A13.4.1.1 Victim is MFCN

Interference power is computed as follows.

$$I_{UAS\ GS \rightarrow MFCN\ BS}(d) = Pf_{UAS\ GS \rightarrow MFCN\ BS} - (PL_{ehata}(d, h_{UAS\ GS}, h_{MFCN\ BS}) - G_{UAS\ GS} - G_{MFCN\ BS}(\theta) + FL)$$

$$I_{UAS\ UE \rightarrow MFCN\ BS}(d) = Pf_{UAS\ UE \rightarrow MFCN\ BS}(PL_{FSPL}(d) - G_{UAS\ UE} - G_{MFCN\ BS}(\theta) + FL)$$

Using similar notations as previous sections. The minimum separation distance is the highest value of d_{min} satisfying:

$$I(d_{min}) - N_{MFCN\ BS} = \frac{I}{N} \Big|_{th, dB}$$

Using similar notations as previous sections. Using similar notations as previous sections. The minimum separation distance is the highest value of d_{min} satisfying:

$$S - 10 \cdot \log_{10} \left(10^{\frac{I(d_{min})}{10}} + 10^{\frac{N_{UAS}}{10}} \right) = SINR_{th}$$

Using similar notations as above.

A13.4.1.2 Victim is UAS

Interference power is computed as follows.

$$I_{MFCN\ UE \rightarrow UAS\ GS}(d) = Pf_{MFCN\ UE \rightarrow UAS\ GS} - (PL_{FSPL}(d) + CL(h_{UAS\ BS}) + CL(h_{MFCN\ UE}) - G_{UAS\ GS} - G_{MFCN\ UE})$$

$$I_{MFCN\ UE \rightarrow UAS\ UE}(d) = Pf_{MFCN\ UE \rightarrow UAS\ UE} - (PL_{FSPL}(d) + CL(h_{MFCN\ UE}) - G_{UAS\ UE} - G_{MFCN\ UE})$$

Using similar notations as before.

Useful signal power is computed as follows.

$$S = UAS_{PTx} - (PL_{FSPL}(r) - G_{UAS\ GS} - G_{UAS\ UE} + CL(h_{UAS\ BS})) \text{ in rural environment (assuming ground clutter)}$$

$$S = UAS_{PTx} - (PL_{FSPL}(r) - G_{UAS\ GS} - G_{UAS\ UE} + CL(h_{UAS\ BS})) \text{ in urban environment (assuming street canyon-like, LoS propagation)}$$

Using similar notations as previous sections. The minimum separation distance is the highest value of d_{min} satisfying:

$$S - 10 \cdot \log_{10} \left(10^{\frac{I(d_{min})}{10}} + 10^{\frac{N_{UAS}}{10}} \right) = SINR_{th}$$

Using similar notations as above.

A13.4.2 Results

urban scenario, range of 1000m

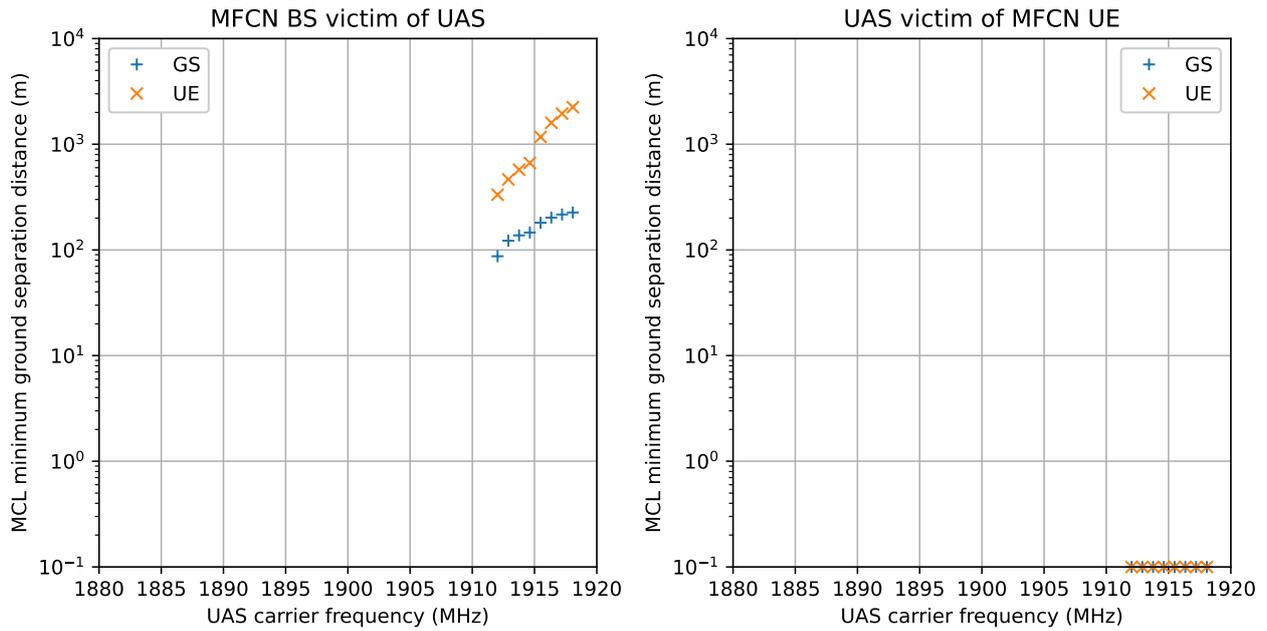


Figure 147: MCL compatibility between MFCN at 1920-1990 MHz and DECT-2020 UAS. Urban scenario, range of 1000 m, UAS UE altitude of 50 m, UAS transmit power of 24 dBm

urban scenario, range of 1000m

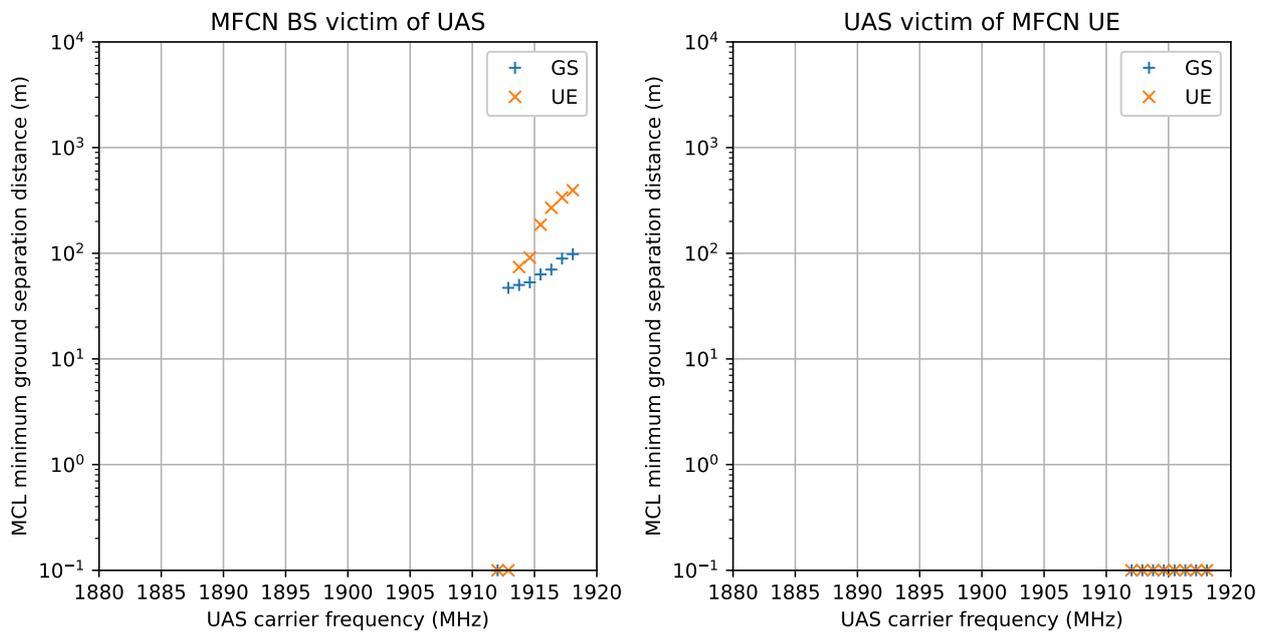


Figure 148: MCL compatibility between MFCN at 1920-1990 MHz and DECT-2020 UAS. Urban scenario, range of 1000 m, UAS UE altitude of 50 m, UAS transmit power of 10 dBm

rural scenario, range of 5650m

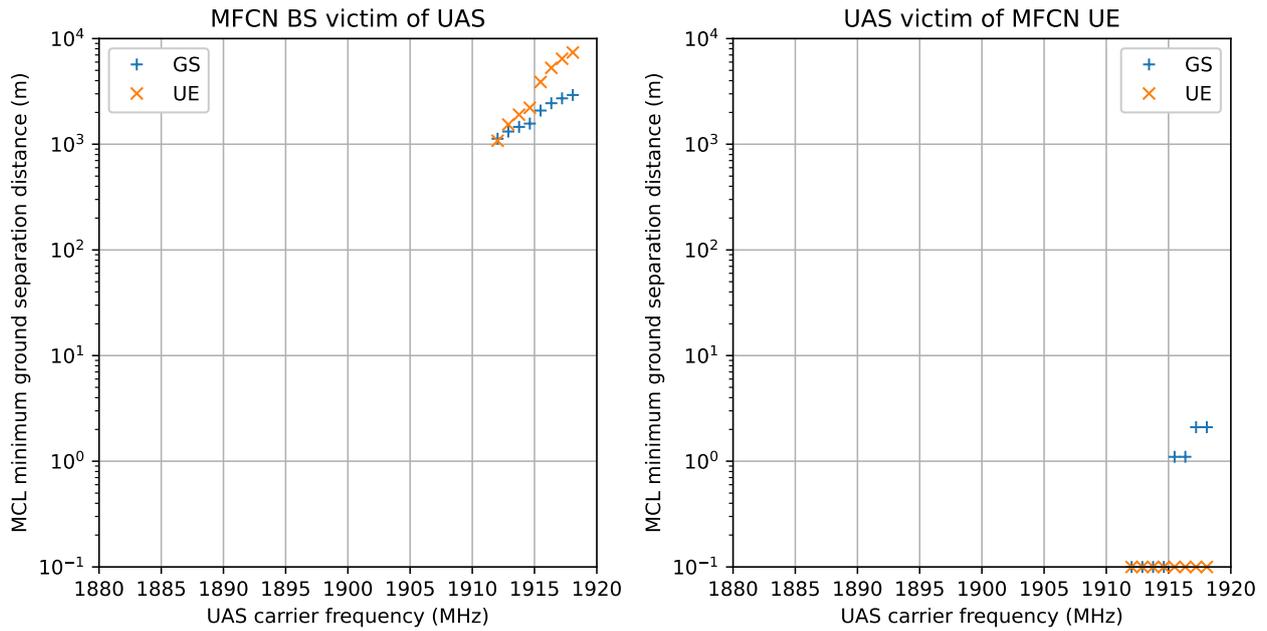


Figure 149: MCL compatibility between MFCN at 1920-1990 MHz and DECT-2020 UAS. Rural scenario, range of 5650 m, UAS UE altitude of 50 m, UAS transmit power of 24 dBm

rural scenario, range of 1000m

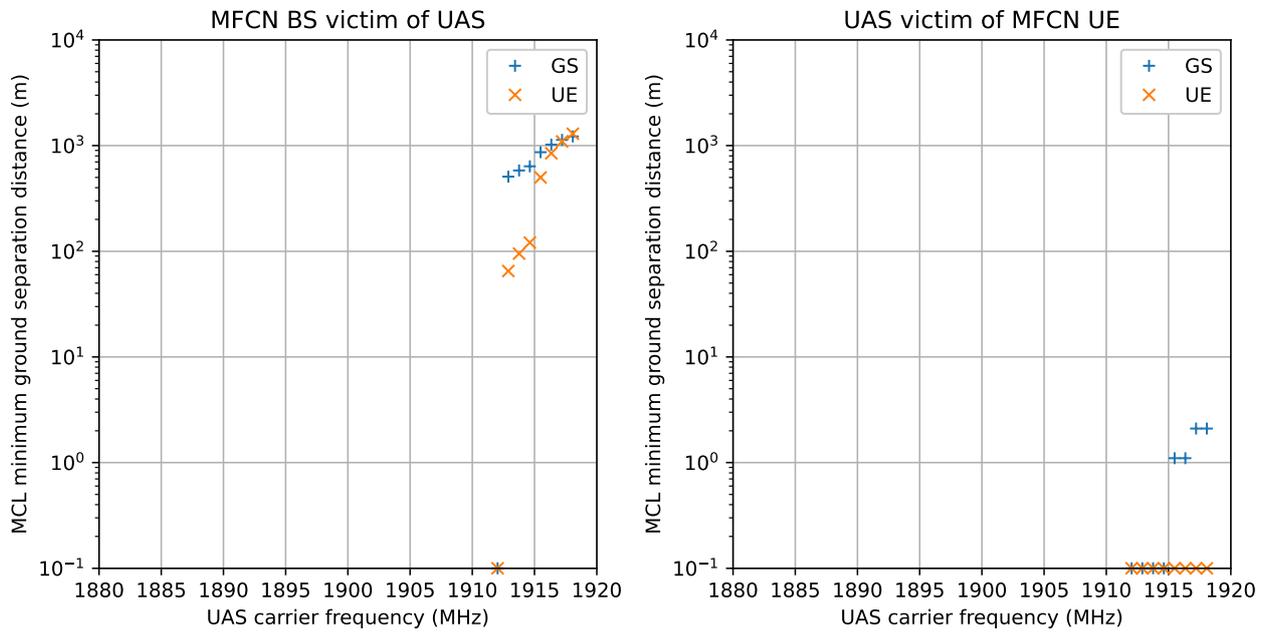


Figure 150: MCL compatibility between MFCN at 1920-1990 MHz and DECT-2020 UAS. Rural scenario, range of 2000 m, UAS UE altitude of 50 m, UAS transmit power of 10 dBm

A13.4.3 Summary

MFCN UE transmitting in 1920-1980 MHz leads to maximum separation distances with UAS GS or UE of 2 m.

Using a transmit power of 24 dBm leads to separation distances up to:

- 2400 m between UAS UE and MFCN BS in urban areas,
- 200 m between UAS GS and MFCN BS in urban areas,
- 7500 m between UAS UE and MFCN BS in rural areas,
- 3000 m between UAS GS and MFCN BS in rural areas.

In urban areas, if the transmit power is reduced to 10 dBm²⁵, then separation distances are lower than:

- 400 m between UAS UE and MFCN BS,
- 100 m between UAS GS and MFCN BS.

In rural areas, if the transmit power is reduced to 10 dBm and the range limited to 1000 m, then separation distances are lower than:

- 1300 m between UAS UE/GS and MFCN BS
- if the carrier frequency is lower than 1914.624 MHz (included):
 - 150 m between UAS UE and MFCN BS,
 - 610 m between UAS GS and MFCN BS.

A13.5 CONCLUSION

Basic MCL compatibility studies were carried in order to quantify the feasibility of deploying UAS using DECT-2020 in 1880-1900 MHz and 1910-1920 MHz.

Given the similarities between LTE and DECT-2020 waveforms, considering the lower transmit power of DECT-2020 (24 dBm), dynamic selection of time slots and frequency channels, and transmit power control on both UAS GS and UAS UE, it is expected that probabilities of interference of UAS using DECT-2020 would be lower than those computed using Monte Carlo studies with UAS using LTE.

A13.5.1 UAS deployed in 1880-1900 MHz

In 1880-1900 MHz, the MCL study of compatibility between MFCN in 1805-1880 MHz and UAS using DECT-2020 in 1880-1900 MHz leads to separation distances of:

- 200 m in urban scenarios;
- Up to 3 km (for UAS carriers close to 1880 MHz, due to interference from MFCN BS to UAS) and no less than 1250 m in rural scenarios (range of 5650 m). These carriers has a lower probability of being chosen by dynamic channel selection algorithm;
- Up to 1 km (for UAS carriers close to 1880 MHz, due to interference from MFCN BS to UAS) and 500 m or less for every other carriers.

Considering compatibility between FRMCS in 1900-1910 MHz and UAS using DECT-2020 in 1880-1900 MHz leads to MCL separation distances of:

- Up to 10 km for DECT carriers between 1896.46 MHz and 1914.624 MHz (due to interference from UAS UE to FRMCS BS). These carriers has a lower probability of being chosen by dynamic channel selection algorithm;
- Less than 3 km for carriers at 1893.024 MHz, 1894.752 MHz (due to interference from UAS UE to FRMCS BS);

²⁵ Assuming that the spectrum emission mask scales accordingly with respect to the original spectrum emission mask at 24

- 1000 m in rural scenarios, assuming a range of 5650 m (due to UAS GS and UE being interfered by FRMCS);
- Less than 300 m in rural scenarios, assuming a range of 1000 m.

A13.5.2 UAS deployed in 1910-1920

Considering compatibility between FRMCS in 1900-1910 MHz and UAS using DECT-2020 in 1910-1920 MHz leads to MCL separation distances of:

- Up to 10 km for DECT carriers between 1896.46 MHz and 1914.624 MHz (due to interference from UAS UE to FRMCS BS). These carriers has a lower probability of being chosen by dynamic channel selection algorithm;
- 3km for carriers higher than 1915.488 MHz (included).

Assuming an UAS transmit power of 10dBm, MCL study of compatibility between MFCN in 1920-1980 MHz and UAS using DECT-2020 in 1910-1920 MHz leads to separation distances of:

- 400 m between UAS UE and MFCN BS, and 100 m between UAS GS and MFCN BS in urban areas;
- 1300 m between UAS UE/GS and MFCN BS for DECT-2020 carrier close to 1920 MHz;
- 150 m between UAS UE and MFCN BS, and 610 m between UAS GS and MFCN BS, for DECT-2020 carriers lower than 1914.624 MHz (included).

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²⁶ Restricted to [TIES users](#) [ITU-R]