CEPT ECC
Electronic Communications Committee

ECC Report 309

Analysis of the usage of aerial UE for communication in current MFCN harmonised bands

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0 EXECUTIVE SUMMARY

In Europe, there is a fast-growing demand to operate Unmanned Aircraft Systems (UAS) under beyond-visual-line-of-sight (BVLOS) conditions, mainly for professional purposes. To enable these intended range of use cases there is the need for communication links between the Unmanned Aircraft (UA), its operator and an intended Unmanned Aerial Vehicles (UAV) Traffic Management (UTM) system.

The term aerial UEs, used in this Report, is equally applicable to either UAs (drones) or UEs in manned aircrafts as helicopters, "flying taxis". There are possible limitations of some assumptions of sharing scenario of some manned aircrafts flying platforms. In particular, scenario for commercial aircraft connectivity differs from those studied in that report.

This ECC Report is analysing spectrum issues relative to usage of aerial UE communications within the current MFCN spectrum harmonised regulatory framework for the different MFCN bands, including potential impact of such use on MFCN networks and other systems and services and possible spectrum regulatory considerations. The evaluation only deals with sharing and compatibility between MFCN with (inter and intra) services in-band and in adjacent band but is not considering civil aviation regulation. CEPT is not responsible to assess whether the regulatory environment for MFCN and respective MFCN deployments comply with requirements from the aviation sector.

The studies have been limited to LTE technology (4G), responding to the current market, with usage of "aerial" UEs up to 10000 m. The communications links of aerial UEs may be used for any type of communication, possibly including command and control and payload within MFCN bands. Furthermore, the intention is to use a technology which is already deployed and available in different frequency bands. These assumptions lead to the conclusion that the most appropriate and currently widely deployed technology which needs to be evaluated is LTE.

From a sharing and compatibility standpoint, a UE installed on-board an unmanned aircraft and a UE installed on-board a manned aircraft (e.g. helicopter or aircraft) are very similar. However, the operational scenarios may differ between these types of flying platforms. In this regard, the Report has studied the compatibility of aerial UEs for several heights of up to 10 km. The studies only considered scenarios where one UE is located on the flying platform. The term aerial UE is equally applicable to an LTE UE installed on-board an UA (drone) and an LTE UE installed on board a manned aircraft (e.g. helicopter).

The use of MFCN for the communication links of aerial UEs within a country may be restricted in certain frequency bands and/or in some geographical areas due to national laws other than national telecommunication laws or the table of frequency allocations of that country.

The intention is to use already existing MFCN BSs, which are typically deployed to provide effective coverage at ground level. At this stage, mobile operators do not intend to develop specific network planning to respond to these new aerial uses. Due to this, coexistence studies are mostly required for UL, due to the elevated position of aerial UEs. No specific studies are required in the DL for non-AAS BSs, since the emissions characteristics are not modified. Studies in the DL would only be required for the case of AAS base stations, where beam steering may lead to beam pointing above the horizon and may modify the emission characteristics. In this Report, the AAS issue has been only addressed for base stations BSs operating in the frequency band 3400-3800 MHz.

This ECC Report could be the basis of developing an additional framework to clarify spectrum regulatory conditions for the usage of aerial UE in the relevant suitable MFCN bands: 700 MHz, 800 MHz, 900 MHz, 1800 MHz, 2 GHz, 2.6 GHz, 3.4-3.8 GHz (with AAS BS scenario only for that band). In this Report aerial UEs are also assumed to be radio equipment subject to RED. Relevant harmonised standards should be developed to respect the results of sharing studies and harmonised technical conditions to be delivered on the basis of this ECC Report.

This Report noted that extensive studies, limited to 300 m altitude, on Enhanced LTE Support for Aerial Vehicles have been performed by 3GPP [1]. These studies conclude that current terrestrial LTE networks can handle flights of drones beyond line of sight, including handover for aerial UEs. The impact of aerial UEs on UL and DL performance remain acceptable when the percentile of aerial UEs (compared to total number of UEs) remains low[1]. 3GPP concluded that no more than 33% of the UEs per cell should be aerial UEs with current technology, to avoid self-interference. Conclusions of those studies have been confirmed by additional studies for aerial UE usage up to 10000 m. In particular co-channel studies have been performed for the 700 MHz, 800 MHz and 2.6 GHz frequency bands. Results can be extrapolated the following bands: 900 MHz, 1800 MHz and 2 GHz. All studies in those bands have focused on non AAS BS. Relevant studies have been done on 3.4-3.8 GHz with AAS base stations. In addition to co channel operation, conditions for coexistence with adjacent services have been studied.

Relevant CEPT cross-border coordination recommendations shall be developed in addition to the analysis already done in the Report. The band 1427-1518 MHz is harmonised for MFCN SDL at European level. Taking into account that aerial applications are mostly either bi-directional (e.g. C2) or dominated by uplink communications from aerial UEs to the network (e.g. earth observation data transmission) it is reasonable to assume that the 1427-1518 MHz band will not be of high interest for aerial UE communication over MFCN, so no further studies are considered in this ECC Report.

The band 2300-2400 MHz is harmonised for MFCN on a Licensed Shared Access (LSA) approach within CEPT, however currently sparsely used. Thus, the band will not be studied in this Report. However, it might be appropriate to conduct future studies in this respect.

According to ECC Decision (18)06 [2] "MFCN in the 24.25-27.5 GHz band shall not be used for connectivity from base stations to terminals on-board UAV and that only communications for connectivity from terminals on-board UAV to base stations is authorised…" Furthermore, ECC Decision (18)06 considers: "Due to its specific characteristics and usage, the 24.25-27.5 GHz MFCN band is not to be used for connectivity from base stations to terminals on board UAV." This requirement essentially prevents network to aerial UE communication. In addition, the connectivity from aerial UEs to BSs may have a significant impact, e.g. on separation distance from EESS/SRS earth stations, which requires further study. This band could be suitable for various high bitrate 5G UAS applications, however, at the time of writing this Report no need for aerial UEs was identified in this frequency band, which therefore was left out of consideration. However, it might be appropriate to conduct future studies in this respect.

The studies in this Report highlight that in some coexistence cases, aerial UEs impact in-band and adjacent band services in a different manner to ground UEs. In particular, the studies concluded that:

- some operational restrictions (e.g. no-fly zones)or additional emission limits specific to aerial UEs would be necessary to avoid interference to other services in some adjacent bands;
- to control the potential interference to its own MFCN, aerial UE density control may be necessary for an MNO, in particular for high payload aerial UE;
- there is no interference problem between neighbouring FDD MFCN networks operating in adjacent channels;
- operational restriction may be required in the case of cross-border coordination, to avoid interference to services including network of another MNO operating in an adjacent geographical area. This could be addressed by the relevant cross-border agreements to be developed based on relevant ECC Recommendation.

In order to be able to implement these coexistence conditions, an MNO should be able to differentiate between an aerial UE and an UE operating on the ground (this could also enhance, for example, roaming operation and differentiation between subscriptions). Such differentiated registration mechanisms for aerial UEs are already being developed by 3GPP. This should be further standardised by SDOs (ETSI in Europe).

The definition of no-fly zones may be required in order to achieve coexistence between some specific services in adjacent bands and aerial UEs operating in a few MFCN frequency bands. These no-fly zones are specific to transmitters in given bands or even in given channels. In this Report, these no-fly zones are defined for spectrum compatibility purposes. Relevant national authorities and users should be informed of flight restriction zones related to spectrum compatibility. Any such flight restriction zones required to achieve coexistence would be defined by the spectrum/telecommunication administrations. Even if 'no-fly-zones'

[1] 3GPP [1] studied 0% (Case 1), 0.1% (Case 2), 7.1% (Case 3), 25% (Case 4) and 50% (Case 5) of aerial UEs. The results indicate significant impact on the network performance for cases 4 and 5.

should be defined at national level (e.g. protection of RAS sites), any information on "no-fly zones" shall be shared among CEPT countries due possible roaming operation of aerial UEs. Additionally, there is also a need to establish a mechanism to ensure that aerial UEs respect the no-fly zone defined by relevant national authorities. Such mechanisms may need activities in standardisation including ETSI in Europe. The practical implementation of such mechanisms at national level may be a complex process.

The conducted coexistence studies conclude that aerial UEs can operate in the MFCN bands listed in the table below, while requiring in some cases additional regulatory measures. The table below only includes the uplink frequency bands for each FDD duplex pair (except for the TDD frequency bands).

Table 1: Frequency bands where aerial UEs connected to non-AAS MFCN (and AAS MFCN BS in 3400-3800 MHz) should be allowed to operate and associated required additional regulatory measures

Aerial UE frequency band	Additional regulatory measure required	Victim system
703-733 MHz	Aerial UEs operating in this band should fly at least 30 m above ground level to avoid interference to DTT receivers[2]	Broadcasting receivers below 694 MHz
	Implementation of measures at national level for terminals operating in the 703-713.5 MHz frequency band through a no-fly zone around RAS sites, or alternative measures (e.g. additional filtering) to reduce second harmonics, if appropriate. Cross-border coordination, through the implementation of no-fly zones or alternative measures (e.g. additional filtering) agreed by affected administrations, may be necessary where no-fly zones extend beyond a border	RAS in 1400-1427 MHz (primary, according to RR 5.340) being affected by second harmonics emissions of the aerial UEs
832-862 MHz	Implementation of measures at national level for terminals operating in the 832-835 MHz frequency band through a no-fly zone around RAS sites, or alternative measures (e.g. additional filtering) to reduce second harmonics, if appropriate. Cross-border coordination, through the implementation of no-fly zones or alternative measures (e.g. additional filtering) agreed by affected administrations, may be necessary where no-fly zones extend beyond a border	RAS in 1660-1670 MHz, (primary, according to RR 5.149) being affected by second harmonics emissions of the aerial UEs
832-862 MHz	No additional measures required. At the same time aggregate interference from the number of ground and aerial UEs as well as interference for aerial UEs with altitude more than 100 m need to be studied to draw the conclusion for this scenario	ARNS
880-915 MHz	No additional measures. Future FRMCS cab-radios are assumed to be designed in a way that ensures robustness against blocking signals emitted by aerial UEs	RMR (GSM-R and FRMCS BS UL) below 880 MHz RMR cab-radio receiving above 919.4 MHz
1710-1785 MHz	Emission limit of -40 dBm/MHz in 1675-1710 MHz for aerial UEs operating in 1710-1785 MHz	MetSat operating in 1675-1710 MHz
1920-1980 MHz	Approach 1: Minimum separation distance of 15 km between CGC base stations and aerial UEs operating below 1980 MHz with OoB emission limit of -7 dBm/(4.5 MHz) (ACLR1); Minimum separation distance of 2.5 km between CGC base stations and aerial UEs operating below 1980 MHz with OoB emission limit of -30 dBm/MHz (spurious);	MSS CGC aeronautical system operating in 1980-2010 MHz

[2] Areas where it can be confirmed that there are no DTT receivers to interfere with could be defined at national level if needed. In such nationally defined areas, this measure is not required

Aerial UE frequency band	Additional regulatory measure required	Victim system
	Zero minimum separation between CGC base stations and aerial UEs operating below 1980 MHz with OoB emission limit of -30 dBm/MHz; there is a risk of interference which is comparable to that of ground UEs, based on single interference worst-case scenario where aerial UE operates up to 1 km altitude a.g.l. Approach 2: No measures are required, based on aggregate Monte Carlo simulation within 61 cells, which compares the interference from aerial UEs to interference from ground UE where aerial UE operates in the range of 40-10000 m a.g.l.	
1920-1980 MHz	No specific measure is necessary to be applied to the aerial UEs operating above 1920 MHz for the protection of FRMCS cab-radio receiver at 1900-1910 MHz.	FRMCS cab-radio receiver at 1900-1910 MHz
2500-2570 MHz	None	Radio astronomy in 2690-2700 MHz
	Administrations should coordinate with their national aviation authorities to ensure that ATC radars above 2700 MHz are protected from interference, through the implementation of no-fly zones or alternative measures (e.g. additional filtering)	Radar operating above 2700 MHz
2570-2620 MHz	Coordination with RAS sites to be established at national level	RAS in 2690-2700 MHz
	Administrations should coordinate with their national aviation authorities to ensure that ATC radars above 2700 MHz are protected from interference, through the implementation of no-fly zones or alternative measures (e.g. additional filtering)	Radar operating above 2700 MHz
3400-3800 MHz	Coordination zones with FSS earth stations on a national level, which should be assessed on a case-by-case basis depending on the number of FSS earth stations and elevation angle of the FSS earth stations antenna. Cross-border coordination may be necessary (see note below) to ensure that earth stations do not suffer interference from aerial UEs operating in other countries. Note: Separation distances of 26.7 km to 290 km would be required to ensure protection of FSS earth stations operating in the band 3400-3800 MHz from aerial UEs operating in the same band	FSS operating in 3400-3800 MHz
3400-3800 MHz	Coordination with FSS earth stations at national level. To avoid the need for specific protection distances associated with each FSS antenna the unwanted emissions of an aerial UE would need to be lower than -60 dBm/MHz	FSS operating in 3800-4200 MHz

Aerial UE frequency band	Additional regulatory measure required	Victim system
3400-3800 MHz	Aerial UE unwanted emission levels below 3400 MHz equal to -50 dBm/MHz, to protect airborne and land-based radars	Radiolocation below 3400 MHz
3400-3800 MHz	Coordination with RAS sites to be established at national level	RAS in 3332-3339 MHz and 3345.8-3352.5 MHz

The requirements on the deployment of AAS BSs have been established based on land terminal use (except for one study dealing with protection of radar operating below 3400 MHz (Annex 20)). Deployments of AAS BSs serving aerial UEs may require further studies, due to beams being formed above the horizon. Therefore, AAS BS deployments meeting the current (land based) requirements may need to be reconsidered if aerial UEs are introduced.

In addition, it has been noted that exclusion and/or coordination zones for MFCN BS have already been implemented at national level in a number of CEPT countries to protect RAS sites from emissions from MFCN operating in harmonised bands. Those zones will also restrict the operational area for aerial UEs. Relevant "no-fly" zones shall be established at national level to protect RAS sites.

To ensure visibility for UAs market development in relevant MFCN bands while ensuring confidence of all spectrum users, there is a need for harmonised spectrum regulatory conditions for “aerial UEs: aerial UEs installed on UAs and manned aircrafts” usages in the relevant suitable MFCN bands.

Finally, additional ECC work is required in order to identify appropriate mechanisms to help administrations to establish cross-border agreements to avoid interference from aerial UEs.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Abbreviation	Explanation
3GPP	3rd Generation Partnership Project
AAS	Active Antenna Systems
ACIR	Adjacent Channel Interference Ratio
ACLR	Adjacent Channel Leakage Ratio
a.g.l.	Above Ground Level
amsl	Above Mean Sea Level
ARNS	Aeronautical Radio Navigation Service
ATC	Air Traffic Control
BS	Base Station
BVLOS	Beyond Visual Line of Sight
C2	Command and control
cdf	Cumulative Distribution Function
CEPT	European Conference of Postal and Telecommunications Administrations
CGC	Complementary Ground Component
COTS	Commercial Off-The-Shelf
DL	Downlink
DTH	Direct-to-Home
DTT	Digital Terrestrial Television
EAN	European Aviation Network
EASA	European Union Aviation Safety Agency
ECC	Electronic Communications Committee
EESS	Earth Exploration-Satellite Service
e.i.r.p.	Equivalent Isotropically Radiated Power
eMBB	Enhanced Mobile Broadband
ES	Earth Station
ETSI	European Telecommunication Standards Institute
E-UTRA	Evolved Universal Terrestrial Radio Access
FDD	Frequency Division Duplex
FRMCS	Future Railway Mobile Communication System
FSS	Fixed-Satellite Service
GSM-R	Global System for Mobile communication - Railway
GSO	Geostationary Satellite Orbit
IF	Intermediate Frequency
ITU-R	International Telecommunication Union - Radiocommunication
LNA	Low Noise Amplifier
LSA	Licensed Shared Access

LTE	Long Term Evolution
MCL	Minimum Coupling Loss
MetSat	Meteorological Satellite
MFCN	Mobile/Fixed Communications Networks
MNO	Mobile Network Operator
MS	Mobile Service
MSS	Mobile-Satellite Service
MXA	Mobile except Aeronautical
NR	New Radio
OoB	Out of Band
OOBE	Out of Band Emissions
PAMR	Public Access Mobile Radio
PMR	Private Mobile Radio
PPDR	Public Protection and Disaster Relief
PRACH	Physical Random Access Channel
PUSCH	Physical Uplink Shared Channel
QoS	Quality of Service
RAS	Radio Astronomy Service
RED	Radio Equipment Directive
R-LAN	Radio Local Area Network
RLS	Radio Location Service
RMR	Railway Mobile Radio
RSBN	Radio Systems for Short-Range Navigation
SEAMCAT	Spectrum Engineering Advanced Monte Carlo Analysis Tool
SEM	Spectrum Emission Mask
SDL	Supplemental Downlink
SDO	Standards Developing Organisation
SINR (or SNIR)	Signal to Interference plus Noise Ratio
SMATV	Satellite Master Antenna Television
SNR	Signal to Noise Ratio
SOS	Space Operations Service
SRS	Space Research Service
SRT	Sardinia Radio Telescope
TDD	Time Division Duplex
TRP	Total Radiated Power
TVG	Total Variable Gain
UA	Unmanned Aircraft
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicles
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System

UTM	UAS Traffic Management
VLBI	Very Long Baseline Interferometry
VSAT	Very Small Aperture Terminal
WSRT	Westerbork Synthesis Radio Telescope

1 INTRODUCTION

The purpose of this ECC Report is to evaluate the use of Mobile/Fixed Communications Networks (MFCN) for aerial UE usages within the current harmonised regulatory framework for the different MFCN bands, including potential impact of such use on MFCN networks and other systems and services and possible regulatory considerations. The evaluation only deals with sharing and compatibility between MFCN with (inter and intra) services in-band and in adjacent band but is not considering civil aviation regulation. CEPT is not responsible to assess whether the regulatory environment for MFCN and respective MFCN deployments comply with requirements from the aviation sector. Currently, there is a fast-growing demand in Europe to operate Unmanned Aircraft Systems (UAS) under beyond-visual-line-of-sight (BVLOS) conditions for professional purposes. This Report aims to answer this demand by identifying coexistence conditions which could be the basis for a harmonised regulatory framework enabling innovative use cases. ANNEX 3: provides an example and overview of the range of use cases and the projected demand for such use.

ECC Report 268 [3] contains the response to a 2015 questionnaire to CEPT administrations. The results show that drones which are currently operated in Europe predominantly use unlicensed bands. However, professional use of UAs requires both a safe environment and affordable cost of equipment. For such professional use, it has been proposed to use existing MFCN for both C2 and payload communication of UAs. The main idea of this concept is to keep the MFCN base station deployment unchanged but use the anyhow available coverage for aerial UEs. Consequently, CEPT has investigated whether the current spectrum regulatory provisions allow the usage of -aerial UEs or whether amendments/changes/additional framework are needed.

The Commission Delegated Regulation (EU) 2019/945 [4] and Commission Implementing Regulation (EU) 2019/947 [5] define several categories of UAs operations, i.e. "Open", "Specific" and "Certified" categories. This Report does not investigate whether communication with MFCN is appropriate for specific drone categories. Such assessment is left to the responsibility of civil aviation authorities.

This study is limited to CEPT harmonised MFCN bands.

2 DEFINITIONS

Term	Definition
Aerial UE	The term aerial UE is equally applicable to an LTE UE installed on-board an UA (drone) and an LTE UE installed on-board a manned aircraft (e.g. helicopter).
No-fly zones	Geographical area where aerial UEs are not allowed to operate. Such area may apply to all aerial UEs or to only some categories of aerial UEs, e.g. aerial UEs operating in a specific band or specific channel.

3 CONDITIONS FOR THE USE OF MFCN NETWORKS FOR UA COMMUNICATION

3.1 OPERATIONAL REQUIREMENTS

3.1.1 Operational requirements linked to spectrum regulation

From a commercial and operational standpoint, UAS manufacturers are interested in low-cost Commercial Off-The-Shelf (COTS)) transmitters allowing them to access existing MFCN to provide connectivity for UAS through usual unmodified mobile networks.

The intention is to use existing MFCN BSs which are typically deployed to provide effective coverage at ground level. At this stage, mobile operators do not intend to develop specific network planning to respond to these new aerial uses.

Given the intention to reuse existing equipment and regulation as much as possible, it is proposed to avoid specific operational requirements, unless required to protect other services or use cases. The goal of this Report is to identify such potential specific operational requirements due to sharing and compatibility challenges. The conducted coexistence studies conclude that aerial UEs can operate in the MFCN Bands: 700 MHz, 800 MHz 900 MHz, 1800 MHz, 2 GHz, 2.6 GHz and 3.4-3.8 GHz, while requiring additional spectrum regulatory measures in some cases (see section 5).

It should also be noted that current national coverage obligations are only defined for ground coverage. Should specific coverage target be desirable, they should be discussed at national level and are outside of the scope of this Report. While current networks are designed for ground coverage, Adaptive Antenna Systems (AAS) could theoretically improve connectivity between MFCN network and aerial UEs without specific network planning due to the BS's ability to steer the beam above the horizon. However, this feature also impacts the sharing and compatibility with services in-band and in adjacent band (see section 5). In this Report the sharing and compatibility of AAS is only addressed for base stations in the frequency band 3400-3800 MHz.

3.1.2 Operational requirements due to other regulations

The use of MFCN for the communication links of aerial UEs within a country may be restricted in certain frequency bands and in some geographical areas due to national laws other than national telecommunication laws or the table of frequency allocations of that country.

The potential aeronautical regulations' operational requirements, e.g. in terms of coverage or reliability of MFCN for the C2 link in specific situations, need to be defined and assessed by the civil aviation authorities. Such operational requirements are outside of the scope of this Report.

Civil aviation authorities are currently developing the concept of a UAS Traffic Management (UTM) system. In Europe, this concept is known as U-Space [6]. Specific requirements may be required for U-Space communications, compared to traditional UA C2 communications. However, such operational requirements are linked to aeronautical regulation and are therefore outside of the scope of this Report.

3.2 SUITABILITY OF MOBILE TECHNOLOGIES FOR UA OPERATIONS

The communication links of UAs are intended to be used primarily for data communication within MFCN bands. Furthermore, the intention is to use a technology which is already deployed and available in different frequency bands. The most appropriate and currently widely deployed technology for this use case is LTE which provides extensive MFCN coverage in CEPT countries. The 5G NR, as an early phase technology in 2020, will also be able to later deliver the required performance when similar coverage to LTE will be achieved.

4 IMPACT ON SERVICING MFCN

3GPP performed extensive studies on Enhanced LTE Support for Aerial Vehicles [1]. The sections below detail the findings of these reports and also include where appropriate the results of analysis done by CEPT when developing this ECC Report.

4.1 CO-CHANNEL INTERFERENCE ON MFCN

4.1.1 Interference on the same MFCN

4.1.1.1 Downlink interference on aerial UEs

In the DL, the percentage of aerial UEs experiencing cell-edge like radio conditions (i.e., poor DL SINR) is much higher as compared to terrestrial UEs. This is because aerial UEs, due to their high line-of-sight propagation probability, receive DL interference from a larger number of cells than a typical terrestrial UE does.

The increase of downlink interference at the aerial UEs level coming from multiple cells would require higher resource utilisation level to deliver the same offered cell data traffic. The increase in resource utilisation level further decreases the spectral efficiency in the network, which in turn degrades downlink throughput performance of both aerial UEs and terrestrial UEs. It is also concluded that the downlink throughput degradation for aerial UEs is more significant than the downlink throughput degradation for terrestrial UEs.

4.1.1.2 UL interference from aerial UEs

Thanks to lower coupling loss (in favour of direct line-of-sight with BS compared to higher BS antenna gain discrimination towards aerial UEs), an aerial UE's PUSCH transmit power is generally significantly lower at high altitude than ground mobile devices. However, aerial UEs at altitude produce more uplink interference in the network (inter-cell interference) than ground mobile devices because free space propagation increases the interference energy received at neighbouring cells in spite of higher BS antenna gain discrimination.

Within the same FDD network, the uplink interference caused by aerial UEs degrades throughput performance of the BS receivers in adjacent cells more than terrestrial UEs do because of lower coupling loss conditions. Therefore, for a given overall traffic and total number of UEs, the number of network resources (resource blocks) required increases with the ratio of aerial UEs. The throughput loss resulting from aerial UEs operation depends on the altitude of the aerial UE, as depicted in ANNEX 5: for different frequency bands (700 MHz, 800 MHz and 2600 MHz). As an example, throughput losses stand for more than 28% at altitude=100 m while it's less than 9% for terrestrial UEs for urban case.

4.1.1.3 Observations from existing 3GPP work

Overall, 3GPP studies conclude that current terrestrial LTE networks can handle flights of UAs beyond line of sights including handover for aerial UEs. The impact of aerial UEs on UL and DL performance remain modest when the percentile of aerial UEs (compared to total number of UEs) remain low[3]. 3GPP concluded that no more than 33% of the UEs per cell should be aerial UEs with current technology, to avoid too much intra-network interference.

Similar conclusions drawn by additional analysis from CEPT for aerial UE usage up to 10000 m (developed in this Report) confirm the network throughput loss with the increase of the aerial UE cell load. In particular co-channel studies have been performed for the 700 MHz, 800 MHz and 2.6 GHz frequency bands. Results can be extrapolated to the following bands: 900 MHz, 1800 MHz and 2 GHz. All studies in those bands have

[3] 3GPP [1] studied 0% (Case 1), 0.1% (Case 2), 7.1% (Case 3), 25% (Case 4) and 50% (Case 5) of aerial UEs. The results indicate significant impact on the network performance for cases 4 and 5.

focused on non AAS BS. Relevant studies have been done on 3.4-3.8 GHz with AAS base stations. In addition, to co channel operation, conditions for coexistence with adjacent services have been studies.

Furthermore, 3GPP initiated several activities in release 15, 16 and 17[4] to improve the support of aerial UEs by the standard and has already published 3GPP TS 22.125 [7]. It is expected that 3GPP standards will be available for MNOs wishing to improve the capacity of their networks to support aerial UEs.

This Report also identifies a need for a mechanism to ensure that aerial UEs respect the no-fly zone defined by spectrum authorities (and those from civil aviation authorities). Such mechanisms may need activities in standardization including ETSI in Europe. The practical implementation of such mechanisms at national level may be a complex process.

4.1.2 Cross-border operations and coordination issues

As mentioned before, the 3GPP studies [1] concluded that the main difference between aerial UEs and terrestrials UEs is that aerial UEs receive and transmit interference to a larger number of base stations in their surroundings, due to the line of sight to a large number of BSs. As a result, it is expected that aerial UEs would have a significant potential impact on the performance of networks across the border, since such networks are operating co-channel. Conclusions of those studies have been confirmed by additional studies for aerial UE usage up to 10000 m developed in this Report.

Current cross-border coordination agreements typically focus on trigger values on the DL, as the main interference mechanism is perceived to occur on the DL. Aerial UEs would require considering both DL and UL in cross-border coordination agreements. The following elements impacting the level of interference generated at the border from aerial UEs include: the payload, power control, altitude, density of aerial UE at the border area.

Relevant CEPT cross-border coordination recommendations shall be developed in addition to the analysis already done in the Report.

This could be based, for example, on:
- Definition of no-fly zones across the border to altogether avoid interference from aerial UEs in other countries;
- Limitation of the density of aerial UEs in the border region to avoid excessive interference from aerial UEs in other countries.

The appropriate mechanism can be selected on a band per band approach and should be considered in the appropriate cross-border coordination recommendations.

4.2 INTERFERENCE ON ADJACENT MFCN

Studies in ANNEX 2: and ANNEX 16: show that the interference from aerial UEs in adjacent channel is negligible compared to the case of adjacent interference caused by ground UEs.

This trend can be explained by:
- comparing the distribution of transmission power for aerial UEs and ground UEs: aerial UEs operate with lower transmission power (than ground UEs) because of a lower coupling loss with their serving BS (due to no obstacles within the path);
- noticing the small effect of Adjacent Channel Interference Ratio (ACIR) in the aggregate interference thus making it negligible towards the noise level (i.e. SNR≈SNIR).

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[4] Includes: Release 15 Work item 'Enhanced LTE Support for Aerial Vehicles' standardised a number of solutions identified in TS 36.777 [1] (RP-181310 [8]) with corresponding conformance test (RP-182324 [9]), a work item on Remote Identification of UASs (SP-180172 [10] and SP-180771 [11]), a study item on 5G enhancements for UAVs (SP-180909 [12]), a study item for an architectural study of supporting Unmanned Aerial Systems Connectivity, Identification, and Tracking (SP-181114 [13]), a Release 16 study item on application layer support for UAS service (SP-181252 [14]).

5 COEXISTENCE OF AERIAL UES OPERATED THROUGH MFCN WITH OTHER SERVICES IN-BAND AND IN ADJACENT BANDS

For low bands (below 1 GHz), it is expected that LTE and 5G NR will share the same emission characteristics due to the difficulty to deploy smart antennas. In such bands, coexistence and sharing studies are only required for the uplink (UL), since the base stations will not be modified.

For higher bands (above 1 GHz), coexistence and sharing studies are required for both:

- the UL, due to the location of 4G and 5G aerial UEs compared with usual UEs on the ground;
- the downlink (DL) for base stations leveraging AAS antennas. The studies below consider only non-AAS base stations, except in the case of the 3400-3800 MHz band.

5.1 MFCN AND AERIAL UE PARAMETERS

Concerning non-AAS base stations covered by this Report, the parameters and assumptions for base stations and networks for coexistence studies of aerial UEs operated through MFCN with other services in-band and in adjacent bands are provided in different annexes depending on the considered scenario.

5.2 700 MHZ BAND

Aerial UEs operating in 703-733 MHz face the following services in adjacent bands:

- MFCN above 736 MHz;
- PPDR between 698 and 703 MHz;
- Broadcasting (DTT) below 694 MHz.

Furthermore, second harmonics of the frequencies between 703-714 MHz fall into the passive band at 1400-1427 MHz which is used by the RAS.

5.2.1 MFCN above 736 MHz

CEPT Report 53 [15] defines emission limits in 733-758 MHz for UEs operating in 703-733 MHz through integration of the 3GPP SEM. The services operating in 733-758 MHz are designed to coexist with such UEs, with minimum separation distance between the terminal transmitting in 733-758 MHz and the terminal receiving in 733-758 MHz. Such two UEs can typically be located a few meters away from each other. Aerial UEs in 703-733 MHz will have both a much larger minimum separation distance and a much lower terminal density, while respecting the same emission limits. As such, aerial UEs in 703-733 MHz and UEs operating in 733-758 MHz will coexist with a sufficient margin than other UEs operating in 703-733 MHz.

5.2.2 PPDR between 698 and 703 MHz

PPDR networks operate in uplink in 698-703 MHz. As such, the coexistence between PPDR networks in 698-703 MHz and aerial UEs in 703-733 MHz is similar to the coexistence within 703-733 MHz of aerial UEs with MFCN networks in adjacent channels.

5.2.3 Broadcasting (DTT) below 694 MHz.

Coexistence between MFCN in 703-733 MHz and DTT receivers operating below 694 MHz was considered in CEPT Report 53 [15]. In this Report it was recommended that MFCN UEs limit unwanted emissions to no more than -42 dBm/8 MHz in the frequency range 470-694 MHz. CEPT Report 53 further indicates: “This value has been derived with regard to fixed DTT reception”.

The recommendations from CEPT Report 53 are encapsulated in ECC Decision (15)01 [16] which states that the out of band emission limit for 700 MHz MFCN UE is -42 dBm/8 MHz in the frequency range 470-694 MHz.

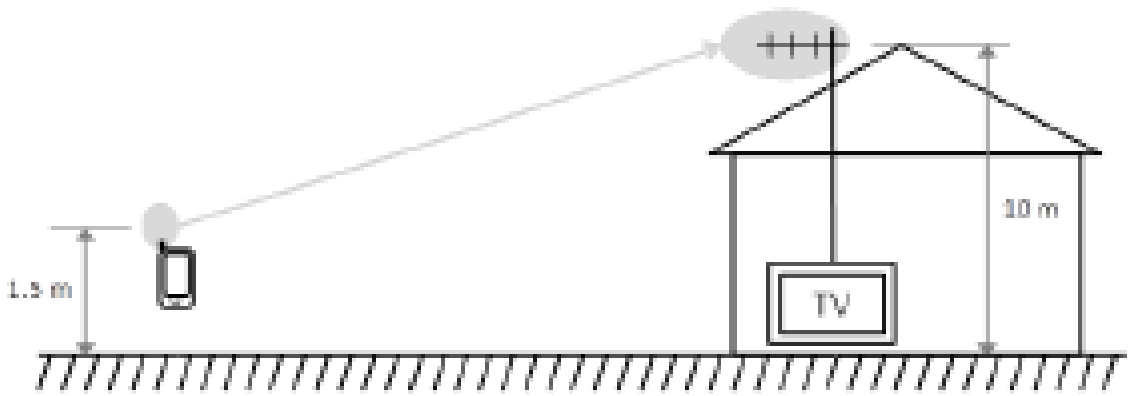

Figure 1: Geometry of MCL analysis in CEPT Report 53

The vertical and horizontal separation distances between the MFCN terminal and the rooftop antenna are respectively 8.5 m and 22 m. At such small distances, the path loss is assumed to be no larger than free-space path loss.

Compared with an MFCN UE an aerial UE, in the same manner as a vehicle mounted UE, will have a more efficient transmit antenna and will not be subject to body loss. As such the maximum e.i.r.p of an aerial UE will be 7 dB or more, higher than the figure assumed in compatibility studies in CEPT Report 53. Moreover, aerial UE will fly above clutter and will effectively be LoS to the DTT receive antenna at all distances.

With respect to aerial UE and interference to DTT receivers the primary concern is aerial UE using the 700 MHz band and flying below 30 m above ground level (a.g.l.) - e.g. delivery drones. Aerial UE flying higher than 30 m, away from populated areas or using LTE frequency band 800 MHz or above should not be a problem to reception of DTT.

As indicated in Annex 4 one of the main use cases is delivery. If, as often hypothesised, UAs are to be used for deliveries to individual addresses, then one could expect that they would pass by many times a day. A quiet suburban road can typically have 4 or 5 delivery vans visit, in addition there are the various supermarket food delivery vehicles and later in the day takeaway deliveries, maybe another 4 or 5 per day.

Any UA delivering to a domestic address will fly close to one or more DTT receive antennas. ECC Report 239 [17] contains an assessment of the area in a suburban environment within which a UE would be within 3 dB and 6 dB of the MCL value. Whilst that assessment was for handheld UE it applies equally to aerial UEs. The assessment concluded that for a typical UK suburban environment 41% of the area is within 3 dB of the MCL value and 68% was within 6 dB of the MCL value, Figure 2. From the information supplied, given the fact that the reference DTT receive antenna pattern (ITU-R BT.419 [18]) is symmetric in the vertical and horizontal planes, it is noted that the 6 dB zone extends to a height of 24 m a.g.l.

Figure 2: Sample suburban area mapping with 3 dB and 6 dB minimum coupling footprints overlaid

Whilst for handheld UE at ground level, given the height of the DTT receive antenna and the DTT receive antenna pattern, the MCL distance is 22 m, aerial UEs will approach much closer than this distance. Given the ground area of an average dwelling, delivery UAs will have to fly close to, within a few metres of a DTT receive antenna, when delivering packages.

It should be noted that the safety and privacy requirements may exclude the operation of aerial UEs in proximity to DTT receivers. The Commission Delegated Regulation (EU) 2019/945 [4] and Commission Implementing Regulation (EU) 2019/947 [5] lay down rules and procedures for the operation of unmanned aircraft includes flight restrictions for UAs, even in the open category, e.g. "UAS operations in subcategory A3 shall be performed […] keeping a safe distance from the boundaries of congested areas, where 'congested area' means any area in a city, town or settlement which is substantially used for residential, commercial or recreational purposes."

In conclusion, aerial UE operating close to populated locations (altitudes less than 30 m a.g.l.) could approach closer than 10 m to a DTT receive antenna which would result in interference to the DTT.

Consequently, aerial UEs using the 703-733 MHz band:

- should be forbidden to fly below a height of 30 m a.g.l.;
- should respect the -42 dBm/8 MHz emission limit in the frequency range of 470-694 MHz.

5.2.4 Compatibility between aerial UEs in 703-713.5 MHz and Radio astronomy in 1400-1427 MHz

The second harmonics of MFCN UEs (including aerial UEs) operating in 703-713.5 MHz fall into the 1400-1427 MHz RAS band. This RAS band is a primary passive band (RR Footnote 5.340 [19]). Both continuum and spectral line observations are frequently carried out.

The protection of services in the far spurious domain is usually not subject of coexistence studies. However, specific attention may be required when issues regarding the second harmonics can be expected.

The study in ANNEX 6: derived interference level at radio astronomy sites based on several aerial UEs spurious emission level assumptions. The study concludes that very large separation distances (100s of km) are required between RAS and aerials UEs operating in 703-713.5 MHz. According to ECC Report 249 [26] (their Figs. 9 and 10), one of the measured LTE800 UE devices produced second harmonics in the 1600 MHz band, with broad-band emissions of about -35 dBm/MHz. The study in Annex 7 assumed that LTE700 UE could also produce similar features and thus for the compatibility with RAS the regulatory limit given in

Recommendation ITU-R SM.329 [33] of -30 dBm/MHz was deemed to be appropriate for this study, however spurious emission limits of -40, -50 and -60 dBm/MHz were also used in this study. The resulting regulatory requirement based on the taken assumptions for the operation of LTE700 aerial UE is to consider the implementation of no-fly zones around radio telescopes operating in the 1400-1427 MHz band in some cases. Cross-border coordination may be necessary where no-fly zones extend beyond a border. The respective no-fly zones are detailed in Table 46 of ANNEX 6:.

The study in ANNEX 7: compared interference levels from UEs on the ground and aerial UEs under assumptions of flat Earth at varying distances and demonstrated that aerial UEs are no more likely to generate interference as UEs on the ground for distances up to several kilometres under line-of-sight conditions. However, local clutter and terrain will have an impact on the comparison between ground and aerial UE, but these effects were not included in the analysis. Given that UEs on the ground are very widely deployed and operating in the 700 MHz band, including in the vicinity of radio astronomy sites, the study suggests that no additional restriction specific to aerial UEs required at CEPT level. Administration may choose to implement local flight restrictions for aerial UEs operating in 703-713.5 MHz around RAS site at national level.

In conclusion, taking into account both theoretical studies and practical considerations, many potential coexistence issues can be resolved through implementation of measures at national level for terminals operating in the 703-713.5 MHz frequency band through a no-fly zone around RAS sites, or alternative measures (e.g. additional filtering) to reduce second harmonics, if appropriate.

Cross-border coordination, through the implementation of no-fly zones or alternative measures (e.g. additional filtering) , may be necessary where no-fly zones extend beyond a border.

5.3 800 MHZ BAND

Aerial UEs operating in 832-862 MHz face the following ARNS services operating in the 800 MHz band:

- Radio systems for short-range navigation (RSBN) Aircraft transmitter in 770-810 MHz;
- Radiolocation service (RLS) 2 (Type 2) Ground radar transmitter in 833-839 MHz;
- RLS 1 (Type1) Ground radar transmitter in 830-839 MHz and 855-861 MHz;
- RLS1 (Type 2) Ground radar transmitter in 842-861 MHz.
- Furthermore, second harmonics of the frequencies between 832-835 MHz and 859-861 MHz fall into RAS bands at 1660-1670 MHz and 1718.8-1722.2 MHz, respectively.

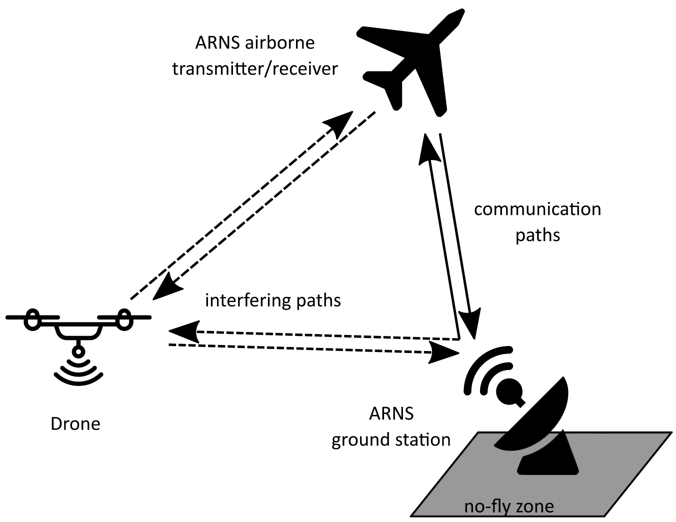

Figure 3: Interference scenario between ARNS and UAV

5.3.1 ARNS airborne receiver

There is a huge gap in the transmitter power of an ARNS ground station (48-82 dBW e.r.p., see also Report ITU-R M.2241 [41]) and a normal mobile phone (-5 dBW).

Furthermore, a normal altitude of an aerial UE is around 100 m. Therefore, for the free space propagation model the interference received by an airborne ARNS receiver from the single ground UE and single aerial UE is nearly the same. At the same time aggregate interference from the number of ground and aerial UEs as well as interference for aerial UEs with altitude more than 100 m need to be studied to draw the conclusion for this scenario.

5.3.2 ARNS Ground radar receiver

In the uplink, an ARNS system might be more effected by aerial UEs communicating on neighbouring frequency bands especially when the aerial UE is located near the ARNS ground station. However, ARNS ground stations are located on airfields where anyhow no-fly zones for aerial UEs are defined and already in existence. This means that there is a sufficient spatial separation of aerial UEs and ARNS ground stations which facilitates coexistence between both communication services.

Furthermore, it should be noted, that interference from ground UEs at elevated positions already exists in today’s network implementations.

Finally, it can be concluded that coexistence between aerial UEs using a MFCN operating in the 800 MHz band is feasible since aerial UEs will not cause more interference to the ARNS service than normal users.

5.3.3 Compatibility between aerial UEs in 832-835 MHz and Radio astronomy in 1660-1670 MHz

Second harmonics of LTE800 UE in the frequency range 832-835 MHz potentially affect the RAS bands at 1660-1670 MHz. The former RAS band is a primary band (RR Footnote 5.149 [19]). This band is mainly used for spectral line observations of the hydroxyl molecule, which plays an important role in the interstellar medium. The 1660-1670 MHz band is furthermore used for continuum observations.

The protection of services in the far spurious domain is usually not subject of coexistence studies. However, specific attention may be required when issues regarding the second harmonics can be expected.

The study in ANNEX 6: derived interference level at radio astronomy sites based on several aerial UEs spurious emission level assumptions. The study concludes that very large separation distances (100s of km) are required between RAS and aerials UEs operating in 832-835 MHz.

According to ECC Report 249 (their Figures 9 and 10) [26], one of the measured LTE800 UE devices produced second harmonics in the 1600 MHz band, with broad-band emissions of about -35 dBm/MHz. The study assumed that other LTE800 UE could produce similar features and thus for the compatibility with RAS the regulatory limit given in Recommendation ITU-R SM.329 [33] limit of -30 dBm/MHz was deemed to be appropriate for this study, however spurious emission limits of -40, -50 and -60 dBm/MHz were also used in this study.

The resulting regulatory requirement based on the taken assumptions for the operation of LTE800 aerial UE is to consider the implementation of no-fly zones around radio telescopes operating in the 1660-1670 MHz band. Cross-border coordination may be necessary where no-fly zones extent beyond a border. The respective no-fly zones are detailed in Table 46 of ANNEX 6:.

The study in ANNEX 7: compared interference levels from UEs on the ground and aerial UEs under assumptions of flat Earth at varying distances and demonstrated that aerial UEs are no more likely to generate interference than UEs on the ground for distances up to several kilometres under line-of-sight conditions. However, local clutter and terrain will have an impact on the comparison between ground and aerial UE, but these effects were not included in the analysis. Local clutter may have an impact on the comparison between ground and aerial UE. Given that UEs on the ground are very widely deployed and operating in the 800 MHz band, including in the vicinity of radio astronomy sites, the study suggests that no additional restriction specific to aerial UEs is required at CEPT level. Administration may choose to implement local flight restrictions for aerial UEs operating in 832-835 MHz around RAS sites at national level.

In conclusion, taking into account both theoretical studies and practical considerations, it can be concluded that many potential coexistence issues can be resolved through implementation of measures at national level for terminals operating in the 832-835 MHz frequency band through a no-fly zone around RAS sites, or alternative measures (e.g. additional filtering) to reduce second harmonics, if appropriate.

Cross-border coordination, through the implementation of no-fly zones or alternative measures (e.g. additional filtering), may be necessary where no-fly zones extend beyond a border.

5.4 900 MHZ BAND

ECC Report 96 [21] and ECC Report 313 [27] identified the services operating in bands adjacent to 880-915 MHz[5] as:

- GSM-R (UL) in 876-880 MHz (in some European countries on a national basis 873-880 MHz);
- GSM-R (DL) in 921-925 MHz (in some European countries on a national basis in 918-925 MHz);
- RMR (UL) in 874.4-880 MHz;
- RMR (DL) in 919.4-925 MHz;
- PMR/PAMR (DL) in 915-921 MHz.

5.4.1 GSM-R and FRMCS in 874.4-880 MHz / 919.4-925 MHz

ECC Report 96 [21] identified the two major interference challenges as:

- Interference from MFCN BSs to GSM-R DL;
- Interference from GSM-R terminals to MFCN UL.

5.4.1.1 Impact of aerial UEs on RMR BS below 880 MHz

Aerial UEs do modify the coexistence situation at 880 MHz because the aerial UEs minimum coupling loss with GSM-R/FRMCS base stations is slightly different to ground based UEs due to their physical operation location.

A Monte Carlo simulation of the interfering field strength generated by 5 aerial UEs is compared with the interfering field strength generated by 15 ground UEs (see ANNEX 2:). The difference in UE density is justified by the LTE networks limited ability to handle airborne UEs due to self-interference issues [1]. Monte Carlo simulations demonstrate that aerial UEs create a lower interference field strength than ground based UEs but also that the variation of the interfering field strength is lower. This can be explained as follows:

- The antenna gain above the horizon from RMR and LTE base stations are similar;
- The propagation difference between the wanted link (aerial UE to LTE BS) and the interfering link (aerial UE to RMR BS) mostly differ due to free-space path loss;
- Free-space path loss varies less than more challenging propagation environment (e.g. Hata).

As a result, the power control of the wanted link ensures that the interfering field strength from aerial UEs is lower than the interfering field strength generated by ground based UEs.

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[5] Harmonised technical conditions in 900 MHz band are under review in order to include 5G in the respective CEPT framework in a technology neutral manner.

Further analysis concluded that, when considering coexistence issues with other systems, GSM-R base stations may accept at most 1 dB desensitisation. This value has been assumed in several former ECC reports, most notably ECC Report 96 [21], 146 [22], 162 [23] and 200 [24] and is similar to the one used for MFCN base stations (see Report ITU-R M.2292 [25]). As a conclusion, RMR base stations, whether they use GSM-R, or FRMCS, or both systems in parallel, do not claim more protection than MFCN base stations, for which is commonly accepted that there is no significant performance degradation when the desensitisation is kept below 1 dB.

The situation between RMR base stations and aerial UEs operating above 880 MHz is similar to the situation where two operators use adjacent FDD uplink frequency blocks, and where one of them operates aerial UEs (see section 4.2).

5.4.2 Impact of aerial UEs on RMR cab-radios above 919.4 MHz

This scenario is different from the one where aerial UEs interfere with RMR/FRMCS base stations because of different deployment characteristics: train mounted antennas exhibit significant gain values at an elevation angle of ~30° whilst base stations sectoral antennas usually point downwards.

Aerial UEs in the uplink band 880-915 MHz may interfere with RMR cab-radios receiving in 919.4-925 MHz, through blocking effects and/or spurious emissions.

5.4.2.1 Blocking effect

ECC Report 313 [27] determined the need to improve the receiver characteristics of the FRMCS cab-radio. compared to 3GPP specification for band 880-960 MHz, so that it can cope with aerial UE using MFCN below 915 MHz. Calculations have shown that the requirements calculated are already fulfilled by GSM-R cab-radios specified in ETSI TS 102 933-1 [28]. In other words, future FRMCS cab-radios are assumed to be designed in a way that ensures robustness against blocking signals emitted by aerial UEs.

5.4.2.2 Spurious emissions

Considering that any UE shall comply with a spurious emission level of -50 dBm/MHz in all MFCN DL bands (as per 3GPP TS 36.101 [29] and TS 38.101-1 [30] which are/should be implemented in ETSI HS) and that within 915-925 MHz the duplexer will provide additional filtering (compared to 3GPP specifications), it is concluded that aerial UE unwanted emissions will not cause harmful interference to RMR cab-radio as unwanted emissions in the RMR downlink band are assumed to be not far from the requirement within the 900 MHz MFCN DL band (-50 dBm/MHz) in the spurious domain as specified in TS 36.101.

5.4.3 PMR/PAMR above 915 MHz

Around 915 MHz, MFCN UEs could potentially interfere with PMR/PAMR terminals in close vicinity. ECC Report 96 [21] concluded that such interference would not be problematic and CEPT Report 41 [116] extended this result to LTE.

While aerial UEs comply with the transmit characteristics of UMTS/LTE UEs, they are typically located much further away from PMR/PAMR terminals due to vertical separation on top of horizontal separation. Furthermore, the density of aerial UEs will be much lower than the density of ground UEs.

Therefore, aerial UEs within 880-915 MHz are not expected to create interference to PMR/PAMR terminals above 915 MHz.

5.5 1500 MHZ BAND

ECC Decision (13)03 [34] and ECC Decision (17)06 [35] govern the harmonised use of the 1427-1518 MHz band (including a guard band in 1517-1518 MHz) for MFCN SDL at European level. Aerial UE applications are mostly either bi-directional (e.g. C2) or dominated by aerial UE to network communication (e.g. earth observation data transmission). At this stage, only a very limited number of applications, for example air traffic information and meteorological information, would potentially be dominated by network to aerial UE communication. It is even unclear, whether these applications would be communicated to the aerial UE itself, or to the UA operator. As such, it is reasonable to assume that the 1427-1518 MHz band will not be used for aerial UE communication over MFCN, so no further studies will be considered in this ECC Report.

5.6 1800 MHZ BAND[6]

ECC Report 96 [21] identified the main applications in adjacent bands as:

- Weather satellites (MetSat) below 1710 MHz;
- Defence systems (fixed telemetry) below 1710 MHz and Wireless broadband (fixed service) above 1785 MHz;
- Radio-Microphones above 1785 MHz;
- In addition, the RAS band 1718.8-1722.2 MHz (see Footnote 5.149 and 5.385 in RR) is in-band with respect to the 1800 MHz IMT band.

5.6.1 Weather satellites (MetSat) below 1710 MHz

Meteorological satellite service (space to earth) systems operate in 1675-1710 MHz. In particular, the 1698-1710 MHz range is used for space to earth data transmission systems for non-geostationary satellites.

The non-geostationary satellite receivers can track the satellites. Therefore, they do not point towards a fixed direction. However, the receivers are always pointing above the horizon, which limits the risk for MFCN UEs located on the ground being in the main beam of the satellite receiver.

In contrast, aerial UEs can be located in the main beam of the satellite receivers, leading to the requirement for extremely low emissions and/or large separation distances to avoid interference to the satellite receiver.

ANNEX 5: determines the required separation between MetSat receiver and aerial UE and includes two studies a single-entry study under worst-case conditions (aerial UE in the main beam of the satellite receiver, free-space path loss, UE transmitting at emission limit, both long term and short-term interference criteria) and a statistical study. The results of the studies are provided in Table 2 below.

Table 2: Separation distance required between aerial UE and MetSat receiver

Aerial UE emissions	Required radius of no-fly zones (km)	
	Worst-case short-term criteria	Statistical analysis
First adjacent channel	30	200
Second adjacent channel	10.8	50
Third adjacent channel (spurious)	4.5	5
-40 dBm/MHz	1.4	0
-50 dBm/MHz	0.45	0

Given the large separation distance required for the first adjacent channel, it is necessary to introduce specific emission limits for the aerial UEs operating in 1710-1785 MHz. These specific limits are applicable for aerial

6 Harmonised technical conditions in 1800 MHz band are under review in order to include 5G in the respective CEPT framework in technology neutral manner

UEs when they are flying above the clutter as they have better propagation conditions towards the MetSat receivers. When the aerial UEs are below the clutter, the interference from the aerial UEs is similar to that from terrestrial UEs and no additional restrictions are required.

Table 3: Regulatory requirements for the operation of aerial UE in 1710-1785 MHz

Regulatory requirement	Value
Aerial UE emission limit in 1675-1710 MHz	-40 dBm/MHz

5.6.2 Defence systems (fixed telemetry) below 1710 MHz and wireless broadband (fixed service) above 1785 MHz

ECC Report 96 [21] underlines that critical interference between MFCN in 1710-1785 MHz and fixed service in adjacent bands is related to Fixed Service station to MFCN BS interference. This scenario is not impacted by aerial UEs. Therefore, the interference situation remains unchanged.

5.6.3 Radio microphones above 1785 MHz

ECC Report 96 [21] studied the potential interference between radio microphones above 1785 MHz and MFCN base stations. This situation remains unchanged since MFCN base stations will not be modified for support of aerial UEs.

Interference from MFCN UEs to radio microphone can occur in very close proximity, as both are typically handheld devices. Aerial UEs have the same emission characteristics as ground UEs but are separated from radio microphones due to elevation and flight safety considerations. Therefore, aerial UEs will not cause more interference to radio microphones than usual MFCN UEs.

5.6.4 RAS at 1718.8-1722.2 MHz

The RAS band 1718.8-1722.2 MHz (secondary allocation, see RR Footnote 5.149 and 5.385 [19]) is mainly used for spectral line observations of the Hydroxyl molecule. This frequency range is in-band with respect to LTE1800 uplink (1710-1785 MHz). Studies in ANNEX 7: demonstrate the need for no-fly zones, although this is a harmonised band for MFCN.

5.7 2 GHZ BAND

Regarding adjacent band compatibility for non-AAS systems, the "2 GHz UL bands" is the 1920-1980 MHz band. The 1920-1980 MHz band is adjacent to:

- The 1900-1920 MHz band, where FRMCS and UAS use are currently being studied by CEPT. CEPT Report 52 defined harmonised technical conditions for the 1900-1920 MHz band;
- The band 1980-2010 MHz which is designated to the MSS in CEPT and is used in Europe by two MSS operators.

5.7.1 Coexistence with FRMCS operating 1900-1910 MHz

The coexistence could be similar to the situation in the 900 MHz band:

- Where the critical interference scenarios (MFCN BS interfering the FRMCS DL and FRMCS terminals interfering the MFCN UL) are actually not modified for non-AAS systems. The position and configuration of non-AAS MFCN BSs is assumed to remain unchanged, and therefore the interference situation is also unchanged.

5.7.1.1 Impact of aerial UEs on FRMCS BS operating in 1900-1910 MHz

Concerning the scenario on MFCN aerial UEs (operating in 1920-1980 MHz) interfering with FRMCS uplink (in 1900-1910 MHz), aerial UEs do modify the coexistence situation in terms of potential interference to FRMCS UL due to their location.

The aerial UEs interfering FRMCS uplink scenario is similar to coexistence situation at 880 MHz between MFCN and GSM-R. The same factors will lead to the same conclusion (see section 4.2), i.e.:

- the antenna gain above the horizon from FRMCS and LTE base stations are similar;
- the propagation difference between the wanted link (aerial UE to LTE BS) and the interfering link (aerial UE to FRMCS BS) mostly differ due to free-space path loss;
- Free-space path loss varies less than more challenging propagation environment (e.g. Hata);
- the aerial UE density is expected to be lower than the ground UE density.

5.7.1.2 Impact of aerial UEs on FRMCS cab-radios operating in 1900-1910 MHz

MFCN aerial UEs may interfere with FRMCS UEs in the frequency band 1900-1910 MHz through unwanted emissions and blocking effects.

ECC Report 314 determined the need to improve the receiver characteristics of the FRMCS cab-radio, compared to 3GPP specification for band #39 which are/should be implemented in ETSI HS, so that it can cope with aerial UE using MFCN above 1920 MHz. FRMCS cab-radios are assumed to be designed in a way that ensures robustness against blocking signals emitted by UAVs.

CEPT studied compatibility between FRMCS cab-radio receiver and aerial UEs (see ANNEX 18:). It shows that the protection of the cab-radio is ensured (with a margin) for different environments (high-speed, low-density, high-Density) even for worst conditions of aerial UEs deployment within the MFCN (i.e. with a high traffic load: from 12 to 50 aerial UEs per cell simultaneously transmitting over more than 60 cells in the vicinity of the railway). Therefore, it can be concluded that no specific measure is necessary to be applied to the aerial UEs operating above 1920 MHz for the protection of FRMCS cab-radio receiver at 1900-1910 MHz.

5.7.1.3 Based on these analysis/studies, there is no need to establish a no-fly zone around railway tracks where FRMCS at 1900 MHz is deployed. Coexistence with potential future other UAS systems

The regulatory framework for the usage of UAS below 1920 MHz is currently under development in CEPT. Respective relevant coexistence scenarios will be clarified if needed.

5.7.2 Coexistence of aerial UEs in the band 1920-1980 MHz with CGC aeronautical ground stations operating above 1980 MHz

With regards to the 2 GHz MFCN band, the scope of this Report is to consider non-AAS MFCN systems. Above 1980 MHz, one operator has already deployed an operational MSS network, the "European Aviation Network" (EAN), which is used to provide communications primarily to passenger aircraft and utilises a complementary ground component (CGC) of base stations across Europe. The EAN CGC base stations receive in the band 1980-2010 MHz, and therefore the potential interference from aerial UE transmission into adjacent band above 1980 MHz is considered.

The EAN CGC base stations are up-tilted to enhance coverage to aircraft. The aircraft are equipped with terminals which communicate with the MSS satellite and terminals which communicate with the CGC base stations.

For the scenario of adjacent band interference from aerial UEs transmitting in the band below 1980 MHz into the MSS space station receiving above 1980 MHz, it is not expected that the potential interference into the MSS satellite from terminals transmitting 23 dBm with a 0 dBi antenna on the ground would be significantly different to that of aerial UEs in the air, given the small variation in distance between the terminal and the satellite receiver, in relative terms. However, the situation could be different for the potential interference from aerial UEs into CGC base station receiving above 1980 MHz due to a number of technical and operational differences between terrestrial base stations and CGC base stations.

The fact that the aerial UEs operate above horizon, and the CGC BS are up-tilted, would result in the aerial UEs entering the main beam direction of the CGC BS. As well as this, the EAN network deploys CGC base stations covering cell sizes of up to 150 km in radius and this necessities the CGC base station to be more sensitive than normal terrestrial base stations, as a result of this, the CGC base stations receivers are designed with a lower noise figure of 3 dB and CGC base station antennas are typically installed with only 1 dB feeder loss or less. However, these observations may be counter-balanced by the fact that aerial UEs may operate with a lower power than regular terminals do (because of a lower coupling loss) but also a lower density.

Consequently, the potential OOBE and spurious interference analysis from aerial UEs transmitting in the band below 1980 MHz into CGC base stations receiving in the band above 1980 MHz are presented in ANNEX 12:.

The results are shown in Table 4:

Table 4: Requirements summary of results for the protection of CGC BS ANNEX 12: and ANNEX 13:

Minimum separation distance required	Regulatory limit required of aerial UE OOBE above 1980 MHz to protect CGC BS at the required separation distance	Comment
15 km	-7 dBm/4.5 MHz (ACLR1)	Based on MCL analysis
2.5 km	-30 dBm/MHz (Spurious)	Based on MCL analysis
0 km	▪ -30 dBm/MHz	▪ There is a risk of interference which is comparable to that of ground UEs, based on single interference worst-case scenario where aerial UE operates up to 1 km altitude a.g.l. ▪ Based on Monte Carlo study 1B, considering aerial UE altitude of up to 300m or up to 10000 m (Annex A12.1.2), no OOBE limit would lead to interference greater than that experienced from ground UEs, hence an OOBE limit of -30 dBm/MHz is determined.
0 km	▪ No OOBE limit required	▪ Based on Monte Carlo study 2 (ANNEX 13:)

Regarding the two Monte Carlo analyses, different modelling and parameter assumptions have led to different conclusions. The different assumptions have been captured in two views in Table 6.

Table 5: Summary of different modelling and assumptions used in Monte Carlo studies

Parameter/ assumption	Monte Carlo study 1B (Annex A12.1.2)	Monte Carlo study 2 (ANNEX 13:)
Simulation area/density of aerial UEs	For the coexistence studies between aerial UEs and CGC base stations at 2 GHz, it was agreed to use an aerial UE altitude range up	Simulates for both rural and urban cases up to 61 MFCN cells with 1 aerial UE per MFCN cell (per 2 RBs).

Parameter/ assumption	Monte Carlo study 1B (Annex A12.1.2)	Monte Carlo study 2 (ANNEX 13:)
	to 10 km and density of 1aerial UE/cell. The additional studies requested before the Report went to public consultation were justified by the need to be consistent with the assumptions used in the MetSat studies, which also considered aerial UE altitude range up to 10 km and a simulation area 535,858 km², based on the visible area for an aerial UE at 10 km altitude. However, the study in ANNEX 13: uses a simulation area of only 990 km² which gives a much lower aggregate interference level. For example, a simulation area of 990 km² results in a probability of interference of 8%, while a 5026 km² simulation area (much lower than 535,858 km² used for MetSat) results in probability of interference of 98.5% Even though the average density of aerial UEs could be lower over such a large area, note that the probability of interference is almost 100% over a fraction of the simulation area, 5026 km², with only 300 aerial UEs, with a density of aerial UES much lower than the MetSat study Hence the study in ANNEX 13:underestimates the interference levels from Aerial UEs into CGC base stations by using a too small a simulation area	As this assumption relates to a high usage of aerial UEs, aerial UE density should be adjusted (i.e. reduced) when extending the simulation area beyond 61 cells. Otherwise this may lead to unrealistic situation e.g. 535,858.32 km², for instance, which is close to the French metropole area, this would lead to 30000 cells at least (rural only area assumed), that is 30000x1 aerial UEs simultaneously transmitting in France (again, ignoring higher cell densities in cities).
SNR assumed for ground and aerial UE	The approach taken in both studies is to first consider the interference from ground UEs to CGC base stations, and secondly from aerial UEs to CGC base stations. The result of the first analysis is used as a benchmark to determine the acceptability of interference in the second analysis. Therefore, the consistency of assumptions for the interference from ground and aerial UEs is critical. Aerial UEs are expected to require real time streaming video, as well as other data services, with similar or higher data rate requirements than ground UEs. The study in ANNEX 12: uses the same SNR for both ground UEs and aerial UEs assuming similar data rates. However, the study in ANNEX 13: uses SNR of 15 dB from ground UEs while the SNR from Aerial UEs is set to 10 dB. This artificially inflates the predicted interference from the ground UEs when compared to the interference from aerial UEs	▪ defines different minimum target SNR at the base station for ground UEs (15 dB) and aerial UEs (10 dB), because of ▪ different target bitrate objectives: around 500 kbps for aerial UEs and 360 kbps for ground UEs. ▪ different number of resources blocks (2 RBs for aerial UEs and 1 RB for ground UEs) Although SNR ground UE>SNR aerial UE, because of different number of RBs: ▪ data rate ground UE<data rate aerial UE (360 kbps<500 kbps) Aligning both data rates for aerial and ground UEs would result in reducing SNR aerial UE.

Parameter/ assumption	Monte Carlo study 1B (Annex A12.1.2)	Monte Carlo study 2 (ANNEX 13:)
Density of ground UEs	The approach taken in both studies is to first consider the interference from ground UEs to CGC base stations, and secondly from aerial UEs to CGC base stations. The result of the first analysis is used as a benchmark to determine the acceptability of interference in the second analysis. Therefore, the accuracy and consistency of modelling of interference from ground UEs is critical. However, the study in ANNEX 13: overestimates the aggregate interference levels received from ground UEs into CGC base stations by using much higher numbers of ground UEs. For the rural case, ANNEX 13: assumes 854 ground UEs in the rural simulation area as opposed to 168 specified by ITU-R Report M.2292 [25] for the same area. For the urban case, ANNEX 13: assumes 854 ground UEs in the urban simulation area as opposed to 30 specified by ITU-R Report M.2292 for the same area	Based on 3GPP TR 36.777, table A.1-1 [1] that accounts for: ▪ the shared access of the channel bandwidth by UEs in a cell, ▪ the fact that UEs are simultaneously transmitting, unlike assumptions from ITU-R Report M.2292 [25] on user density in active mode because this parameter has to be understood as UEs are not necessarily transmitting. This density should be multiplied by the number of UEs sharing the channel bandwidth.

5.7.3 Coexistence with EESS/SRS/SOS ground stations operating in 2025-2110 MHz

The possible impact of EESS/SRS/SOS ground stations in the 2025-2110 MHz band on aerial UEs operating in the 2 GHz is assessed.

Recommendation ITU-R SA.1154 [31] indicates that EESS/SRS/SOS ground stations can transmit with up to 66 to 78 dBW, i.e. 96 to 108 dBm, with maximum gain reduced by 20 to 30 dB outside of a 5° angle, depending on the diameter of the antenna. This corresponds to narrowband interference level between 66 dBm and 88 dBm, that should be compared with the voluntarily in-band MFCN BS e.i.r.p. limits between 61 dBm/(5 MHz) and 66 dBm/(5 MHz). Additionally, MFCN UEs would benefit from duplexer attenuation to mitigate interference from EESS/SRS/SOS ground stations not operating immediately adjacent to 2110 MHz. The likely modest impact outside of the main lobe of the EESS/SRS/SOS ground stations, coupled with the wide range of e.i.r.p. values and the large potential benefits from duplexer attenuation indicate that the impact from EESS/SRS/SOS ground stations is expected to be modest but could be assessed more precisely at national level for the largest/more powerful EESS/SRS/SOS ground stations.

5.8 2.6 GHZ BAND

MFCN networks operate in 2500-2690 MHz under ECC Decision (05)05 [32]. FDD networks operate in UL in 2500-2570 MHz, while TDD networks operate in 2570-2620 MHz.

5.8.1 2.6 GHz FDD, non-AAS

Regarding adjacent band compatibility for non-AAS systems, the 2.6 GHz FDD UL band is the 2500-2570 MHz band. The 2500-2570 MHz band is adjacent to:

- FS, MSS (space to earth) and MS below 2500 MHz;
- the 2570-2620 MHz TDD band;

- MSS and MS services below 2500 MHz as well as MFCN TDD above 2570 MHz are operating with receivers on the ground, for which interference would be higher from a ground FDD UE operating in close proximity. Aerial UE being located further away will result in lower interference to MS and MSS terminals or MFCN TDD UEs;
- FS stations below 2500 MHz point typically towards the horizon. As such, any aerial UE operating at twice the station height would not create more interference than a UE on the ground. Given the expected low density of aerial UEs and the low likelihood for an aerial UE to be located precisely in the main beam of the FS station, at low altitude, it is unlikely that aerial UEs would result in significant interference to services in adjacent bands.

5.8.2 2.6 GHz TDD, non-AAS

The 2.6 GHz TDD band is the 2570-2620 MHz band. Regarding adjacent band compatibility for non-AAS systems, the 2570-2620 MHz band is adjacent to:

- the 2500-2570 MHz MFCN UL band;
- the 2620-2690 MHz MFCN DL band.

Aerial UEs operating in 2570-2620 MHz will not create more interference to MFCN networks deployed in 2500-2570 MHz than aerial UEs operating in adjacent channels within 2500-2570 MHz.

The potential interference from aerial UE within 2570-2620 MHz to MFCN UEs operating above 2620 MHz is similar to the situation at 2570 MHz. Since aerial UEs are located further away from MFCN ground UEs, the potential interference will be lower than the interference that can occur today due to ground UEs.

5.8.2.1 Coexistence of aerial UEs operating below 2620 MHz with radar operating above 2700 MHz

Studies on the radar receiver interference protection threshold show that Air Traffic Control (ATC) radars could require a separation distance in order to protect the ATC radar where this distance depends on the level on unwanted emissions. The studies investigated two levels on unwanted emissions which led to the results given in Table 6. Administrations should coordinate with their national aviation authorities to ensure that 2700-3100 MHz radars are protected from interference, through the implementation of no-fly zones or alternative measures.

Table 6: Results of MCL calculations for unwanted emission interference to ATC radar above 2700 MHz

UE Unwanted Emission Level	Required Path Loss	Separation Distance
−50 dBm / MHz	98.8 dB	0.8 km
−30 dBm / MHz	118.8 dB	7.7 km

Studies on the radar receiver overload threshold (blocking) has also been investigated and led to the following results for different categories of radar systems:

Table 7: Results for blocking of radars above 2700 MHz

Scenario	Blocking Protection Level	Required Isolation Loss	Separation Distance
Meteo System 1	-30 dBm	96.7 dB	610 m
Meteo System 2	0 dBm	66.7 dB	20 m
ATC	-22 dBm	79 dB	80 m

Recalling that these blocking results are achieved for a worst-case scenario and that the largest separation distance is lower than 1 km, it can be concluded that there is no need to take into account in the compatibility analysis the blocking effect on any kind of the radars operating above 2700 MHz caused by aerial terminals transmitting below 2620 MHz.

5.8.3 RAS at 2655-2690 MHz

The RAS band 2655-2690 MHz (secondary allocation, see RR Footnote 5.149 [19]) is mainly used for continuum observations. Studies in Annex 7 RAS demonstrate the need for no-fly zones, although this is a harmonised band for MFCN. Relevant no-fly zones shall be established at national level based on respective studies.

5.8.4 RAS at 2690-2700 MHz

Spurious emissions of LTE2600 UE in the TDD frequency range 2570-2620 MHz potentially affects the RAS bands at 2690-2700 MHz, which is a primary passive band. This band is used for continuum observations. Some considerations regarding unwanted emissions are described in ANNEX 7:. The study in ANNEX 7: was performed for various power levels between -60 and -90 dBm/MHz, but it must be noted that without existing measurements of UE, strictly the Recommendation ITU-R SM.329 [33] limits of -30 dBm/MHz would apply.

Resulting regulatory requirements for the operation of LTE2600 aerial UE in the 2690-2700 MHz RAS band as derived in Table 46 of the ANNEX 6:. The table shows that for spurious emission levels below -80 dBm/MHz or if the altitude of the aerial UE is up to 300 m then no-fly zones by national coordination should be possible. Relevant no-fly zones shall be established at national level based on respective studies.

5.9 3.4-3.8 GHZ BAND

5.9.1 Aerial UE as an interferer

5.9.1.1 Aerial UE as an interferer to radar operating below 3400 MHz

According to the current MFCN harmonised framework applicable to UE, additional mitigation measures to protect radar below 3400 MHz from aerial UEs may be necessary, for example, geographical separation or an additional guard band. For non-AAS aerial UEs operating with macro base stations AAS above 3410 MHz, one single entry worst-case analysis shows that for an unwanted emissions level of -50 dBm/MHz, a separation distance from land-based radars around 1 km for any radio environment (rural, suburban and urban) can be achieved while it is more than 10 km for -30 dBm/MHz unwanted emission levels. Another study indicates that for the same level of unwanted emissions (i.e. -50 dBm/MHz), the protection threshold of an airborne radar receiver from interference caused by multiples aerial UEs is exceeded for less than 0.01% of the cases (this percentage of exceedance is generally corresponding to the case where aerial UEs are less than 1 km away from the aircraft).

5.9.1.2 Aerial UE as an interferer to FSS receiver operating in 3400-3800 MHz

The band 3400-3800 MHz is used for receiving earth stations in the FSS and aerial UEs could be a source of interference to earth stations.

Several mobile-satellite operators use the lower end of the 3400-3800 MHz band for their feeder links. A very high degree of availability is required because of the nature of the service. This band is also used by other FSS services, such as very small aperture terminal (VSAT) networks, internet providers, point-to-multipoint links, satellite news gathering, TV and data broadcasting to satellite master antenna television (SMATV), direct-to-home (DTH) receivers, and disaster relief.

Aerial UEs transmit and FSS earth stations receive in 3400-3800 MHz band, and therefore co-channel interference analysis has been carried out in the study contained in ANNEX 15:.

The results show that separation distances of 26.7 km to 290 km would be required to ensure protection of FSS earth stations operating in the band 3400-3800 MHz from aerial UEs operating in the same band.

It should be noted that given the size of the minimum separation distances (290 km in the worst case), cross-border coordination may be necessary to ensure that earth stations do not suffer interference from aerial UEs operating in another country.

5.9.1.3 FSS above 3.8 GHz

MFCN systems, either 4G or 5G NR operating in the band 3400-3800 MHz have the potential to cause interference to FSS earth stations in the adjacent band 3800-4200 MHz.

The study in ANNEX 11: assesses the protection distances required to limit interference to FSS operating in the band 3800-4200 MHz from aerial UEs. For this study the aerial UE OOBE characteristics are in line with ETSI TS 136 101 [36].

As OOBE characteristics of 5G NR systems conforming to ETSI TS 138 101 are similar, protection distances for such systems, though not studied, would be similar.

The result of the study in ANNEX 11: shows that:

- To avoid the need for specific protection distances associated with each FSS antenna the unwanted emissions from an aerial UE would need to be lower;
- To reduce the potential for interference and effectively enable unrestricted access to airspace for aerial UE, with respect to FSS operating in the adjacent frequency band, the unwanted emissions of aerial UE would need to be limited to -60 dBm/MHz in the frequency range 3800-4200 MHz.

The study in ANNEX 16:also analyses compatibility of IMT aerial UEs operating in 3400-3800 MHz with FSS earth stations in the adjacent band 3800-4200 MHz, with OOBE characteristics of the IMT UEs as in ETSI TS 136 101.

Results from this study give maximum separation distances of 3.7 km for the baseline case and 19.7 km for case with low elevation angle, when the IMT and FSS channels are immediately adjacent to each other. A few MHz separation between the lower edge of the FSS channel and upper edge of IMT makes substantial difference to the results, with maximum separation distances reducing to 0.5 km and 5.5 km respectively when we take account of practical frequency assignment data for FSS systems closest to the 3.8 GHz boundary.

The study in ANNEX 16: indicates that adjacent band compatibility between IMT aerial UEs in 3400-3800 MHz and FSS earth stations in 3800-4200 MHz can be dealt with by means of coordination/no-fly zones on a case-by-case basis at national level.

5.9.1.4 RAS at 3345.8-3352.5 MHz

The band 3345.8-3352.5 MHz has no allocation in the RR for RAS but is considered in Footnote 5.149 [19], which urges administrations to protect RAS stations operating in this band. It is mainly used for measurements of the CH molecule in the interstellar medium. Thus, the spectroscopy thresholds of Recommendation ITU-R RA.769 [37] apply (see also ANNEX 6:). Spurious emission levels of -50 and -59 dBm/MHz were used in this study as an example of the implementation of lower than usual spurious limits. These limits were implemented for Base stations in order to protect the RAS and military radars below 3400 MHz (see ECC Report 281 [38]).

The resulting regulatory requirements is to consider the implementation of no-fly zones around radio telescopes operating in the 3345.8-3352.5 MHz band on the national basis. The respective no-fly zones radius are detailed in Table 46 in ANNEX 6:.

5.9.2 AAS base stations as interferer

5.9.2.1 AAS base stations as interferer to radars below 3400 MHz

In addition, considering the update of 3400-3800 MHz framework to accommodate AAS, it has to be noted that OOBE limits have been established (see ECC Report 281 [38] and CEPT Report 67 [39]) based on statistical simulations with land terminal usage only. Aerial UEs associated with dynamic tilt of AAS would significantly change the result of the simulations. Nevertheless, compatibility studies between radar and drones in MFCN have been carried out at 3400 MHz. Analysis of the cumulative effect of multiple sources of interference was carried out on a statistical basis because of the variability of several parameters (e.g. the positioning of the drones: distance/altitude and the airborne radar: orientation of the beam radar antenna). (see ANNEX 19:)

The impact of different ASS BS antenna beams directions on radars operating below 3.4 GHz due to usage of aerial UE up to 10000 m has been studied. This study concludes that unwanted emissions limit as defined in ECC Decision 11(06) [40], in terms of TRP (-52 dBm/MHz), is sufficient to ensure protection of radars I and AA (probability of interference ≤0.01%). This study noted also that according to the current radar operating knowledge, it’s considered that radar L-D operates mainly below 3.3 GHz. It is assumed that these unwanted emissions fall down below -59.3 dBm/MHz below 3.3 GHz.

5.10 26 GHZ BAND

According to ECC Decision (18)06 [2] "MFCN in the 24.25-27.5 GHz band shall not be used for connectivity from base stations to terminals on-board UAV and that only communications for connectivity from terminals on-board UAV to base stations is authorised…". Furthermore, ECC Decision (18)06 considers: "Due to its specific characteristics and usage, the 24.25-27.5 GHz MFCN band is not to be used for connectivity from base stations to terminals on board UAV." This requirement essentially prevents network to aerial UE communication.

In addition, the connectivity from aerial UEs to BSs may have a significant impact, e.g. on separation distance from EESS/SRS earth stations, which requires further study.

This band could be suitable for various high bitrate 5G UAS applications, however, for the time being there is no need to study this band for UAS communication in this Report. There might the need for further studies, if appropriate.

6 CONCLUSIONS

This Report highlight that in some coexistence cases, aerial UEs do not impact in-band and adjacent band services in a similar manner to ground UEs. In particular, the studies concluded that:

- some operational restrictions ("no-fly" zones) or additional emission limits specific to aerial UEs would be necessary to avoid interference to other services in some adjacent bands;
- to control the potential interference to its own MFCN, aerial UE density control may be necessary for an MNO, in particular for high payload aerial UEs;
- there is no interference problem between neighbouring FDD MFCN networks operating in adjacent channels;
- operational restriction may be required in the case of cross-border coordination, to avoid interference to services including network of another MNO operating in an adjacent geographical area. This could be addressed by the relevant cross-border agreements to be developed based on relevant ECC Recommendations.

In order to be able to implement these coexistence conditions, an MNO should be able to differentiate between an aerial UE and a UE operating on the ground (this could also enhance, for example, roaming operation and differentiation between subscriptions). Such differentiated registration mechanisms for aerial UEs are already being developed by 3GPP.

The definition of no-fly zones is required in order to achieve coexistence between some specific services in adjacent bands and aerial UEs operating in a few MFCN frequency bands. These no-fly zones are specific to transmitters in given bands or even in given channels. In this Report, these no-fly zones are defined for spectrum compatibility purposes. Relevant national authorities and users should be informed of flight restriction zones related to spectrum compatibility. Any such flight restriction zones required to achieve coexistence would be defined by the spectrum/telecommunication authority. Even if no-fly-zones should be defined at national level (e.g. protection of RAS sites), the information on no-fly zones shall be shared among CEPT countries due possible roaming operation of aerial UEs. Additionally, there is also a need to establish a mechanism to ensure that aerial UEs respect the no-fly zone defined by relevant national authorities. Such mechanisms may need activities in standardisation including ETSI in Europe. The practical implementation of such mechanisms at national level may be a complex process.

The conducted coexistence studies conclude that aerial UEs can operate in the MFCN bands listed in the table below, while requiring in some cases additional regulatory measures. The table only includes the uplink frequency bands for each FDD duplex pair (except for the TDD frequency bands).

Table 8: Frequency bands where aerial UEs connected to non-AAS MFCN (and AAS MFCN BS in 3400-3800 MHz) should be allowed to operate and associated required additional regulatory measures

Aerial UE frequency band	Additional regulatory measure required	Victim system
703-733 MHz	Aerial UEs operating in this band should fly at least 30 m above ground level to avoid interference to DTT receivers[7]	Broadcasting receivers below 694 MHz
	Implementation of measures at national level for terminals operating in the 703-713.5 MHz frequency band through a no-fly zone around RAS sites, or alternative measures (e.g. additional	RAS in 1400-1427 MHz (primary, according to RR 5.340 [19]) being affected by second harmonics emissions of the aerial UEs

[7] Areas where it can be confirmed that there are no DTT receivers to interfere with could be defined at national level if needed. In such nationally defined areas, this measure is not required

Aerial UE frequency band	Additional regulatory measure required	Victim system
	filtering) to reduce second harmonics, if appropriate. Cross-border coordination, through the implementation of no-fly zones or alternative measures (e.g. additional filtering), agreed by affected administrations, may be necessary where no-fly zones extend beyond a border	
832-862 MHz	Implementation of measures at national level for terminals operating in the 832-835 MHz frequency band through a no-fly zone around RAS sites, or alternative measures (e.g. additional filtering) to reduce second harmonics, if appropriate Cross-border coordination, through the implementation of no-fly zones or alternative measures (e.g. additional filtering), agreed by affected administrations, may be necessary where no-fly zones extend beyond a border	RAS in 1660-1670 MHz, (primary, according to RR 5.149 [19]) being affected by second harmonics emissions of the aerial UEs
832-862 MHz	No additional measures required. At the same time aggregate interference from the number of ground and aerial UEs as well as interference for aerial UEs with altitude more than 100 m need to be studied to draw the conclusion for this scenario	ARNS
880-915 MHz	No additional measures Future FRMCS cab-radios are assumed to be designed in a way that ensures robustness against blocking signals emitted by aerial UEs	RMR (GSM-R and FRMCS BS UL) below 880 MHz RMR cab-radio receiving above 919.4 MHz
1710-1785 MHz	Emission limit of -40 dBm/MHz in 1675-1710 MHz for aerial UEs operating in 1710-1785 MHz	MetSat operating in 1675-1710 MHz
1920-1980 MHz	Approach 1: ▪ Minimum separation distance of 15 km between CGC base stations and aerial UEs operating below 1980 MHz with OoB emission limit of -7 dBm/(4.5 MHz) (ACLR1); ▪ Minimum separation distance of 2.5 km between CGC base stations and aerial UEs operating below 1980 MHz with OoB emission limit of -30 dBm/MHz (spurious);	MSS CGC aeronautical system operating in 1980-2010 MHz

Aerial UE frequency band	Additional regulatory measure required	Victim system
	▪ Zero minimum separation between CGC base stations and aerial UEs operating below 1980 MHz with OoB emission limit of -30 dBm/MHz; there is a risk of interference which is comparable to that of ground UEs, based on single interference worst-case scenario where aerial UE operates up to 1 km altitude a.g.l. Approach 2: ▪ No measures are required, based on aggregate Monte Carlo simulation within 61 cells, which compares the interference from aerial UEs to interference from ground UE where aerial UE operates in the range of 40-10000m a.g.l. .	
1920-1980 MHz	▪ No specific measure is necessary to be applied to the aerial UEs operating above 1920 MHz for the protection of FRMCS cab-radio receiver at 1900-1910 MHz	FRMCS cab-radio receiver in 1900-1910 MHz
2500-2570 MHz	▪ None	RAS in 2690-2700 MHz
	▪ Administrations should coordinate with their national aviation authorities to ensure that ATC radars above 2700 MHz are protected from interference, through the implementation of no-fly zones or alternative measures (e.g. additional filtering).	Radar operating above 2700 MHz
2570-2620 MHz	▪ Coordination with RAS sites to be established at national level	RAS in 2690-2700 MHz
	▪ Administrations should coordinate with their national aviation authorities to ensure that ATC radars above 2700 MHz are protected from interference, through the implementation of no-fly zones or alternative measures (e.g. additional filtering)	Radar operating above 2700 MHz
3400-3800 MHz	Coordination zones with FSS earth stations on a national level, which should be assessed on a case-by-case basis depending on the number of FSS earth stations and elevation angle of the FSS earth stations antenna. Cross-	FSS operating in 3400-3800 MHz

Aerial UE frequency band	Additional regulatory measure required	Victim system
	border coordination may be necessary (see note below) to ensure that earth stations do not suffer interference from aerial UEs operating in other countries. Note: Separation distances of 26.7 km to 290 km would be required to ensure protection of FSS earth stations operating in the band 3400-3800 MHz from aerial UEs operating in the same band	
3400-3800 MHz	Coordination with FSS earth stations at national level To avoid the need for specific protection distances associated with each FSS antenna the unwanted emissions of an aerial UE would need to be lower than -60 dBm/MHz	FSS operating in 3800-4200 MHz
3400-3800 MHz	Aerial UE unwanted emission levels below 3400 MHz equal to -50 dBm/MHz, to protect airborne and land-based radars	Radiolocation below 3400 MHz
3400-3800 MHz	Coordination with RAS sites to be established at national level Note: Deployment of AAS BSs may need to be reconsidered if beams are formed above horizon	RAS in 3332-3339 and 3345.8-3352.5 MHz

The requirements on the deployment of AAS BSs have been established based on land terminal use (except for one study dealing with protection of radar operating below 3400 MHz (ANNEX 19:)). Deployments of AAS BSs serving aerial UEs may require further studies, due to beams being formed above the horizon. Therefore, AAS BS deployments meeting the current (land based) requirements may need to be reconsidered if aerial UEs are introduced.

In addition, it has been noted that exclusion and/or coordination zones for MFCN BS have already been implemented at national level in a number of CEPT countries to protect RAS sites from emissions from MFCN operating in harmonised bands. Those zones will also restrict the operational area for aerial UEs. Relevant "no-fly" zones shall be established at national level to protect RAS sites.

Finally, additional ECC work is required in order to identify appropriate mechanisms to help administrations to establish cross-border agreements to avoid interference from aerial UEs.

ANNEX 1: STUDY ON THE IMPACT OF MOBILE COMMUNICATIONS WITH DRONES AT 800 MHZ ON ARNS

A1.1 CONTENT OF THE STUDY

Up to now most use-case scenarios for drones require a pilot on the ground with line of sight. In future concepts drones will be utilised for a variety of tasks like delivery, agriculture, security and observation, industry, and search and rescue. These use-cases require a mobile communication service to some kind of control instance. The mobile network operators (MNO) might have an interest in providing this service in near future having already deployed the cellular network which technically can be used for mobile communications in low altitudes. These networks already provide a high coverage and reliability. In Germany and most other countries of ITU's Region 1, the frequency range between 694 MHz and 960 MHz is utilised for mobile communication especially in rural areas with intermediate demand on data traffic but high coverage area. Providing mobile communication services for drones only on other frequency bands like 1800 MHz or 2600 MHz would not be sufficient in terms of coverage.

The frequency range between 694 MHz and 960 MHz is identified for the use by administrations wishing to implement International Mobile Telecommunications (IMT)[8]. However, restrictions with respect to the use of aeronautical mobile [19] exist, which may prevent the use of drones equipped with the functionality of mobile terminals. This restriction may be dropped, if it can be shown, that the use of mobile terminals in drones does not yield more interference then already present with the current use of mobile terminals. This study investigates the additional impact drones might have on the interference situation for Aeronautical Radio Navigation Service (ARNS).

According to footnote 5.312 of the radio regulations, some countries[9] operate aeronautical radio navigation services in parts of the frequency range between 694 MHz and 960 MHz. Aeronautical Radio Navigation Services is according to article 1.46 of ITU's Radio Regulations defined as 'A radio navigation service intended for the benefit and for the safe operation of aircraft' [19].

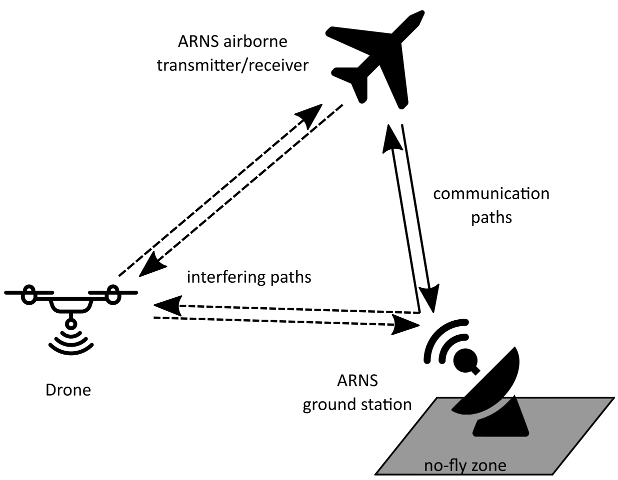

Figure 4: Aeronautical Radio Navigation Service System with a Drone as victim/interferer

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[8] [19] 5.317A: The parts of the frequency band 698-960 MHz in Region 2 and the frequency bands 694-790 MHz in Region 1 and 790-960 MHz in Regions 1 and 3 which are allocated to the mobile service on a primary basis are identified for use by administrations wishing to implement International Mobile Telecommunications (IMT) – see Resolutions 224 (Rev.WRC-15), 760 (WRC-15) and 749 (Rev.WRC-15), where applicable. This identification does not preclude the use of these frequency bands by any application of the services to which they are allocated and does not establish priority in the Radio Regulations. (WRC-15)

[9] In Armenia, Azerbaijan, Belarus, the Russian Federation, Georgia, Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, Turkmenistan and Ukraine, the frequency band 645-862 MHz, in Bulgaria the frequency bands 646-686 MHz, 726-758 MHz, 766-814 MHz and 822-862 MHz

The ARNS service is a so-called safety-of-life service and must be protected from harmful interference. However, for aircraft with a normal altitude of 10000 m the difference of interference from a UE on ground level or from a UE at 100 m altitude received in the downlink of ARNS is negligible. Furthermore, there is a huge gap in the transmitter power of an ARNS ground station (48-82 dBW e.r.p. [41]) and a normal mobile phone (-5 dBW[10]). Thus, a disturbance by UEs in downlink can be excluded.

In the uplink an ARNS system might be more effected by drones communicating on neighbouring frequency bands especially when the drone is located near the ARNS ground station. This potential problem can be solved with no-fly zones around such ground stations. Since no-fly zones around airports already exist for drones and the ARNS ground station are located near airfields [42], no further actions are necessary. Furthermore, it should be noted that interference from elevated positions already exists in today’s network from observations platforms and high rise buildings.

It can be concluded that aerial UEs will not introduce more interference to ARNS than normal users do.

It remains to check whether drones could become victims by interference from ARNS. Due to the precisely directed beam of the ARNS base station and compliance with the no-fly zone (see above), no impairment of downlink communication of the drone is expected. A misaligned ARNS ground station would also affect communications with UEs at ground level which should be prevented by existing coordination procedures. The uplink of the drone communication could be disturbed by the ARNS airborne transmitter, which is why a certain band gap is necessary. Nevertheless, this is again not a drone-specific problem, as the transmitter would also similarly interfere with the uplink of ground UEs since the distance to the aircraft is roughly the same. It can be concluded, that ARNS does not provide more harmful interference to drones than to traditionally used UEs.

A1.2 CONCLUSIONS

Investigations on interference of Drones communication in the mobile communication network with ARNS shows, that in countries in which ARNS is operated in the frequency range around 800 MHz the use of mobile terminals in drones is possible. However, it may be necessary to introduce no-fly zones around the ARNS ground station. Apart from these zones ARNS does not affect mobile radio communication for drones.

Since Drones and normal UEs are equipped with the same hardware, no further analyses on out-of-band emission are necessary. The existing emission masks of the ARNS system (see [42], annex 2) fit to the deployed IMT system. Investigations in [43] concludes that only the coordination distances between IMT base stations and ARNS needs to be considered, since the coordination distances between UEs and ARNS is considerably smaller. Therefore, Drones with an altitude up to 100 m do not need to be further considered due to their similar behaviour with normal UEs.

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[10] 25 dBm = 316 mW is the UE maximum output power for LTE/5G devices **Error! Reference source not found.**

ANNEX 2: ADJACENT CHANNEL CO-EXISTENCE SIMULATION FOR DRONES OPERATION IN THE BANDS 700 MHZ, 800 MHZ AND 2600 MHZ AND USE CASES

A2.1 ADJACENT BAND CO-EXISTENCE SIMULATION SCENARIOS

The objective is to simulate the potential interference from a drone flying within the coverage area of a radio site of the network A to a network B operating in adjacent channel, as on shown in Figure 5 and Figure 6.

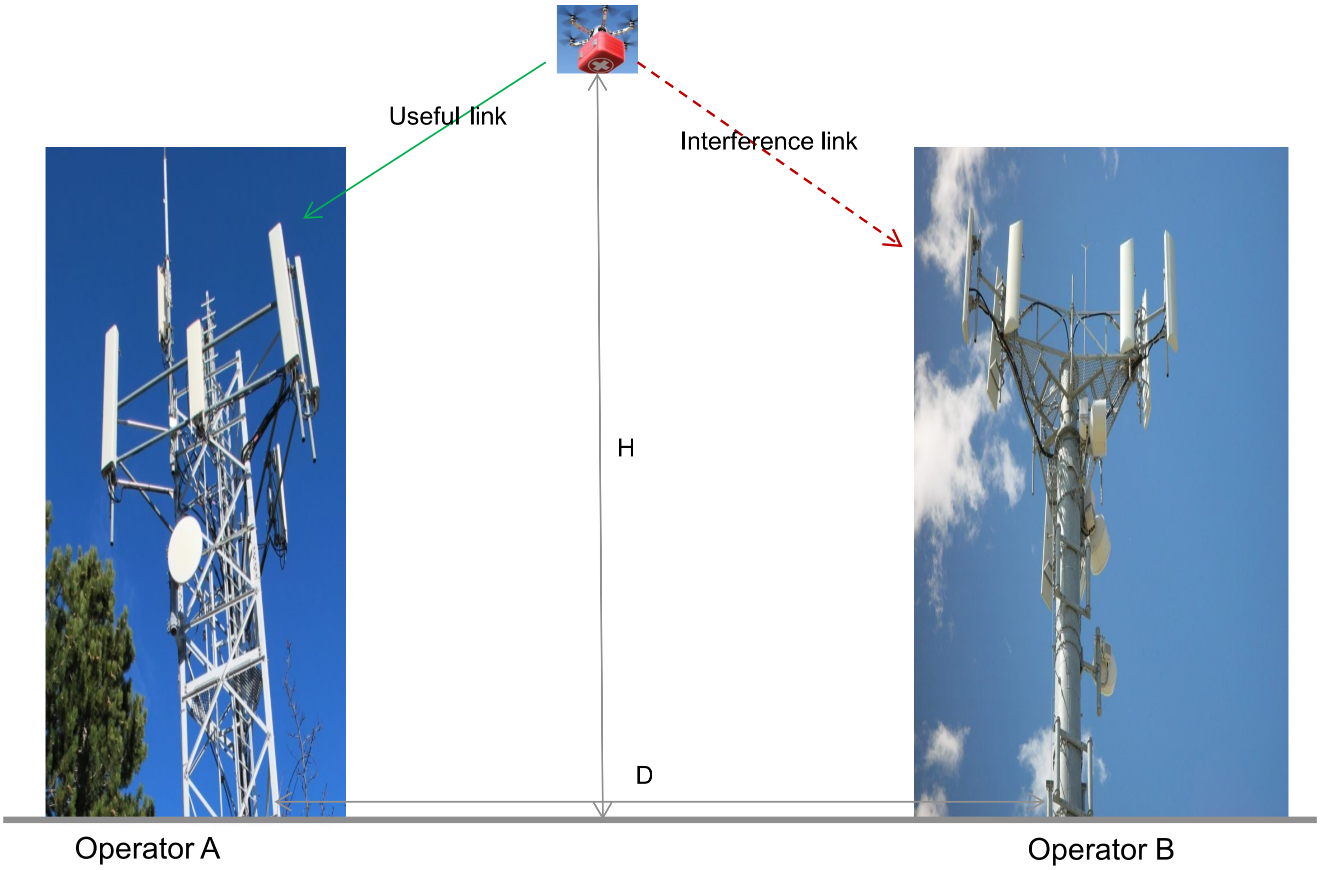


Figure 5: Coexistence study

Two simulation scenarios are considered, the first scenario is proposed based on 3GPP TR36.942 uncoordinated case, as shown in Figure 6. For this uncoordinated case, the reference cell (a single sector in the centre of the network) BSs of the network A and B are shifted (D=$\sqrt{3}R$, X=R*(1+cos(60°), Y=R*cos(30°) where R refers to the cell radius). In this scenario 1, it is assumed that the drone is flying at an altitude between 30 m and 300 m following a uniform distribution.

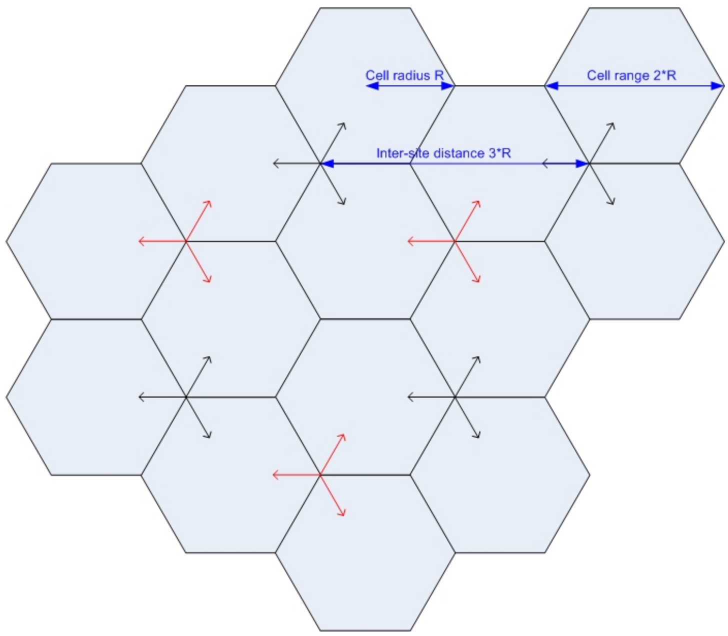


Figure 6: Multi operator cell layout - uncoordinated operation (scenario 1)

Simulations are performed on two steps for Scenario 1:

- Step A: the interference from network A uplink with normal UEs located within the network A coverage area to the network B uplink is simulated, network B uplink throughput loss is simulated;
- Step B: the network B uplink throughput loss is simulated cause by a drone UE per cell flying within the network A coverage (each drone per cell, in all cells).

The second scenario is that Network A is a single tri-sector site, network B is a network cluster of 19 tri-sector sites, as illustrated in Figure 7.

The comparison of simulation results obtained from step A and step B allows to evaluate the possible impact of drone operation on the neighbouring network operating in adjacent channel.

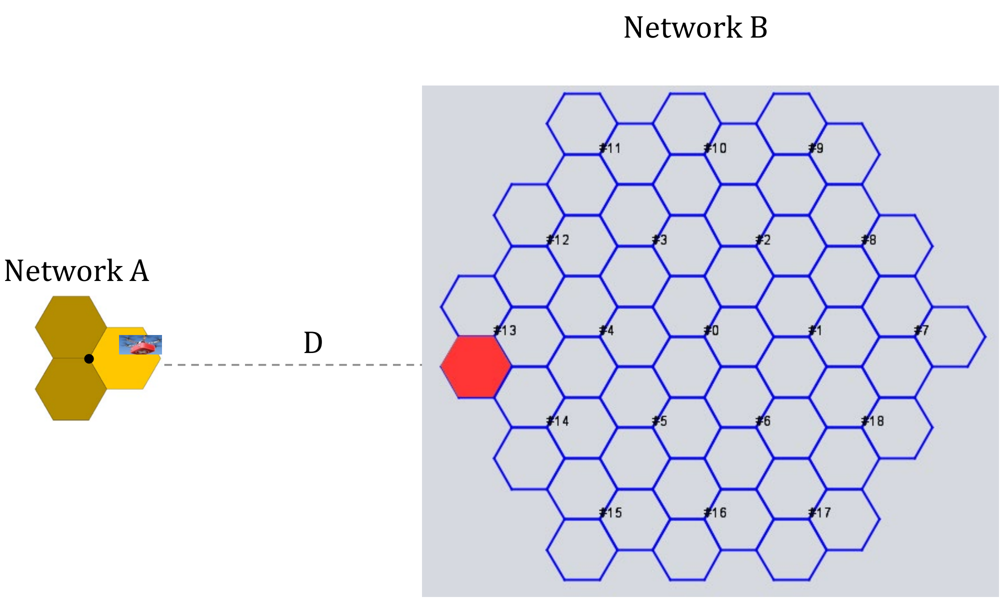


Figure 7: Coexistence simulation scenario (Scenario 2)

A2.2 SIMULATION ASSUMPTIONS AND RESULTS FOR DRONE OPERATION IN 700 AND 2600 MHZ BAND

A2.2.1 Simulation assumptions

The simulation assumptions are summarised in the below table.

Table 9: Simulation assumptions for drones operation in 700, 800 and 2600 MHz band in Urban areas

Parameter	Network A	Network B	Reference
System	LTE	LTE	
Duplex mode	FDD	FDD	3GPP TS36.104 [44]
Channel bandwidth (MHz)	10 MHz (UL: 703-713 MHz) (UL: 842-852 MHz) (UL: 2500-2510 MHz)	10 MHz (UL: 713-723 MHz) (UL: 842-852 MHz) (UL: 2510-2520 MHz)	LTE 10 MHz channel
Centre frequency (MHz)	UL: 708 UL: 2505	UL: 718 UL: 2515	
MIMO	2x2	2x2	
BS Tx Power	43 dBm/10 MHz per MIMO branch 46 dBm/10 MHz per Cell	43 dBm/10 MHz per MIMO branch 46 dBm/10 MHz per BS	Report ITU-R M.2292 [25]
Antenna	Recommendation ITU-R F.1336 (recommends 3.1) [45] ka = 0.7 kp = 0.7 kh = 0.7 kv = 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 [45].	Recommendation ITU-R F.1336 (recommends 3.1) [45] ka = 0.7 kp = 0.7 kh = 0.7 kv = 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 [45].	Report ITU-R M.2292 [25]
Antenna height (m)	700-800 MHz: 30 (Urban) 40 (Rural)	700-800 MHz: 30 (Urban) 40 (Rural)	Report ITU-R M.2292 [25] Doc ITU-R WP5D 416 [46]

Parameter	Network A	Network B	Reference
	2600 MHz: 20 (Urban) 30 (Rural)	2600 MHz: 20 (Urban) 30 (Rural)	
BS Antenna gain (dBi)	700-800 MHz 15 (Urban) 18 (Rural) 2600 MHz 16 (Urban) 18 (Rural)	700-800 MHz 15 (Urban) 18 (Rural) 2600 MHz 16 (Urban) 18 (Rural)	ECC Report 82 [47] (for 700 MHz with similarity to 800 MHz) ITU-R M.2292 [25] for 2600 MHz
Feeder loss (dB)	3	3	ITU-R M.2292 [25]
Downtilt	700-800 MHz 6° (Urban) 3° (Rural) 2600 MHz 10° (Urban) 3° (Rural)	700-800 MHz 6° (Urban) 3° (Rural) 2600 MHz 10° (Urban) 3° (Rural)	ITU-R M.2292 [25] Based on national data (rural)
Maximum e.i.r.p. (dBm)	58 dBm 61 dBm	58 dBm 61 dBm	ITU-R M.2292 [25]
BS Noise figure	5	5	ITU-R M.2292 [25]
BS ACLR (dB)	45	45	3GPP TS36.104 [44]
BS ACS	45	45	3GPP TS36.104 [44]
Site type	Tri-sector	Tri-sector	
Cell Range (m)	700-800 MHz 600 (Urban) 8000 (Rural) 2600 MHz 400 (Urban) 4000 (Rural)	700-800 MHz 600 (Urban) 8000 (Rural) 2600 MHz 400 (Urban) 4000 (Rural)	ECC PT1(10)128 [117] ITU-R M.2292 [25]
Handover Margin (dB)	1	1	ECC PT1(10)128
SINR Minimum (dB)	-10	-10	ECC PT1(10)128 and 3GPP TR 36.942 [48]
UE Tx Power (dBm)	23	23	3GPP TS 36.101 **Error! Reference source not found.** Depending the simulation results, 26 dBm for drone will be studied

Parameter	Network A	Network B	Reference
UE Antenna height (m)	For normal UE in urban[11]: 1.5, 4.5, 7.5, 10.5, 13,5, 16.5, 19.5[12] For normal UE in rural: 1.5 m For drone: 30, 50, 100, 150, 200, 250, 300	For normal UE in urban: 1.5, 4.5, 7.5, 10.5, 13,5, 16.5, 19.52 For normal UE in rural: 1.5 m	6-7 floors are considered in urban area
UE Antenna gain (dBi)	-3	-3	
Indoor penetration loss (dB)	20 dB (Urban) 10 dB (Rural)	20 dB (Urban) 10 dB (Rural)	
Body loss (dB)	0 for drone 1 dB for normal UE	1	
Minimum Tx Power (dBm)	-40	-40	ECC PT1(10)128 [117]
UE noise figure (dB)	9	9	ITU-R M.2292 [25]
UE ACLR (dB)	30 for 23 dBm UE	30	3GPP TS36.101 **Error! Reference source not found.**
UE ACS (dB)	33	33	3GPP TS36.101 **Error! Reference source not found.**
Number UE/Cell	1	1	Due to limitation of UE partial band SEM, it is proposed to use 1 UE/cell in the simulations
BS to UE propagation model	ITU-R P.1546 Urban/Rural for H<30 m=1,5 Free Space Loss (ITU-R P.525-3 (UEs being drones) for H>= 30 m	ITU-R P.1546-5Urban/Rural for H<30 m Urban	ITU-R P.1546 [49] ITU-R P.525-3 [50] ITU-R P.1546-5 [49]
Standard deviation (dB)	6 (Urban) 8 (Rural) 5 for Free Space model	6 (Urban) 8 (Rural)	
UE and drone transmission power scheme	Power control Algorithm over	Power control Algorithm over	3GPP TR 36.942 [48] (Section 12.1.4) and ITU-R M.2101-0 [51]

[11] Based on 3 m height of floor

[12] 19.5 m is only valid for 700 MHz because the typical height of a building for 2600 MHz is 20 m

Parameter	Network A	Network B	Reference
	-40 to 23 dBm output power range	-40 to 23 dBm output power range	
Distance between reference cell BS (m) of network A and B	700-800 MHz: D=519 m (Urban) D=6,9 km (Rural) 2600 MHz: D=346 m (Urban) D=3.5 km (Rural) $(=\sqrt{3}\, Cell\ Range\ /2)$		3GPP TR 36.942 [48]
Propagation model for interference link from Drone to the victim network Part B BS	Free Space (ITU-R P.525-3) for H>= 30 m		ITU-R P.525-3 [50]
Standard deviation for the interference link	5 dB for Free Space		
Indoor/outdoor UEs	Urban: 70% indoor, 30% outdoor Rural: 50% indoor, 50% outdoor		ITU-R M.2292 [25]
UEs distribution per floor	Ground floor (h=1,5 m): 25%/30% [13] 1st floor (h=4,5 m): 25%/30% 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% [14]		

A2.2.2 Simulation results

Simulations are run using SEAMCAT tool version 5.3.0 with the parameters configuration described in previous section over 104 events. SEAMCAT Scenarios Workspace are attached to this Report for various environments (rural, urban), various deployment (regular UEs, drones over one single cell/all network for the interferer), different frequency ranges (700, 800 and 2600 MHz) in order to draw a general view of the coexistence with an adjacent block.

Due to the fact that there is no possibility to reflect the parameter:

- 3 dB BS feeder loss;
- the UE body loss in the simulation tool.

[13] 25% for 700 MHz Band, 30% for 2600 MHz because the typical size of building (in urban environment) is lower when deploying antenna in higher frequency.

[14] Only for the 700 MHz band case.

and in order to avoid affecting the value of the BS antenna peak gain in the computation of the radiation pattern (based on Recommendation ITU-R F-1336-4 [45]), body loss and BS feeder loss were subtracted from the UE antenna gain value, i.e. -3-3-1=-7 dBi for the normal UEs and -3-3-0=-6 dBi for the aerial UEs.

The reference cell is the sector (cell) at the network edge, as shown in Figure 7, corresponding to the yellow hexagon for the network Part A and the red hexagon for the network Part B. The simulation results of network average (over the whole network cluster) UL throughput loss with a normal UEs as interferers are given in the below table.

Table 10: System UL throughput Loss caused by normal UEs (Scenario 1, Step A)

Environment	700-800 MHz	2600 MHz
Urban	2.7%	2.5%
Rural	2.5%	3.5%

Results depicted above for 800 MHz frequency range are identical to the 700 MHz because all deployment parameters (e.g. cell radius, BS peak gain...) are the same and noticing that the difference in path loss between these two frequencies are generally balanced with the (aerial and normal) UEs transmission power for both the interfering and victim links.

The simulation results in Table 10 shows the uplink throughput loss caused by normal UEs is around 2-3%, this is in line with 3GPP TR 36.942 (in particular section 7.1.1.4) [48].

The simulation results for the co-existence scenario 1 Step B where it is assumed one drone per cell in the whole network A which is shifted of a distance D from the network B reference cell BS, where it was assumed that drone is flying randomly at altitudes between 30 m and 300 m with a random uniform distribution, are given in Table 11. It can be seen from Table 11 that the interference from drones operating in the network A (all cells, one drone per cell) does not create too much interference to the uplink of the network B. The network B average uplink throughput loss is below 0.2%.

Table 11: System UL throughput loss caused by drone, 1 drone per cell in all cells (Scenario 1 Step B)

Environment	700-800 MHz	2600 MHz
Urban	0.1%	0.2%
Rural	0.1%	0.01%

Lower throughput loss for interference caused by drones compared to aggregate interference generated by (indoor/outdoor) UEs can be explained by:

- comparing the distribution of transmit power for UAS and (indoor/outdoor) UEs: drones operate with lower transmit power (than UEs) because of a lower coupling loss with their serving BS (due to no obstacles within the path);
- noticing the effect of Adjacent Channel Interference Ratio (ACIR) in the aggregate interference resulting in making it negligible towards the noise level (i.e. SNR≈SNIR).

The simulation results for the adjacent channel co-existence scenario 2 in urban area and in rural area are given in Table 12 and

Table 13.

Table 12: UL throughput loss in urban area (UL TP[15] loss caused by drone) (Scenario 2)

Drone height (m)	Ref_Cell 700-800 MHz	Network average 700-800 MHz	Ref_Cell 2600 MHz	Network average 2600 MHz
30	0.276%	0.008%	0.126%	0.006%
50	0.061%	0.004%	0.136%	0.008%
100	0.098%	0.01%	0.112%	0.009%
120	0.12%	0.012%	0.104%	0.009%
200	0.1%	0.013%	0.092%	0.011%
300	0.107%	0.014%	0.102%	0.016%
10000	0.1%	0.1%	0.077%	0.083%

Table 13: UL throughput loss in rural area(UL TP loss caused by drone) (Scenario 2)

Drone height (m)	Ref_Cell 700-800 MHz	Network average 700-800 MHz	Ref_Cell 2600 MHz	Network average 2600 MHz
30	0.444%	0.01%	0.316%	0.007%
50	0.23%	0.006%	0.147%	0.004%
100	0.111%	0.004%	0.09%	0.003%
120	0.094%	0.004%	0.076%	0.004%
200	0.083%	0.004%	0.104%	0.006%
300	0.076%	0.005%	0.16%	0.011%
10000	0.167%	0.049%	0.106%	0.052%

The simulation results show the impact from the interfering cell where a drone is flying within its coverage area on the neighbouring cells of the adjacent network operating in adjacent channel is very limited, the uplink throughput loss is always (for any environment, any altitude, any considered frequency bands) below 0.....5%.

A2.3 CONCLUSIONS AND PROPOSALS

Based on the simulation results presented in section A2.2.2, the following conclusions can be made: the victim network (reference cell and network average) uplink throughput loss remains at an acceptable level (<0.5%), the drone operation in a network will not create more interference to the adjacent network operating in adjacent channel than (indoor/outdoor) UEs.

[15] Throughput

A2.4 APPENDIX

SEAMCAT Workspaces of several scenarios simulations for the adjacent band studies presented in this document

Adjacent.zip

A2.4.1 Application of the power control algorithm for user terminals and drones

The current power algorithm implemented on SEAMCAT (extracted from 3GPP TR 36.942 [48]) does not take as input the Quality of Service targeted by the application (i.e. SNRmin) or the amount of resource blocks allocated to each terminal. Moreover this approach relates to the LTE/LTE-Advanced (series 36) and it's recommended for 5G NR to refer to series 38 (see 3GPP TS 38.213, Section 7.1.1 [52]) or in a more synthetic way to Recommendation ITU-R M.2101, section 4.1 [51], section[51]which describes a generic formula applicable for both IMT-Advanced (LTE-Advanced) and IMT-2020 (5G NR). That's why this analysis calculates a coupling loss percentile (dB) in line with a SNRmin and a number of resource blocks allocated to the terminal (drone for the Interfering Link or UE for the victim link).

The Coupling Loss Percentile is given by the following formula:

$$CL(p\%) = P_{max} - P_{O\_PUSCH} - 10\log_{10}(M_{PUSCH}) \quad (1)$$

Where:

- P_{max} is the maximum transmit power by UE;
- M_{PUSCH} depicts the number of Resource Blocks dividing the (occupied) channel bandwidth under Physical Uplink Shared CHannel (PUSCH);
- P_{O_PUSCH} denotes to be the minimum received power per resource block (assuming 180 kHz here[16]) that can be processed by the radio link receiver to process the data stream in accordance with a given QoS and is equal to:
  -114 dBm/MHz+10log10(180 kHz/1 MHz)+NoiseFigureBS+ SNRmin

The application of the formula for different values taken by these parameters is expressed in the below table:

Table 14: Coupling loss percentile

Noise Figure (dB)	SNRmin (dB)	P_{O_PUSCH} (dBm)	NbRBs	CLx 95th percentile
5	-10	-126.4	1	149.4
5	-10	-126.4	50	132.4
5	-10	-126.4	100	129.4
5	-6	-122.4	100	125.4
5	6	-110.4	100	113.4

The selected configuration in the study is the one highlighted in yellow.

[16] Which may be a different value for other frequency ranges because of propagation conditions as well as channel bandwidth of the system).

The formula expressing the transmit power P_{O_PUSCH} or P_t is the same as the one implemented on SEAMCAT:

$$P_t = P_{max} + min[1, max(P_{max} - P_{min}, CL - CL(95\%))] \qquad (2)$$

A2.4.2 Recommendation ITU-R P-1546-5 Propagation model [49]

When distributing the user terminal position within the cell (especially in floors above 10 m) and accounts the reduced effect of the clutter loss when UEs are in high heights, Hata model may not be suitable. That is why it is proposed to use Recommendation ITU-R P.1546-5 to cover these issues, noting that this approach is a point-to-area model.

A2.4.3 Calibration of the scenario for indoor/outdoor UEs in two different sites

Based on Report ITU-R M.2292 [25], the terminal indoor usage below 1 GHz is 70% in urban area and 50% in rural area. For indoor terminals, it's expected higher concentration of users in the two first floors (in many cases mainly on ground floors of buildings as shops or offices), that's why 50% of the indoor users are located in the two first floors (1.5 m meaning being in the ground floor, 4.5 m=1.5 m+3 m (height of floor) meaning being in the first floor):

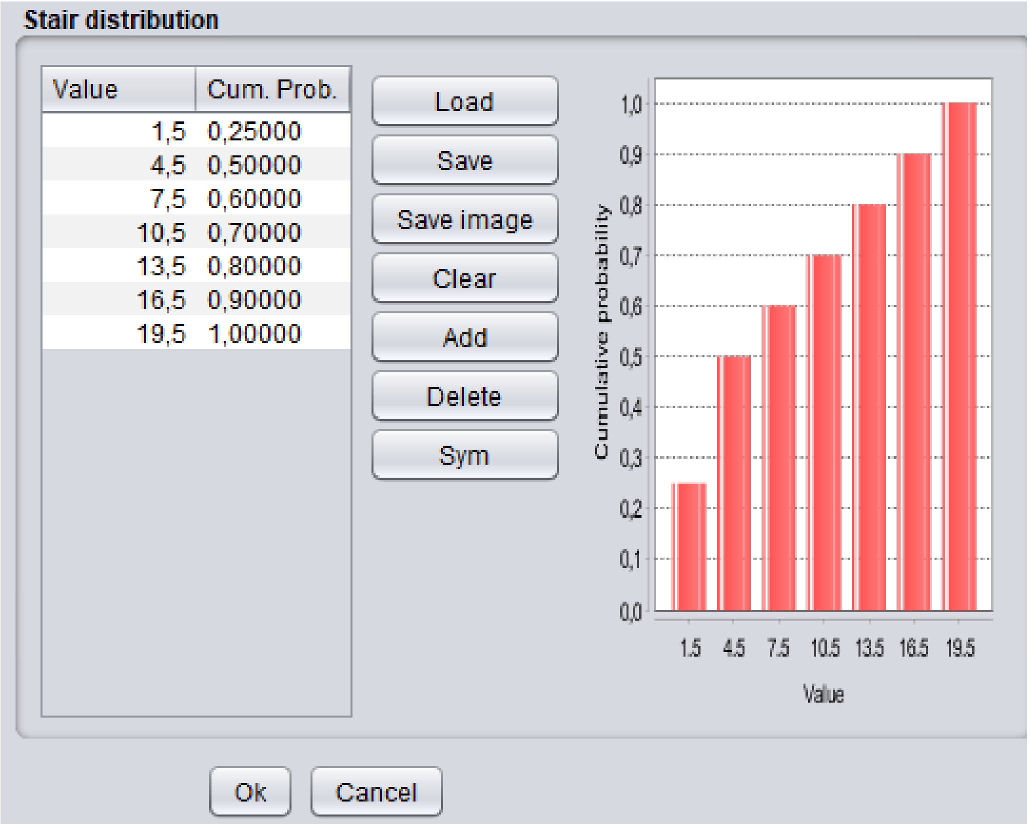


Figure 8: Height distribution of indoor UEs

In rural areas it is assumed that both outdoor and indoor UEs are located on the ground floor with a UE height of 1.5 m.

ANNEX 3: RANGE AND USE CASES

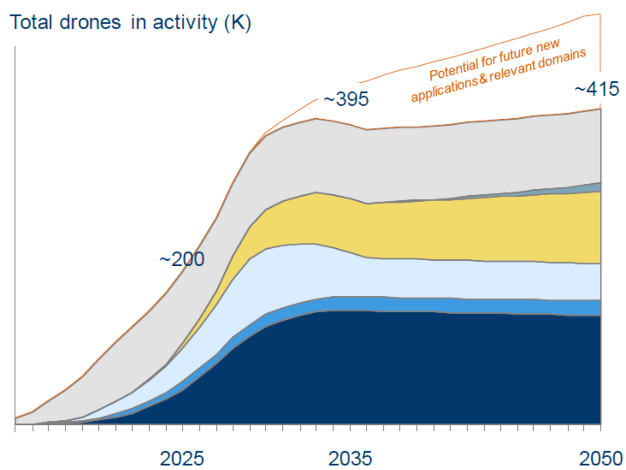
A3.1 RANGE OF UAS

UAs are extremely varied in size, shape, flying abilities and missions. As an illustrative example, Airbus's UAs portfolio includes small and large UAs, with or without passenger, with extremely varying capabilities in terms of flight capabilities (including speed and height). The full range of UAs is even much wider, when considering UAs as small as toys quadcopters and other recreational devices.

While not all UAs would necessarily seek connectivity to MFCN networks (e.g. military drones), some companies are working under the assumptions that larger UAs carrying passengers (e.g. urban air mobility) would seek connectivity to the mobile network.

A3.2 UAS USE CASES

The SESAR European Drones Outlook Study [53] provides an outlook of the drone use cases until 2050. The study expects the agriculture, energy, PPDR and delivery sectors to leverage drones.



Split between 'certified' and other, primarily 'specific', drones under EASA framework

	2035		2050	
	Specific	Certified	Specific	Certified
Other growth	~100	--	~100	--
Mobility	<1	<1	<1	~10
Delivery	~70	<1	~95	<1
P.S.S.[1]	~60	<1	~50	<1
Energy[2]	~10	~5	~15	~5
Agriculture	~150	--	~145	--
Total	**~390**	**~5**	**~400**	**~15**
excl. tethered	*~390*	*~1*	*~400*	*~10*

1. P.S.S. is public safety & security; first response visual line of sight drones carried in vehicle and beyond line of sight operated from central stations categorised as 'Specific' with long endurance used by government authorities for missions such as border security categorised as 'Certified'; 2. Tethered drones used for wind production at high-altitudes (~450m) included as 'Certified' drones while all short and long range inspection included as 'Specific'
Note: figures are rounded to the nearest 5K units; differences in totals due to rounding
Source: Press search, expert interviews with technology providers, operators, future users in each sector and policy makers, Eurostat, BCG analysis

Figure 9: Demand Outlook by industry domain.
Source: SESAR European Drones Outlook Study [53]

The report also indicates that 'The majority of government and commercial potential demand is for drones expected to perform beyond visual line of sight (BVLOS) missions', highlighting the need for connectivity for the majority of drones.

However, these BVLOS drones are very varied as stressed by the Report:

- "90000 drones [are] forecasted by 2035 mostly for delivery purposes and flying at low altitudes. […] Agriculture chemical spraying and seeding represents a smaller portion, approximately 25 000, of the estimate for light load drones flying at these low altitudes;
- Drones with longer endurances and flying well above 150 metres are expected for border security, maritime surveillance and other environment assessments (e.g., forestry and national park surveillance);

- UAS are expected to be varied, need connectivity and fly at vastly varying height and speed."

A3.3 UAS CATEGORIES OF OPERATION

The Commission Implementing Decision on the rules and procedures for the operation of unmanned aircraft [5] classifies drone operations according to the nature and risk of the operation or activity, the operational characteristics of the unmanned aircraft concerned and the characteristics of the area of operations such as the population density, surface characteristics, and the presence of buildings. The risk level criteria as well as other criteria should be used to establish three categories of operations: the ‘open’, ‘specific’ and ‘certified’ categories, as illustrated in the below figure:

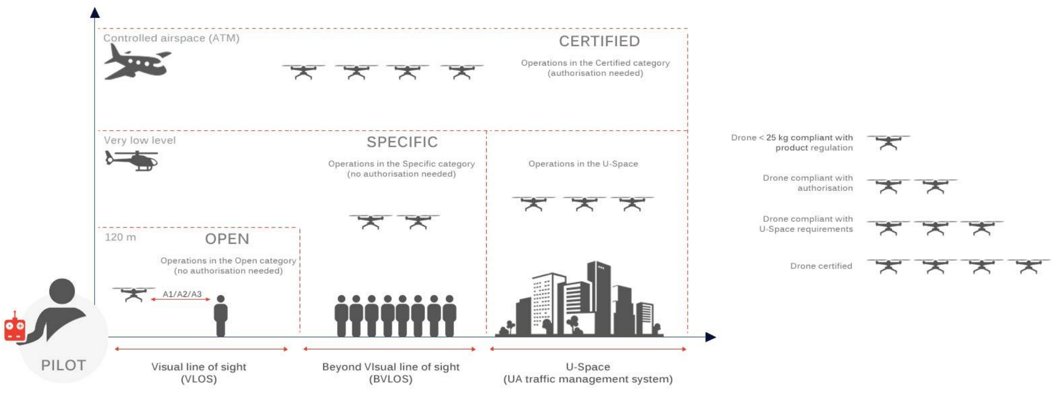


Figure 10: Illustration of drones classification.
Source: http://dronerules.eu/en/professional/eu_regulations_updates

The current Report investigates MFCN connectivity for 'open' and 'specific' UAS.

A3.4 OTHER AERIAL UES

It should be also noticed that aerial UEs are of interest for use cases beyond UAS.

On one hand, aircraft for commercial aviation tend to fly higher and typically rely on dedicated networks such as the European Aviation Network (EAN). It can be expected that UAS flying at such height and speed would typically leverage the same type of connectivity.

On the other hand, helicopters and private airplanes are typically flying at low to very low levels and would also benefit significantly from connectivity to mobile networks.

3GPP did not distinguish between UAs, helicopters and private airplanes and simply referred to aerial UEs, in order to cover all potential use cases.

A3.5 UAS TRAFFIC MANAGEMENT

UAS which will be treated in this Report are too small and fly too low to be seen on today's usual radars and there are too many of them to be managed by classical human-centric air-traffic management systems. This leads to the concept of a dedicated UAS Traffic Management (UTM) which could boost the commercial UAS market. Such a system makes UAS operations safe and compliant and enables fast and efficient usage of UAS for different use cases. To become operational both the UTM system and the UAS payload require a communication towards the UAS by using a mobile connection.

ANNEX 4: COEXISTENCE STUDIES WITH THE METEOROLOGICAL SATELLITE SERVICE IN THE 1800 MHZ BAND

A4.1 INTRODUCTION)

The present annex present coexistence and compatibility studies between aerial UEs operated above 1710 MHz and meteorological satellite service earth stations in the 1675-1710 MHz band.

Two different studies are considered, study 1 considering a generic approach for an hypothetical MetSat earth station with single entry and aggregate scenarios whereas study 2 addresses separation distances under a single entry scenarios for a specific MetSat earth station.

A4.2 STUDY 1

A4.2.1 Introduction

These studies consider the coexistence of aerial UEs in the 1800 MHz band and an earth station of the meteorological satellite service below the 1710 MHz band. The earth stations of the meteorology satellite service (space to earth) are operating below 1710 MHz and point above the horizon. Hence, an ordinary UE on the ground is safe from sending emissions in the main beam direction of the earth station. However, this does not apply to aerial UEs which may enter the mainbeam direction of the earth station. This corresponds to a new coexistence situation with the meteorology satellite service (space to earth) in the 1800 MHz band.

This annex provides three different studies to analyse the coexistence situation.

- Worst-Case Study - Single Entry derives the necessary separation distance from the short-term protection criteria while considering the worst case for a single entry scenario. This study provides a first estimate but does not take into account the aggregated effect or the actual deployment of aerial UEs.
- A4.2.4: Statistical Study - Aggregate Interference derives the necessary separation distance by a statistical analysis. Multiple aerial UEs are deployed to statistically examine their impact. Based on the results, compliance with short and long term protection criteria can be assessed, therefore providing more realistic results.
- A4.2.5: Comparison Study - ground UE and aerial UE examines the worst-case interference caused by a single UE on the ground which operates in the first adjacent channel to the MetSat band. In fact, this scenario is the worst possible case under current regulations and experience shows that no major problems have occurred yet. Afterwards, the worst-case interference from an aerial UE which limits its emissions to the MetSat band to -40 dBm/MHz is examined. In the end, both results are compared to assess the created interference of aerial UEs, respecting the specific out of band emission limit of -40 dBm/MHz.

The studies provide the justification to select an appropriate aerial UE emission limit below 1710 MHz.

A4.2.2 System Parameters

Table 15: Aerial UE parameters

<table>
<tr><th>Parameter</th><th>Value</th><th colspan="2">Reference</th></tr>
<tr><td>Carrier frequency</td><td>1712.5 MHz - 1st adjacent channel
1717.5 MHz - 2nd adjacent channel
1722.5 MHz - 3rd adjacent channel</td><td rowspan="2">3GPP 36.101 V15.4.0 Error! Reference source not found.</td><td></td></tr>
<tr><td>EUTRA band</td><td>3</td><td>Table 5.5-1</td></tr>
</table>

Parameter	Value	Reference	
Channel bandwidth	5 MHz		Table 5.6.1-1
Transmitted power	23 dBm		Table 6.2.2-1 Class 3
Antenna gain	0 dBi		

There are different types of MetSat operating in 1670-1710 MHz (see Table 16). The MetOp system is considered as worst-case scenario.

Table 16: MetSat satellite systems

Satellite	Orbit height (km)	Inclination (degrees)	Lower frequency (MHz)	Upper frequency (MHz)
FY-1	870 870	98.7 98.7	1698 1705.5	1703 1710
MetOp	827 827	98.7 98.7	1698.75 1704.75	1703.25 1709.25
SPOT	822	98.7	1703	1705
METEOR	1020 1020	99.6 99.6	1698.5 1703.5	1701.5 1706.5
NOAA	850 850	98.7 98.7	1698.75 1704.75	1703.25 1709.25
ADMIN1-A	840	98.7	1698	1702
ADMIN1-B	840	98.7	1702	1706
ADMIN2-A	840	98.7	1702	1706
ADMIN2-B	840	98.7	1706	1710
ADMIN3	840	98.7	1706	1710

Table 17: MetOp system parameters

Parameter	Value	Reference
Carrier frequency	1707 MHz	ITU-R WP7B Contribution 368, Annex 2, table 6 [54]
Receiving bandwidth	4.5 MHz	
Maximum gain	28 dBi	
Antenna pattern	ITU-R S.465-6 [55] and ITU-R S.2196 [56]	
Long-term protection criteria Permissible interfering power to be exceeded no more than 20% of the time for a terrestrial path	-150 dBW per 2668 kHz, equal to -117.73 dBm in the receiving bandwidth	ITU-R SA.1027-5 [57]
Short-term protection criteria Permissible interfering power to be exceeded no more than 0.0094% of the time for a terrestrial path	-138 dBW per 2668 kHz, equal to -105.73 dBm in the receiving bandwidth	ITU-R SA.1027-5 [57]

Table 18: Aerial UE unwanted emissions

Case	Unwanted emissions type in MetSat receiving bandwidth	Reference	Unwanted emissions value in MetOp receiving bandwidth
1st adjacent channel - 1712.5 MHz	ACLR1	3GPP 36.101 V15.4.0 table 6.6.2.3.1-1 **Error! Reference source not found.**	-7 dBm
2nd adjacent channel - 1717.5 MHz	Out of band and spurious emissions	3GPP 36.101 V15.4.0 table 6.6.2.1.1-1 and 6.6.3.1-2 **Error! Reference source not found.**	-15.95 dBm
3rd adjacent channel - 1722.5 MHz	Spurious emissions	3GPP 36.101 V15.4.0 table 6.6.3.1-2 **Error! Reference source not found.**	-23.46 dBm
Arbitrary channel with stringent emission limit	-40 dBm per MHz	Additionally studied	-33.46 dBm
Arbitrary channel with stringent emission limit	-50 dBm per MHz	Additionally studied	-43.46 dBm

A4.2.3 Worst-Case Study - Single Entry

A4.2.3.1 Methodology

Determine the Minimum Coupling Loss

Based on the permissible interference level for the short-term protection criteria, the minimum coupling loss station is calculated according the following formula:

$$A_{MCL}(\varphi) = G_{RX}(\varphi) + G_{TX} + I_{Unwanted} - P_{Metop} \quad (3)$$

Where:

- $A_{MCL}(\varphi)$: Minimum coupling loss, required to fulfil protection criteria of the MetSat, dependent on the main beam offset angle to the MetSat earth station. A positive value is considered as a loss;
- $Gain_{RX}(\varphi)$: Gain of the MetSat earth station, dependent on the offset angle to the mainbeam direction
- $Gain_{TX}$: Gain of the aerial UE. As an isotropic radiator is assumed the value is zero;
- $I_{Unwanted}$: Unwanted emissions of the aerial UE into the receiving bandwidth of the MetOp earth station.

The values can be found in Table 18;

- P_{Metop}: Permissible interference in the receiving bandwidth of the MetSat according to the short-term protection criteria.

Determine the required separation distance from the Minimum Coupling Loss

The required separation distance is then derived from the minimum coupling loss by using the free-space path loss model.

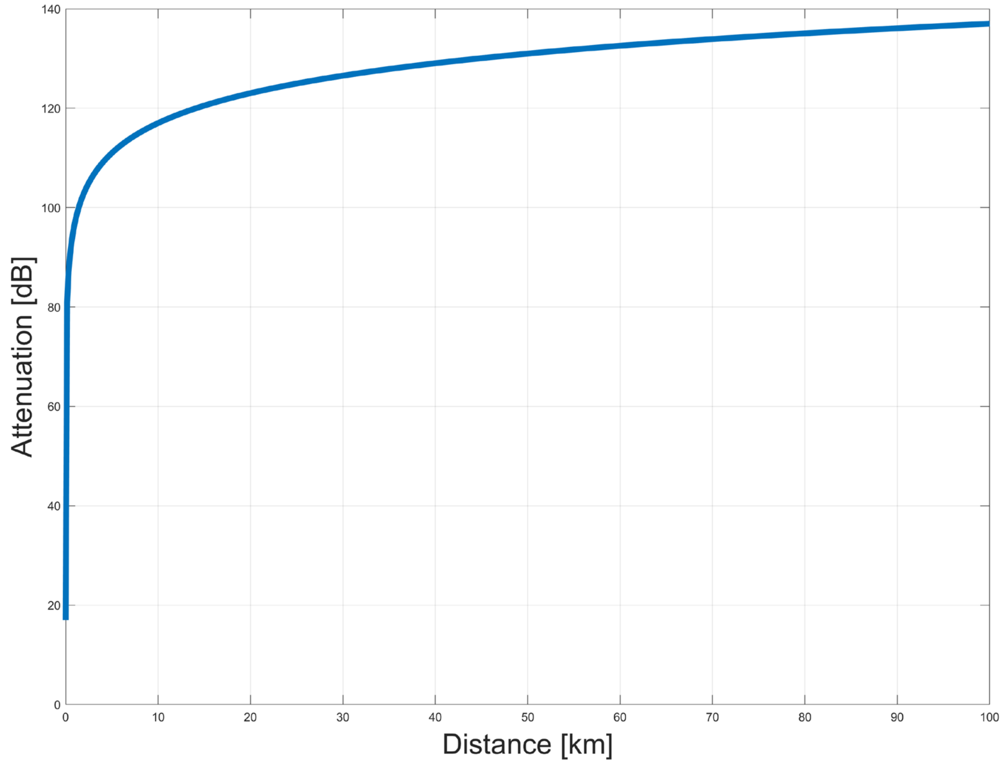


Figure 11: Free-space path loss at 1700 MHz

A5.2.3.2 Results

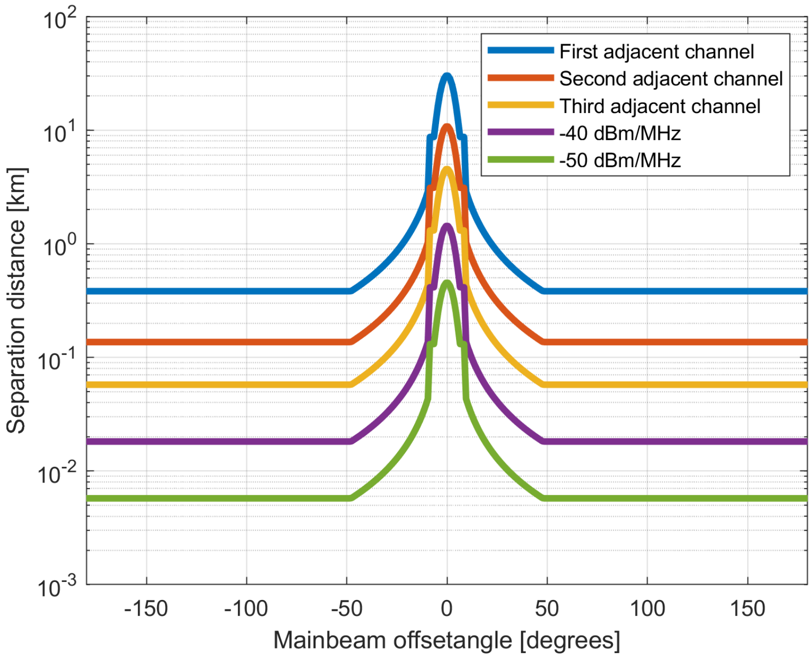


Figure 12: Worst-case results for single entry

Table 19: Worst-case study results

Aerial UE emissions	Required separation distance (km)
First adjacent channel	30
Second adjacent channel	10.8
Third adjacent channel	4.5
-40 dBm/MHz	1.4
-50 dBm/MHz	0.45

To summarise, these separation distances ensure that the permissible interference according to the short-term protection criteria of the MetSat earth station for the terrestrial path is never exceeded for a single entry. However, this study is conducted under worst-case assumptions and the required separation distances are significantly smaller, when the aerial UE is not within the main beam of the earth station. Furthermore, it needs also to be noted that permissible interference according to the short-term protection criteria of the MetSat earth stations may be exceeded 0.0094% of the time.

A4.2.4 Statistical Study - Aggregate Interference

A4.2.4.1 Additional assumptions

Further assumptions are required for the statistical analysis, as indicated in the table below.

Table 20: Additional parameters for statistical study

Parameter	Value
Aerial UE flight height	Uniform distribution [0-10000 m]
Aerial UE density	1.5915e-08 aerial UE per m^2 equivalent to 5 UAs per cell (10 km radius)
Maximum Interference Distance Considered	413 km (Horizon distance at 10 km altitude)

A4.2.4.2 Methodology

Deploy aerial UEs around the earth station

Aerial UEs are randomly placed from zero to 10000 m in altitude and at a distance from the earth station, which starts at the border of the flight exclusion zone, up to 413 km. The value of 413 km for the outer boundary originates from the horizon distance of 413 km for an altitude of 10000 m above ground. Figure 13 illustrates the placement of UAVs around the earth station.

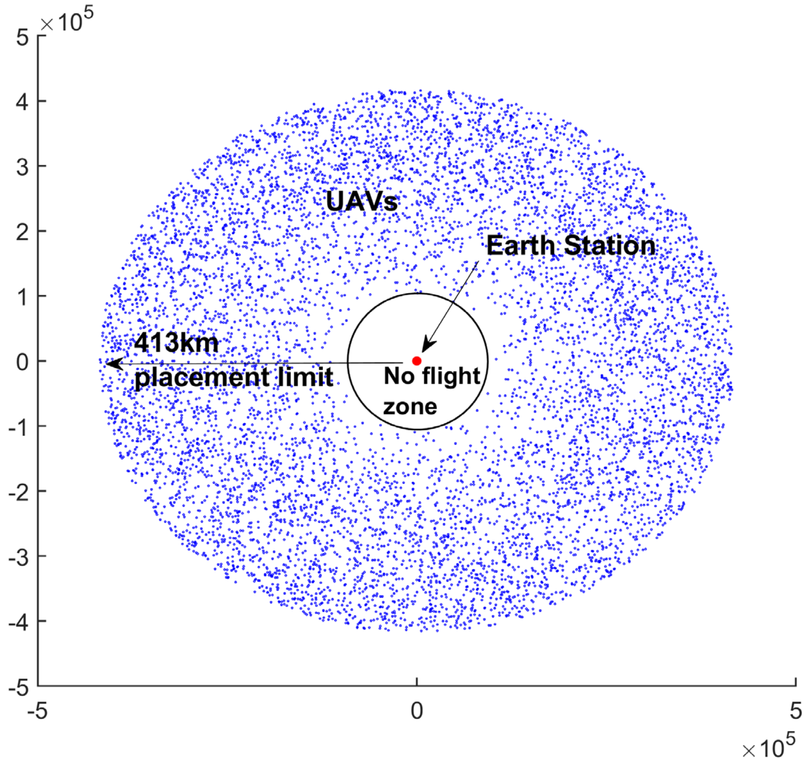


Figure 13: Aerial UE placement in statistical study

A4.2.4.3 Place the MetOp satellite

The MetOp satellite is placed randomly on the orbit surface, respecting the minimum elevation angle of 5 degrees above the horizon plane of the earth station.

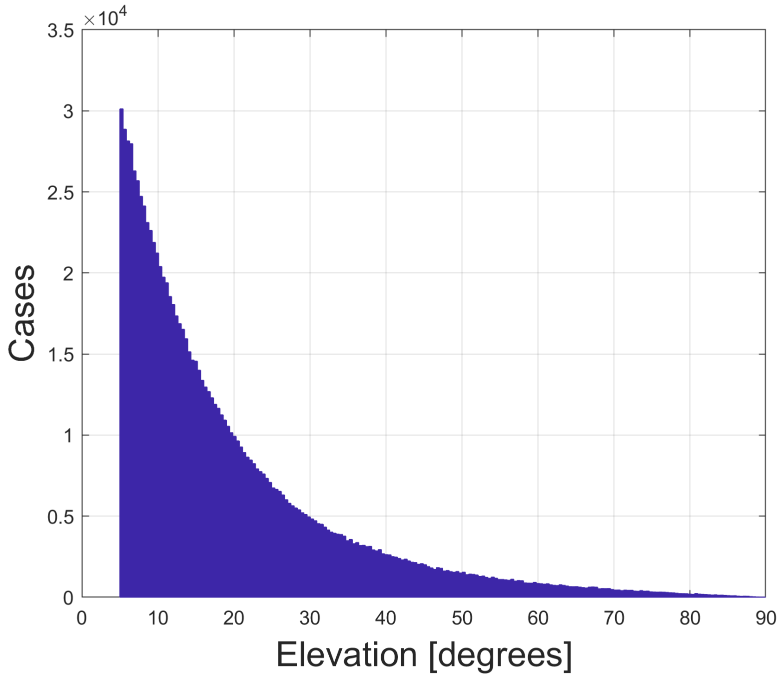


Figure 14: Histogram of the satellite elevation

Based on the satellite position, the pointing direction of the earth station is determined:

$$\overrightarrow{ES_{Mainbeam}} = \overrightarrow{\mathrm{SAT_{Loc}}} - \overrightarrow{\mathrm{ES_{Loc}}} \quad (4)$$

Where:

- $\overrightarrow{ES_{Mainbeam}}$: Vector pointing from the MetOp earth station towards the Satellite. Hence, it represents the direction of the MetOp mainbeam;
- $\overrightarrow{\mathrm{SAT_{Loc}}}$: Location vector of the satellite;
- $\overrightarrow{\mathrm{ES_{Loc}}}$: Location vector of the MetOp earth station.

A4.2.4.4 Determine the gain of the earth station towards each UAV

The vector of the earth station towards the satellite and the vector of the earth station can be used to determine the main beam offset angle for each UAV:

$$ES_{UAV_i Offsetangle} = offsetangle(\overrightarrow{\mathrm{ES_{Mainbeam}}}, \overrightarrow{\mathrm{ES_{UAV_1}}}) \quad (5)$$

Where:

- $ES_{UAV_i Offsetangle}$: Mainbeam offset angle of the MetOp earth station towards the i-th aerial UE;
- $\overrightarrow{\mathrm{ES_{Mainbeam}}}$: Mainbeam direction of the MetOp earth station;
- $\overrightarrow{\mathrm{ES_{UAV_1}}}$: Vector of from the MetOp earth station towards the i-th aerial UE;
- $offsetangle(\overrightarrow{\mathrm{x1}}, \overrightarrow{\mathrm{x2}})$: A function to determine the offset angle between two vectors.

Afterwards, the antenna gain from the earth station towards the i-th aerial UE can be determined by looking up the Gain corresponding to the mainbeam offset angle in the antenna diagram.

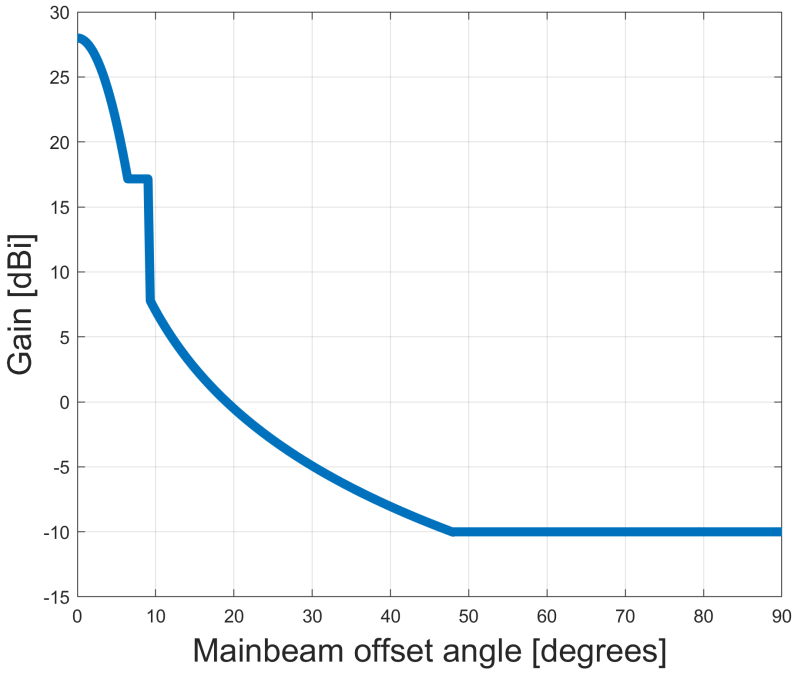


Figure 15: MetOp Antenna Diagram

A4.2.4.5 Determine the interference of a single UAV towards the earth station

Firstly, the distance from the earth station to each UAV is calculated. This distance is used in conjunction with the free-space path loss model to determine the attenuation for each UAV. Afterwards the received interference from each UAV can be determined:

$$ES_{UAV_iInterference} = ES_{UAV_iGain} - ES_{UAV_iFSPL} + UAV_{UnwantedEmissions} \quad (6)$$

Where:

- $ES_{UAV_iInterference}$: The received interference by the MetOp earth station, caused by the i-th aerial UE;
- ES_{UAV_iGain}: The MetOp earth station gain toward the i-th aerial UE;
- ES_{UAV_iFSPL}: The free-space path loss between the MetOp earth station and the i-th aerial UE;
- $UAV_{UnwantedEmissions}$: The unwanted emissions of the aerial UE into the receiving bandwidth of the MetOp earth station.

A4.2.4.6 Determine the aggregate interference of all UAVs towards the earth station

The received interference of each UAV is then summed up to determine the total received interference at the earth station:

$$ES_{InterferenceTotal} = 10\, log_{10}\left(\sum_{i=1}^{N} 10^{\frac{ES_{UAV_iInterference}}{10}}\right) \quad (7)$$

Where:

- $ES_{InterferenceTotal}$: The total interference received by the MetOp earth station;
- $ES_{UAV_iInterference}$: The received interference by the MetOp earth station, caused by the i-th aerial UE;
- N: The number of aerial UEs simulated.

A4.2.4.7 Compute the empirical cumulative density function

The previous steps are repeated sufficiently often to receive an array containing the aggregate interference of each scenario. The empirical distribution function of these results is provided. From the distribution functions, it is straightforward to determine whether the protection criteria (both short term and long term) are fulfilled or not.

A4.2.4.8 Results

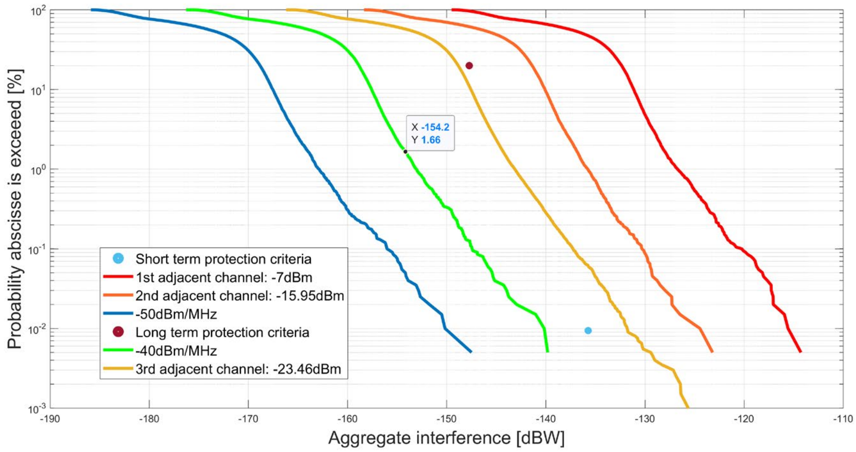


Figure 16: cdf of aggregate interference - no flight exclusion zone

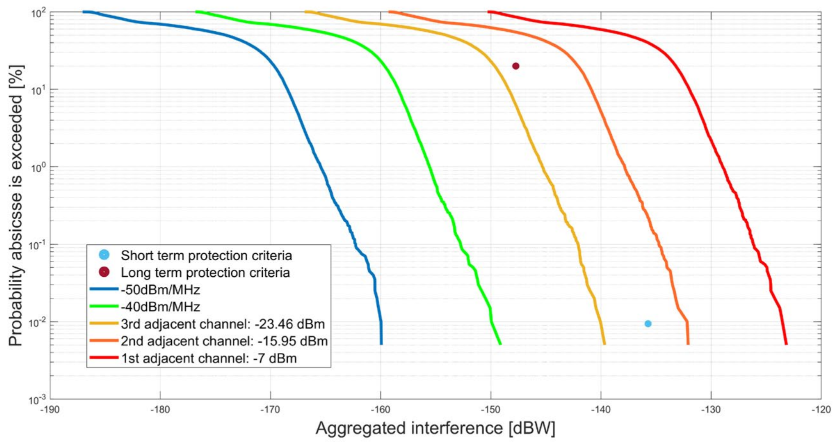


Figure 17: cdf of aggregate interference – 5 km flight exclusion zone

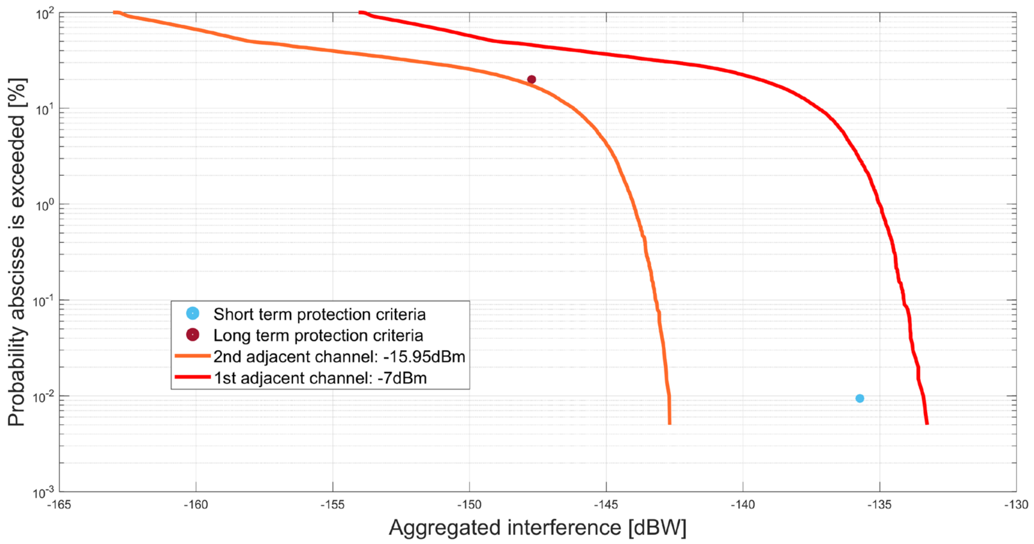


Figure 18: cdf of aggregate interference – 50 km flight exclusion zone

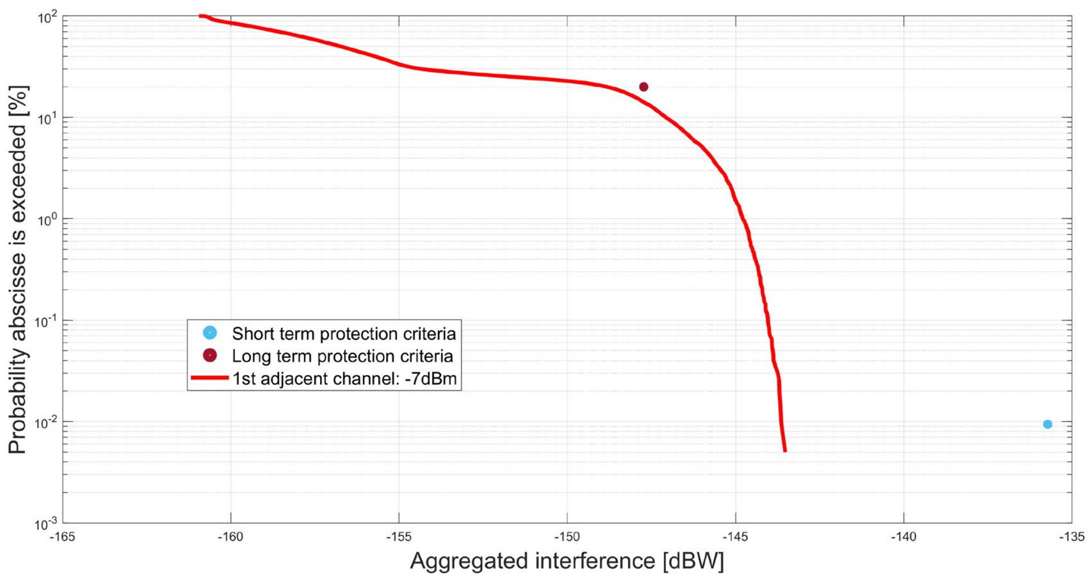


Figure 19: cdf of aggregate interference – 50 km flight exclusion zone

Considering the results of the statistical study, the following separation distances are required to ensure compliance with long term and short-term protection criteria of the MetOp earth station under the considered scenario.

Table 21: Statistical study results summary

Aerial UE emissions	Flight exclusion zone radius (km)
First adjacent channel	200
Second adjacent channel	50
Third adjacent channel	5
-40 dBm/MHz	0
-50 dBm/MHz	0

A4.2.5 Comparison Study - ground UE and aerial UE

A4.2.5.1 Additional parameters

Table 22: Comparison Study - aerial UE parameters

Parameter	Value
Out of band emissions to 1670-1710 MHz	-40 dBm/MHz, equal to -33.73 dBm in the MetOp receiving bandwidth
Altitude	▪ 30 m ▪ 300 m ▪ 1000 m ▪ 10000 m

Table 23: Comparison Study - ground UE parameters

Parameter	Value	Reference
Out of band emissions to 1670-1710 MHz	-7 dBm	3GPP 36.101 V15.4.0 table 6.6.2.3.1-1 **Error! Reference source not found.**
Height	2 m	

A4.2.5.2 Methodology

The MetOp earth station generally points at least 5 degrees above the horizon. Based on this assumption, the maximum possible gain for a given elevation angle can be derived as shown in Figure 18.

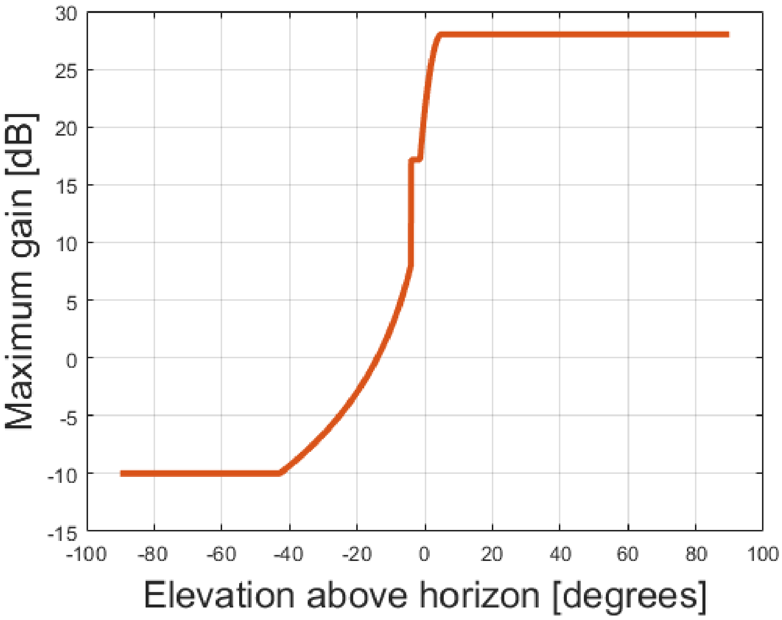


Figure 20: Maximum gain at a given elevation angle

As a next step, ground and aerial UEs are linearly placed at different horizontal distances from a MetOp earth station. For each of these UEs:

- Determine the elevation angle from the MetOp earth station towards each UE and look up the maximum possible gain;
- Determine the line of sight distance and look up the attenuation according to P.452-16. The path losses for p=20% and an interferer at a given altitude are shown in Figure 21;
- Depending on whether it is an aerial or ground UE, determine the emissions into the MetOp receiving bandwidth. Choose -7 dBm for the ground UEs and -33.73 dBm for the aerial UEs.

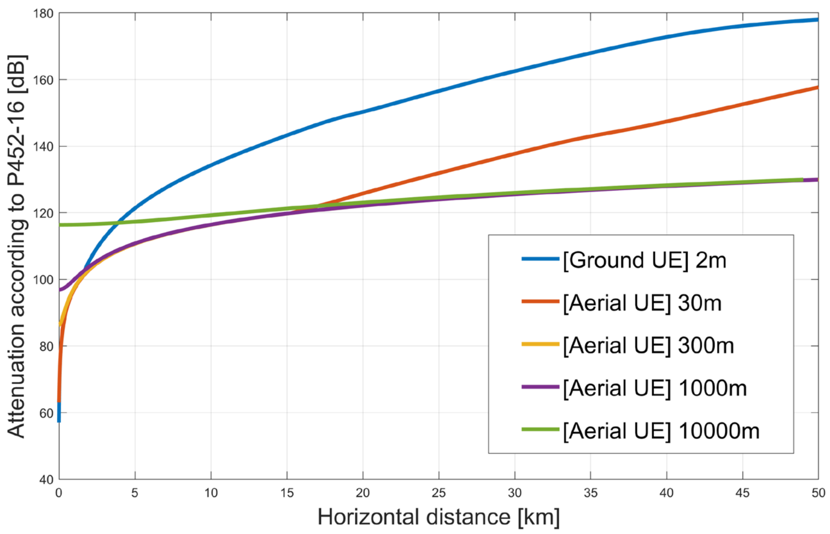


Figure 21: Attenuation according to P.452-16 [59]

Sum up these three values for each UE to obtain the worst-case interference at a given horizontal distance to the MetOp earth station.

A4.2.5.3 Results

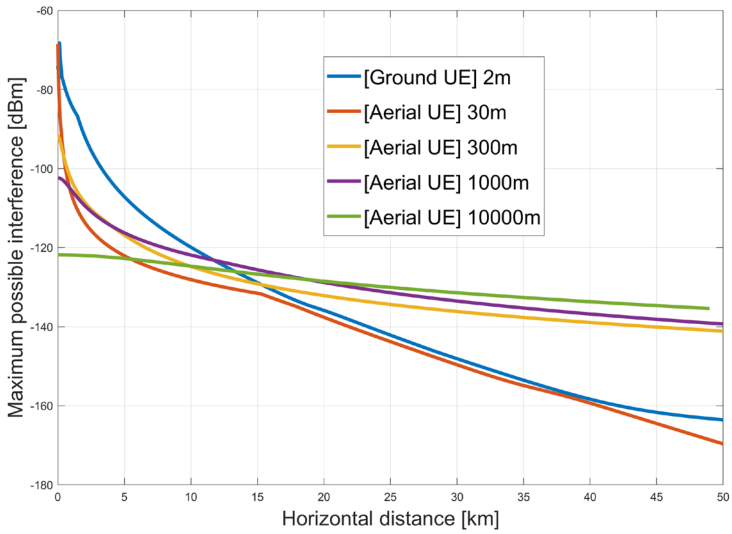


Figure 22: Maximum possible interference

Up to a distance of approximately 12 kilometres, the maximum possible interference from an aerial UE limiting its emissions into the MetSat band to -40 dBm/MHz will always be less than that of an ordinary UE operating at the first adjacent channel. At horizontal distances greater than 12 km, the possible interference of an aerial UE may be higher than that of an ordinary UE.

A4.2.6 Summary of Studies and conclusion

To recall, three different studies have been conducted:

The first study considered a single entry scenario under worst-case assumptions and derived the required separation distances based on the short-term protection criteria. These results provide a first estimate but are not realistic because the deployment characteristics and aggregate effects are not considered.

The second study followed a statistical approach and analysed the inference of multiple aerial UEs and examined how compliance with the protection criteria can be ensured. The results suggest that for out of band emissions which are lower than -40 dBm/MHz, no flight exclusion zone is required to ensure protection of MetOp earth stations. This is because the probability that an aerial UE enters the mainbeam of the MetOp earth station is statistically very low. In contrast to this, very big separation distances are required if no specific emission limits are set.

Table 24: Summary of the single entry and statistical study

Aerial UE emissions	Required separation distance / flight exclusion zone radius (km)	
	Worst-case single entry	Statistical analysis
First adjacent channel	30	200
Second adjacent channel	10.8	50

Aerial UE emissions	Required separation distance / flight exclusion zone radius (km)	
	Worst-case single entry	Statistical analysis
Third adjacent channel (spurious)	4.5	5
-40 dBm/MHz	1.4	0
-50 dBm/MHz	0.45	0

The last study complements the statistical study by examining the interference in the close proximity of the earth station. The study compares the worst-case interference of a ground UE operating in the first adjacent channel to the worst-case interference of an aerial UE with specific out of band emissions of -40 dBm/MHz. The study shows that up to a distance of approximately 12 km a ground UE will create more interference than an aerial UE. In other words, up to 12 km from the MetOp earth station, an aerial UE with emission limits of -40 dBm/MHz generates less interference to MetOp earth stations than a ground UE operating in 1710-1715 MHz. Experience has shown that ground UEs operating in the vicinity of earth stations belonging to the meteorological satellite service do no cause interference issues. Hence, an aerial UE in the proximity of up to 12 km will cause less interference than currently possible by a ground UE.

Summarising the results, it can be concluded that a specific out of band emission limit of -40 dBm/MHz into 1670-1710 MHz would ensure sufficient protection of the meteorological satellite service, while not requiring any flight exclusion zones around the earth station.

A4.3 STUDY 2

A4.3.1 Introduction

The 1710-1785 MHz MFCN frequency band is currently considered in the “uplink” direction, i.e. transmissions from UE on board drone to BS.

This band is adjacent to the 1675-1710 MHz Meteorological Satellite service band (Space-to-Earth) and compatibility analysis is necessary to assess the possible impact on MetSat receiving earth stations.

The present study provides calculations for the Non-GSO MetSat satellites (operating in the 1698-1710 MHz band) and GSO MetSat satellites (operating in the 1675-1698 MHz band).

A4.3.2 Assumptions

A4.3.2.1 MetSat

At this stage, separation distance calculations have been made considering the receiving station in Meteo France CMS (Lannion) has been considered (3° 28’ 26” W – 48° 45’ 02” N).

For non-GSO satellites, the MetOp channel 1704.75 – 1709.25 (i.e. 4.5 MHz bandwidth) has been used with the following parameters:

- Antenna gain: 23 dBi;
- Long-term protection criteria (20%) -150 dBW/2668 kHz (see Recommendation ITU-R SA.1027-5 [57]);
- Short-term protection criteria (0.0094%) -138 dBW/ 2668 kHz (see Recommendation ITU-R SA.1027-5).

For GSO satellites, has been used with the following parameters:

- bandwidth: 4.5 MHz;

- Antenna gain: 45.1 dBi (see Recommendation ITU-R SA.1161 [58] as recently revised by June 2019 SG7 meeting);
- Pointing elevation: 10°;
- Long-term protection criteria (20%): -158.1 dBW/MHz (see Recommendation ITU-R SA.1161 as recently revised by June 2019 SG7 meeting);
- Short-term protection criteria (0.0094%): -153.6 dBW/MHz (see Recommendation ITU-R SA.1161 as recently revised by June 2019 SG7 meeting).

A4.3.2.2 MFCN

MFCN UE has been considered with the following parameters:

- maximum power: 23 dBm;
- antenna gain: 0 dBi;
- ACLR = 30 dB;
- Altitude = 300 m and 10000 m (this later to be confirmed);
- Emission mask for 5 MHz bandwidth (as below).

Table 25: MFCN UE emission mask for 5 MHz channel bandwidth

ΔfOOB (MHz)	Spectrum emission limit (dBm)	Measurement bandwidth
± 0-1	-15	30 kHz
± 1-2.5	-10	1 MHz
± 2.5-2.8	-10	1 MHz
± 2.8-5	-10	1 MHz
± 5-6	-13	1 MHz
± 6-10	-25	1 MHz
± 10-15		1 MHz
± 15-20		1 MHz
± 20-25		1 MHz

On this basis, the following MFCN unwanted emissions power in the MetOp channel can be calculated:

Table 26: MFCN unwanted emissions levels in the MetSat band

MFCN Channel	Basis for calculation	Emission in MetOp channel (dBm/4.5 MHz)
First	ACLR (See note)	-7
First	Emission mask (See note)	-1.7
Second	Emission mask	-15.9
Third	Emission mask	-23.5

For the GSO case (which is more than 12 MHz from the MFCN band edge), only the value of -23.5 dBm/4.5 MHz (i.e. -30 dBm/MHz) is considered.

For both the non-GSO and GSO cases, a value of -33.5 dBm/4.5 MHz (i.e. -40 dBm/MHz) has also been addressed.

A4.3.3 Calculations for non-GSO satellites

A4.3.3.1 Methodology

Necessary separation distances have been calculated using the TVG methodology (Time Variable Gain), that account for the variation of the gain of the EESS earth station towards the location of the UAS as it tracks a non-GSO satellite.

The distribution of gain of the EESS antenna towards the UAS is then convolved with the propagation model (P.452 [59]). This methodology is described in Appendix 7 of the RR [19] (and is e.g. the basis for the coordination distances calculation methodology with 5G at 26 GHz as in ECC Recommendation (19)01 [60].

A4.3.3.2 First MFCN channel (300 m altitude and Emission mask)

Calculation leads to around 33 km separation

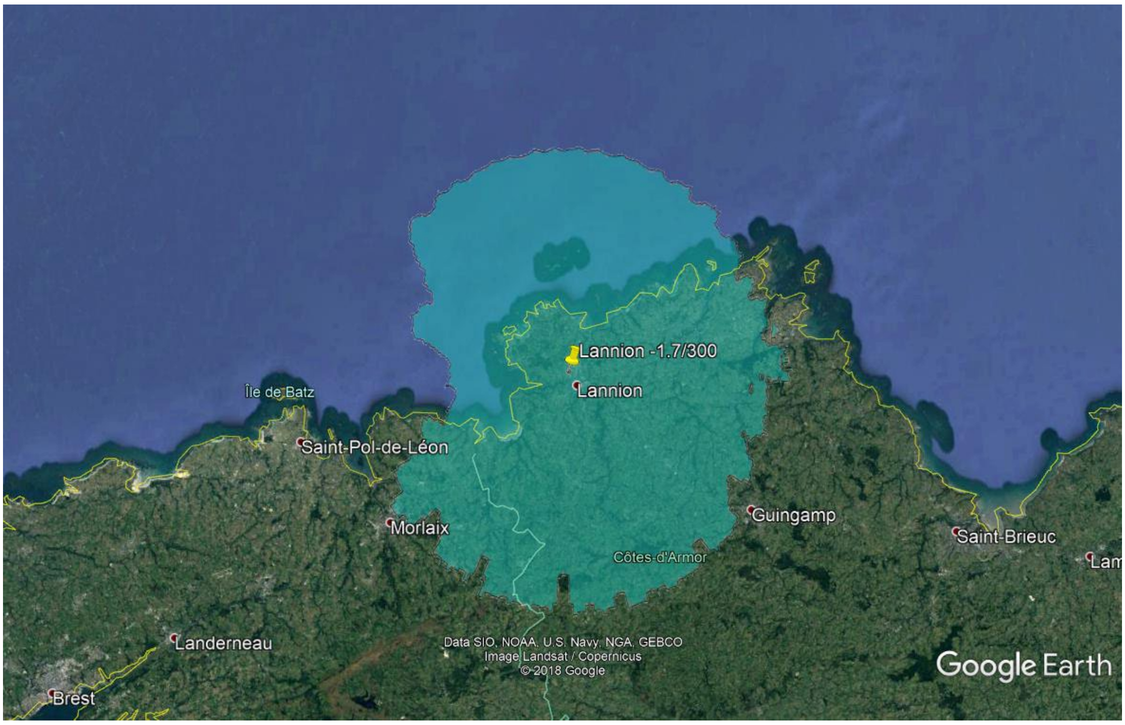


Figure 23: First MFCN channel (300 m altitude and Emission mask)

A4.3.3.3 First MFCN channel (300 m altitude and ACLR)

Calculation leads to around 19 km separation

Figure 24: First MFCN channel (300 m altitude and ACLR)

A4.3.3.4 Second MFCN channel (300 m altitude and emission mask)

Calculation leads to around 8.5 km separation

Figure 25: Second MFCN channel (300 m altitude and emission mask)

A4.3.3.5 Third MFCN channel (300 m altitude and emission mask)

Calculation leads to around 4.5 km separation

Figure 26: Third MFCN channel (300 m altitude and emission mask)

A4.3.3.6 Third MFCN channel (10000 m altitude and emission mask)

Calculation leads to around 5.5 km separation

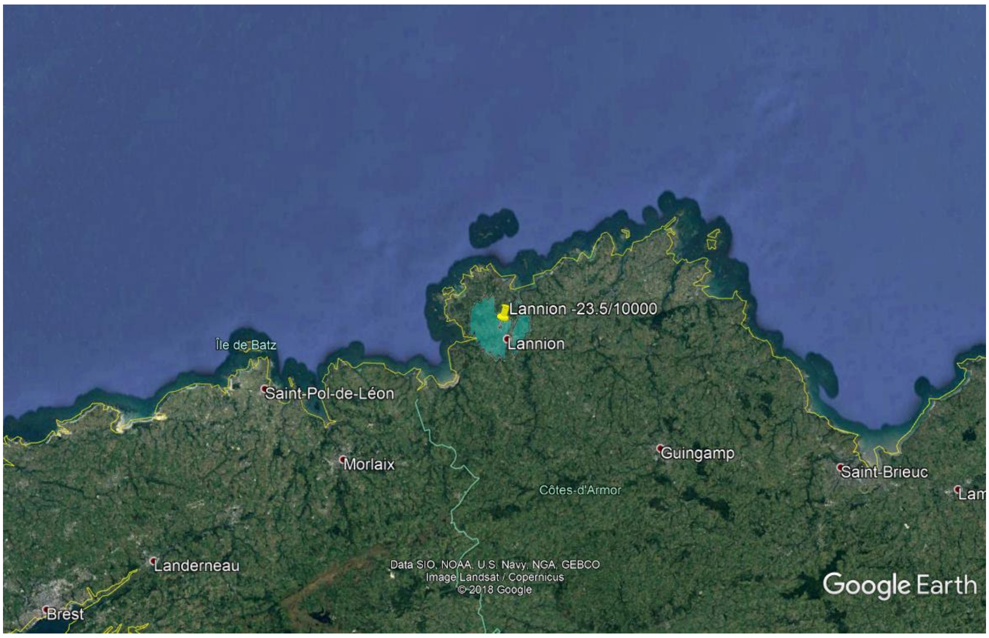


Figure 27: Third MFCN channel (10000 m altitude and emission mask)

A4.3.3.7 Limitation to -40 dBm/MHz (300 m altitude)

Calculation leads to around 2 km separation

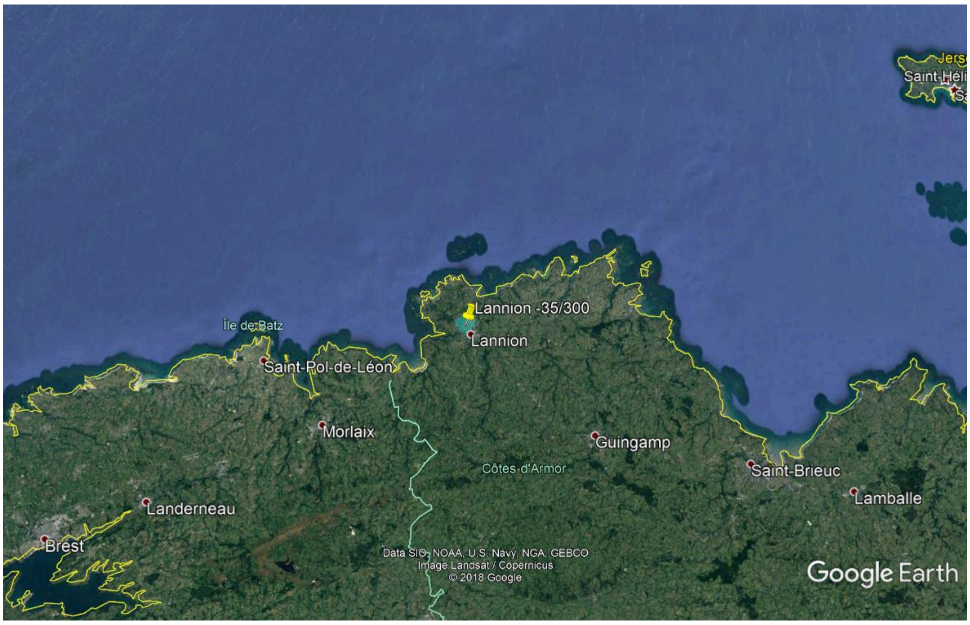


Figure 28: Limitation to -40 dBm/MHz (300 m altitude)

A4.3.3.8 First MFCN channel (1.5 m altitude and emission mask)

Calculation leads to a maximum of 8 km separation for very specific location (hills). On a more general case, separation distances are of few km, somehow consistent with the case of a UAS at 300 m and a -40 dBm/MHz unwanted emission level.

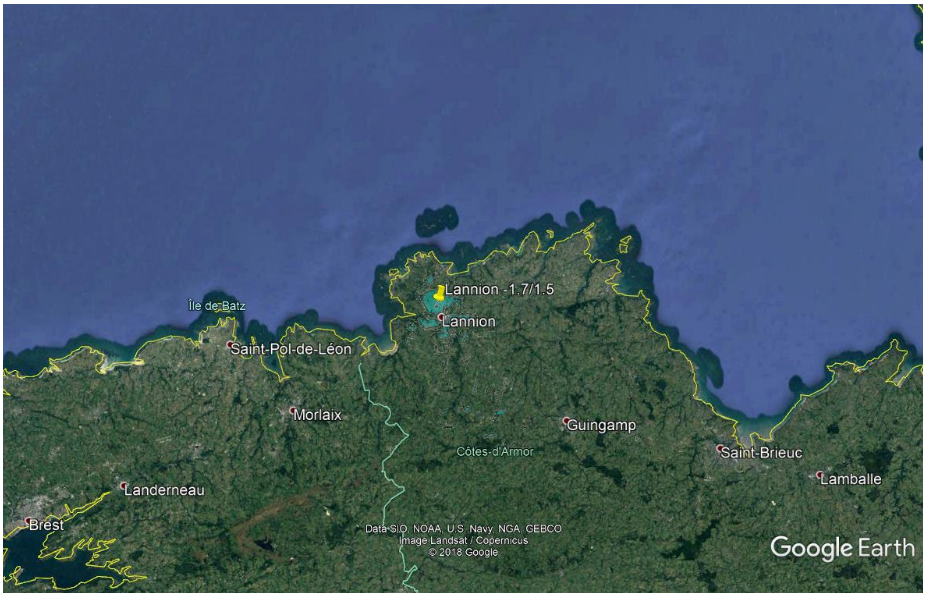


Figure 29: First MFCN channel (1.5 m altitude and emission mask)

A4.3.4 Calculations for GSO satellites

A4.3.4.1 Methodology

Necessary separation distances have been calculated using the TVG methodology (Time Variable Gain), although not fully necessary since the EESS earth station pointing is fixed. The distribution of gain of the EESS antenna towards the UAS is convolved with the propagation model (P.452 [59]).

A4.3.4.2 300 m altitude and -30 dBm/MHz unwanted emission

Calculation leads to around 4 km separation

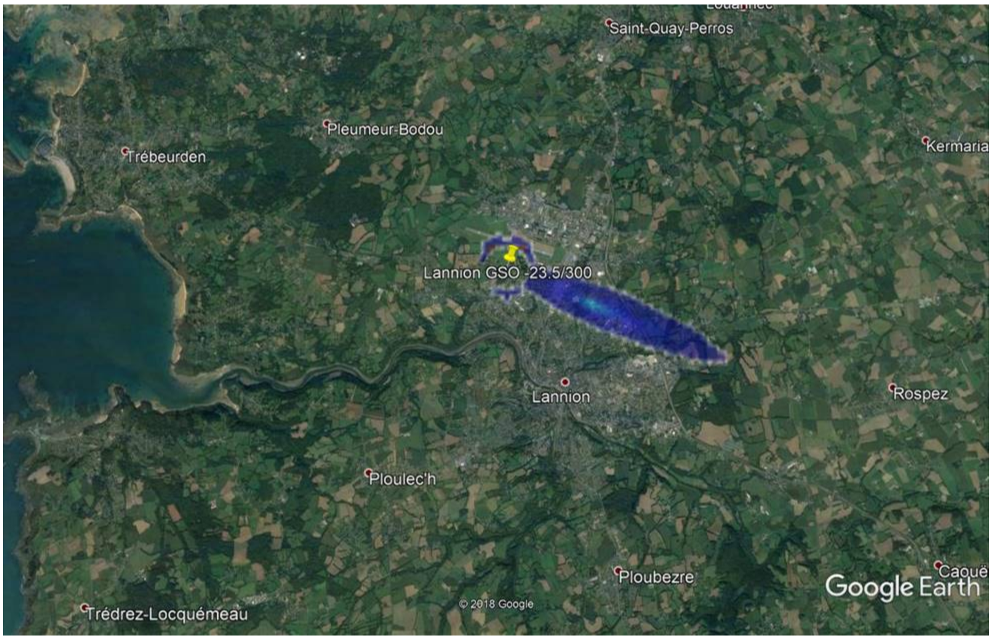


Figure 30: 300 m altitude and -30 dBm/MHz unwanted emission

A4.3.4.3 10000 m altitude and -30 dBm/MHz unwanted emission

Calculation leads to around 0.5 km separation

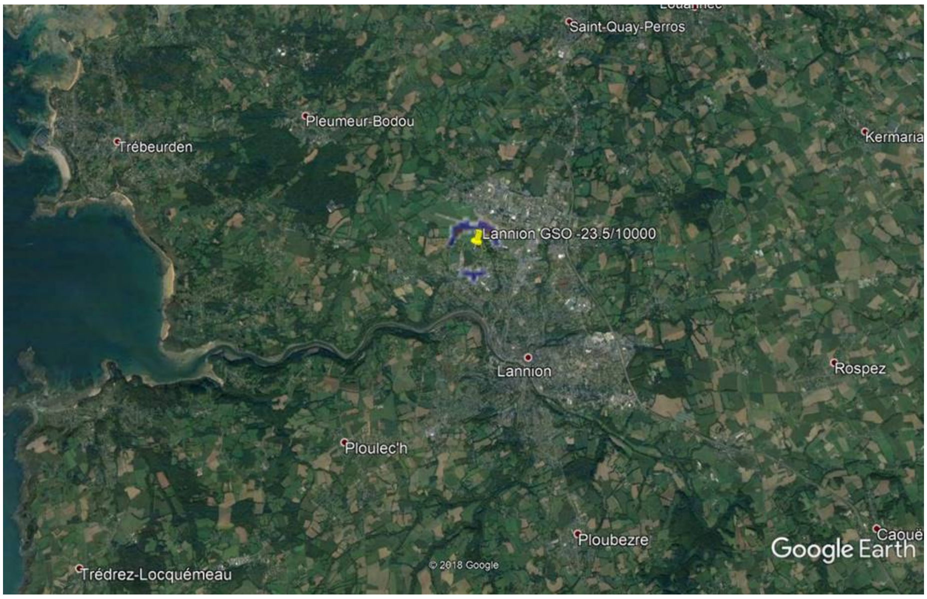


Figure 31: 10000 m altitude and -30 dBm/MHz unwanted emission

A4.3.4.4 300 m altitude and -40 dBm/MHz unwanted emission

Calculation leads to around 2.3 km separation

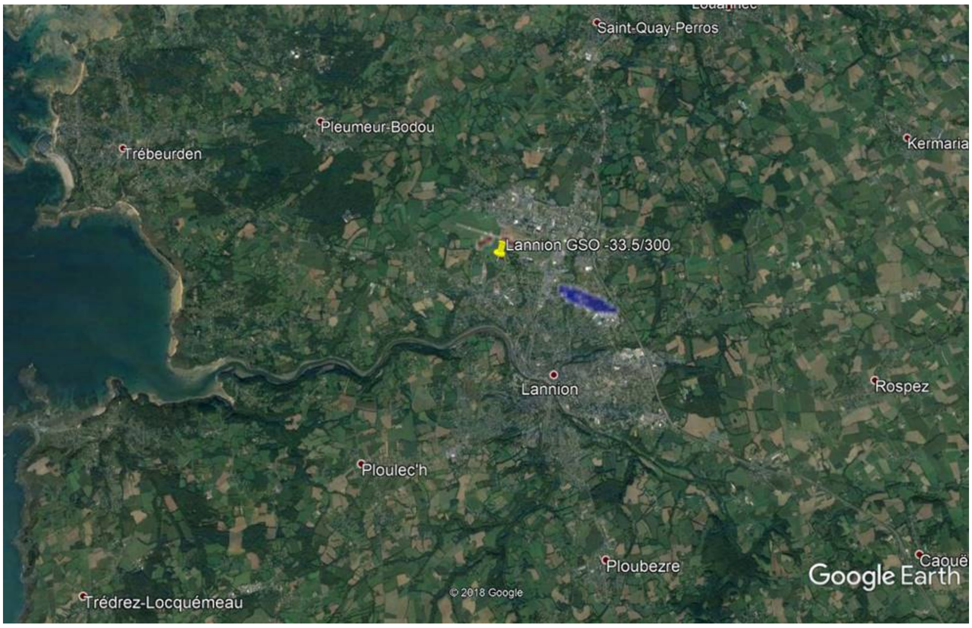


Figure 32: 300 m altitude and -40 dBm/MHz unwanted emission

A4.3.4.5 10000 m altitude and -40 dBm/MHz unwanted emission

Calculation leads to around 0.5 km separation

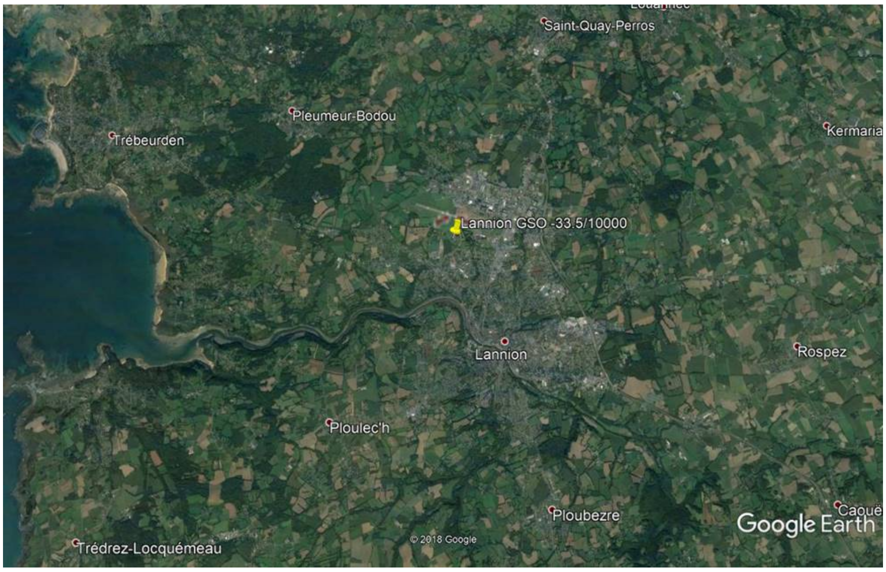


Figure 33: 10000 m altitude and -40 dBm/MHz unwanted emission

A4.3.4.6 1.5 m altitude and -40 dBm/MHz unwanted emission

Calculation leads to around 0.5 km separation

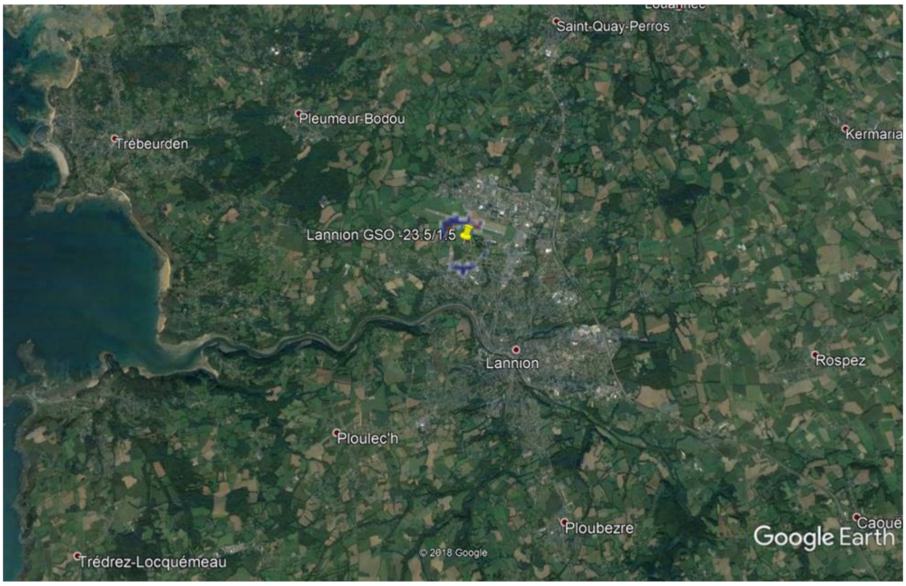


Figure 34: 1.5 m altitude and -40 dBm/MHz unwanted emission

A4.3.5 Conclusion

The present Report provides compatibility analyses between drones using 1.8 GHz MFCN networks and MetSat receiving earth stations within non-GSO systems (operating in the 1698-1710 MHz band) and GSO systems (operating in the 1675-1698 MHz band).

These calculations have been made for various scenarios of assumptions related to the UAS MFCN stations altitude and unwanted emission levels. Comparison has also been made with "regular" UEs (i.e. terrestrial) using MFCN networks.

These calculations are summarised in the table below:

Table 27: Summary of results of Study 2

MetSat	UAS altitude (m)	UAS unwanted emission in the MetSat band (dBm/4.5 MHz)	Separation distance (km)
Non-GSO	300	-1.7	33
	300	-7	19
	300	-15.9	8.5
	300	-23.5	4.5
	10000	-23.5	5.5
	300	-33.5	2
	1.5 (terrestrial UE)	-7	8 max - 2 typical

MetSat	UAS altitude (m)	UAS unwanted emission in the MetSat band (dBm/4.5 MHz)	Separation distance (km)
GSO	300	-23.5	4
	10000	-23.5	0.5
	300	-33.5	2.3
	10000	-33.5	0.5
	1.5 (terrestrial UE)	-33.5	0.5

For the non-GSO case it shows that without additional conditions, such MFCN use on drone can lead to interference to MetSat receiving stations, in particular when considering the first and second MFCN channels.

It is highlighted here that the location of a number of MetSat stations in the 1675-1710 MHz band is not known, hence that the compatibility with MFCN UEs on drones cannot be handled with coordination between the stations.

To this respect, for both non-GSO and GSO cases, the calculations show that an unwanted emission level of -33.5 dBm/4.5 MHz (i.e. -40 dBm/MHz) applied to UAS UEs would lead to similar necessary separation distances than those calculated for "regular" terrestrial UEs.

It can hence be concluded that an unwanted emission level of -40 dBm/MHz applied to UAS UEs operating above 1710 MHz would ensure protection of Meteorological Satellite service receiving Earth stations operating in the 1675-1710 MHz band.

A4.4 CONCLUSIONS OF COMPATIBILITY BETWEEN UAS UES AND METSAT AROUND 1710 MHZ

Both studies 1 and 2 presented in this Annex lead to the same conclusion that to ensure protection of Meteorological Satellite service receiving Earth stations operating in the 1675-1710 MHz band from UAS UEs operating above 1710 MHz, an unwanted emission level of -40 dBm/MHz need to be applied to these UAS UEs. In-band co-channel co-existence simulation for drone operation in 700-800-2600 MHz band

ANNEX 5: IN-BAND CO-CHANNEL CO-EXISTENCE SIMULATION SCENARIOS

The objective is to simulate the potential interference from a cell where a drone flying within its coverage area to the adjacent cells. As shown in the below figure , the intra-operator network is split into two parts: part A contains a cell (one sector) where a drone is flying within its coverage, the part B is composed of the cells in adjacent area to the part A. The objective is to simulate the impact of a drone flying in the cell of part A on the network part B.

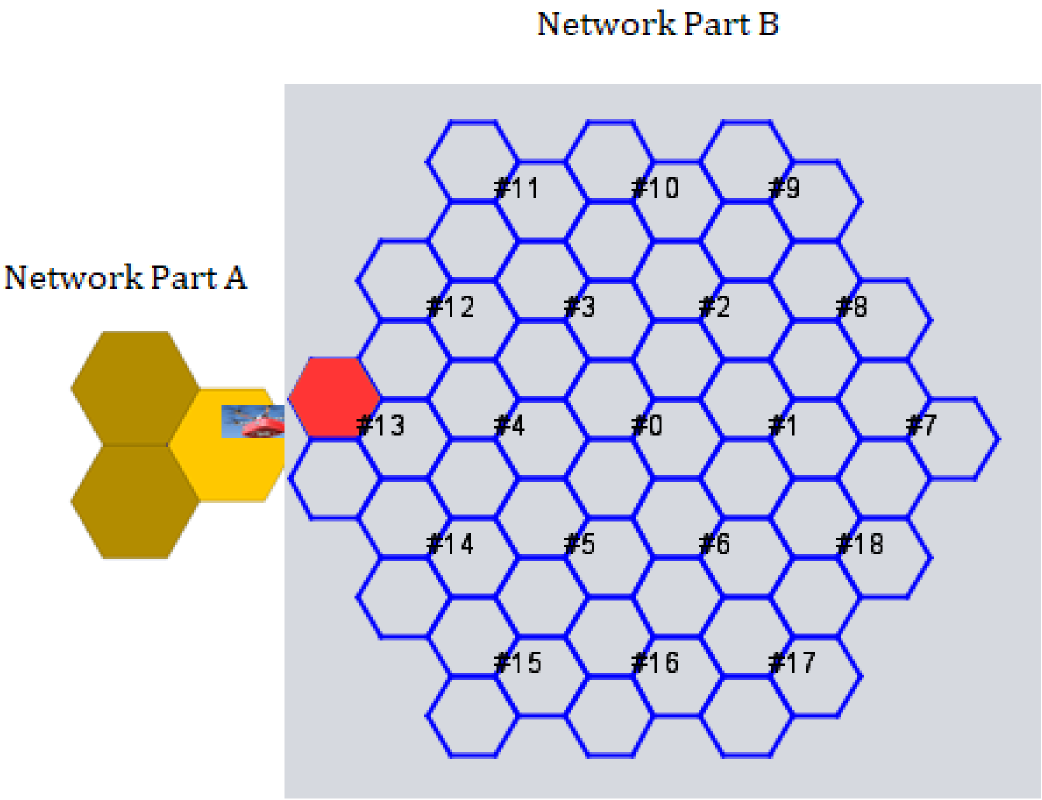


Figure 35: Intra-network co-channel co-existence simulation scenario

Simulations are performed in two steps:

- Step A: the interference from network part A uplink with normal UEs located within the network part A coverage area (one single cell/sector) to the network part B, network part B uplink throughput loss is simulated.
- Step B: the network part B uplink throughput loss caused by a drone UE flying within the network part A coverage is simulated. Similarly to UEs, drones operate in transmitting (UL) to its serving BS under power control scheme.

The comparison of simulation results obtained from step A and step B allows to evaluate the possible impact of drone operation on the neighbouring part of the same network operating in co-channel compared to the current situation with (indoor/outdoor) UEs located within the network.

A5.1 SIMULATION ASSUMPTIONS AND RESULTS FOR DRONE OPERATION IN 700, 800 AND 2600 MHZ BAND

A5.1.1 Simulation assumptions

The simulation assumptions are summarised in the below table.

Table 28: Simulation assumptions for drones operation in 700, 800 and 2600 MHz band in Urban and Rural area

Parameter	Network Part A	Network Part B	Reference
System	LTE	LTE	
Duplex mode	FDD	FDD	3GPP TS36.104 [44]
Channel bandwidth (MHz)	10 MHz (UL: 703-713 MHz) (UL: 842-852 MHz) (UL: 2500-2510 MHz)	10 MHz (UL: 703-713 MHz) (UL: 842-852 MHz) (UL: 2500-2510 MHz)	LTE 10 MHz channel
Centre frequency (MHz)	UL: 708 UL: 2505	UL: 708 UL: 2505	
MIMO	2x2	2x2	
BS Tx Power	43 dBm/10 MHz per MIMO branch 46 dBm/10 MHz per cell	43 dBm/10 MHz per MIMO branch 46 dBm/10 MHz per cell	Report ITU-R M.2292 [25]
Antenna	Recommendation ITU-R F.1336 (recommends 3.1) [45] ka = 0.7 kp = 0.7 kh = 0.7 kv = 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 [45].	Recommendation ITU-R F.1336 (recommends 3.1) [45] ka = 0.7 kp = 0.7 kh = 0.7 kv = 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 [45]	Report ITU-R M.2292 [25]
Antenna height (m)	700-800 MHz: 30 (Urban) 40 (Rural) 2600 MHz: 20 (Urban) 30 (Rural)	700-800 MHz: 30 (Urban) 40 (Rural) 2600 MHz: 20 (Urban) 30 (Rural)	Report ITU-R M.2292 [25] Doc WP5D#416 [46]
BS Antenna gain (dBi)	700-800 MHz 15 (Urban) 18 (Rural) 2600 MHz	700-800 MHz 15 (Urban) 18 (Rural) 2600 MHz	ECC Report 82 [47] (for 700 MHz with similarity to 800 MHz) ITU-R report M.2292 [25] for 2600 MHz

Parameter	Network Part A	Network Part B	Reference
	16 (Urban) 18 (Rural)	16 (Urban) 18 (Rural)	
Feeder loss (dB)	3	3	Report ITU-R M.2292 [25]
Downtilt	700-800 MHz 6° (Urban) 3° (Rural) 2600 MHz 10° (Urban) 3° (Rural)	700-800 MHz 6° (Urban) 3° (Rural) 2600 MHz 10° (Urban) 3° (Rural)	Report ITU-R M.2292 [25] Based on national data for 700-800 MHz band urban
Maximum e.i.r.p. (dBm)	58 dBm 61 dBm	58 dBm 61 dBm	Report ITU-R M.2292 [25]
BS Noise figure	5	5	Report ITU-R M.2292 [25]
Site type	Tri-sector	Tri-sector	
Cell Range (m)	700-800 MHz 600 (Urban) 8000 (Rural) 2600 MHz 400 (Urban) 4000 (Rural)	700-800 MHz 600 (Urban) 8000 (Rural) 2600 MHz 400 (Urban) 4000 (Rural)	ECC PT1(10)128 [117] Report ITU-R M.2292 [25]
Handover Margin (dB)	1	1	ECC PT1(10)128 [117]
SINR Minimum (dB)	-10	-10	ECC PT1(10)128 [117] and 3GPP TR 36.942 [48]
UE Tx Power (dBm)	23	23	3GPP TS36.101 **Error! Reference source not found.**
UE Antenna height (m)	For normal UE in urban[17]: 1.5, 4.5, 7.5, 10.5, 13,5, 16.5, 19.5[18] For normal UE in rural: 1.5 m For drone: 30, 50, 100, 150, 200, 250, 300	For normal UE in urban: 1.5, 4.5, 7.5, 10.5, 13,5, 16.5, 19.52 For normal UE in rural: 1.5 m	6-7 floors are considered in urban area
UE Antenna gain (dBi)	-3	-3	
Indoor penetration loss (dB)	20 dB (Urban) 10 dB (Rural)	20 dB (Urban) 10 dB (Rural)	
Body loss (dB)	0 for drone	1	

[17] Based on 3 m height of floor.

[18] 19.5 m is only valid for 700 MHz because the typical height of a building for 2600 MHz is 20 m.

Parameter	Network Part A	Network Part B	Reference
	1 dB for normal UE		
Minimum Tx Power (dBm)	-40	-40	ECC PT1(10)128 [117]
UE noise figure (dB)	9	9	Report ITU-R M.2292 [25]
Number of UEs/Cell	1	1	
BS to UE propagation model	Free Space (UEs being drones)	ITU-R P.1546-5 Urban/Rural for H<30 m	Report ITU-R P.1546-5 [49]
Standard deviation (dB)	6 (Urban) 8 (Rural)	6 (Urban) 8 (Rural)	
UEs distribution per floor	ground floor (h=1.5 m): 25%/30%[19] 1st floor (h=4.5 m): 25%/30% 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%[20]		See Appendix (section A5.3.4)
Propagation model for interference link from Drone to the victim network Part B BS	Free Space for H>= 30 m With 5 dB standard deviation		
Standard deviation for the interference link	5 dB for Free Space		
Separation distance between reference cell of Part A and Part B	Cell Range *(3/2) corresponding to the BS Inter-Site distance 700-800 MHz: 900 m in Urban,12 km in Rural 2600 MHz: 600 m in Urban, 6 km in Rural		
Indoor/outdoor UEs	Urban: 70% indoor, 30% outdoor Rural: 50% indoor, 50% outdoor		

[19] 25% for 700 MHz Band, 30% for 2600 MHz because the typical size of building (in urban environment) is lower when deploying antenna in higher frequency.

[20] Only for the 700 MHz band case.

Parameter	Network Part A	Network Part B	Reference
UE and drone transmission power scheme	Power control Algorithm over -40.23 dBm output power range	Power control Algorithm over -40.23 dBm output power range	3GPP TR 36.942 [48] (Section 12.1.4) and Recommendation ITU-R M.2101-0 [51]

A5.1.2 Simulation results

Simulations are run using SEAMCAT tool version 5.3.0 with the parameters configuration described in previous section over 10000 events. SEAMCAT Scenarios Workspace are attached to this contribution for various environments (rural, urban), various deployment (regular UEs, drones over one single cell/all network for the interferer), different frequency ranges (700, 800 and 2600 MHz) in order to draw a general view of the co-channel coexistence.

Due to the fact that there is:

- no field to fill the 3 dB BS feeder loss;
- no field to fill the UE body loss.

and in order to avoid affecting the value of the BS antenna peak gain in the computation of the radiation pattern (based on Recommendation ITU-R F-1336-4 [45]), body loss and BS feeder loss were subtracted from the UE antenna gain value, i.e. -3-3-1=-7 dBi for the normal UEs and -3-3-0=-6 dBi for the aerial UEs.

The reference cell is the sector (cell) at the network edge, as shown in Figure 35 corresponding to the yellow hexagon for the network Part A and the red hexagon for the network Part B. The simulation results of network average (over the whole network cluster) UL throughput loss with a normal UEs as interferers are given in the below table.

Table 29:Simulation result (caused by normal UEs) Co-channel (Step A)

Throughput loss	700-800 MHz	2600 MHz
Urban	Cell Ref: 8.7% System: 0.4%	Cell Ref: 5.5% System: 0.2%
Rural	Cell Ref: 1.5% System: 0.1%	Cell Ref: 4.0% System: 0.1%

Results depicted above for 800 MHz frequency range are identical to the 700 MHz because all deployment parameters (e.g. cell radius, BS peak gain...) are the same and noticing that the difference in path loss between these two frequencies are generally balanced with the (aerial and normal) UEs transmission power for both the interfering and victim links.

The above table shows that in urban area, the reference cell uplink throughput loss is lower than 9% and network average uplink throughput loss is lower than 1%. In rural area, the reference cell uplink throughput loss is lower than 4%, network average throughput loss is quite low. This corroborates the idea that inter-cell interference within the same mobile network is not an issue for normal UEs.

Caution should be taken if comparing these results achieved in co-channel scenario with the one presented in the other document for the adjacent use case recalled in the below table:

Table 30: Simulation result (caused by normal UEs) Adjacent channel (Step A)

Throughput loss	700-800 MHz	2600 MHz
Urban	2.7%	2.5%
Rural	2.5%	3.5%

The reason why Network throughput loss is unexpectedly higher for the adjacent case (compared to the co-channel case addressed above) comes from different assumptions taken on the calculation of the interference:

- for the adjacent case, the interference from a mobile operator network (19 sites – 51 cells/sectors) onto another one (in another spectrum block) (19 sites – 51 cells/sectors) is sought with an uncoordinated distance "separating"[21] these two networks D=$\sqrt{3}$ Cell Radius;
- for the co-channel case, the interference within the same mobile network is assessed from only one cell (called reference cell of Part A) to the other cells (Part B of the same network) with BS inter-site distance D=3xCell Radius.

The simulation results of the network part B uplink throughput loss caused by a drone flying at different heights within the cell (single sector) of the network part A for Urban area are given in Table 31. The (network and reference cell) throughput can be significantly degraded with the altitude of the drones, achieving more than 70% for any frequencies range in some cases (generally for altitude>5000 m). For altitude >120 m, the average network throughput loss is generally higher than 5% for urban areas. This level of interference is much higher than for normal UEs due to visibility of UAS with respect to the other BSs. Moreover, the degradation of the throughput with the altitude of the drone up to 5000-6000 m also reflects the sensitive balance between the increase of the transmission power of the aircraft, the BS discrimination antenna gain and the distance from the victim BSs. Both metrics (Ref Cell and Network average) achieve their extrema in similar altitude ranges[22].

Table 31: Simulation result in urban area (Throughput loss caused by drone): Step B

Drone height (m)	Ref_Cell 700-800 MHz	Network average 700-800 MHz	Ref_Cell 2600 MHz	Network average 2600 MHz
30	12.6%	1.5%	14.7%	1.8%
50	14.4%	1.9%	23.2%	3.2%
100	29.8%	6.1%	30.3%	4.7%
120	34.4%	7.7%	31.7%	5.1%
200	35.1%	8.6%	38.9%	7.4%
300	40.3%	9.6%	49.4%	11.4%
500	50.4%	13.4%	63.0%	21.8%
1000	68.2%	28.7%	69.3%	42.9%
5000	72.4%	70.5%	73.0%	70.1%

[21] There is an overlap between these two networks as they relate to two different mobile operators.

[22] The fact they don't exactly achieve their maximum at the same altitude is due to the fact that the computation of the free space loss also includes an additional variation (with 5 dB standard deviation)

Drone height (m)	Ref_Cell 700-800 MHz	Network average 700-800 MHz	Ref_Cell 2600 MHz	Network average 2600 MHz
6000	72.7%	72.0%	73.0%	70.7%
7000	73.2%	72.3%	71.9%	70.6%
8000	72.7%	72.2%	70.6%	69.4%
9000	73.6%	72.7%	68.6%	67.7%
10000	73.2%	72.9%	66.7%	65.5%

The simulation results for rural area in Table 32 show that the network part B uplink throughput loss is lower compared to urban area, but remains high for the different frequencies ranges, e.g. more than 10% for the reference cell in 700, 800 and 2600 MHz bands from 30 m altitude.

Table 32: Simulation result in Rural Area (Throughput loss caused by drone : Step B

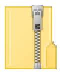
Drone height (m)	Ref_Cell 700-800 MHz	Network average 700-800 MHz	Ref_Cell 2600 MHz	Network average 2600 MHz
30	12.7%	1.4%	12.3%	1.4%
50	12.4%	1.4%	13.2%	1.4%
100	13.2%	1.5%	15.0%	1.9%
120	13.6%	1.6%	16.2%	2.1%
200	15.7%	2.1%	23.8%	4.1%
300	19.9%	3.1%	32.5%	7.0%
500	29.4%	6.1%	32.9%	8.2%
1000	33.7%	8.5%	37.8%	8.1%
5000	57.1%	14.7%	70.0%	28.9%
6000	62.1%	18.0%	71.0%	33.5%
7000	66.0%	21.0%	70.9%	36.6%
8000	67.6%	23.9%	68.9%	38.9%
9000	68.9%	27.0%	67.5%	40.1%
10000	70.3%	29.9%	64.9%	40.1%

A5.2 CONCLUSIONS AND PROPOSALS

Based on the simulation results presented in section 3, the following conclusion can be made: when a drone is flying within a cell in a cellular network, it causes always more interference than ground UEs (in one cell) to the other cells. More specifically, a drone will likely cause interference to the neighbouring cells resulting in a potential important uplink throughput loss in several cases, e.g. up to around 73% (for both Reference cell and the whole system) for urban area. For Rural area, it can be up to 70% uplink throughput loss for the reference cell (taken as adjacent to the interfering cell) and 40% for the whole system.

A5.3 APPENDIX

SEAMCAT Workspaces of several scenarios simulations for the co-channel studies presented in this document



CoChannel.zip

A5.3.1 Application of the power control algorithm for user terminals and drones.

See A2.4.1.

A5.3.2 Choice of cell reference for the interfering and victim mobile networks

The cell reference is taken as the sector to be the closest of the source of interference.

In the in-band co-channel simulation, the interfering network part A and the victim reference cell of the network part B have to follow the continues hexagon network layout as shown in Figure 1 (Section 2), the separation distance is 3xR where R is the cell radius, Cell range is 2xR following 3GPP network layout.

The separation distance between two neighbouring BS is the inter-site distance 3xR, for urban area, it is 3x300 m= 900 m, for rural area, it is 3x4 km =12 km.

A5.3.3 Recommendation ITU-R P-1546-5 Propagation model [49]

See A2.4.2.

A5.3.4 Calibration of the scenario for indoor/outdoor UEs in two different sites

See A2.4.3.

ANNEX 6: RAS STUDY

A6.1 INTRODUCTION

Radio astronomical observatories in CEPT countries study the universe over a large range of frequencies between few MHz up to THz. At decimetre wavelengths, RAS stations such as Effelsberg (DE), Jodrell Bank (UK), Nançay (France), WSRT (Netherlands), or the recently constructed SRT (Italy) utilise large paraboloids with thousands of square metres collecting area for extremely sensitive observations.

ITU-R has acknowledged the importance of radio astronomy long ago and has reserved several bands for exclusive use of RAS in the so-called passive bands (e.g., 1420–1427 MHz or 2690–2700 MHz; see RR 5.340 [19]) or by allocating them as primary or secondary service (e.g., 608–614 MHz, 1660-1670 MHz, 1718.8–1722.2 MHz, or 2655–2690 MHz, RR 5.149). Furthermore, administrations are urged to protect RAS in several other frequency ranges (e.g., 1330–1400 MHz or 3345.8–3352.5 MHz in RR 5.149). Protection criteria are given in Recommendation ITU-R RA.769-2 [37] and tables with pre-computed values are attached in RA.769 for most of the aforementioned frequencies. Usually, a distinction is made between various observing modes, e.g., continuum, spectral-line or VLBI, which need different levels of protection, with continuum observations requiring the most stringent protection levels, and VLBI needing only moderate protection (if interference is local to the RAS sites). Note that sometimes the term “broadband” is used, which corresponds to “continuum” observations (see Table 1 of Recommendation ITU-R RA.769-2) and “narrowband” corresponds to “spectral line” observations (see Table 2 of Recommendation ITU-R RA.769-2) respectively. Both in-band emissions in these RAS bands and emissions from outside these RAS bands falling into them should remain below the thresholds for detrimental interference given in Recommendation ITU-R RA.769-2, subject to Recommendation ITU-R RA.1513 [61] which provides with 2% data loss to the RAS due to interference by all stations of one service, and with an aggregate data loss of 5% in any band from all services.

MFCN (user) equipment on-board aircrafts and unmanned aerial vehicles (UAVs) has the potential to seriously harm RAS operations, especially if line-of-sight conditions apply. Given the large possible flight height of such devices, a significant number of them could be located within the 0 dBi contour of the RAS antenna pattern (which has a radius of about 19°; see Recommendation ITU-R RA.1513-2). Such devices could cross the main-beam leading to enormous amplification of the signals by up to 80 dBi for a 100-m class instrument. In the worst case, the receiver front-end could even be damaged by the MFCN in-band signal if the incident power exceeds some threshold levels as discussed in Report ITU-R RA.2188 [62]. However, given the small angular extent of the RAS antenna beam and near side lobes, such a situation is relatively unlikely

In the following, separation distances for the single-interferer spurious-domain case are derived, for (1) a generic (zero-height) environment and (2) specific RAS locations. The uplink portion of the MFCN bands under consideration for aerial UEs are all separated by several tens of MHz from the RAS bands, which means that compatibility calculations need to be based on spurious emission levels.

For adjacent services, if not specified otherwise, Recommendation ITU-R SM.329 [33] defines a regulatory limit of -36 dBm/MHz (30 MHz < f < 1 GHz) / -30 dBm/MHz (f > 1 GHz) for spurious emissions of Category B land mobile devices (BS and UE). However, ECC Report 249 [26] (see also Report ITU-R SM.2421 [63]) finds that in practice most real MFCN devices stay significantly below these limits for frequencies that are separated by more than 20- 100 MHz depending on the carrier frequency. The details depend very much on the individual vendor, carrier frequency, and whether the BS or UE is under test. While BS often employ physical filters to suppress spectral side lobes, UE spurious emissions could be detected to larger frequency offsets in some cases. One important exception to this is harmonic emission. For example, ECC Report 249 shows that one LTE800 UE device produced broad second-harmonic emission at 1600 MHz barely below the -30 dBm/MHz level. It should also be noted that "digital transmitters in comparison to analogue ones have no spikes" (Rep. ITU-R SM.2421).

ECC Recommendation (19)02 [64] aims to improve spectrum efficiency by proposing that spectrum management compatibility studies use more realistic out-of-band and spurious emission levels, if available, as the default value of -30 dBm/MHz is unrealistically high in many cases. However, ECC Recommendation

(19)02 also acknowledges that a large number of high-quality measurements for all kinds of devices and manufactures must be available to ensure a statistically solid set of emission levels. It also states that due to the nature of technological development, such information can quickly become outdated and therefore all involved parties are urged to keep the database of spurious emission levels up-to-date.

Unfortunately, both, ECC Recommendation (19)02 and ECC Report 249, do not give advice how to deal with a situation where all available measurements of a device class indicate low spurious emission levels, which are then used for compatibility calculations, but as the regulatory limits are kept unchanged it is not possible to enforce such low emission levels for all devices on the market.

Among the potential victim services, the passive services (EESS, SRS, and RAS) require special attention owing to their high sensitivity. Recommendation ITU-R SM.1542 [65] considers

- *f) that the RAS, the EESS (passive) and SRS (passive) are based on the reception of emissions at much lower power levels than are generally used in other radio services;*
- *g) that, due to these low received power levels, these passive services are generally more susceptible to interference from unwanted emissions than other services;*
- *h) that several footnotes to the Radio Regulations (RR) (such as Nos. 5.149, 5.340, 5.372) draw attention to the protection of these passive services, particularly from spaceborne, airborne, or high altitude platform stations (HAPSs), (for the radio astronomy stations) and from earth stations, HAPS, and high density fixed system (HDFS) stations (for the space-based passive services);*
- *l)* **that general limits for spurious emissions may not protect to the desired extent the passive services from interference***;*

and recommends

- *2 that when designating frequency bands for specific terrestrial applications such as HAPS or HDFS, their proximity to frequency bands allocated to the RAS or the EESS (passive), and the SRS (passive) be taken into account;*
- *3 that where possible allocations adjacent to existing passive services bands should be such as to minimize the potential for interference;*
- *4 that the use of zones around stations used for radio astronomy observations where active services are excluded or restricted should be considered as a means of minimizing interference due to unwanted emissions from terrestrial transmitters;*

The compatibility with RAS and aerial UEs is studied in the following for the single-interferer and aggregated scenarios. For the former, both, the generic (i.e., flat-Earth) and site-specific (i.e., accounting for terrain heights) case is considered. Due to the lack of real deployment information around existing RAS sites, the aggregated scenario could only be studied for the generic case.

A6.2 TECHNICAL PARAMETERS

A6.2.1 IMT Parameters

In the spurious domain of the IMT bands under consideration, a maximum pfd (e.i.r.p) of -36 dBm/MHz (30 MHz < f < 1 GHz) / -30 dBm/MHz (f > 1 GHz) for Category B land mobile devices (BS and UE) is specified in Recommendation ITU-R SM.329. However, as explained in the introduction, there are good reasons to assume much lower spurious emission levels in many cases. As this depends strongly on the specific situation, e.g., which RAS band is considered, the power levels assumed in this study are given in the following sub-section (RAS station parameters). Since standard cell-phone equipment is employed, the antennas are omni-directional with a gain of 0 dBi. Different flight heights are assumed, as they have significant impact on the results (defining the LoS area and the number of effective diffraction edges).

A6.2.2 RAS station Parameters

Threshold levels for interference detrimental to RAS observations are listed in Table 33 to Table 38; they are based on Recommendation ITU-R RA.769 [37]. For the generic analyses a RAS station having an isotropic antenna (0 dBi; see Recommendation ITU-R RA.1513-2 [61]) with a height of 50 m above the ground is assumed. Several different RAS bands are potentially affected:

1 Second harmonics of the LTE700 UE in the frequency range 703-714 MHz could fall into the RAS band at 1400-1427 MHz This RAS band is a primary passive band (RR Footnote 5.340 [19]). Both continuum and spectral line observations are frequently carried out. According to ECC Report 249 (Figs. 9 and 10) [26], one of the measured LTE800 UE devices produced second harmonics in the 1600 MHz band, with broad-band emissions of about -35 dBm/MHz. It can therefore be concluded that LTE700 UE could also produce similar features and thus for the compatibility with RAS the regulatory limit given in Recommendation ITU-R SM.329 [33] of -30 dBm/MHz seems appropriate for this study. For information, also the levels -40, -50, and -60 dBm/MHz were employed in the calculations.

2 Second harmonics of LTE800 UE in the frequency range 832-835 MHz and 859-861 MHz potentially affect the RAS bands at 1660-1670 MHz and 1718.8-1722.2 MHz. The former RAS band is a primary band (RR Footnote 5.149), the latter has a secondary allocation (RR Footnote 5.149). Both bands are used for spectral line observations of the hydroxyl molecule, which plays an important role in the interstellar medium. The 1660-1670 MHz band is furthermore used for continuum observations. According to ECC Report 249 (Figs. 9 and 10), one of the measured LTE800 UE devices produced second harmonics in the 1600 MHz band, with broad-band emissions of about -35 dBm/MHz. It can therefore be concluded that other LTE800 UE could produce similar features and thus for the compatibility with RAS the regulatory limit given in Recommendation ITU-R SM.329 limit of -30 dBm/MHz seems appropriate for this study. For information, also the levels -40, -50, and -60 dBm/MHz were employed in the calculations. Note that since both RAS bands are very close to each other in frequency, only the 1660-1670 MHz band was used for calculations. The results apply to both.

3 The RAS band 1718.8-1722.2 MHz (secondary allocation RR Footnote 5.149 and 5.385) is mainly used for spectral line observations of the Hydroxyl molecule. This frequency range is in-band with respect to LTE1800 uplink (1710-1785 MHz). Therefore, the average spectral power to be used for compatibility studies is 20 dBm/MHz.

4 Spurious emissions of LTE2600 UE in the TDD frequency range 2570-2620 MHz potentially affects the RAS bands at 2655-2690 MHz and 2690-2700 MHz. The latter RAS band is a primary passive band (RR Footnote 5.340), the former has a secondary allocation (RR Footnote 5.149). Both bands are used for continuum observations. According to ECC Report 249, figure 41, one of the measured LTE2600 BS produced spurious emissions that could be detected out to a frequency offset of up to 100 MHz, though with very low spectral power levels of about -50 to -80 dBm/MHz in the 2655-2690 MHz RAS band and -90 to -95 dBm/MHz in the 2690-2700 MHz RAS band. Unfortunately, no UE device was under test and given other results in the ECC Report 249 it seems possible, that UE could have higher spurious emission levels owing to the lack of physical filters. Therefore, the compatibility studies are performed for various power levels between -60 and -90 dBm/MHz, but it must be noted that without existing measurements of UE, strictly the Recommendation ITU-R SM.329 limits of -30 dBm/MHz would apply.

5 In order to protect RAS and the military service (Radar) below 3.4 GHz, ECC Report 281 [38] implements lower than usual spurious limits of -59 or -50 dBm/MHz, respectively. The RAS band 3345.8-3352.5 MHz has no allocation in the RR but is considered in RR Footnote 5.149, which urges administrations to protect RAS stations operating in this band. It is mainly used for measurements of the CH molecule in the interstellar medium. Thus, the spectroscopy thresholds of Recommendation ITU-R RA.769 apply.

Note that for the compatibility calculations in this study, if both continuum and spectral-line observations are performed in a given band, the stricter RAS threshold was used.

Table 33: RAS thresholds (1400–1427 MHz, continuum mode)

RAS allocation status RR Footnotes RAS use	RAS protection criteria according to Recommendation ITU-R RA.769-2		
Primary allocation RR No. 5.340 Broadband		Power entering receiver	Spectral PFD
	Continuum measurements)	−205 dB(W/27 MHz)	−255 dB(W/m2 Hz)
	Antenna noise temp. (K)	12	
	Receiver noise temp. (K)	10	
	Frequency (MHz)	1400–1427 MHz	

Table 34: RAS thresholds (1660–1670 MHz, continuum mode)

RAS allocation status RR Footnotes RAS use	RAS protection criteria according to Recommendation ITU-R RA.769-2		
Primary allocation RR No. 5.149 Broadband		Power entering receiver	Spectral PFD
	Continuum measurements)	−207 dB(W/10 MHz)	−251 dB(W/m2 Hz)
	Antenna noise temp. (K)	12	
	Receiver noise temp. (K)	10	
	Frequency (MHz)	1718.8–1722.2 MHz	

Table 35: RAS thresholds (1718.8–1722.2 MHz, spectral-line mode); extrapolated

RAS allocation status RR Footnotes RAS use	RAS protection criteria according to Recommendation ITU-R RA.769-2		
Secondary allocation RR No. 5.149 Spectral-line		Power entering receiver	Spectral PFD
	Continuum measurements)	−220 dB(W/20 kHz)	−237 dB(W/m2 Hz)
	Antenna noise temp. (K)	12	
	Receiver noise temp. (K)	10	
	Frequency (MHz)	1718.8–1722.2 MHz	

Table 36: RAS thresholds (2655–2690 MHz, continuum mode); extrapolated

RAS allocation status RR Footnotes RAS use	RAS protection criteria according to Recommendation ITU-R RA.769-2		
Secondary allocation RR No. 5.149 Broadband		Power entering receiver	Spectral PFD
	Continuum measurements)	−207 dB(W/10 MHz)	−247 dB(W/m2 Hz)
	Antenna noise temp. (K)	12	
	Receiver noise temp. (K)	10	
	Frequency (MHz)	2655–2690 MHz	

Table 37: RAS thresholds (2690–2700 MHz, continuum mode)

RAS allocation status RR Footnotes RAS use	RAS protection criteria according to Recommendation ITU-R RA.769-2		
Primary allocation RR No. 5.340 Broadband		Power entering receiver	Spectral PFD
	Continuum measurements)	−207 dB(W/10 MHz)	−247 dB(W/m2 Hz)
	Antenna noise temp. (K)	12	
	Receiver noise temp. (K)	10	
	Frequency (MHz)	2690–2700 MHz	

Table 38: RAS thresholds (3345.8–3352.5 MHz, spectral-line mode); extrapolated

RAS allocation status RR Footnotes RAS use	RAS protection criteria according to Recommendation ITU-R RA.769-2		
No allocation RR No. 5.149 Spectral-line		Power entering receiver	Spectral PFD
	Continuum measurements)	−220 dB(W/20 kHz)	−237 dB(W/m2 Hz)
	Antenna noise temp. (K)	12	
	Receiver noise temp. (K)	10	
	Frequency (MHz)	3345.8–3352.5 MHz	

A6.2.3 Additional parameters / Path propagation loss

Path propagation was calculated according to the model in Recommendation ITU-R P.452-16 [59], using a "time percent" parameter of 2% (for single-interferer scenarios) and 50% (for aggregated scenarios), respectively, a temperature of 20°C and 1013 hPa. At the typical flight heights, clutter loss is non-existent. For comparison, also UEs on the ground (1.5 m height) were simulated, to indicate a baseline.

A6.3 SINGLE INTERFERER STUDY

A6.3.1 Generic Case

For the generic analysis, terrain heights have been set to zero (amsl). Five RAS bands have been considered: 1420–1427 MHz, 1660–1670 MHz, 1718.8–1722.2 MHz, 2655–2690/2690–2700, and 3345.8–3352.5 MHz (see previous sub-section). In Figure 36 to Figure 40 the resulting margin (i.e., the difference between RAS threshold levels and received emission) is displayed. A negative margin means that the thresholds are exceeded, which leads to data loss at the observatory. It can be seen that even for low flight heights of 300 m, the necessary separation distances exceed 200 km (at 1.4 and 1.6 / 1.7 GHz) owing to the potentially high spurious emission level of -30 dBm/MHz of the second harmonics of the LTE700/LTE800 UE. The situation is less problematic for the 2.7 and 3.4 GHz bands, where the spurious power is likely of the order of -60 dBm/MHz or less, leading to separation distances of at most 25 km. The larger the flight height, the larger is the distance to the local horizon where diffraction kicks in. Usually, a single diffraction edge already provides a large additional attenuation, which helps to achieve compatibility. Note that an aerial UE device close to the boresight of the RAS telescope will be subject to higher antenna gain, which would further decrease the margin and thus increase the necessary separation distance.

For comparison Figure 36 to Figure 40 also visualise the margins vs. distance for UE located on ground (1.5 m height). This marks the "baseline" of standard MFCN use and helps to understand the relative impact of lifting UE devices into the air. For the 1.5 m calculations no clutter loss was assumed, so in reality the propagation loss could even be up to 20-30 dB higher (and thus the margin). Or even more, for indoor UEs, which are subject to building entry loss.

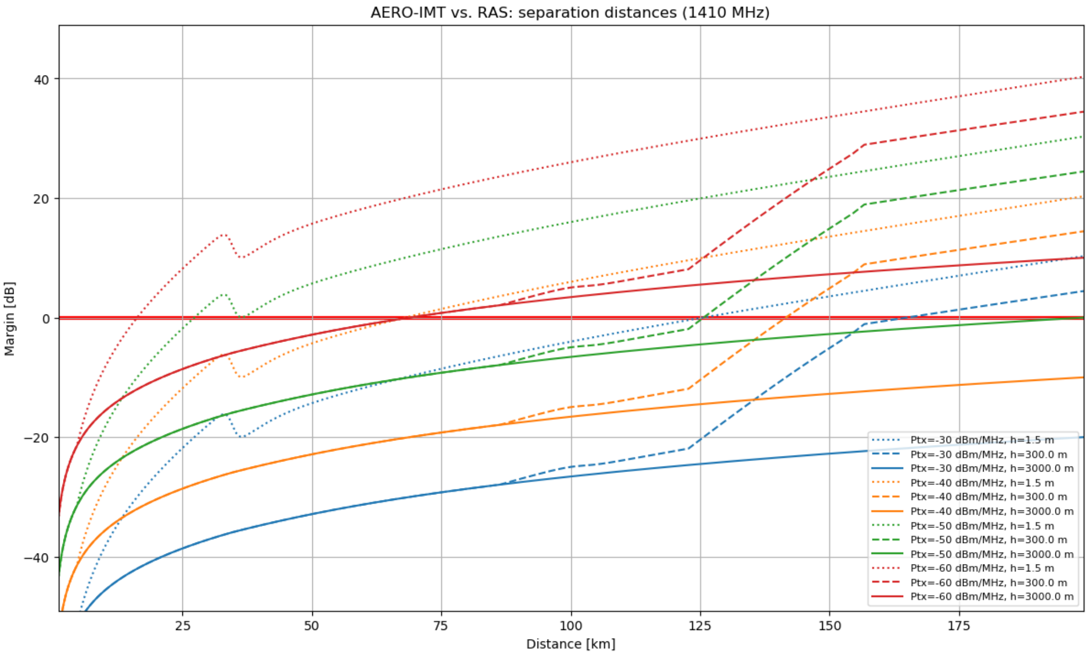


Figure 36: Margin vs. distance for the single-interferer generic case (1420–1427 MHz, continuum mode)

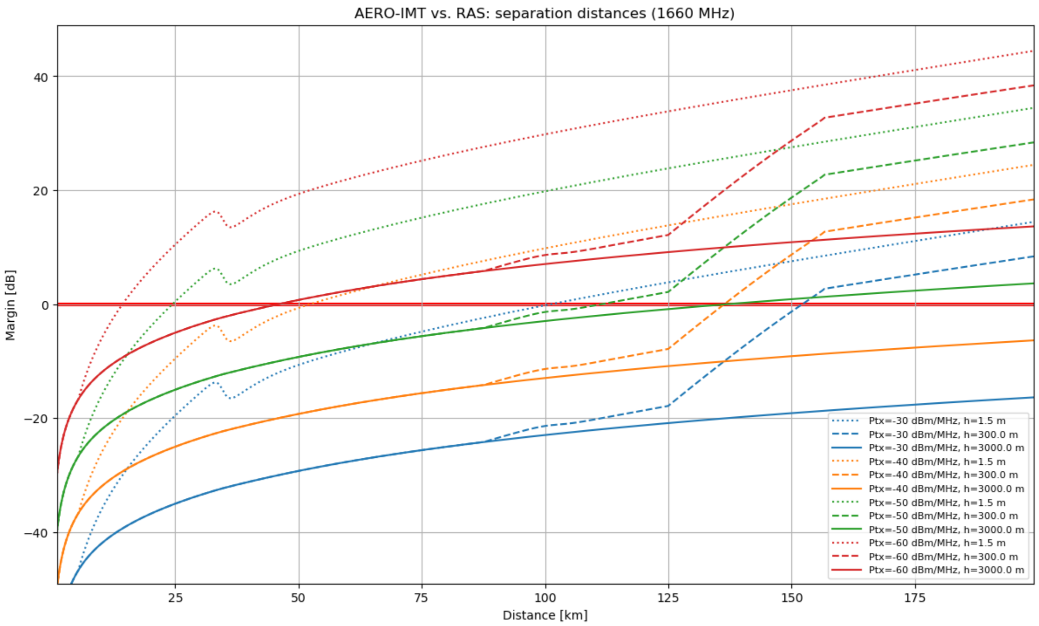


Figure 37: Margin vs. distance for the single-interferer generic case (1660–1670 MHz, continuum mode)

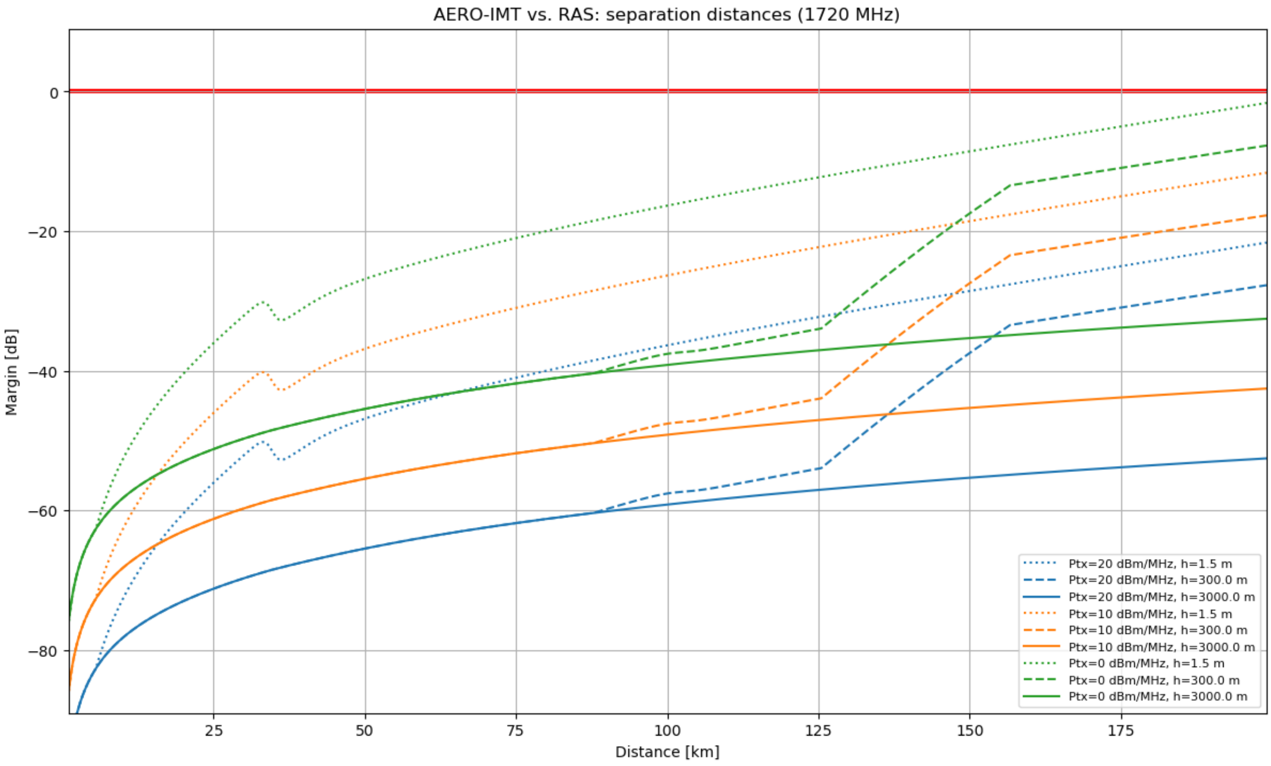


Figure 38: Margin vs. distance for the single-interferer generic case (1718.8–1722.2 MHz, spectral-line mode; in-band)

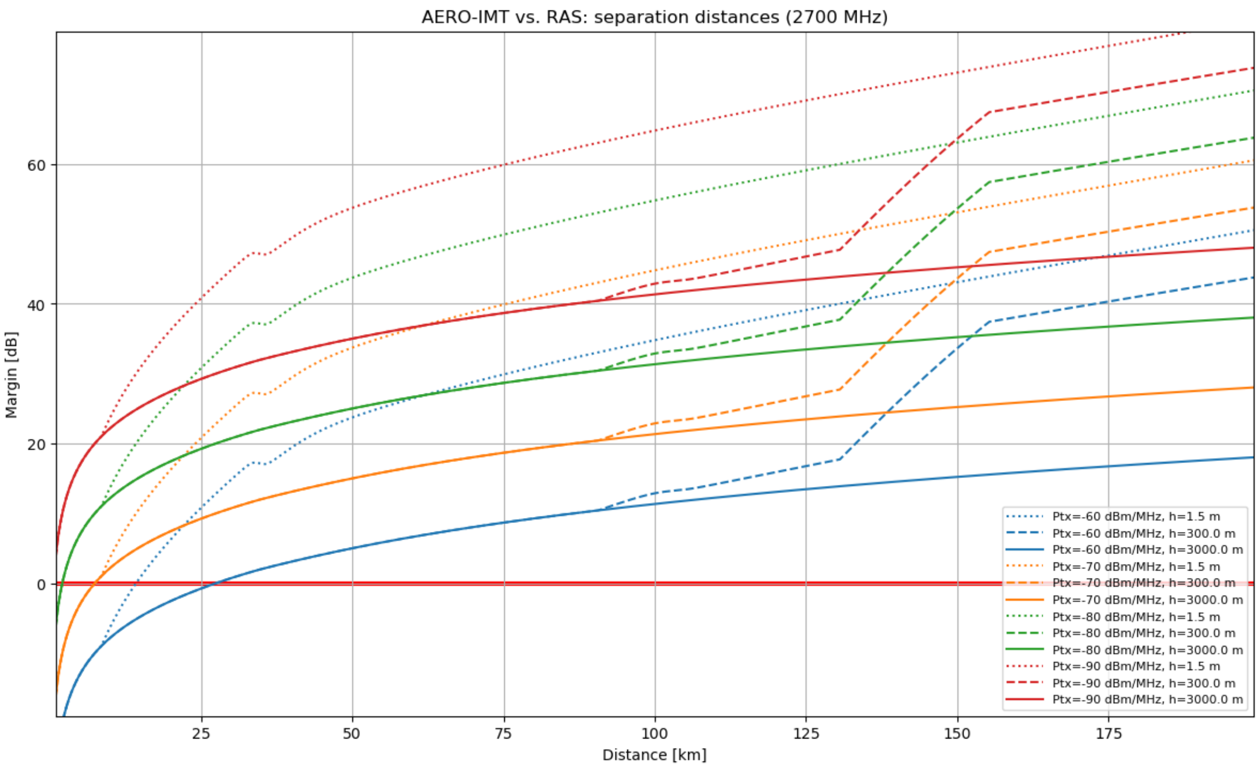


Figure 39: Margin vs. distance for the single-interferer generic case (2655–2690 / 2690–2700 MHz, continuum mode)

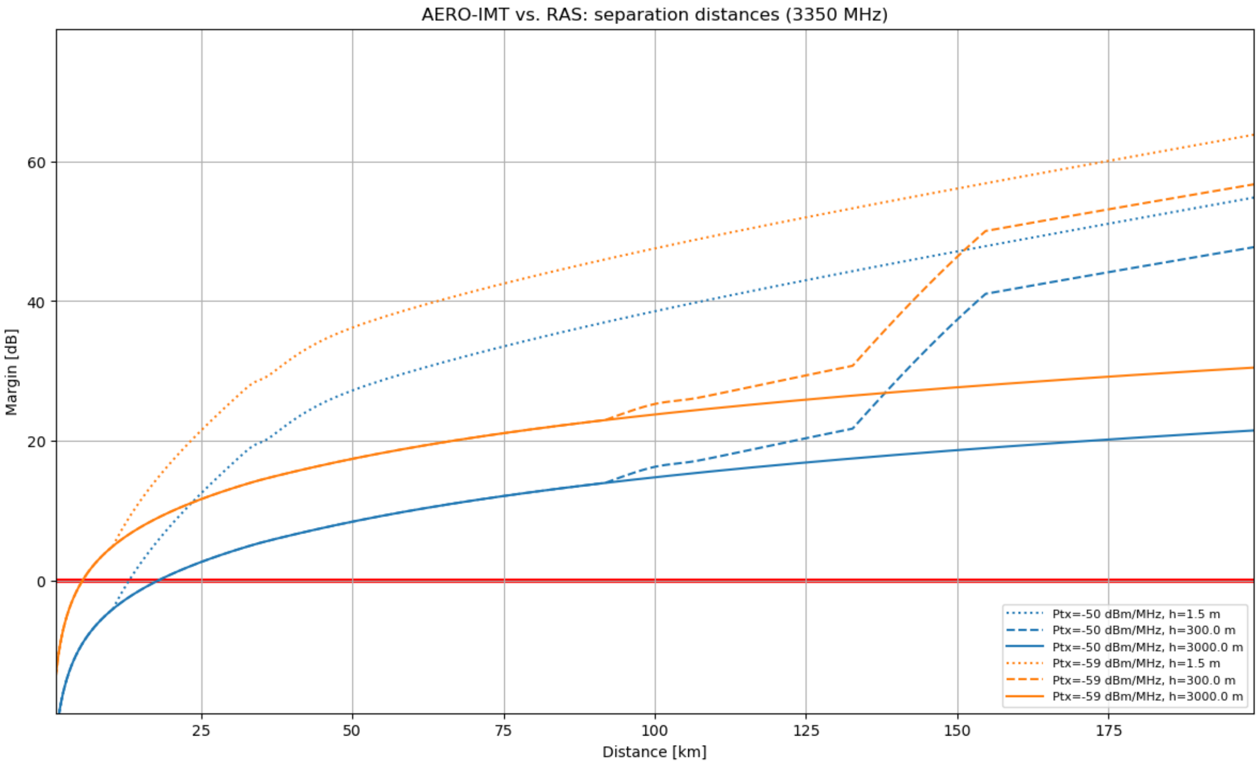


Figure 40: Margin vs. distance for the single-interferer generic case (3345.8-3352.5 MHz, spectral-line mode)

A6.3.2 Site-specific Cases

For five European observatories, case studies have been carried out, which take the local environment into account, most importantly the topographical situation. For example, the Effelsberg observatory, which is situated in a valley, is affected to a much lower degree than the WSRT in the Netherlands for which the situation is much closer to the generic study results. The calculations were performed for all of the five potentially affected RAS bands and six different UE heights (1.5, 100, 300, 1000, 3000, and 10000 m), leading to 150 distinct maps with coordination zone areas. Here we show one example, the result of the 300-m height 1420-1427 MHz zone around Effelsberg. All other results are contained in the attached zip-file. In Figure 41 contours for the margin=0 dB isocurve are visualised, for four different spurious emission power levels (–30/–40/–50/–60 dBm/MHz). The white circles mark distances from the RAS station in steps of 50 km. For reference, also the line-of-sight area is drawn (black contour). Even for Effelsberg, where the local terrain is very favourable, the resulting separation distances are up to 100 km (and further for larger flight heights) in some directions. Again, for the two bands at 2.7 and 3.4 GHz the necessary separation distances are smaller owing to the much lower emission levels far off the IMT frequencies.

It can also be useful to compare the results to the current situation, where IMT UE is based on the ground, at heights of typically about 1 to 2 m (outdoor). Under many circumstances, there will be additional clutter loss, because the user terminals are located in towns and cities. But even in rural environments for a fair fraction of the area, clutter loss can be introduced from forests etc. Therefore, the calculations for UE heights of 1.5 m (see above) were done with three different values of clutter loss, 0, 10 and 20 dB. In Figure 42 the example of 20 dB is shown (other parameters as in Figure 41). It can be seen that the necessary coordination zone is significantly smaller than for IMT on board aerial vehicles.

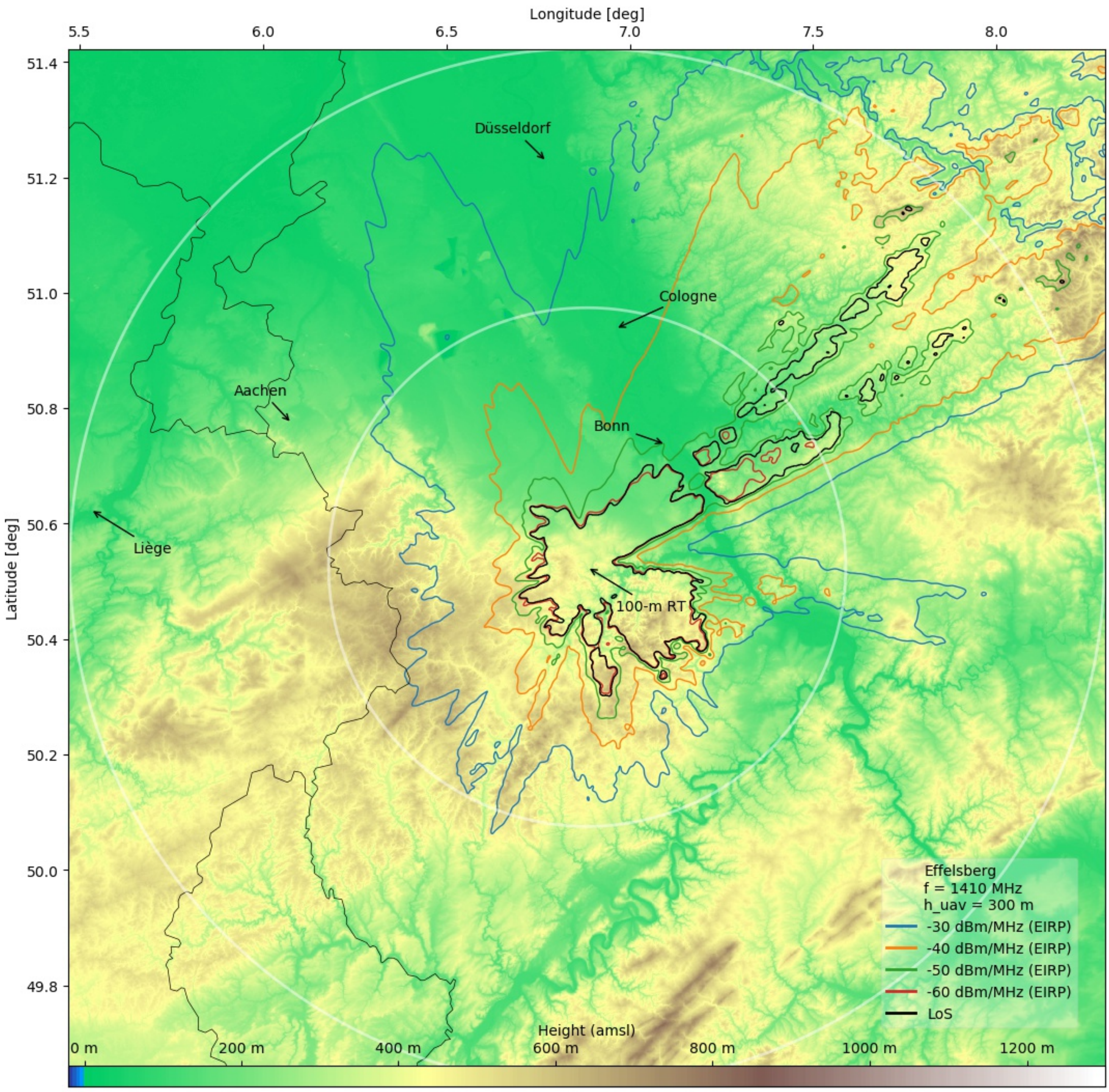


Figure 41: Coordination zones for the single-interferer generic case (1420–1427 MHz, continuum mode, UE at 300-m height) for various levels of spurious emission (–30/–40/–50/–60 dBm/MHz). The black contour marks the line-of-sight area for an aerial vehicle at 300-m. Other cases can be found in the attached zip-file.

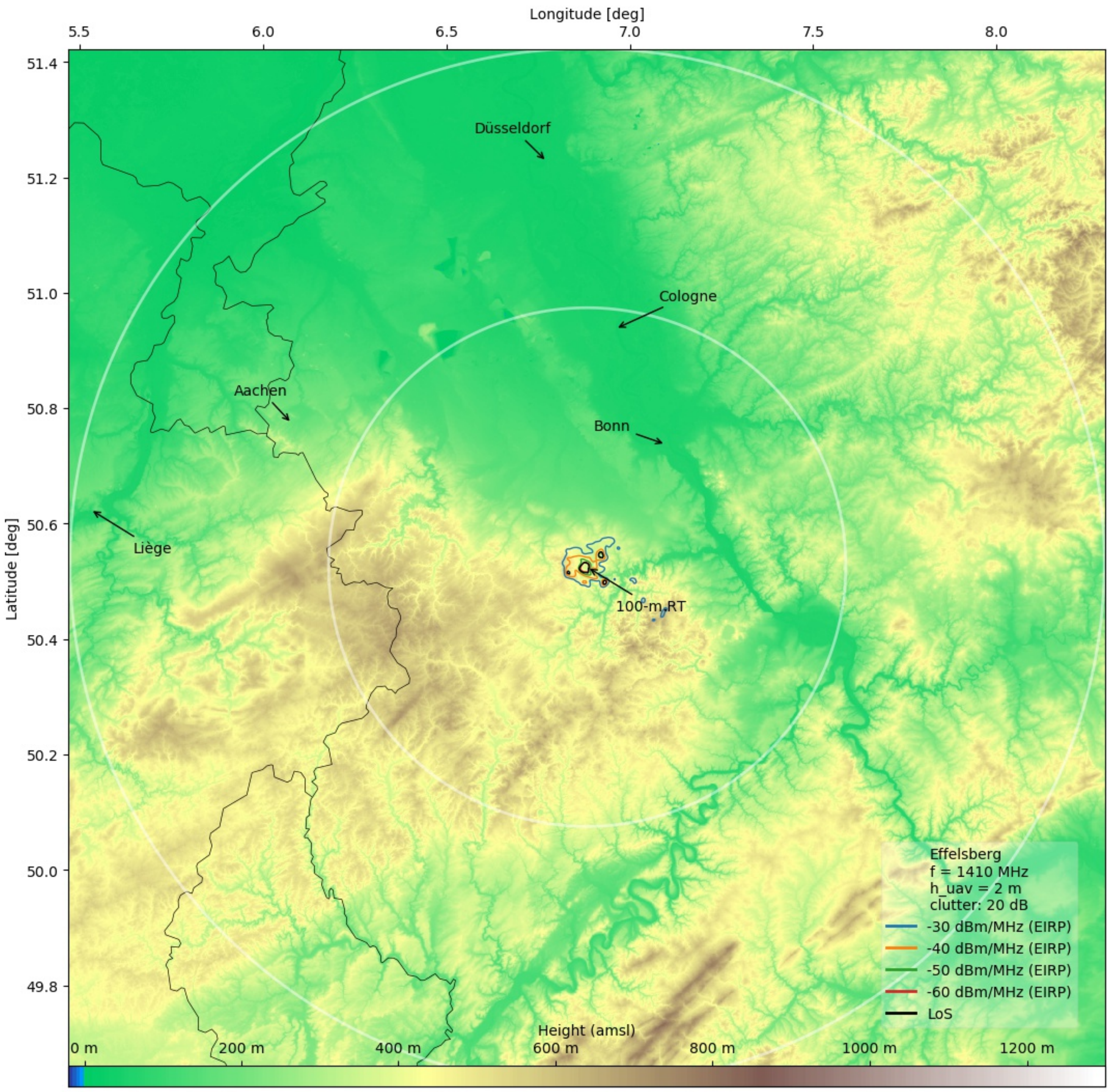


Figure 42: Coordination zones for the single-interferer generic case (1420–1427 MHz, continuum mode, UE at 1.5-m height, assuming 20 dB clutter loss) for various levels of spurious emission (–30/–40/–50/–60 dBm/MHz). The black contour marks the line-of-sight area for an aerial vehicle at 1.5-m. Other cases can be found in the attached zip-file.

A6.3.3 Fly-by Cases

In the previous sub-sections, the calculations were based on a static situation, where aerial vehicles were assumed to stay at a certain position (or distance). For slower aircraft such as octocopters, this assumption is well justified. However, traffic planes usually cross the airspace above a RAS station relatively quickly and − assuming a straight flight vector − with varying distance and thus with varying path propagation loss. To assess how much these fly-by cases differ from the previous calculations, one can integrate over the motion path of the plane.

Again, far side-lobe reception with 0-dBi antenna gain according to ITU-R RA. 769-2 [37] is assumed, as direct passages through the main beam or near side lobes are considered as very unlikely, given the small angular extent of the RAS antenna beam. The received interference power from a passing aircraft will vary strongly with time, peaking around the time of highest elevation as seen from the RAS station. Radio astronomical measurements average the received signal power over (integration) time and frequency intervals. Emission limits for aircraft should therefore be related to the average received power level from a passing aircraft.

The RAS station and the aircraft are designated with subscripts *rx* and *tx* respectively. The aircraft is assumed to operate at a constant height h_{tx} above ground (flat terrain) and the nominal height of the RAS receiver is $h_{rx} = 50\,m$. We chose a Cartesian coordinate system with its origin at the geo-centre and the coordinates of the RAS station being $\vec{r}_{rx} = r_{rx}(1 \quad 0 \quad 0)^T$ with $r_{rx} = r_{earth} + h_{rx}$ being the distance of the RAS receiver from the centre of the earth (6370 km). The trajectory of the aircraft is then given by

$$\vec{r}_{tx}(t,\varphi) = r_{tx}\begin{pmatrix} \cos\varphi & 0 & \sin\varphi \\ 0 & 1 & 0 \\ -\sin\varphi & 0 & \cos\varphi \end{pmatrix}\begin{pmatrix} \cos(\omega_{tx}t) \\ \sin(\omega_{tx}t) \\ 0 \end{pmatrix}, \quad (8)$$

Where:

- φ is the offset angle between the highest elevation of the aircraft and the zenith of the RAS station;
- $r_{tx} = r_{earth} + h_{tx}$ is the geocentric radius of the aircraft trajectory;
- $\omega_{tx} = 2\pi\, v_{tx}/r_{tx}$ its angular velocity, given its great circle velocity v_{tx}.

The LOS radii for the RAS station and the aircraft are respectively given as:

$$d_{lr} = r_{earth}\cos^{-1}\left(\frac{r_{earth}}{r_{earth} + h_{rx}}\right) \text{ and } d_{lt} = r_{earth}\cos^{-1}\left(\frac{r_{earth}}{r_{earth} + h_{tx}}\right). \quad (9)$$

The LOS horizon for a given height h_{tx} is then the sum $d_{hor} = d_{lr} + d_{lt}$. The distance between receiver and transmitter is then given as the norm or the position vector difference $\mathrm{d}(t,\varphi) = |\vec{r}_{tx}(t,\varphi) - \vec{r}_{rx}|$.

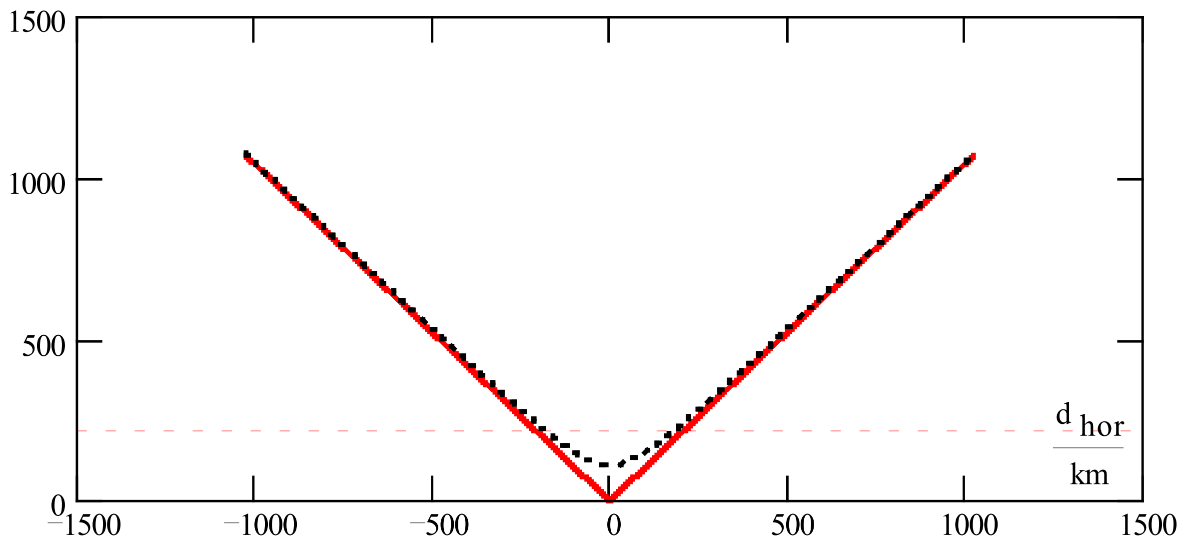


Figure 43: Distance of an aircraft (in km) from the RAS station as a function of time (in seconds, centred at the time of closest approach) for $h_{tx} = 3000\,m$ and $v_{tx} = 600\,km/h$. The red line gives the distance for a passage through the zenith of the RAS station and the black dotted line for a passage that comes as close as 110 km (half the horizon distance). Note the short time of the aircraft being within the LOS horizon

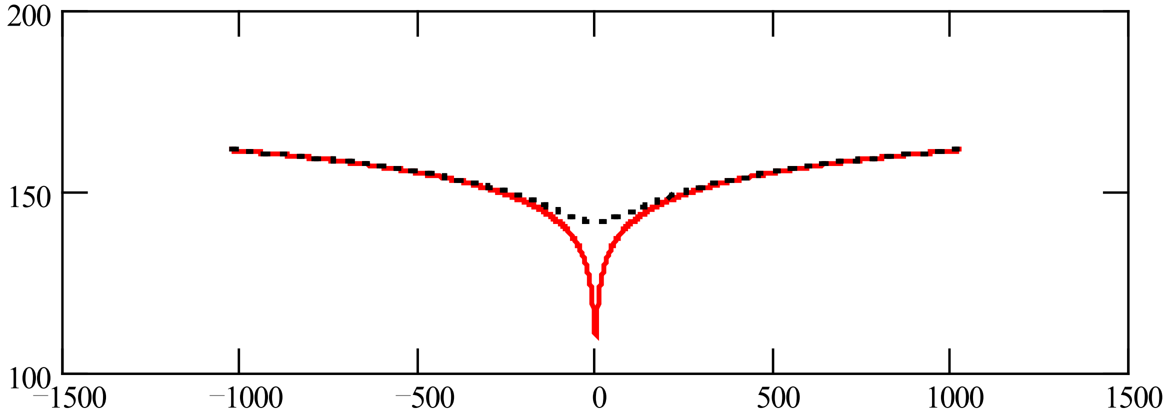


Figure 44: LOS attenuation (in dB) of emissions at 2.7 GHz as a function of time for passing close to a RAS station. The red line gives the attenuation for a passage through the zenith of the RAS station and the black dotted line for a passage that comes as close as 110 km (half the horizon distance)

Figure 43 provides an example of the distance d as a function of time for an interval of 2000 seconds centred on the time of closest approach. Using the elementary attenuation law $L_f(d) = \left(\frac{4\pi d}{\lambda}\right)^2$ (see Recommendation ITU-R P.525 [50]) for LOS propagation we note in Figure 44 that the attenuation exhibits a more or less strong dip at the time of the zenith passage possibly resulting in a short, but intense burst of interference if the aircraft passes directly over the RAS site. The average power received from a unit strength emitter is then given by:

$$P_{avg}(t_{int}, \varphi) = \left(\frac{\lambda}{4\pi}\right)^2 \frac{1}{t_{int}} \int_{-t_{vis}}^{t_{vis}} dt' \; d(t', \varphi)^{-2}, \tag{10}$$

With t_{vis} being the time it takes for the aircraft to reach the LOS horizon after its closest approach to the telescope, and t_{int} the total integration time of the RAS receiver. This isn't strictly necessary as the possible contributions from outside the LOS range are less than a dB or two in the extreme cases of distant passes, even when one doesn't correct for the additional trans-horizon attenuation. Setting $L_{avg} = {P_{avg}}^{-1}$ obtains typical numbers of $L_{avg} = 128\, dB$ for an overhead pass at a height of 3000 m, a velocity of 600 km/s and for a frequency of 2.7 GHz with an integration time of 2000 s. L_{avg}increases to 154 dB when the distance of closest approach is half of the horizon distance of 220 km. Table 39 and Table 40 provide lists of effective attenuations for aircraft on frequency bands allocated to RAS. These purely geometrical results may be scaled with frequency using the table entries for ΔP and Δf of Recommendation ITU-R RA.769-2 to derive the single interferer emission limits:

$$S_{lim}(t_{int}, \varphi)[dBm/MHz] = \Delta P - 5\log(t_{int}/2000\, s) - 10\log\left(P_{avg}(t_{int}, \varphi)\right) - 10\log(\Delta f) + 30 \tag{11}$$

for varying integration times t_{int} and offset angle φ.Other parameters are kept constant here.

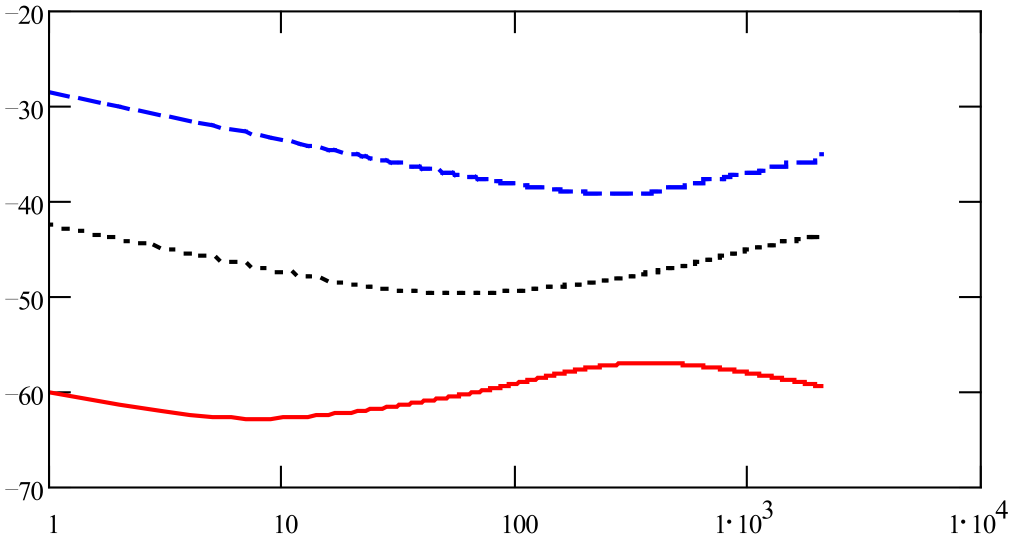


Figure 45: Emission limits in dBm/MHz for 2.7 GHz as function of integration time (in seconds), parameterised by distance of closest approach of an aircraft at a height of $h_{tx} = 3000\ m$ and $v_{tx} = e\ km/h$. Red: Overhead passage; Black dots: passage at 2.2 km distance; Blue dashes: passage at 110 km distance

Figure 45 shows such limits for 2.7 GHz as a function of integration time (in seconds), parameterised by distance of closest approach of an aircraft at a height of $h_{tx} = \mathbf{3000}\ m$ and $\boldsymbol{v_{tx}} = \mathbf{600}\ \boldsymbol{km/h}$. There is a distinct minimum of the limits for compatible emission for t_{int}, closely related to the time in which the aircraft is visible from the telescope site, usually of the order of 3−5 dB below the emission limit for $t_{int} = 2000\ s$. Typical emission limits for a direct overhead passage (with the geometric and frequency parameter given above) are $S_{lim}(t_{int} = 2000\ s) = -59\ dBm/MHz$ with a minimum $S_{lim} = -62\ dBm/MHz$. Note that these limits are always more stringent than the -30 dBm/MHz given for spurious emissions from most equipment.

The results of the calculations are given in Table 41 to Table 44. The first three columns have been taken from Recommendation ITU-R RA.769-2 [37] and the emission limits in subsequent columns refer to the bandwidths given in column 2. We deal with low flying and slow aircraft and commercial aircraft separately using typical heights and velocities. Two entries are given for each scenario: a passage through the zenith of the telescope and another one at the boundary of the LOS horizon. Note that the average attenuations for the zenith passage are independent of heights as the angular velocity decreases with increasing height while at the same time the geocentric horizon angle increases, both effects compensate the r^{-2}decrease of received powers. The emission limits at the LOS boundary are indicative of the minimum requirement for an exclusion zone based on the LOS horizon: If emissions are above those limits, then the LOS horizon is a natural boundary for an exclusion zone to protect RAS sites from unwanted emissions of individual aircraft. We give separate tables for the RAS continuum and spectral-line observing modes.

Individual low flying (h = 300 m) and slow aircraft (v < 200 km/h) are potential detrimental interferers up to 100 GHz even at the perimeter of the LOS boundary when their broad band emissions are of the order of -30 dBm/MHz, whereas for faster aircraft the same emission will be able to create interference up to 5 GHz. The latter is also true for narrow band emissions from slow aircraft. Aircraft that enter the LOS boundary require operation within very stringent emission limits, ranging from -80 dBm/MHz to -60 dBm/MHz, depending on frequency.

Individual commercial aircraft operate in heights where LOS based exclusion zones are becoming quite extensive, with radii of up to 400 km, effectively the size of many European countries. Compatible emission limits range from -70 dBm/MHz for low frequencies up to -30 dBm/MHz for mm wavelengths, independent of height. Narrowband emissions can also be critical here.

Note: the table contain numbers for a single aircraft. As the numbers were calculated for 0 dBi RAS gain, the aggregated emission will be the sum of all aircraft with less than horizon distance (each contributing a different amount power, of course).

Table 39: Effective attenuations for low flying aircraft

Frequency (MHz)	Effective Attenuation L_{avg} for an aircraft at $h = 300\ m$ (dB)					
	$v = 0\ km/h$		$v = 10\ km/h$		$v = 200\ km/h$	
	Zenith	$d_{min} = 87\ km$	Zenith	$d_{min} = 87\ km$	Zenith	$d_{min} = 87\ km$
408	84	123	95	123	108	134
611	88	127	99	127	112	138
1414	95	134	106	134	119	145
1665	96	135	107	135	120	147
2695	101	139	111	140	125	151
4995	106	145	117	145	130	156
10650	113	151	123	151	136	163
15380	116	155	127	155	140	166
22360	119	158	130	158	143	169
23800	120	158	130	158	143	170
31550	122	161	133	161	146	172
43000	125	164	136	164	149	175
89000	131	170	142	170	155	181
150000	136	174	146	174	159	186
224000	139	178	150	178	163	189

Table 40: Effective attenuations for commercial aircraft

Frequency (MHz)	Effective Attenuation L_{avg} for an aircraft at $h = 3\ km$ and $h = 10\ km$ (dB)			
	$h = 3\ km$		$h = 10\ km$	
	Zenith	$d_{min} = 210\ km$	Zenith	$d_{min} = 363\ km$
408	111	143	111	145
611	114	147	115	149
1414	122	154	122	156
1665	123	155	123	158
2695	127	159	128	162
4995	132	165	133	167
10650	139	171	140	174
15380	142	175	143	177
22360	146	178	146	180
23800	146	178	147	181
31550	149	181	149	183
43000	151	184	152	186
89000	158	190	158	192
150000	162	194	163	197
224000	166	198	166	200

Table 41: Limits of unwanted broad band emissions for low flying ($h = 300\ m$) aircraft

Frequency (MHz)	ΔP (dBW)	Δf (MHz)	Emission limit (dBm/MHz)					
			$v = 0\ km/h$		$v = 10\ km/h$		$v = 200\ km/h$	
			Zenith	$d_{min} = 87\ km$	Zenith	$d_{min} = 87\ km$	Zenith	$d_{min} = 87\ km$
408	-203	4	-95	-56	-84	-56	-71	-45
611	-202	6	-92	-53	-81	-53	-68	-42
1414	-205	27	-94	-56	-83	-55	-70	-44
1665	-207	10	-91	-52	-80	-52	-67	-41
2695	-207	10	-86	-48	-76	-48	-63	-36
4995	-207	10	-81	-42	-70	-42	-57	-31
10650	-202	100	-79	-41	-69	-41	-56	-29
15380	-202	50	-73	-34	-62	-34	-49	-23
22360	-195	290	-71	-32	-60	-32	-47	-21
23800	-195	400	-71	-33	-61	-33	-48	-21
31550	-192	500	-67	-28	-56	-28	-43	-17
43000	-191	1000	-66	-28	-56	-27	-42	-16
89000	-189	8000	-67	-28	-56	-28	-43	-17
150000	-189	8000	-63	-24	-52	-24	-39	-12
224000	-188	8000	-58	-19	-47	-19	-34	-8

Table 42: Limits of unwanted narrow band emissions for low flying ($h = 300\ m$) aircraft

Frequency (MHz)	ΔP (dBW)	Δf (kHz)	Emission limit (dBm/MHz)					
			$v = 0\ km/h$		$v = 10\ km/h$		$v = 200\ km/h$	
			Zenith	$d_{min} = 87\ km$	Zenith	$d_{min} = 87\ km$	Zenith	$d_{min} = 87\ km$
1420	-220	20	-78	-39	-67	-39	-54	-28
1612	-220	20	-77	-38	-66	-38	-53	-27
1665	-220	20	-77	-38	-66	-38	-53	-27
4830	-218	50	-69	-31	-58	-30	-45	-19
14490	-214	150	-61	-22	-50	-22	-37	-11
22200	-210	250	-55	-16	-44	-16	-31	-5
23700	-210	250	-54	-16	-44	-16	-31	-4
43000	-207	500	-49	-11	-38	-10	-25	1
48000	-207	500	-48	-10	-38	-10	-24	2
88600	-209	1000	-48	-9	-37	-9	-24	2
150000	-209	1000	-43	-5	-33	-5	-20	7
220000	-207	1000	-38	1	-27	1	-14	12
265000	-207	1000	-37	2	-26	2	-13	14

Table 43: Limits of unwanted broad band emissions from commercial aircraft

Frequency (MHz)	ΔP (dBW)	Δf (MHz)	Emission limit (dBm/MHz)			
			$h = 3\ km$		$h = 10\ km$	
			Zenith	$d_{min} = 210\ km$	Zenith	$d_{min} = 363\ km$
408	-203	4	-68	-36	-68	-44
611	-202	6	-66	-33	-65	-41
1414	-205	27	-68	-35	-67	-43
1665	-207	10	-64	-32	-64	-40
2695	-207	10	-60	-28	-59	-35
4995	-207	10	-55	-22	-54	-30
10650	-202	100	-53	-21	-53	-29
15380	-202	50	-47	-14	-46	-22
22360	-195	290	-44	-12	-44	-20
23800	-195	400	-45	-13	-45	-21
31550	-192	500	-41	-8	-40	-16
43000	-191	1000	-40	-7	-39	-15
89000	-189	8000	-41	-8	-40	-16
150000	-189	8000	-36	-4	-36	-12
224000	-188	8000	-32	1	-31	-7

Table 44: Limits of unwanted narrow band emissions from commercial aircraft

Frequency (MHz)	ΔP (dBW)	Δf (kHz)	Emission limit (dBm/MHz)			
			$h = 3\ km$		$h = 10\ km$	
			Zenith	$d_{min} = 210\ km$	Zenith	$d_{min} = 363\ km$
1420	-220	20	-51	-19	-51	-27
1612	-220	20	-50	-18	-50	-26
1665	-220	20	-50	-18	-50	-26
4830	-218	50	-43	-10	-42	-18
14490	-214	150	-34	-2	-34	-10
22200	-210	250	-29	4	-28	-4
23700	-210	250	-28	4	-28	-4
43000	-207	500	-23	10	-22	2
48000	-207	500	-22	10	-21	3
88600	-209	1000	-22	11	-21	3
150000	-209	1000	-17	15	-17	7
220000	-207	1000	-12	21	-11	13
265000	-207	1000	-10	22	-10	14

A6.4 AGGREGATED SCENARIO

To assess the situation for a full cell-phone network in the vicinity of a RAS station, an aggregation study is performed. According to Recommendation ITU-R RA.1513 [61] all stations of one service must not lead to more than 2% data loss to the RAS (i.e., exceed the threshold levels given in Recommendation ITU-R RA.769 [37]). Likewise, the aggregate data loss produced by all services must not exceed 5%. Here, we will base our analysis on the 2% value considering only aeronautical UE, but it is important to understand that the UE on the ground, as well as the BS also contribute to the emission of the IMT service and in principle count against the 2% limit, too. Nevertheless, it is fair to assume that the aeronautical UE will effectively contribute much stronger to the aggregated received power at a RAS station (for devices at similar distances), such that the other two contributors can be neglected for the purpose of this study. To not apply the 2% cut twice, for the aggregation scenario we work with a "time percent" parameter of $p = 50\%$ in the Recommendation ITU-R P.452-16 [59] propagation model.

In an aggregation scenario, the deployment of the devices is important, i.e., the spatial and height distribution of the UE. For the spatial distribution, the typical number density can be derived from the intersite distance (ISD) of BS cells of 10 km and the assumption that five UE devices are active per cell. This leads to a UE device density of 0.016 per square kilometre. We anticipate, based on previous IMT studies (e.g., ECC Report 281 [38], ECC Report 308 [66]) that there will be a difference in the distribution according to (sub)urban and rural zones. Therefore, this study assigns UE to rural and urban zones with a ratio of 1:10.

The resulting densities are 0.0145/km^2 (urban) and 0.00145/km^2 (rural). For a uniform spatial distribution of UE this distinction would be irrelevant, but we also want to compare the uniform deployment with a more clustered spatial distribution, which was introduced in ECC Report 281 [38] (see also below). For the flight heights, a uniform distribution is employed (independent on spatial distribution!), but with varying maximal flight heights of 1.5 m, 100 m, 300 m, 1000 m, 3000 m, and 10000 m to allow the comparison of different scenarios (e.g., hobby drones vs. traffic planes). For more realistic results, the actual height distribution of e.g. traffic planes should be used, but such information was not available to us at the time of writing this Report.

For the simulation, a quadratic box with a size 2000 km × 2000 km having grid cells of size 2 km × 2 km is used. As explained in ECC Report 281 a relatively simple Gaussian-convolution with different spatial kernel sizes of a box with random numbers on a regular grid followed by a percentile-based threshold can be used to simulate a map of "urban zones", which resembles a typical distribution of towns and cities in the relatively densely populated region of middle Europe. The result of this procedure is visualised in Figure 46. Based on these two classifications, UE devices are sampled into the simulation box such that the overall desired device density is obtained. After assigning flight heights, the 3D positions of all devices are known; see Figure 47. In the next step the path propagation loss between each UE device and the RAS station (which is situated in the centre of the map) is inferred. The result is displayed in Figure 48. (Note that plots for the scenario of uniform spatial densities are omitted here.)

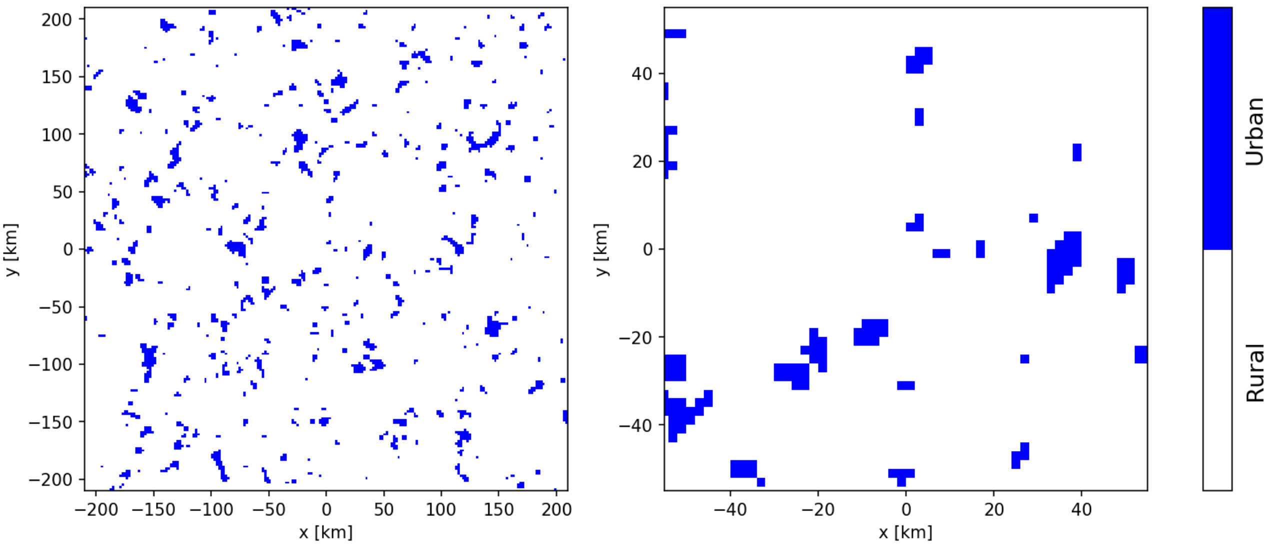


Figure 46: Example outcome of the clustering approach (see ECC Report 281 [38]) to define rural and urban zones in the simulation box

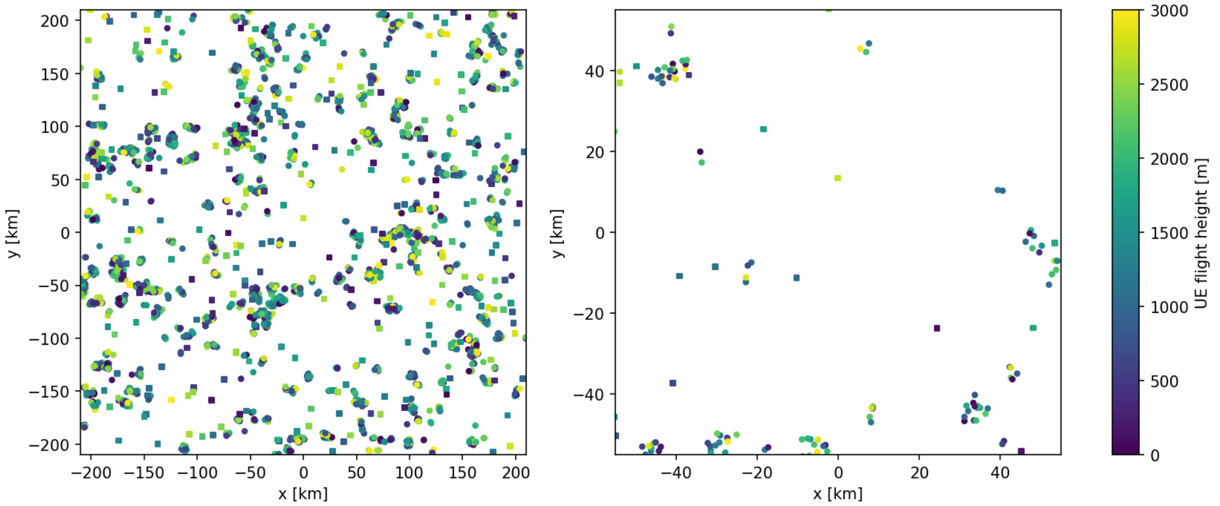


Figure 47: Distribution of aerial UE devices in the simulation box for rural (squares) and urban (circles) zones for a maximum flight height of 3000 m

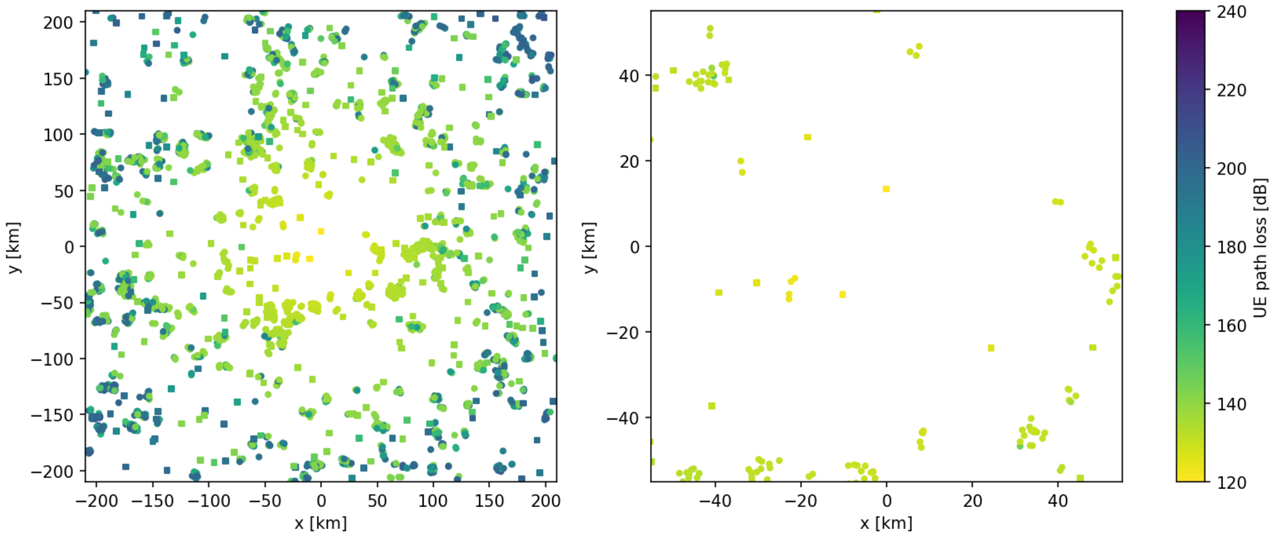


Figure 48: Example distribution of aerial UE devices and the resulting path propagation loss to the RAS station (located at map centre) for a maximum flight height of 3000 m and a frequency of 1.4 GHz

For each scenario (five different frequencies/RAS bands with six different maximum flight altitudes each) the simulation was repeated 100 times to allow the assessment of statistical uncertainties. For each simulation run it is possible to determine the aggregated received spectral power at the RAS station and compare it with the Recommendation ITU-R RA.769 [37] threshold levels. In all cases the aggregated power exceeds the permitted thresholds. To determine the necessary size of a coordination zone around the RAS station, one can repeat the aggregation but leaving out all devices within a certain radius around the RAS site. The result is presented in Figure 49 for increasing radii of the exclusion sphere (projected distance in x-y plane!). The grey curves mark the result of each individual of the 100 simulation runs. The green and cyan curves are the 50% and 98% percentiles of the distribution. The 98% percentile can be used to determine the minimal coordination zone size for the 2% data loss case − it is given by the crossing point of the 98%-curve with the RAS threshold.

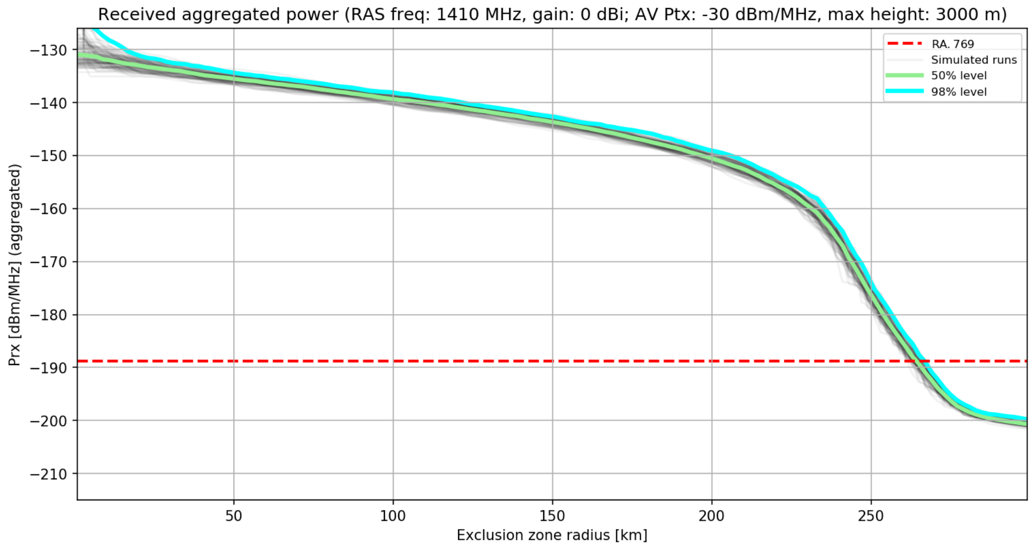


Figure 49: Aggregated spectral power as a function of exclusion zone radius for the RAS frequency 1.4 GHz and 0 dBi receiver gain, a maximum flight height of 3000 m and assuming a transmitted power level of -30 dBm/MHz. The grey curves mark the result of each individual of the 100 simulation runs. The green and cyan curves are the 50% and 98% percentiles of the distribution

However, the above approach is still based on 0 dBi RAS gain, which would mean that the RAS antenna is either isotropic or that one only considers the 19° cone according to Recommendation ITU-R RA.1513-2 [61] (although it must be noted that within this cone also much higher gains are occurring). For the aggregate scenario, the transmitters are distributed all around the RAS station. Thus, it is better to work with a proper antenna pattern model and use methods, which are usually employed for satellite networks, such as the EPFD technique (Recommendation ITU-R M.1583 [67]. The idea is to simulate a large number of random RAS antenna pointings and for each of them calculate the aggregated received power of all transmitters accounting for the effective RAS gain. If the radial-symmetric antenna pattern of Recommendation ITU-R RA.1631 [68] is used, the effective RAS gain only depends on the true angular distance between each UE device and the RAS antenna boresight. Only the 98% percentile is of interest (i.e., the 2% most powerful contributors − which means that at most 2% of the fraction of the sky are affected). To determine the 98% value with the necessary accuracy, it suffices to use about 1000 RAS pointings that are uniformly distributed across the sky.

The result of this is shown in Figure 50. The grey curves mark the result of each individual of 1000 random antenna pointings for *one* simulation run. The cyan curve marks the 98% percentile of the distribution and thus is a proxy for the 2% acceptable data loss (here to be understood as fraction of the sky, which is lost). As the outcome of this is subject to scatter (e.g., it depends on the details of the randomly determined rural and urban zone classification), this is again repeated 100 times. The median of all 98% curves is displayed in Figure 51. To assess the typical scatter, also the 2.5% to 97.5% percentile ranges are plotted, which indicate the 95% confidence interval for each of the median curves.

In total, 60 different cases (two deployment schemes, i.e., uniform and clustered, and six different maximum flight altitudes for each of the five RAS bands) have been computed. Figure 50 and Figure 51 contain one example result (1.4 GHz, 3000 m maximum flight height, clustered distribution).All other cases are attached in a zip file for convenience. The resulting necessary coordination zone sizes are compiled in

Table 45 and Table 46.

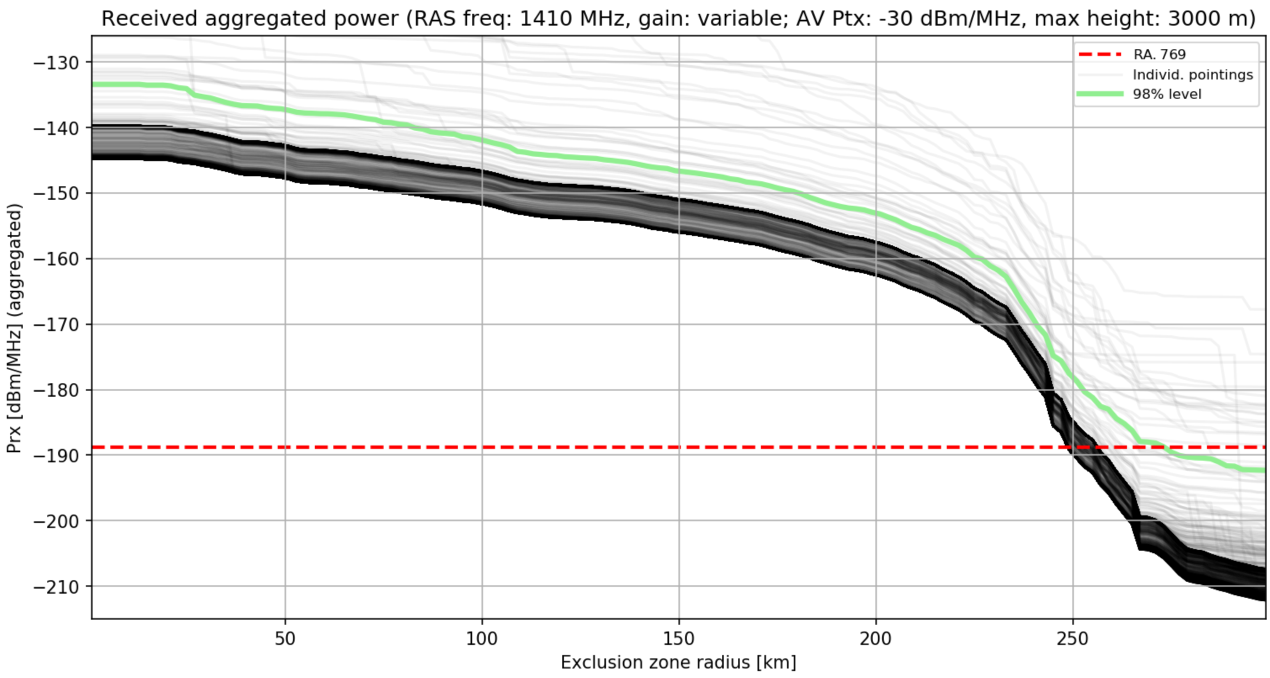


Figure 50: Aggregated spectral power as a function of exclusion zone radius for the RAS frequency 1.4 GHz and variable receiver gain, a maximum flight height of 3000 m and assuming a transmitted power level of -30 dBm/MHz. The gray curves mark the result of each individual of 1000 random antenna pointings for *one* simulation run. The cyan curve marks the 98% percentile of the distribution and thus is a proxy for the 2% acceptable data loss (here to be understood as fraction of the sky, which is lost)

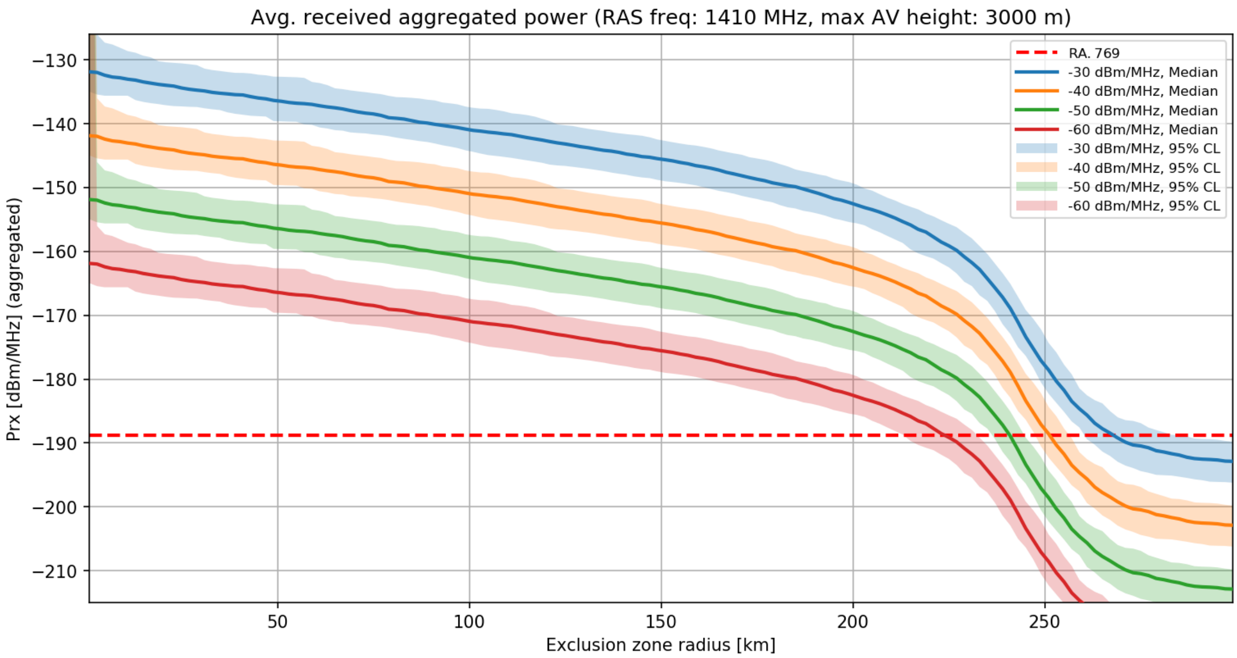


Figure 51: After 100 iterations, the median of all 98% curves (compare Figure 50) is determined. To assess the typical scatter, also the 2.5% to 97.5% percentile ranges are plotted, which indicate the 95% confidence interval

Again, this result can be compared to a user terminal on the ground (at 1.5 m), which is subject to additional propagation loss introduced by local clutter. In Figure 52, the same scenario was analysed as for Figure 51 but with the UE device at 1.5 m and 20 dB additional clutter attenuation. The necessary coordination zone size is significantly smaller.

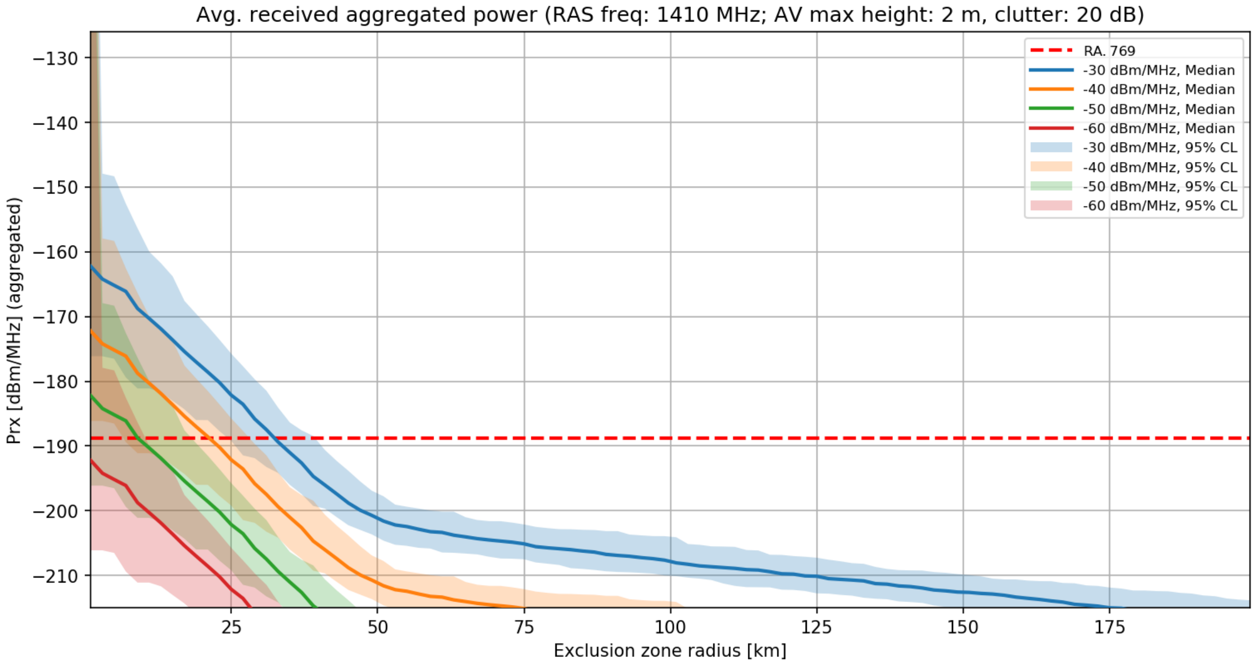


Figure 52: Same as Figure 51 but for UE on the ground (1.5 m) that is subject to clutter loss (here 20 dB). The necessary coordination zone size is significantly smaller

Table 45: Coordination zone sizes from aggregation study (uniform deployment)

Frequency (GHz)	Height (m)	1.5	1.5	1.5	100	300	1000	3000	10000
	Clutter (dB)	0	10	20	n/a	n/a	n/a	n/a	n/a
	Ptx (dBm/MHz)	Coordination zone size (km)							
1.41	-60	23	13	5	65	91	143	225	385
	-50	35	23	13	75	103	155	241	421
	-40	49	35	23	87	115	169	253	433
	-30	117	49	35	147	159	209	269	441
1.66	-60	21	9	1	61	89	137	213	361
	-50	31	21	9	71	99	149	239	413
	-40	43	31	21	81	109	163	249	431
	-30	81	43	31	103	125	179	261	439
1.72	0	253	141	53	291	297	347	409	459

Frequency (GHz)	Height (m)	1.5	1.5	1.5	100	300	1000	3000	10000
	Clutter (dB)	0	10	20	n/a	n/a	n/a	n/a	n/a
	Ptx (dBm/MHz)	Coordination zone size (km)							
	10	371	253	141	417	419	465	>500	>500
	20	495	371	253	>500	>500	>500	>500	>500
2.7	-90	1	1	1	1	1	1	1	1
	-80	1	1	1	17	33	17	3	1
	-70	9	1	1	45	69	91	101	139
	-60	19	9	1	59	85	129	193	317
3.35	-59	9	1	1	41	63	81	79	89
	-50	19	7	1	55	81	119	169	269

Table 46: Coordination zone sizes from aggregation study (clustered deployment)

Frequency (GHz)	Height (m)	1.5	1.5	1.5	100	300	1000	3000	10000
	Clutter (dB)	0	10	20	n/a	n/a	n/a	n/a	n/a
	Ptx (dBm/MHz)	Coordination zone size (km)							
1.41	-60	23	11	1	65	91	141	225	385
	-50	33	23	11	75	101	155	241	421
	-40	47	33	23	87	113	167	253	433
	-30	111	47	33	149	161	203	269	441
1.66	-60	19	9	1	61	87	137	215	361
	-50	31	19	9	71	97	149	239	413
	-40	41	31	19	81	109	163	249	431
	-30	73	41	31	105	125	177	259	439
1.72	0	243	135	51	295	303	345	409	459
	10	363	243	135	423	427	465	>500	>500
	20	487	363	243	>500	>500	>500	>500	>500
2.7	-90	1	1	1	1	1	1	1	1
	-80	1	1	1	15	27	17	1	1
	-70	7	1	1	45	67	89	103	139

Frequency (GHz)	Height (m)	1.5	1.5	1.5	100	300	1000	3000	10000
	Clutter (dB)	0	10	20	n/a	n/a	n/a	n/a	n/a
	Ptx (dBm/MHz)	Coordination zone size (km)							
	-60	19	7	1	57	83	129	193	317
3.35	-59	7	1	1	41	59	79	79	93
	-50	17	3	1	55	79	119	169	267

A6.5 SUMMARY

In the spurious domain, the compatibility between aerial UEs and RAS requires substantial separation distances of several dozen up to hundreds of kilometres depending sensitively on the given circumstances such as flight height, frequency and local topography.

Also for the aggregated analysis, which takes into account the likelihood of UE terminals to be located close to the boresight of the RAS antenna (with much higher gain), the resulting coordination zone sizes can be very large, especially for large flight heights or if the spurious emission level is close to nominal value of -30 dBm/MHz, i.e. the regulatory limit. While in several cases the spurious emission will be much smaller than permitted by the regulatory limit of -30 dBm/MHz, there are situations, e.g., the second harmonics of LTE700/800 that fall into the primary RAS bands at 1.41 and 1.66 GHz, where measurements (e.g., ECC Report 249 [26]) have demonstrated that real devices can have such high spectral sidelobes.

For all scenarios it can be concluded that compared to user terminals on the ground, UE onboard aerial vehicles produce much higher power levels at the RAS receiver. This is because the terminals on the ground are subject to higher path propagation loss (e.g., caused by diffraction) and additional clutter losses at the terminal.

ANNEX 7: COMPARISON OF AN AERIAL AND A GROUND UE EMITTING INTO RAS BANDS

A7.1 INTRODUCTION

The spurious emissions from devices can vary significantly according to specific implementation of said devices. Spurious emission far from the in-band may also vary significantly in time and intensity depending on the state of the device, for example its transmit power. Spurious emission limits are set to be respected under any conditions and at any time, corresponding to absolute worst case. These technical aspects explain why it is not possible to assess the interference generated by spurious emission on the basis of the integration of spurious emission limits. Such study could only derive an upper bound to the interference generated. Should such upper bound lead to scenarios where interference occurs, it would only indicate that the study does not exclude the possibility of interference, without proving any actual risk of interference.

It is assumed throughout the report that aerial UEs will be equivalent to UEs on the ground from an RF standpoint. In particular, the spurious emission from aerial UEs will be perfectly equivalent to the emissions from UEs on the ground. Therefore, a far superior approach is to compare the potential interference from UEs on the ground to the interference from aerial UEs and to ensure that aerial UEs do not cause more interference than UEs on the ground.

The 700 and 800 MHz bands have been harmonised for MFCN through ECC Decision (15)01 [16] and ECC Decision (09)03 [69] since 2015 and 2009, respectively. They are many millions of terminals operating in these bands, without geographical restriction. Though these terminals from a regulatory perspective can operate very close to RAS site, a conservative analysis can ensure that an aerial UE does not cause more interference than a ground UE located a few km away from the RAS site. This is already conservative. The analysis also includes an inherent safety margin since the density of aerial UEs is expected to be much lower than the density of ground UEs.

A7.2 PARAMETERS

The radio astronomy bands under discussion in this Report are listed in the table below.

Table 47: Radio Astronomy Bands

Radio Astronomy Band	Allocation
1400-1427 MHz	Primary + 5.340
1660-1670 MHz	Primary + 5.149

Table 48: P.452-16 Parameters [59]

Parameter	Value
Frequency	1410 MHz
RX height	50 m
TX height	2 m, 30 m, 300 m, 3000 m, 10000 m
Water concentration	3 g/m^3
Surface pressure	1,013.25 hPa
Refraction index gradient	40/km
Surface temperature	15 deg C
Latitude	45 deg
Time percentage	2%

Table 49: RAS station parameter

Parameter	Value	Reference
Height	50 m	CG_UAS_5
Antenna Gain	0 dBi isotropic	CG_UAS_5

It was assumed during the studies that direct passages through the main beam or near side lobes are very unlikely, given the small angular extent of the RAS antenna beam. All potential interferer are located in the sidelobes of the RAS antenna. An omnidirectional antenna with 0 dBi was assumed by RAS stakeholders as appropriate to model the sidelobes of the RAS antenna, in line with Recommendation ITU-R RA. 769-2 [37].

A7.3 METHODOLOGY

The study considers a generic flat earth case and assumes that the RAS station is located at 50 m above the ground. UEs are then place at different heights, namely 2 m (representing the terrestrial UE), 30 m, 300 m, 3000 m, and 10000 m, but at the same horizontal distances from the RAS station.

Afterwards, the distance from the RAS station is calculated for each UE. Based on this distance, the propagation loss to the RAS station can be calculated. The results in Figure 53 and Figure 54show the propagation loss from the UE towards the RAS station at a given horizontal distance.

Taking into the account the RAS antenna gain, a further figure is derived which shows the equivalent coupling loss distance. It estimates which horizontal separation distance an aerial UE would require to experience the same effective signal attenuation as a ground UE.

A7.4 RESULTS

Figure 53 shows the propagation loss of terrestrial and aerial UEs at a given horizontal distance from the RAS station. One can see that ground UEs have a greater propagation loss at large distances than aerial UEs. However, at distance below approximately 6 kilometres, low flying aerial UEs have an almost identical or even higher propagation loss than ground UEs. The propagation loss for distances up to 10 kilometres is plotted in Figure 54.

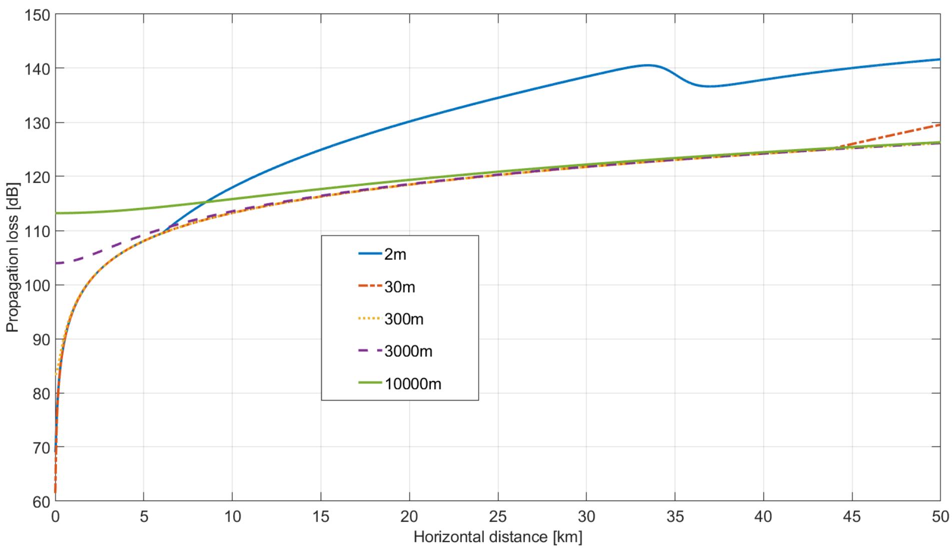


Figure 53: Propagation loss - up to 50 km

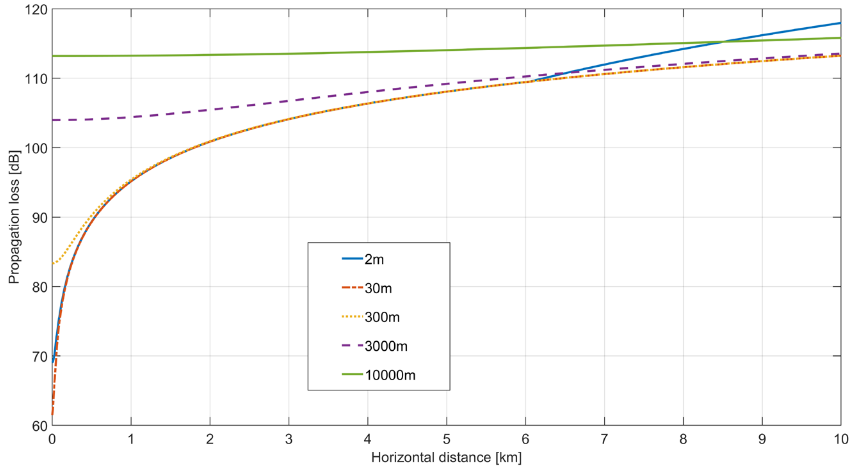


Figure 54: Propagation loss - up to 10 km

The difference in propagation loss at short distance can be explained with the additional geometric separation of flying UEs. The table below summarises the thresholds up to which distance the aerial UE will have more or a similar propagation loss when compared to a ground UE.

Table 50: Threshold distances

Aerial UE height	Horizontal threshold distance
30 m	6000 m
300 m	6000 m
3000 m	6500 m
10000 m	8500 m

The figure below shows the equivalent coupling loss distances, an aerial UE would require having the same coupling loss as a ground UE.

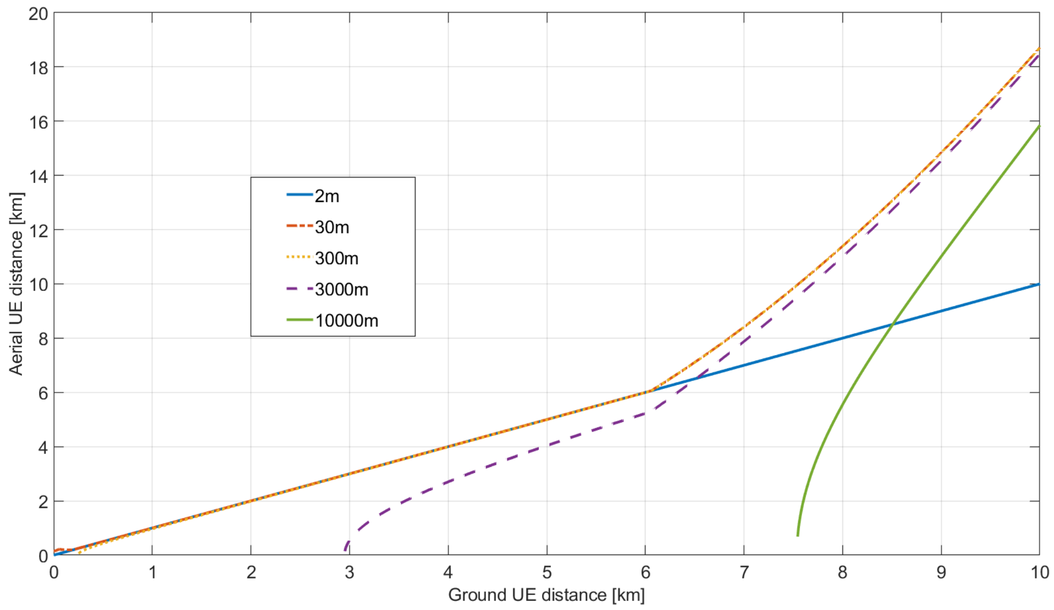


Figure 55: Equivalent coupling loss distances

A7.5 CONCLUSION

From the results above, it can be concluded that aerial UEs will have an equivalent or higher coupling loss than a ground UE when they are located within a distance of up to approximately 6 kilometres from the RAS station. Within this zone, high flying aerial UEs will have a higher coupling loss because of their bigger geometric separation, whereas low flying aerial UEs will have a coupling loss similar to ground UEs.

The table below summarises the thresholds up to which distance the aerial UE will have a similar or even higher coupling loss when compared to a ground UE.

Table 51: Threshold distances

Aerial UE height	Horizontal threshold distance
30 m	6000 m
300 m	6000 m
3000 m	6500 m
10000 m	8500 m

Taking into account that there are no exclusion zones for terrestrial UEs around RAS stations established and that aerial UEs will be have a higher propagation loss or a similar propagation loss when they are in the vicinity of RAS station, establishing flight exclusion zones is not reasonable. Additionally, it needs to be taken into account that the number of aerial UEs will be significantly lower than the number of ground UEs.

For administrations wishing to establish flight exclusion zones on a national level, a figure with equivalent coupling loss distances of aerial UEs is provided below. An administration deciding at national level for a flight exclusion zone of 5 km around a RAS site would already ensure that the maximum interference from aerial UEs is at least 12 dB lower than the interference from a ground UE operating at 1 km from the RAS site. This already takes into account significant safety margins due to the fact that the aerial UE density is much lower than the ground UE density.

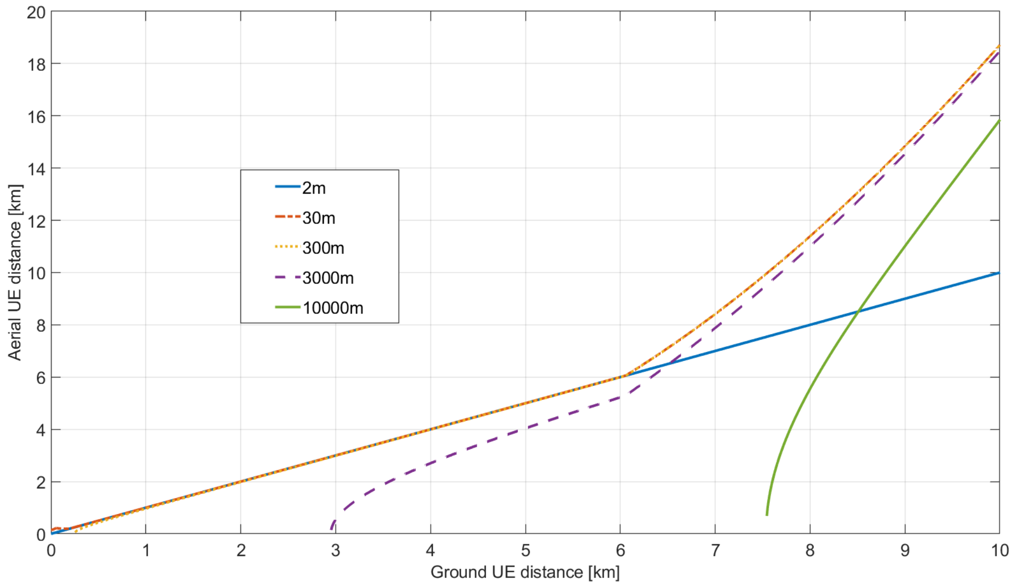


Figure 56: Equivalent coupling loss distances

Given that the second harmonics emission are very likely to vary with the channel used, the only terminals expected to create potential interference are the ones operating in 703-713.5 MHz and 832-835 MHz. Further studies should be conducted to confirm or infirm this assumption. This would enable potential flight restriction zones to be limited to specific MFCN channels, instead of affecting entire bands.

ANNEX 8: ANALYSIS OF THE BLOCKING EFFECT ON THE RADAR OPERATING ABOVE 2700 MHZ CAUSED BY DRONES IN MFCN BELOW 2620 MHZ

A8.1 CHARACTERISTICS AND PROTECTION OF RADARS

The frequency band 2700-2900 MHz is used by several different types of radars on land-based fixed and transportable platforms. Functions performed by radar systems in the frequency band are of different nature:

Air surveillance e.g. consisting in particular of terminal approach/airport surveillance radars for civil air traffic, worldwide weather observation with the detection of severe weather elements such as tornadoes, hurricanes and violent thunderstorms. These weather radars also provide quantitative area precipitation measurements so important in hydrologic forecasting of potential flooding.

Interference into radars operating in 2700-2900 MHz may occur for the following reasons:

- Unwanted emissions from the IMT stations occurring in the frequency range above 2700 MHz. This type of interference can be mitigated at the IMT base station (BS) by adding transmitter filters and exploiting the frequency separation between the radar systems and the base station (at least 10 MHz if BS operates in Downlink of the FDD band plan in 2620-2690 MHz). IMT UEs would operate further with at least 80 MHz frequency separation in the duplex gap of the FDD band plan, i.e. 2570-2620 MHz, corresponding to the spurious range of the MFCN band;
- Radar receiving frequencies below 2700 MHz, this is split into the following interference mechanisms:
- Adjacent channel/band reception which is a result of the wanted emission of the IMT base station. This type of interference is caused by insufficient RF front-end plus IF filtering in the radar receiver. Similar observation as for the unwanted emissions can be made;
- Blocking of the radar receiver which is a result of the wanted emission of the IMT base station. This type of interference is caused by insufficient RF filtering and the design of the radar receiver front-end; ECC Report 174 [70] addressed that case within the same frequency band for non-AAS stations (BS and UE) but the mobile terminals scenario only related to typical UEs (outdoor and indoor) and not aerial ones for which the visibility over the radar may reduce the propagation loss and not ensure the blocking protection ratio.

To ensure the blocking protection ratio, it is necessary to define a radar receiver blocking level suitable for an in-band emission 80-100 MHz away from the edge of the radar band. However, the Recommendation ITU-R related to such use in 2700-2900 MHz i.e. Recommendation ITU-R M.1464-2 [71] does not provide receiver RF saturation level values. Moreover, although the blocking of radars by mobile terminals has been addressed within this frequency range for non-AAS terminal (ECC Report 174), the blocking threshold was not provided in this deliverable. Consequently, since this parameter depends on the other characteristics of the radar, such as the gain of the low noise amplifier (LNA) (in particular the architecture of receiver RF chain LNA before intermediate frequency (IF) transposition), and varies with the frequency separation between the (radiolocation system) band edge and the upper edge of the aerial (UE) interferer channel, information was collected from the French national meteorological and civil aviation entities in addition to the radar characteristics available from Recommendation ITU-R M.1464-1 [72] and Recommendation ITU-R M 1849-2 [73]:

Table 52: Radar characteristics

Range of radar application	Blocking System 1	Blocking System 2	Peak Radar antenna gain	Insertion Loss
Air Traffic Control (ATC)	-22 dBm		34 dBi[23]	<1 dB[24]
Meteorological	-30 dBm	0 dBm	45.7 dBi[25]	2 dB

One could notice that the characteristics of these 2 radars considered for this analysis are sufficient for analysing the impact of the other categories of radars as the ones corresponding to the highest value of the peak gain antenna.

A8.2 CHARACTERISTICS OF UAS IN MFCN

Unmanned Aircraft Systems used for MFCN can be understood as airborne user equipment. Consequently, if the interference of the UAS on the radars is under study, Uplink (UL) of MFCN is used for assessing this impact. Considering the emission characteristics of a drone, it is worth noticing that the transmitting component of UAS operates under power control assumption as described in 3GPP TS 38.213 (Section 7) [74]. Since the New Radio interface (NR) addressed in this study relates to C-Band, the antenna of the UAS is designed under Non-AAS because the spacing between radiating elements is too large to enable planar array technology if its volume gets close to a user terminal. Thus, UAS antenna gain is assumed to be omnidirectional with -3 dBi gain value (similarly to IMT-Advanced in Report ITU-R M.2292 [25]) and 0 dBi (similarly to 3GPP TR 36.777 [1]) without any body loss.

Moreover, the investigation of the interference due to overload threshold only requires the knowledge of the e.i.r.p. characteristic of the aerial UE, i.e. transmission power and antenna gain. The maximum transmission power of an aerial UE is assumed to be the same as for typical UEs (indoor or outdoor), i.e. 23 dBm from Report ITU-R M.2292.

A8.3 ANALYSIS OF THE COEXISTENCE

The interfering signal coming from aerial UE and causing overload of the radar receiver can be expressed using the following formula:

$$PR_i(dBm/MHz) = P_{aerialUE}(dBm) + G_{aerialUE}(dBi) - PL(dB) - LR + G_{radar}(dBi) \qquad (12)$$

Where:

- PR_i is the power at the radar receiver, coming from aerial UE;
- $P_{aerialUE}$ refers to the in-band conducted power;
- $G_{aerialUE}$ is the aerial UE transmitting antenna gain towards the radar;
- G_{radar} is the radar receiving antenna gain in the direction of aerial UEi;
- PL relates to the path loss between aerial UE and the radar;
- LR relates to the insertion loss of the radar receiver.

Although it is possible for the radar to face multiple aerial UEs, it’s important to highlight that the cumulative effect of several aerial UEs on the blocking protection criterion may not be taken as representing a realistic

[23] Radar C from Recommendation ITU-R M.1464-1 [72]

[24] Taken as 0 dB

[25] Radar 1 from Recommendation ITU-R M.1849-2 [73]

scenario since signals from different sources of interference are not likely to be radiated with the same power at the same time and be subject to the same propagation conditions (coherence band conditions) which is an important condition to trigger an overload of the first components of the radar receiver (generally the LNA component). For that reason, the interference caused by one aerial UE is investigated in this document.

The proposed method for assessing the impact of in-band emission of aerial UE is the Minimum Coupling Loss (MCL), i.e. assuming:

- for the transmission power of the source of interference: max conducted power of the aerial UE;
- for the (transmitted and received) antenna gain: peak values both receiver and interferer. Hence, 0 dBi antenna gain is considered for the aerial terminal in this analysis;
- for the propagation loss: free space loss is assumed following Recommendation ITU-R P.525-4 [76].

The result of the MCL method for different scenarios is provided in the following table:

Table 53: Result of the MCL method for different scenarios

Scenario	Blocking Protection Level	Required Isolation Loss	Separation Distance
Meteo System 1	-30 dBm	96.7 dB	610 m
Meteo System 2	0 dBm	66.7 dB	20 m
ATC	-22 dBm	79 dB	80 m

Recalling that these results are achieved for a worst-case scenario and that the largest separation distance is lower than 1 km, it can be concluded that there is no need to take into account in the compatibility analysis the blocking effect on any kind of the radars operating above 2700 MHz caused by aerial terminals transmitting below 2620 MHz.

ANNEX 9: COEXISTENCE BETWEEN DRONES IN MFCN AND AIRBORNE RADARS IN 3400 MHZ BAND

A9.1 CHARACTERISTICS OF THE AIRBORNE RADARS

Radars considered for the study are airborne systems A-A as described in Recommendation ITU-R M.1465-3 [75] for which characteristics used in this study are provided in the table below:

Table 54: Airborne radar characteristics

Parameters	Unit	A-A
3 dB azimuth beamwidth	degree	1.2
3 dB elevation beamwidth	degree	6
Antenna polarisation	N/A[26]	Not Available
Typical peak antenna gain	dBi	40
Altitude	m	9000
Noise Factor (NF)	dB	3.0
Protection criterion (I/N)	dB	-6
Maximum acceptable interference	dBm/MHz	-117[27]
Vertical scan range	degree	-60..+60
Horizontal scan type	degree	Mechanical Rotating
Horizontal scan range	degree	0..360

Such airborne systems are used for long-range surveillance or target tracking and typically operate about 9000 m in altitude. The location of the antenna (top of an airframe but not in front because of its large size) explains why it is not possible for the radar antenna to perform vertical scanning to the nadir (leading to 60° lower bound). In the study, the antenna is assumed to scan the area up to 5°. Due to lack of information regarding the antenna polarisation, no loss due to polarisation is assumed between the airborne radar and the drone.

A9.2 CHARACTERISTICS OF UAS IN MFCN

A9.2.1 General overview

Unmanned Aircraft Systems used for MFCN can be understood as airborne user equipment. Consequently, if the interference of the UAS on the military radars is under study, Uplink (UL) of MFCN is used for assessing this impact. Considering the emission characteristics of a drone, it is worth noticing that the transmitting component of UAS operates under power control assumption as described in 3GPP TS 38.213 (Section 7) [74]. Since the New Radio interface (NR) addressed in this study relates to C-Band, the antenna of the UAS is designed under Non-AAS because the spacing between radiating elements is too large to enable planar array technology if its volume gets close to a user terminal. Thus, UAS antenna gain is assumed to be omnidirectional with -3 dBi gain value (similarly to IMT-Advanced in Report ITU-R M.2292 [25]) when considered as an average value (used in in statistical study) and 0 dBi for a worst-case scenario of sharing

[26] Not Applicable

[27] Noting that the noise (including the noise factor) level N is equal to -114+NF=-111 dBm/MHz and I_{max}=I/N+N=--6-111=-117 dBm/MHz

study. Moreover, in absence of direct user, no body loss is considered for the aerial UE. Finally, the study assumes a range of altitudes (above the ground) for an UAS in flight mode (0 .. 10000 m).

A9.2.2 Unwanted emission levels

If MFCN UAS operates above 3410 MHz, this means that there is 10 MHz frequency separation between the edge of the MFCN operating band and the edge of the band allocated to the radiolocation, namely 3400 MHz, corresponding to the out-of-band emissions interval in the upper part of the radiolocation band. 3GPP TS 38.101 [77] specifies the maximum out-of-band (OoB) levels for the New Radio (NR) systems on different channel bandwidth, in particular those equal or higher than 20 MHz (Table 6.5.2.2-1):

Table 55:Out of Band emissions for NR systems

<table>
<tr><th>ΔfOOB
(MHz)</th><th>20
MHz</th><th>25
MHz</th><th>30
MHz</th><th>40
MHz</th><th>50
MHz</th><th>60
MHz</th><th>80
MHz</th><th>90
MHz</th><th>100
MHz</th><th>Measurement bandwidth</th></tr>
<tr><td>± 1-5</td><td>-10</td><td>-10</td><td>-10</td><td>-10</td><td>-10</td><td>-10</td><td>-10</td><td>-10</td><td>-10</td><td rowspan="20">1 MHz</td></tr>
<tr><td>± 5-6</td><td rowspan="4">-13</td><td rowspan="5">-13</td><td rowspan="6">-13</td><td rowspan="8">-13</td><td rowspan="10">-13</td><td rowspan="12">-13</td><td rowspan="14">-13</td><td rowspan="16">-13</td><td rowspan="18">-13</td></tr>
<tr><td>± 6-10</td></tr>
<tr><td>± 10-15</td></tr>
<tr><td>± 15-20</td></tr>
<tr><td>± 20-25</td><td>-25</td></tr>
<tr><td>± 25-30</td><td></td><td>-25</td></tr>
<tr><td>± 30-35</td><td></td><td></td><td>-25</td></tr>
<tr><td>± 35-40</td><td></td><td></td><td></td></tr>
<tr><td>± 40-45</td><td></td><td></td><td></td><td>-25</td></tr>
<tr><td>± 45-50</td><td></td><td></td><td></td><td></td></tr>
<tr><td>± 50-55</td><td></td><td></td><td></td><td></td><td>-25</td></tr>
<tr><td>± 55-60</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>± 60-65</td><td></td><td></td><td></td><td></td><td></td><td>-25</td></tr>
<tr><td>± 65-80</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>± 80-85</td><td></td><td></td><td></td><td></td><td></td><td></td><td>-25</td></tr>
<tr><td>± 85-90</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>± 90-95</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>-25</td></tr>
<tr><td>± 95-100</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>± 100-105</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>-25</td></tr>
</table>

The resulting OoB level should be -13 dBm/MHz.

A9.3 ANALYSIS OF THE SCENARIOS OF COEXISTENCE

A9.3.1 Single entry Deterministic study

As described in Recommendation ITU-R M.1465-3 [75], airborne radars operate over a range of scanned elevation angles below and above the horizon to provide long-range surveillance, target tracking and ATC. That explains why the main beam of the radar antenna can point in the direction of the drone whatever its altitude, as depicted in the below figure:

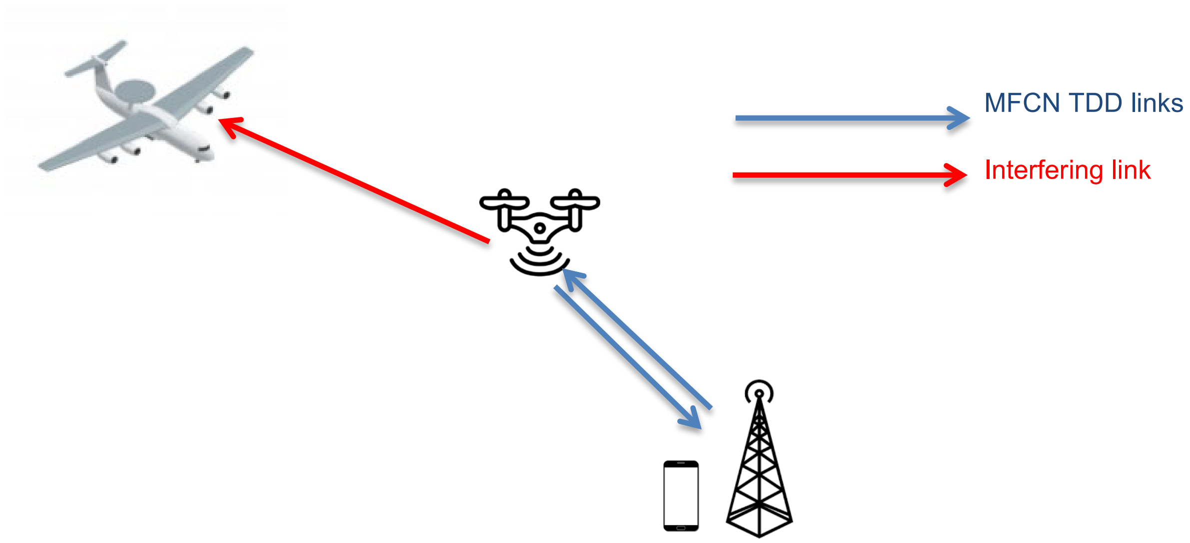


Figure 57: Radio links for a single transmitting aerial UE

Moreover, if UAS operates above 3410 MHz, a compatibility analysis between drones and land-based radar is carried out in adjacent band with out-of-band OoB levels affecting the radiolocation upper band. The resulting required isolation loss can be expressed using the following formula:

$$\text{Isolation (dB)} = \text{e.i.r.p.}_{\text{UE\_OOB}}\ (\text{dBm/MHz}) - \text{I}_{\text{max}}\ (\text{dBm/MHz}) + \text{G}_{\text{radar}}(\text{dBi}) \quad (13)$$
$$= \text{OOB level (dBm/MHz)} + \text{G}_{\text{UE}}(\text{dBi}) - \text{I}_{\text{max}}\ (\text{dBm/MHz}) + \text{G}_{\text{radar}}(\text{dBi})$$

Assuming free space propagation (modelled through Recommendation ITU-R P.525-3 [50]) between UAS and radar type, worst-case scenario with peak antenna gains, i.e. G_{UE} =0 dBi and G_{radar} =40 dBi, the application of the formula on the required isolation loss gives the following results for different levels of unwanted emissions[28]:

Table 56:Results for UAS interference to airborne radars for different levels of unwanted emissions

Scenario	Required Isolation Loss (dB)	Separation distance (km)
-13 dBm/MHz	144	112
-30 dBm/MHz	127	17
-40 dBm/MHz	117	5
-50 dBm/MHz	107	1.6

Reminding that these values were derived for Minimum Coupling Loss (MCL) analysis, it is worth mentioning that both airborne radar and UAS are in motion which suggests that this situation could happen scarcely and could be transient. This is why it is important to investigate on a statistical manner the interference from UAS onto the radar receiver by considering probability distributions on several parameters such as UAS altitude, the distance between UAS and the aircraft or the orientation of the radar antenna (vertical and horizontal scanning) in order to evaluate the likelihood of the worst-case scenario. Moreover, it should be noted that a geographical separation would not be a practical solution to ensure the protection of aeronautical radars used over a majority of CEPT countries.

[28] If the frequency separation between MFCN UAS and airborne radar is sufficiently larger (i.e. drones operate above X MHz where X>3410) to consider spurious emissions below 3.4 GHz (i.e. -30 dBm/MHz) or/and if additional filtering is applied to the drone transmitter.

A9.3.2 Aggregate statistical analysis of the impact from aerial UEs onto airborne radar

A9.3.2.1 Additional assumptions on the radar antenna pattern and the simulation setting

As indicated in the previous section, the mobility of the airborne radar and the drone leads to consider from a statistical point of view the impact of the UAS on the radar receiver. In addition, more than one drone can operate within a serving cell, which is why cumulative effect of multiple aerial UEs is investigated in this section. This analysis assumes that drones are in the vicinity of the aircraft (at horizontal distance equal or less than 5 km) at different altitudes (0 to 10000 m) and that the radar antenna points to different directions (-60 up to +5°) with a given mechanical scan (0..360°) following for all parameters a uniform distribution.

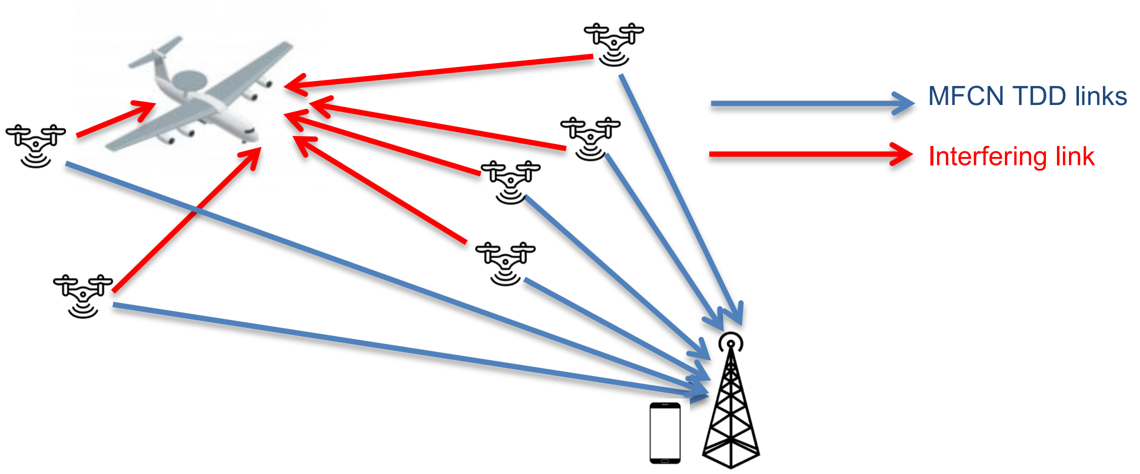


Figure 58: Radio links for multiple transmitting aerial UEs

Reminding that the band under study is dedicated to 5G NR, the density of aerial UEs within a cell is assessed based on the following information:

a) the UE density given in Report ITU-R M.2412-0 [78] on Guidelines for evaluation of radio interface technologies for IMT-2020 for this frequency range (4 GHz) on Rural eMBB: 10 simultaneous UEs per BS[29];

b) Macro site is divided into three hexagons or three cells as described in Figure 3 of Report M.2412-0 and Section 8.3.3 on Rural-eMBB;

c) the density of aerial UEs is expected to be lower than the one for the ground UEs for different reasons:

d) physical separation between two drones is needed to avoid collisions during the flight

e) cell area for drone is larger than for ground UEs because lower (due to free-space) path loss.

Based on a. and b. it is understood that the density of ground UEs is 10 UEs per cells i.e. 3x10=30 UEs per site. From c., the density of aerial UEs is calculated by assessing a cell radius for aerial UEs. However as drones can operate at different altitudes (e.g. between 0 m and 10000 m) and cell radius depends on this height above the ground, it is proposed to use similar assumption as given in ANNEX 4:i.e. with cell range=5 km for 3400 MHz frequency range compared to one at 10 km for 1700 MHz[30]. The resulting site area (3 hexagons) is roughly 195 km^2, leading to AreaDisk(5 km radius)/AreaSite(5 km cell range)≈ 48 aerial UEs.

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[29] *TRxP Transmission Reception Point*

[30] Because of the free space loss formula $\lambda/(4\pi d)=c/(4\pi fd)$.

Once could notice that for another radio environment (urban, suburban area), the density of aerial UEs could be higher than the assumed value because of a smaller cell radius although the simulation area (e.g. 5 km around the airborne radar) cannot be gridded only for such environment.

In such environment, the full 3D radar antenna pattern needs to be computed in order to assess the received interference at the aircraft. In absence of data related to real antennas mounted on this category of aircraft, this pattern can be built applying Recommendation ITU-R M.1851 on Mathematical models for radiodetermination radar systems antenna patterns for use in interference analyses [79]. Indeed characteristics of the radar antenna given from Recommendation ITU-R M.1465 [75] generally match with the range limits given in Table 1 of Recommendation ITU-R M.1851.

The methodology for designing this pattern is described in Section 2 of Recommendation ITU-R M.1851 and assumes for this study:

- Uniform value of 1 for the shape of field distribution (See Table 2 of Recommendation ITU-R M.1851-1) in order to achieve first sidelobe level in the order of -10 dBi as suggested by Recommendation ITU-R M.1465-3: It provides 40 dBi main beam gain and its side lobe gain has been estimated to be −10 dBi.
- Theoretical pattern (see Table 3 of Recommendation ITU-R M.1851-1):
  - 3 dB horizontal beamwidth=1.2°;
  - 3 dB vertical beamwidth=6°;
  - Peak gain=40 dBi.

The 3D pattern is computed following Section 5 on Recommendation ITU-R M.1851-1[31] and is plotted in the below figure:

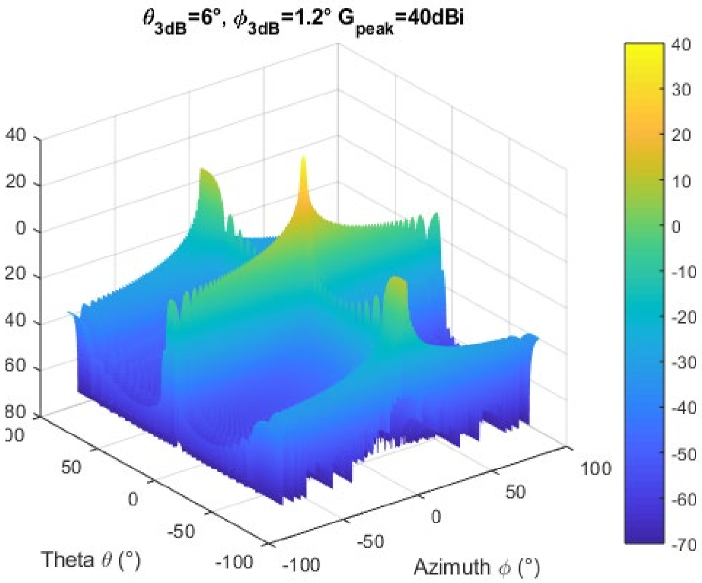

Figure 59: 3D Radiation pattern of the airborne radar (AA) antenna used in the study

Note that this radiation pattern cannot be considered as a worst case from the coexistence point of view as it accounts for the theoretical mask and not the peak or average ones.

Based on this pattern and the parameters related to the mobility of the UAS and airborne radar (beam pointing of the radar antenna, position of UAs with respect to the aircraft), it is possible to calculate the radar antenna gain in the direction of the drone G_{radar} φ,θ and derive the received interference as follows:

Ireceived (dBm/MHz)=oob level(dBm/MHz) – PathLossdrone,airborne radar (dB) - G_{radar}φ,θ (dBi) (14)

[31] Noting that factor '20' in Equation (17) should be replaced by '10' to keep similar 2D slice radiation pattern (in elevation and azimuth)

The computation of this interference is performed over 9.6*107 samples in order to get a satisfactory reliable statistic of the probability of exceeding the protection criterion.

A9.3.3 Analysis of the results

Distribution of received interference from a (48) multiple UASs (as cdf) is plotted for different unwanted emissions levels (4 scenarios: -13, -30, -40 and -50 dBm/MHz) in the below figure. The maximum acceptable interference level is also displayed in the graph through a red vertical line in (-117 dBm/MHz) in order to evaluate the probability of interfering the airborne radar. For each scenario (depicted by a coloured curve), the exceedance of the protection criterion can be read by looking at the intersection of the curve with the red vertical line. For the sake of readability, these intersections are tagged. This means that for each curve, the part at the right side of the red vertical line corresponds to the cases of interference threshold exceedance.

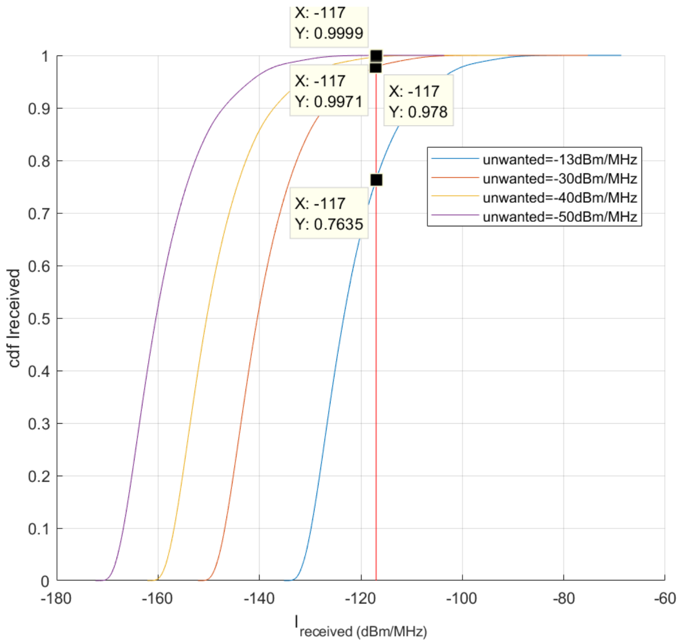

Figure 60: Probability aggregate interference from aerial UEs exceeds protection criterion

At first glance, the regular shape of all curves proves that the number of samples used to compute the aggregate interference received by the airborne radar. Then the lower unwanted emissions levels, the further the curve from the (red) vertical line depicting the airborne radar protection criterion. Afterwards, cdf curves for different unwanted emissions levels have similar shapes and their positioning within the figure match with the gap between different unwanted emissions levels.

When the unwanted emissions level is -13 dBm/MHz, the protection criterion is exceeded for a more than 23% of the case. From level=-40 dBm/MHz, the maximum acceptable level is achieved for less than 0.3%. Finally, it can be seen that the protection criterion is not exceeded for more than 99.99% from OoB<=-50 dBm/MHz.

A9.4 CONCLUSIONS

Compatibility studies between airborne radar and drones in MFCN were carried out at 3400 MHz by considering in a first step a single interference worst-case scenario for given unwanted emission levels. Under these same levels, a second analysis of the cumulative effect of multiple sources of interference was carried out on a statistical basis because of the variability of several parameters (e.g. the positioning of the drones: distance/altitude and the airborne radar: orientation of the beam radar antenna). From these results, it appears that the operation of aerial UEs at unwanted emissions level≤ -50 dBm/MHz can ensure a very low probability of interference (≤0.01%).

ANNEX 10: COEXISTENCE BETWEEN DRONES IN MFCN AND LAND-BASED RADARS IN 3400 MHZ BAND

A10.1 CHARACTERISTICS OF LAND-BASED RADARS

Radars considered for the study are land-based systems, more specifically:

- type I from Recommendation ITU-R M.1464-2 [71] , with maximum vertical scan +50°;
- types L-D from Recommendation ITU-R M.1465-3 [75] with maximum vertical scan +50°.

Table 57: Land based radar characteristics

Parameters	Unit	Type I	Type L-D
3 dB azimuth beamwidth	degree	1.5	1.0-4.0
Antenna polarisation	N/A[32]	linear or circular or switched	Vertical
Typical peak antenna gain	dBi	33.5	40
3 dB elevation beamwidth	degree	4.8	5.0
Antenna height (above the ground)	m	4 to 30 m (10 m is taken)	10 m
Noise Factor	dB	2.0	4.0
Protection criterion (I/N)	dB	-6	
Maximum acceptable interference	dBm/MHz	-118	-116

A10.2 CHARACTERISTICS OF UAS IN MFCN

A10.2.1 General overview

Unmanned Aircraft Systems used for MFCN can be understood as airborne user equipment. Consequently, if the interference of the UAS on the radars is under study, Uplink (UL) of MFCN is used for assessing this impact. Considering the emission characteristics of a drone, it is worth noticing that the transmitting component of UAS operates under power control assumption as described in 3GPP TS 38.213 (Section 7) [74]. Since the New Radio interface (NR) addressed in this study relates to C-Band, the antenna of the UAS is designed under Non-AAS because the spacing between radiating elements is too large to enable planar array technology if its volume gets close to a user terminal. Thus, UAS antenna gain is assumed to be omnidirectional with -3 dBi gain value (similarly to IMT-Advanced in Report ITU-R M.2292 [25]) and 0 dBi (similarly to 3GPP TR 36.777 [1]) without any body loss. Finally, the study assumes a 150 m altitude (above the ground) for an UAS in flight mode.

A10.2.2 Characteristics of the MFCN UL

In order to model the UL between UAS and a NR BS, it’s important to indicate the frequency range as well as the deployment characteristics of the MFCN for different environments. In this study, MFCN (BS and UEs including potential UASs) is assumed to operate above 3410 MHz (because EC Decision 2019/235 **Error! Reference source not found.** indicates the need to protect radars operating below 3400 MHz and it’s likely that guard band may be needed to achieve -52 dBm/MHz TRP unwanted emission limits from BSs). Macro BS is assumed to be connected with UAS and parameters related to this scenario is provided in the below table, mainly extracted from Report ITU-R M.2292 [25].

[32] Not Applicable

Table 58: MFCN UL characteristics

Parameter	Unit	Value
Cell radius	m	150 (urban), 300 (suburban) 2000 (rural)
Cell range	m	2xCell radius
Base station Noise Figure	dB	5
Base station antenna height	m	20 (urban) 25 (suburban) 30 (rural)
Channel Bandwidth	MHz	20..100
SNR QoS target (video)	dB	-6, 6
Number Resource Blocks used for video application	N/A	50 (x180 kHz) 6 (x180 kHz)

Some other parameters deserve further clarifications concerning the:

- required QoS SNR: it's expected that UAS usage would focus on video applications which might require few Mb/s data rate as a minimum requirement to operate properly. Depending on the amount of UASs that may operate simultaneously within the same cell, different SNR targets are considered based on tables from the standard[33] giving the correspondence between SNR and spectrum efficiency. It has also to be mentioned that UAS is assumed not to access all frequency resource blocks of a given cell because "ground"[34] UEs are connected to the serving BS at the same time, that's why Half of the total number of resource blocks is assumed to be available for the drone (e.g. 50 RBs available in 20 MHz). Details of the calculation of these SNR targets are provided in A10.4;
- rural environment: in absence of information on the rural case between 3 and 6 GHz (for Report ITU-R M.2292), values provided above relates to the frequency range between 2 and 3 GHz;
- channel bandwidth: no specific value was assigned to the band 3400-3800 MHz, that's why it is proposed to assume low and high (reasonable) size of channel, accounting the propagation conditions offered by the C Band (in terms of maximum delay spread affecting the coherence band of the channel) i.e. 20 and 100 MHz.

A10.2.3 Unwanted emission levels

If MFCN UAS operates above 3410 MHz, this means that there is 10 MHz frequency separation between the edge of the MFCN operating band and the edge of the band allocated to the radiolocation, namely 3400 MHz, corresponding to the out-of-band emissions interval in the upper part of the radiolocation band. 3GPP TS 38.101 [77] specifies the maximum out-of-band (OoB) levels for the New Radio (NR) systems on different channel bandwidth, in particular those equal or higher than 20 MHz (Table 6.5.2.2-1) (see also ANNEX 9:, Table 55).

[33] See 3GPP TR 36.942 although this applies to LTE-Advanced.

[34] In the street or in the buildings (at low or high floors) but not on aircraftsaircraftsaircraftsaircraftsaircrafts

The resulting OoB level should be -13 dBm/MHz.

A10.2.4 Overview of the scenario of coexistence

As indicated in previous section, land-based radars operate over a range of scanned elevation angles above the horizon to provide search and tracking functions for airborne vehicles along extend flight paths as described in Recommendation ITU-R M.1465-3 (see section 2.1.1) [75]. That explains why the main beam of the radar antenna can point above the horizon in the direction of the drone as depicted in the below figure:

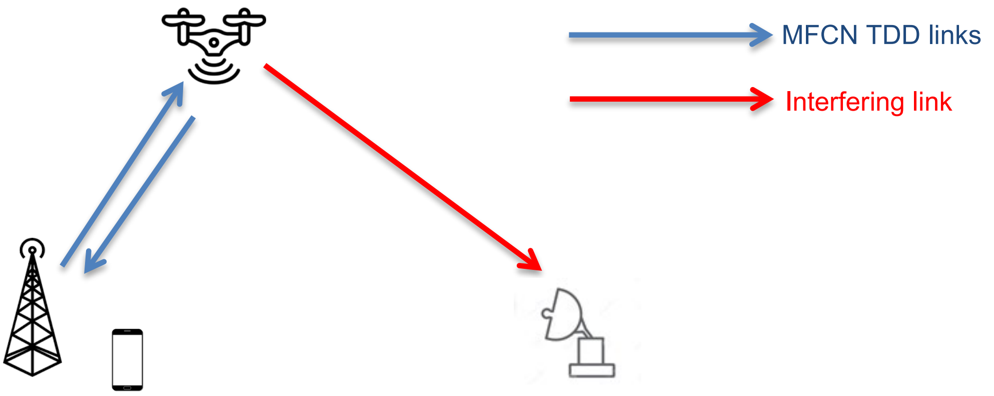

Figure 61: Coexistence scenario

Moreover, if UAS operates above 3410 MHz, a compatibility analysis between drone and land-based radar is carried out in adjacent band with out-of-band OoB levels affecting the radiolocation upper band. The resulting required isolation loss can be expressed using the following formula:

$$\text{Isolation (dB)} = \text{EIRP}_{\text{UE\_OOB}}\,(\text{dBm/MHz}) - Loss_{Polarisation}\,(\text{dB}) - \text{I}_{\text{max}}\,(\text{dBm/MHz}) + \text{G}_{\text{radar}}(\text{dBi}) \quad (15)$$

$$= \text{OOB level (dBm/MHz)} + \text{G}_{\text{UE}}(\text{dBi}) - \text{I}_{\text{max}}\,(\text{dBm/MHz}) + \text{G}_{\text{radar}}(\text{dBi}) - Loss_{Polarisation}\,(\text{dB})$$

Assuming:

- 1.5 dB polarisation loss because the main lobe of the radar can point in the direction of the UAS (modelled through an omni-directional antenna);
- for land-based radars;
- Type I free space propagation (modelled through Recommendation ITU-R P.525-3 [50]) and diffraction due to the smooth curvature of the Earth between UAS (at 150 m altitude) and radar type (at 10 m) depending on the required isolation loss;
- Type L-D free-space Loss and diffraction due to the smooth curvature of the Earth.

The application of the formula on the required isolation loss gives the following results:

Table 59: Results of interference to land radars

Scenario	$G_{aerialUE}$ (dB)	Unwanted emissions level (dBm/MHz)	Required Isolation Loss (dB)	Separation distance (km)
Type I	-3	-13	134	35
Type I	0	-13	137	49.2
Type L-D	-3	-13	138.5	50.7
Type L-D	0	-13	141.5	53.8

Reminding that these values were derived from an unwanted emissions level computed on an UAS transmitting at full power, it's worth mentioning that in practice the UAS in connection with the serving ground BS from MFCN in C Band may operate at lower power than Pmax because it takes benefit of the "existing" ground MFCN and is subject to lower path loss. Operating with lower power than Pmax may reduce the OoB level of the UAS (down to a lower bound) resulting in mitigating the required isolation loss and the separation distance so far. This is why it is important to investigate the statistical behaviour of the UAS within a cell to assess the impact on the land radars with Macro BS in order to facilitate Line of Sight (LoS) propagation conditions.

If the frequency separation between MFCN UAS and land-based radar is sufficiently larger (i.e. drones operate above X MHz where X>3410) to consider spurious emissions below 3.4 GHz (i.e. -30 dBm/MHz), the application of the required isolation loss formula leads to the following results:

Table 60:Results for increased frequency separation

Scenario	$G_{aerial\ UE}$ (dB)	Unwanted emissions level (dBm/MHz)	Required Isolation Loss (dB)	Separation distance (km)
Type I	-3	-30	117	5
Type I	0	-30	120	7
Type I	0	-40	110	2.3
Type I	0	-50	100	0.7
Type L-D	-3	-30	121.5	8.4
Type L-D	0	-30	124.5	11.8
Type L-D	0	-40	114.5	3.8
Type L-D	0	-50	104.5	1.2

A10.2.5 statistical analysis of the impact from UAs onto the land-based radar

This analysis assumes that due to the few amount of traffic offloaded to the UAS by the cell (compared to the one dedicated for "ground" users), MFCN BSs shall not modify their beam-steering behaviour within the cell with the introduction of UAS and won't point above the horizon. For that reason, current beam-steering statistics of the BS antenna show pointing below the horizon as highlighted by the below figure:

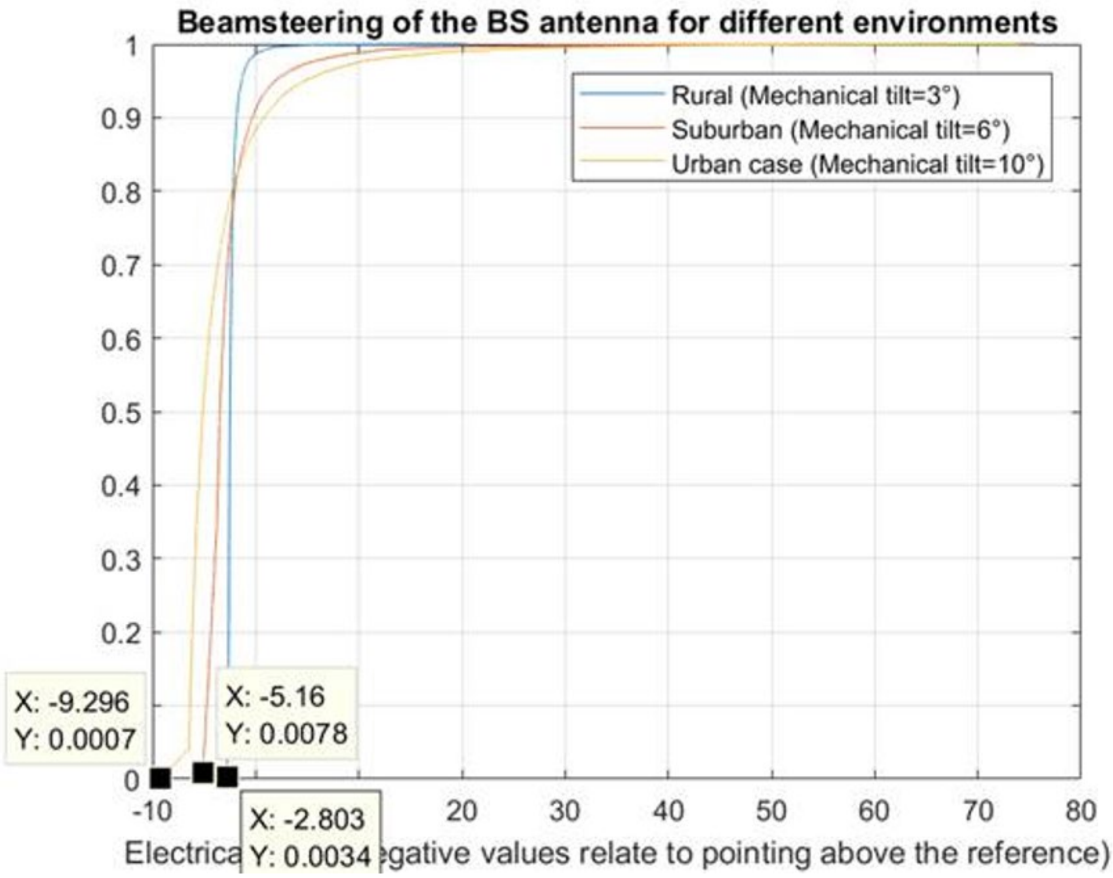

Figure 62: Beamsteering of the BS antenna for different environments

Although negative values of electrical tilts only reveal the possibility for the beam to be pointed above the reference (given by the mechanical tilt) but not the horizon. In addition, it's expected that the BS antenna gain in the direction of the drone won't be likely a peak value because of the altitude of the drone and the pointing direction of the beam to the ground although it is recognised that the further the UAS, the lowest the discrimination angle of the BS antenna with respect to the horizon.

More precisely typical UEs locations are generated using a uniform distribution (in (x,y)) within the cell in indoor/outdoor environments in accordance with several parameters such as the indoor terminal usage, the cell range given by Report ITU-R M.2292 [25], noting that for the rural case, assumption was extracted from the frequency range between 2 and 3 GHz (4 km) in absence of information for this environment between 3 and 6 GHz (see Appendix 2 - A10.5 for more information).

The BS antenna gain serving the typical UEs is generated by modelling the electronic beam in the direction of each UE (assuming one UE using all resource blocks) and following Recommendation ITU-R M.2101 [51] and parameters from ECC Report 283 [80] (see Appendix 2 - A10.5).

If a UAS operates (in this study) at fixed altitude (150 m), its geographical position within the cell (x,y) may vary, which is why a uniform distribution of the (x,y) drone positioning inside the cell is considered. The following figure represents the antenna gain of the BS serving cell in the direction of the UAS over a set of 104 events.

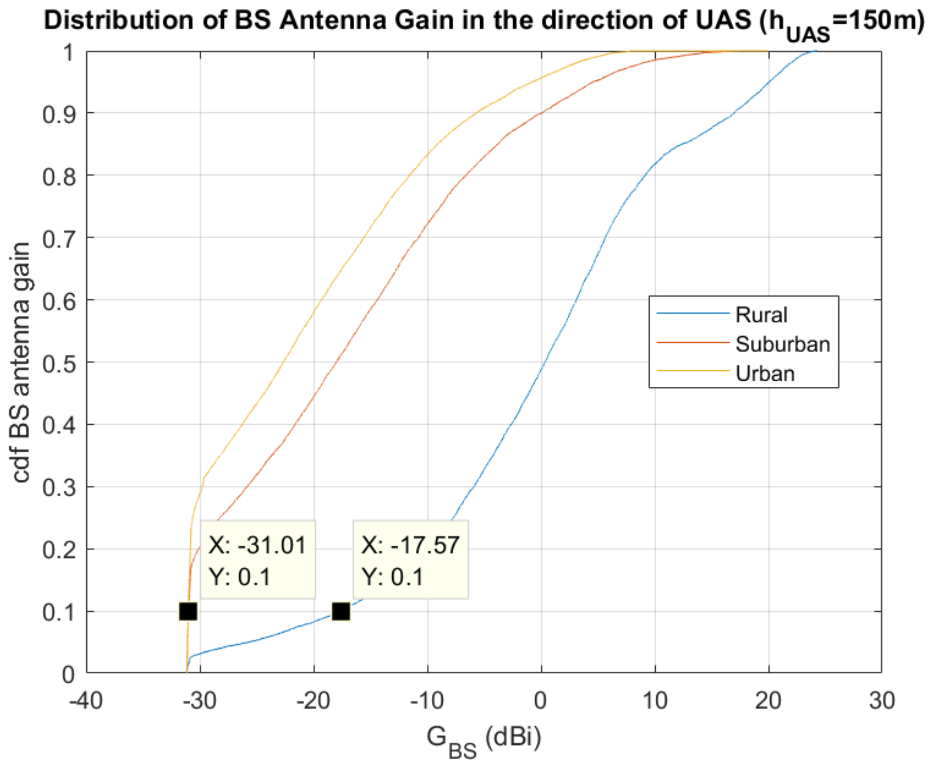

Figure 63: Distribution of BS antenna gain in the direction of UAS

High gain values can be achieved because the UAS may be located at the edge of the cell (resulting in discrimination angle tending towards 0°), especially for the rural case with much higher distance(BS,UAS)=cell range (4 km) compared to the other cases (300 m and 600 m). Moreover, it can be noticed that in urban and suburban environments, the BS antenna gain can be lower than -31 dB for 10% of the cases, leading to conclude (based on elements from Annex 2) that Pmax is almost achieved for the UAS in more than 10% of the case (assuming -3 dBi antenna gain for the aerial UE). This is further confirmed when representing the distribution of the UAS transmit power for different user cases involving:

- environments (urban, suburban and rural);
- channel bandwidth (20 MHz and 100 MHz);
- QoS SNR target (SNR=-6 dB and SNR=6 dB).

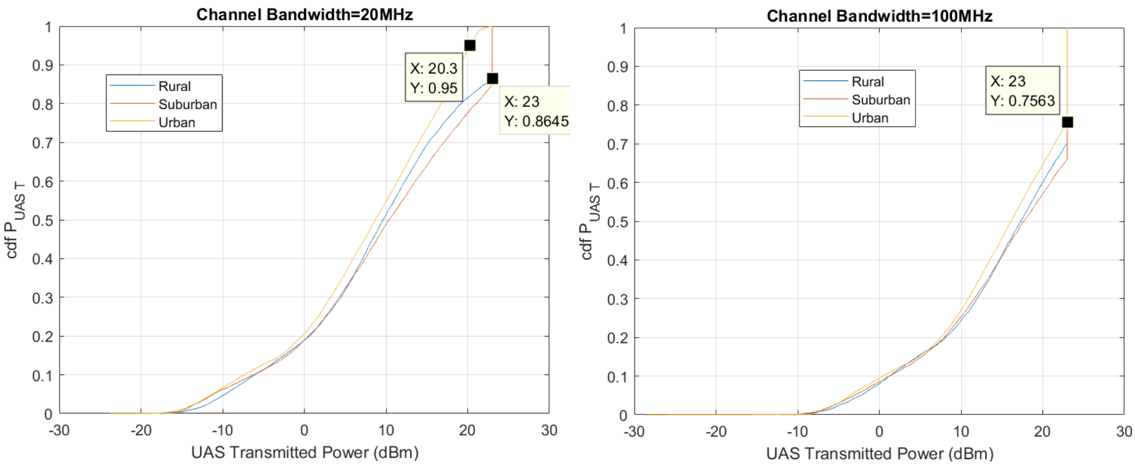

Figure 64: cdf of UAS transmitted power for different channel bandwidths

The increase of number of resource blocks allocated to UAS (e.g. when using higher channel bandwidth like 100 MHz) tends to increase the portion of UAS transmitting with maximum power based on the comparison between two different channel bandwidths in the same environment (see figures above), e.g. for urban more than 13% of UAS with 50 RBs while it is more than 24% for 250 RBs.

Moreover, if the SNR_{min} target is increased (e.g. from -6 dB to 6 dB), the proportion of UAS terminals with max power is also noticeable, e.g. for rural environment there is more than 40% transmitting with Pmax with SNR_{min}=6 dB compared to more than 13% for the case with SNR_{min}=-6 dB:

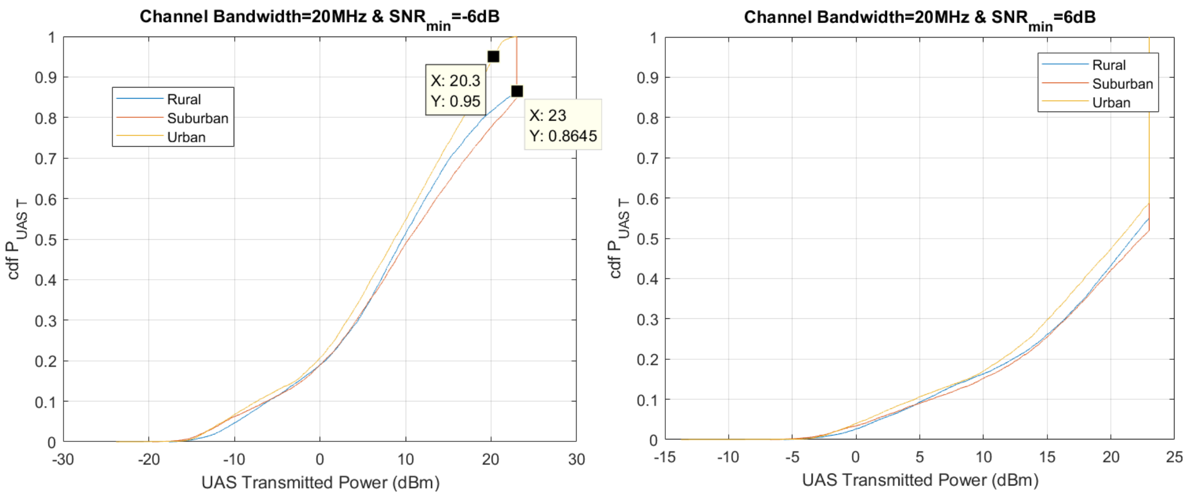

Figure 65: cdf of UAS transmitted power for different SNR_{min}

It can be concluded that for any case, the probability of having UAS with max power is not negligible (more than 10%), i.e. the resulting separation distance between UAS and land-based radars could be around 40-84 km for unwanted emissions levels=-13 dBm/MHz.

A10.3 CONCLUSIONS

Compatibility studies between several categories of land-based radars (radars type I and L-D) and drones using MFCN were carried out at 3400 MHz and led to an unwanted emissions level:

- equal to -13 dBm/MHz to separation distances higher than 35 km for all use cases (up to 54 km),
- equal to -50 dBm/MHz to separation distances around 1 km (i.e. 0.7 to 1.2 km).

These separation distances resulted from the geographical visibility of the radiolocation system (from the UAS) and the fact that the drone may transmit at full power for a non-negligible number of cases.

A10.4 APPENDIX 1: CALCULATION OF THE QOS SNR FOR UAS APPLICATION

A10.4.1 Minimum data rate for video application

Minimum data rate required for video link depends on the resolution (SD, HD, 4K…) but also on the choice of the codec (having an influence on the compression rate). For instance, the required bit rate for a connection through Netflix is between 0.5 and 5 Mb/s for different QoS[35].

A10.4.2 Performance criterion for video link

[35] https://help.netflix.com/en/node/306

3GPP TR 36.942 [48] on 4G LTE-Advanced provides a look-up table between spectral efficiency and SNR values:

Table 61: SNR vs spectral efficiency

SNR	Capacity (bps/Hz)		Capacity (kbps per 375 kHz RB)	
dB	DL	UL	DL	UL
-15	0	0	0	0
-14	0	0	0	0
-13	0	0	0	0
-12	0	0	0	0
-11	0	0	0	0
-10	0.08	0.06	31	21
-9	0.10	0.07	38	26
-8	0.13	0.08	48	32
-7	0.16	0.10	59	39
-6	0.19	0.13	73	48
-5	0.24	0.16	89	59
-4	0.29	0.19	109	73
-3	0.35	0.23	132	88
-2	0.42	0.28	159	106
-1	0.51	0.34	190	127
0	0.60	0.40	225	150
1	0.71	0.47	265	176
2	0.82	0.55	308	206
3	0.95	0.63	356	237
4	1.09	0.72	408	272
5	1.23	0.82	463	309
6	1.39	0.93	521	347

Considering an UL with 1 Mb/s minimum data rate using half of the available resources in 20 MHz:

for one UAS (i.e. all RBs in 10 MHz)

$$\eta_{1user} = \frac{10^6 b/s}{50\times180\times10^3} = 0.1111 \text{ bits/(s.Hz) covered for SNR=-6 dB} \quad (16)$$

for 8 simultaneous UASs, i.e. an average of 6 RBs[36] for each one, this requires a minimum of

$$\eta_{8users} = \frac{10^6 b/s}{6\times180\times10^3} = 0.9259 \text{ bits/(s.Hz) covered for SNR=6 dB} \quad (17)$$

A10.5 APPENDIX 2: INTERIM RESULTS ON THE COMPUTATION OF TRANSMIT POWER OF UAS

[36] Assuming 1RB=180 kHz, noting that for 5G NR, the carrier spacing may be higher than 15 kHz (typically used in 4G), e.g. 30 kHz.

A10.5.1 Coupling gain of the UL

The computation of the coupling gain in UL is expressed by the following formula:

$$\text{Coupling Gain} = G_{BS}(\text{dBi}) - \text{PL} + G_{UAS}(\text{dBi}) \quad (18)$$

where different values are exhibited in the below table

Table 62:Coupling gain for different paths

GBS (dBi)	Distance[37](UAS,BS) (m)	PL(UAS,BS) (dB)	GUE (dBi)	Coupling Gains (dB)	CLx 95th percentile	PUE (dBm)
-30	350	94.0	-3	127	128.5	21.5
-30	150	86.6	-3	119.6	128.5	14.1
10	350	94.0	-3	87	128.5	-18.5
10	150	86.6	-3	79.6	128.5	-25.9
-30	350	94.0	-3	127	125.7	23.0
-30	150	86.6	-3	119.6	125.7	16.9
10	350	94.0	-3	87	125.7	-15.7
10	150	86.6	-3	79.6	125.7	-23.1

These results show that the probability for the UAS to transmit at Pmax is very low. For that reason, a statistical analysis of the transmit power from UAS at UL is done within a cell where BS serves ground UEs located at random positions while a drone at fixed altitude (150 m) is surrounding the cell at random (x,y) location for different environments (rural, urban and suburban).

A10.5.2 2D Distribution of UEs served by Macro BS

As Macro BS may not only serve UAS within the cell, “ground” UEs locations are generated following a 2D uniform distribution to model these terminals connected to the BS for different environments as depicted by the below figures, noting that due to absence of information for the rural scenario between 3 and 6 GHz (from Report ITU-R M.2292 [25]), values from the frequency range between 2 and 3 GHz are taken:

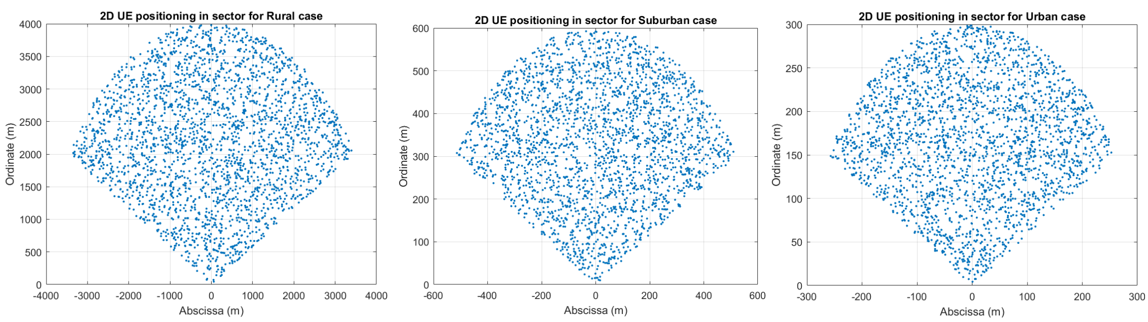

Figure 66: 2D UE positioning in sector

37 Corresponding to the “oblique” line linking the UAS and the BS antenna.

A10.5.3 Computation of Macro BS antenna radiation pattern

Although the interference calculated in this study relates to the drone, it is necessary to compute the radio UL in order to estimate the transmit power of the UAS. The modelling of the UL requires knowing the antenna behaviour of the BS. Since Macro BS operating in C Band likely use AAS, antenna performing beam-forming is considered in the computation of the UL. Characteristics of the planar arrays are provided below, extracted from ECC Report 283 [80]:

Table 63: Characteristics of BS planar arrays

Antenna array 8x8	Unit	Value
Maximum composite antenna Gain	dBi	26
BS Ohmic Loss	dB	0
Maximum element gain	dBi	8
H/V 3 dB beamwidth	°	80/65
Am and SLA	dB	30 for both
Horizontal and Vertical element spacing	N/A	0.6λ for horizontal 0.9λ for vertical

Moreover, a Liaison Statement (LS) to 3GPP was agreed on the need to introduce a normalisation factor to the calculation of the antenna directivity in each direction (using the formula in 3GPP TR 37.840 Table 5.4.4.2-3 [81] and Recommendation ITU-R M.2101, table 4 [51]) in order to ensure that the total array directivity is equal to 0 dB.

3GPP confirmed that it was relevant to apply such normalisation factor. Recalling the 3GPP expression for the composite array radiation pattern (TR 37.840):

$$\breve{G}_{dB}(\theta,\varphi) = A_{E\,dB}(\theta,\varphi) + 10\log_{10}\left\{1 + \rho\left[\left|\sum_{m=1}^{N_H}\sum_{n=1}^{N_V} w_{m,n}v_{m,n}\right|^2 - 1\right]\right\} \quad (19)$$

This actual array gain that has to be used in any sharing studies should be normalised as follows:

$$D(\theta,\varphi) = \frac{\breve{G}(\theta,\varphi)}{\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi}\breve{G}(\theta,\varphi)\sin(\theta)\,d\theta d\varphi} \quad (20)$$

to ensure that $TRP = P_{Tx}$ where P_{Tx} is the conducted power input to the array system.

Moreover, as indicated in the above equation, the correlation factor ρ between the elements of the antenna panel is required to compute the composite array radiation pattern. Referring to a previous (multi-industries) contribution "the correlation of out-of-block emissions across the antenna elements is uncertain." Although a 3GPP contribution (R4-125474 [82]) indicates that the impact (in terms of interference level) of unwanted out-of-block signal across antenna elements on the BSs from another mobile network is insensitive to the correlation factor of the elements of the interferer antenna panel, this observation hasn't yet be generalised to other systems/services. Consequently, this contribution accounts for this normalisation factor in the computation of the IMT2020 BS antenna gain and addresses the fully correlated case.

Finally, the computation of the BS antenna gain requires statistics of beam pointing orientation, i.e. electrical tilt and phi-scan angles because AAS are subject to time varying beam directions. For this reason, the electrical tilt and phi-scan angles distribution for BS antenna at 20 m/25 m/30 m (Macro-BS urban/suburban/rural) are provided.

ANNEX 11: STUDY FOR FSS 3800–4200 MHZ

MFCN systems, either 4G or 5G NR operating in the band 3400-3800 MHz have the potential to cause interference to FSS operating in the adjacent band 3800-4200 MHz. As 5G NR systems operating with bandwidths up to 100 MHz (ECC Report 281 [38]) they have the potential to cause interference to 25% of the adjacent band, 3800-4200 MHz, used by FSS.

This study assess' the protection distances required to limit interference to FSS operating in the band 3800-4200 MHz from aerial UE. For this study, the aerial UE OOBE characteristics are in line with ETSI TS 136 101 [36].

As OOBE characteristics of 5G NR systems conforming to ETSI TS 138 101 are similar, protection distances for such systems, though not studied, would be similar.

Table 64: Representative feeder link earth station characteristics used in this study

FSS system parameters	
Frequency band	3800-4200 MHz
Channel bandwidth	5 MHz
Earth station antenna radiation pattern	Recommendation ITU-R S.580 [95] Recommendation ITU-R S.465 [55]
Representative earth station gain (dBi)	48.8 dBi (range 41-54 dBi)
Representative Antenna diameter (m)	9 m (range 3.7-16.4 m)
Noise temperature (including the contributions of the antenna, feed and LNA/LNB referred to the input of the LNA/LNB receiver)	70 K
Antenna elevation angle	5-85°
Antenna height	10 m

The antenna elevation angle is relative to local horizontal at 0° of elevation. 5° is considered as the minimum operational elevation angle.

Table 65: Representative UAS UE characteristics used in this study

Parameter	Value	Unit
Frequency band	3.4-3.8	GHz
Frequency centre	3.7975	GHz
Channel bandwidth	5	MHz (range 5-100 MHz)
Transmitted power	23	dBm
Antenna gain	0	dBi

A11.1 INTERFERENCE PROTECTION CRITERIA

In this study, the potential interference into FSS earth stations has been evaluated based on protection criteria of I/N = -12.2 dB, in accordance with Recommendation ITU-R S.1432 [96].

A11.2 PROPAGATION MODEL

The UAS UEs are assumed to operate above the horizon while the FSS earth station deployed as feeder link is with elevation of 5 to 85 degrees. For this assessment line of sight propagation has been assumed.

A11.3 ANALYSIS AND MITIGATION

The table below is an example of the protection distances required to limit interference to receiving FSS earth station to an I/N = -12.2 dB; in this case the aerial UE is effectively around the back of the FSS antenna.

Table 66: Example of protection distance calculation with aerial UE 48 degrees off bore sight

Parameter	co-channel	±0-1 MHz	±1-2.5 MHz	±2.5-2.8 MHz	±2.8-5 MHz	±5-6 MHz	±6-10 MHz
Frequency (MHz)	3800	3800	3800	3800	3800	3800	3800
UAS UE Bandwidth (MHz)	5.00						
UAS UE Transmit (dBm)	23.00						
UAS antenna gain (dBi)	0.00						
Emission limit (dBm)/channel bandwidth	23.00	-15.00	-10.00	-10.00	-10.00	-13.00	-25.00
Measurement bandwidth (MHz)	5.00	0.03	1.00	1.00	1.00	1.00	1.00
UAS UE e.i.r.p. spectral Density (dBm/Hz)	-44.0	-59.8	-70.0	-70.0	-70.0	-73.0	-85.0
Polarisation Loss and FSS ES feeder loss	6.0	6.0	6.0	6.0	6.0	6.0	6.0
FSS ES Peak antenna gain (dBi)	48.8	48.8	48.8	48.8	48.8	48.8	48.8
Angle to UAS UE from bore sight (degrees)	48.0	48.0	48.0	48.0	48.0	48.0	48.0
FSS gain at angle to UAS (dBi)	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0
Interference received at FSS ES (dBm/Hz)	-60.0	-75.8	-86.0	-86.0	-86.0	-89.0	-101.0
RX noise temp (K)	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Rx noise temp (dBK)	18.5	18.5	18.5	18.5	18.5	18.5	18.5
FSS ES Noise PSD (dBm/Hz)	-180.2	-180.2	-180.2	-180.2	-180.2	-180.2	-180.2
I/N Protection Criteria (dB)	-12.2	-12.2	-12.2	-12.2	-12.2	-12.2	-12.2
Allowable interference PSD (dBm/Hz)	-192.4	-192.4	-192.4	-192.4	-192.4	-192.4	-192.4
Link Loss required to meet protection (dB)	132.4	116.6	106.4	106.4	106.4	103.4	91.4
Separation Distance required Free Space model (km)	26.1	4.2	1.3	1.3	1.3	0.9	0.2

The protection distance varies as a function of the bearing of the aerial UE from the boresight of the receiving antenna in the below table.

Table 67: Separation distances needed to protect FSS earth stations operating in the band 3800-4200 MHz from aerial UE using the upper frequency blocks of LTE 3400-3800 MHz

Emission limit (dBm)/channel bandwidth	-15.00	-10.00	-13.00	-25.00
Measurement bandwidth (MHz)	0.03	1.00	1.00	1.00
UAS UE e.i.r.p. spectral Density (dBm/Hz)	-59.77	-70.00	-73.00	-85.00
UAS UE angle offset from FSS antenna bore sight (degrees)	Separation distance (km)			
1	533.54	164.33	116.34	29.22
2	224.33	69.09	48.91	12.29
3	135.13	41.62	29.47	7.40
4	94.32	29.05	20.57	5.17
5	71.36	21.98	15.56	3.91
6	56.82	17.50	12.39	3.11
7	46.86	14.43	10.22	2.57
8	39.66	12.21	8.65	2.17
9	34.23	10.54	7.46	1.87
10	30.00	9.24	6.54	1.64
11	26.63	8.20	5.81	1.46
12	23.89	7.36	5.21	1.31
13	21.61	6.66	4.71	1.18
14	19.70	6.07	4.30	1.08
15	18.07	5.57	3.94	0.99
16	16.67	5.14	3.64	0.91
17	15.46	4.76	3.37	0.85
18	14.39	4.43	3.14	0.79
19	13.45	4.14	2.93	0.74
20	12.61	3.89	2.75	0.69
25	9.54	2.94	2.08	0.52
30	7.60	2.34	1.66	0.42
35	6.27	1.93	1.37	0.34
40	5.30	1.63	1.16	0.29
≥48	4.24	1.31	0.92	0.23

UK teleports have antenna covering a range of azimuths from approximately 100° to 250° ETN with elevation angles varying between about 5° on the easterly and westerly extremes, increasing to around 30° when the antenna point towards the south. Dishes located further south than the UK may, depending on the azimuth, use greater elevation angles (up to 85°).

Antennas range in size between 3.7 m and 16.4 m with 3 dB beamwidths of between approximately 1° and 0.2° and antenna gain ranging between 41 and 54 dBi. The larger antenna typically being used at the extremes of the arc - low elevation angles and narrow beams.

Whilst protection distance for aerial UE operating 'effectively behind' a FSS antenna, that is 48° or more off the arc covered by antenna - where the full antenna discrimination is available, are small, these distances increase significantly as the aerial UE get closer to the bore sight of the FSS antenna. Based on the results of this analysis, a range of protection distances would be required around a teleport to ensure protection of FSS earth stations operating in the band 3800-4200 MHz from aerial UEs operating in the adjacent band.

To avoid the need for specific protection distances associated with each FSS antenna the unwanted emissions from an aerial UE would need to be lower.

To reduce the potential for interference and effectively enable unrestricted access to airspace for aerial UE, with respect to FSS operating in the adjacent frequency band, the unwanted emissions of aerial UE would need to be limited to -60 dBm/MHz in the frequency range 3800-4200 MHz.

ANNEX 12: AERIAL UES OPERATING IN THE BAND 1920-1980 MHZ UNWANTED EMISSION INTERFERENCE INTO CGC AERONAUTICAL GROUND STATIONS RECEIVING ABOVE 1980 MHZ

A12.1 STUDY 1

This Annex deals with the potential OOBE and spurious emission interferences from UAS UEs transmitting in the band below 1980 MHz into aeronautical CGC base stations receiving in the band above 1980 MHz.

Above 1980 MHz, one operator has already deployed an operational MSS network, the "European Aviation Network" (EAN), is used to provide communications primarily to aircraft passengers and utilises a complementary ground component (CGC) of base stations across Europe

The EAN CGC base stations are up-tilted to enhance coverage to aircraft. The aircraft are equipped with terminals which communicate with the MSS satellite and terminals which communicate with the CGC base stations.

The fact that the UAS UEs operate above horizon, and the CGC BS are up-tilted, would result in the UAS UEs entering the main beam direction of the CGC BS. As well as this, the EAN network deploys CGC base stations covering cell sizes of up to 150 km in radius and this necessities the CGC base station to be more sensitive than normal terrestrial base stations, as a result of this, the CGC base stations receivers are designed with a lower noise figure of 3 dB and CGC base station antennas are typically installed with only 1 dB feeder loss or less.

Under Study 1, two sets of analysis were carried out, in Study 1A, a single entry simulation and in Study 1B, a Monte Carlo based simulation.

A12.1.1 Study 1A: Single Entry analysis

A12.1.1.1 System Parameters

This section provides the CGC base station and UAS UE technical and operational parameters used in these studies.

The below table provides the UAS UE technical and operational parameters assumed in the interference analysis for the 2 GHz. The reference for these parameters is this ECC Report.

Table 68: UAS UE technical and operational parameters

Parameter	Value
Carrier frequency	1980 MHz
Channel bandwidth	5 MHz
Transmitted power	23 dBm
Antenna gain	0 dBi
UAS Altitude	40 m to 4 km a.g.l.
OOBE	-7 dBm/5 MHz (first adjacent channel based on ACLR1 = 30 dB) 3GPP 36.101 V15.4.0 [29]**Error! Reference source not found.**
	-12 dBm/5 MHz (second adjacent channel based on integration of spectrum emission masks) 3GPP 36.101 V15.4.0 **Error! Reference source not found.**

Parameter	Value
Spurious emission	-30 dBm/MHz (third adjacent channel, spurious domain)

The table below provides the CGC base station technical and operational parameters used in the interference analysis for the 2.1 GHz.

Table 69: CGC Base station technical and operational parameters

Parameter	Value	Unit
Cell Radius	Up to 150	km
Antenna Height	30	m
Sectorisation	3	sectors
Up-tilt	10	deg
Antenna pattern		See Figure 67 and Figure 68 below
Antenna polarisation	Linear (+/- 45)	deg
Feeder Loss	1	dB
Maximum CGC BS antenna gain	13.8	dBi
Carrier frequency	1982.5	MHz
Channel bandwidth	5	MHz
CGC BS Noise figure	3	dB
System Noise Temperature	288.6	K

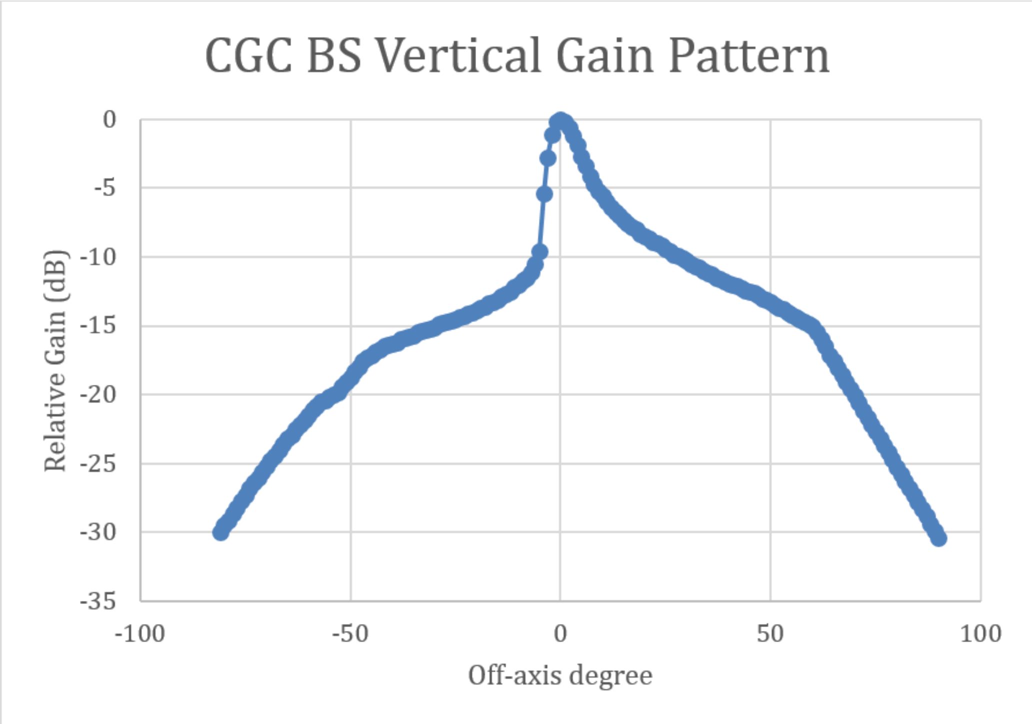

Figure 67: CGC base station antenna vertical gain pattern

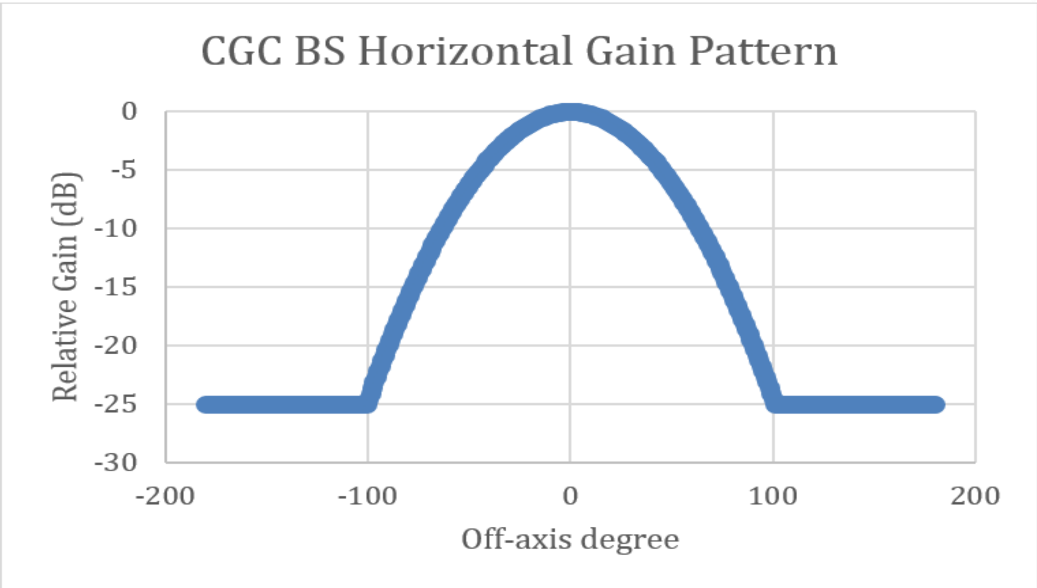

Figure 68: CGC base station antenna horizontal gain pattern

A12.1.1.2Interference Protection Criteria

From Report ITU-R M.2292 [25], the protection criteria for terrestrial mobile base stations is I/N of -6 dB, the same report specifies the feeder loss and noise figure for base station as 3 dB and 5 dB respectively.

For the EAN network, which deploys CGC base stations covering a cell size of up to 150 km in radius, the CGC BS have to be designed to be more sensitive to be able to provide the required service at the edge of such wide coverage area. Considering also that it is typical to use a lower criterion with respect to interference from OoB emissions, an appropriate I/N protection criteria for the CGC BSs is I/N -10 dB.

A12.1.1.3Propagation Model

The UAS UEs are assumed to operate above the horizon from the perspective of the CGC base station. ITU-R P.528-3 [86] propagation model, which is recommended for use in aeronautical mobile services, is typically used for this type of studies, however, this propagation model is not valid for path distances of less than 1 km. In this study, UAS flights altitudes from 40 m to 4 km a.g.l are considered. For line of sight case, the ITU-R P.528 and the free space loss give the same results, and since all the scenarios considered in this study are line of sight cases, therefore, the free space loss is used in these studies.

A12.1.1.4Methodology

Assuming one UAS UE interfering with a CGC base station, the received interference power level at the earth station is calculated according to the equation:

$$I_{UAS} = P_{UAS} + G_{UAS} + G_{CGC}(\varphi) - L \qquad (21)$$

Where:

- I_{UAS}: Received interference power level at the earth station (dBm);
- P_{UAS}: Transmitted power of UAS system (dBm);
- G_{UAS}: Antenna gain of UAS system (dBi);
- $G_{CGC}(\varphi)$: Receive antenna gain of the CGC base station (dBi);
- L: Path loss (dB);
- φ: The off-axis angle of the interference signal.

A12.1.1.5Technical Studies and Results

This section evaluates a baseline single entry interference analysis. The interference analysis conducted is an adjacent band interference, OOBE and spurious emission from UAS UE into CGC base station using the methodology described above and the parameters provided in section A12.1.1.1.

The interference analysis considered interference levels received by CGC BS from the OOBE of the UAS UE first adjacent channel, second adjacent channel, and from the spurious emission of the UAS UE while the UAS is flying at different altitudes ranging from 40 m to 4 km above a CGC base station. Figure 69 below shows the resulting plots of the I/N values calculated against distances between UAS UE and CGC base station corresponding to the UAS UE OOBE of first adjacent channel, OOBE of second adjacent channel and its spurious emission respectively.

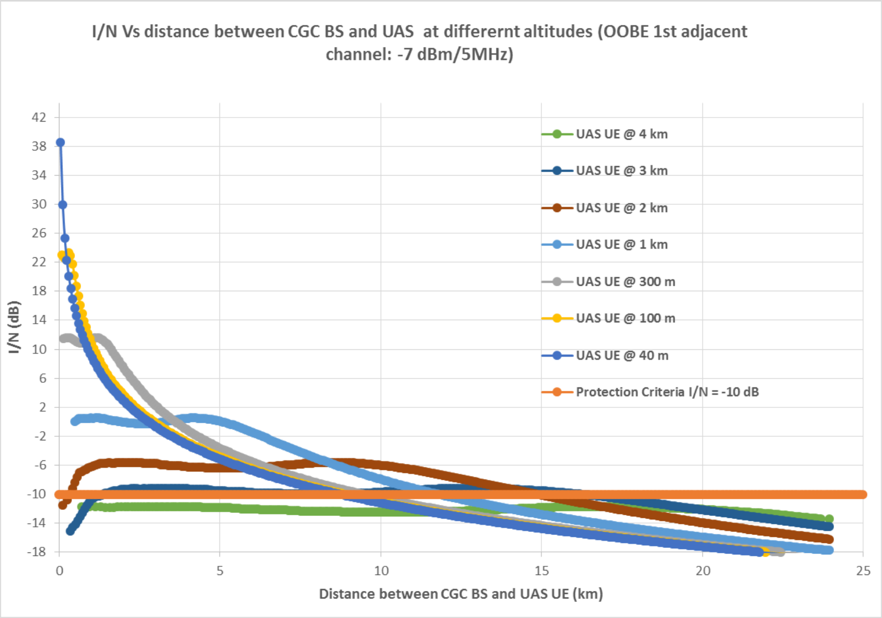

Figure 69: Plot of I/N against distance resulting from the OOBE of first adjacent channel of the UAS UE

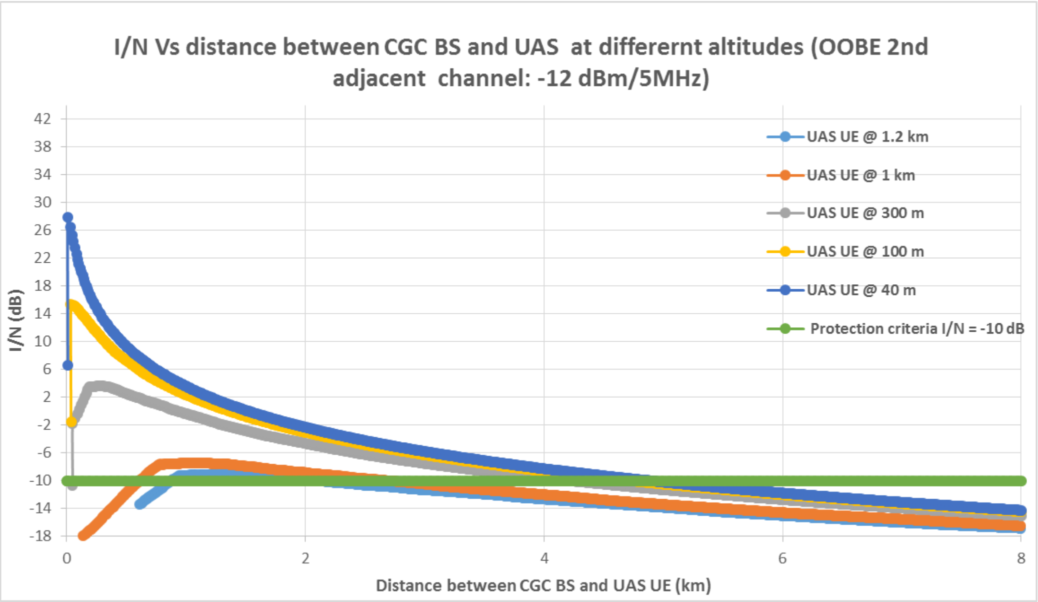

Figure 70: Plot of I/N against distance resulting from the OOBE of second adjacent channel of the UAS UE

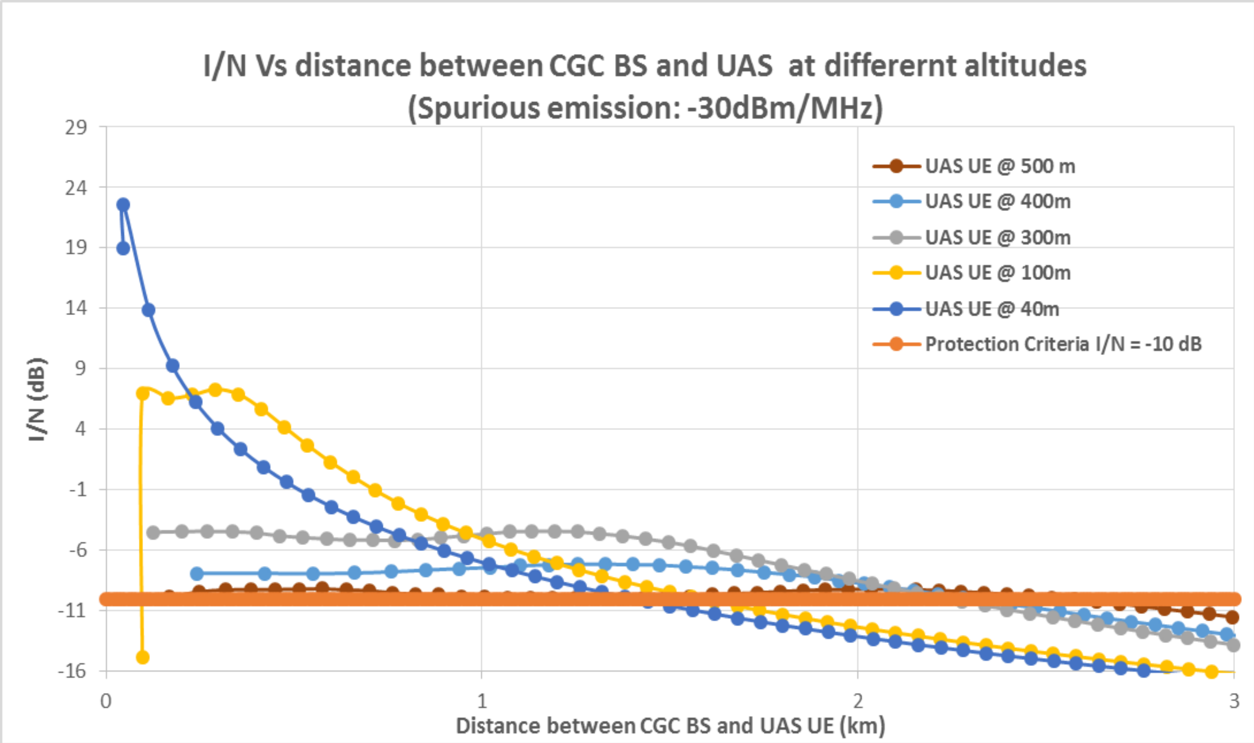

Figure 71: Plot of I/N against distance resulting from spurious emission of the UAS UE

<u>Analysis and Mitigation</u>

Looking at the results shown in Figure 69 to Figure 71, the following can be summarised:

- Figure 69 shows the levels of interference received at the CGC BS from the OOBE of the first adjacent channel of the UAS UE when the UAS is at different altitudes and distances from the CGC BS. As the results show, when the UAS is flying at an altitude of 3 km and above, there is no risk of interference, while when the UAS is flying at an altitude below 3 km, there is harmful interference and a separation distance of about 15 km is required between the CGC BS and UAS UE to ensure that the permissible interference level, at the CGC base station is never exceeded for a single UA.
- Figure 70 shows the levels of interference received at the CGC BS from the OOBE of the second adjacent channel of the UAS UE when the UAS is at different altitudes and distances from the CGC BS. As the results show, when the UAS is flying at an altitude of 1.2 km and above, there is no risk of interference, while when the UAS is flying at an altitude below 1.2 km, there is harmful interference and a separation distance of about 5 km is required between the CGC BS and UAS UE to ensure that the permissible interference level, at the base station is never exceeded for a single UA;
- Figure 71 shows the levels of interference received at the CGC BS from the spurious emission of the UAS UE when the UAS is at different altitudes and distances from the CGC BS. As the results show, when the UAS is flying at an altitude of 500 m and above, there is no risk of interference, while when the UAS is flying at an altitude below 500 m, there is harmful interference and a separation distance of about 2.5 km is required between the CGC BS and UAS UE to ensure that the permissible interference level, at the base station is never exceeded for a single UA.

The above analysis is summarised below in Table 70 showing the separation distance required between the CGC BS and the UAS UE to ensure protection of CGC BS from the interference of different UAS UE emission levels for different UAS altitudes. Looking at the results in Table 70, it can be stated that the interference from the UAS UE spurious emission is not the liming case for the operation of UAS UE in the 2.1 GHz MFCN band, i.e., the separation distances required to ensure protection of CGC BS from the OOBE of the UAS UE, would also address any interference that might be caused by the spurious emission of the UAS UE.

Table 70: Separation distance required between the CGC BS and the UAS UE to ensure protection of CGC BS for different UAS UE emission levels and altitudes

UAS UE OOBE/spurious level	UAS altitude	Required separation distance
-7 dBm/5 MHz (first adjacent channel)	Below 3 km	15 km
-12 dBm/5 MHz (second adjacent channel)	Below 1.2 km	5 km
-30 dBm/MHz (spurious)	Below 500 m	2.5 km

A12.1.1.6Comparison study of aerial and ground UE interference into CGC BS receivers

In section A12.1.1.5, the interference analysis from aerial UE at different altitudes into CGC BS was carried out. In this section, the interference from ground UE into a CGC BS is analysed in order to compare the interference level from ground UE to the results of interference from aerial UE into CGC BS receivers. Also, a further comparison study of the interference levels received by the CGC BS from an aerial UE with reduced OOBE level was compared to the interference levels received from ordinary ground UEs without reduced OOBE level.

The analysis of ground UE into CGC BS was a single entry interference caused by a single UE on the ground which operates in the first adjacent channel to the CGC BS band.

The following ground and aerial UE system parameters where used in the comparison analysis.

Table 71: Ground and aerial UE parameters for comparison study:

Parameter	Value (ground UE)	Value (aerial UE)	Reference
Out of band emissions Above 1980 MHz	-7 dBm/4.5 MHz	-7 dBm/4.5 MHz	3GPP 36.101 V15.4.0 table 6.6.2.3.1-1 [29]**Error! Reference source not found.**
Height	1.5 m	1 km, 300 m, 100 m, 40 m	
Maximum transmit power	23 dBm	23 dBm	
Antenna gain used	-3 dBi	0 dBi	
UE body loss (when held close to the head and in hand)	4 dB for voice calls and 1 dB for data calls	0 dB	
Protection criteria (I/N)	-10 dB	-10 dB	See section A12.1.1.2 for rationale
Propagation model	Hata model for rural	Recommendation ITU-R P.525-4 [76]	

Using the above parameters and the methodology described in section A12.1.1.4, interference levels received by CGC BS from a ground UE were simulated at different horizontal distances from the CGC BS. Figure 72 below shows the resulting plots of the I/N values calculated against distances between the ground UE and CGC base station, together with the corresponding results of an aerial UE at the same horizontal distances and different altitudes of 40, 100, 300 and 1000 m above a CGC base station. For the ground UE, two UE body loss values were used, 4 dB (when the UE is held close to the head during voice calls) and 1 dB (when the UE is held in the hand during data calls).

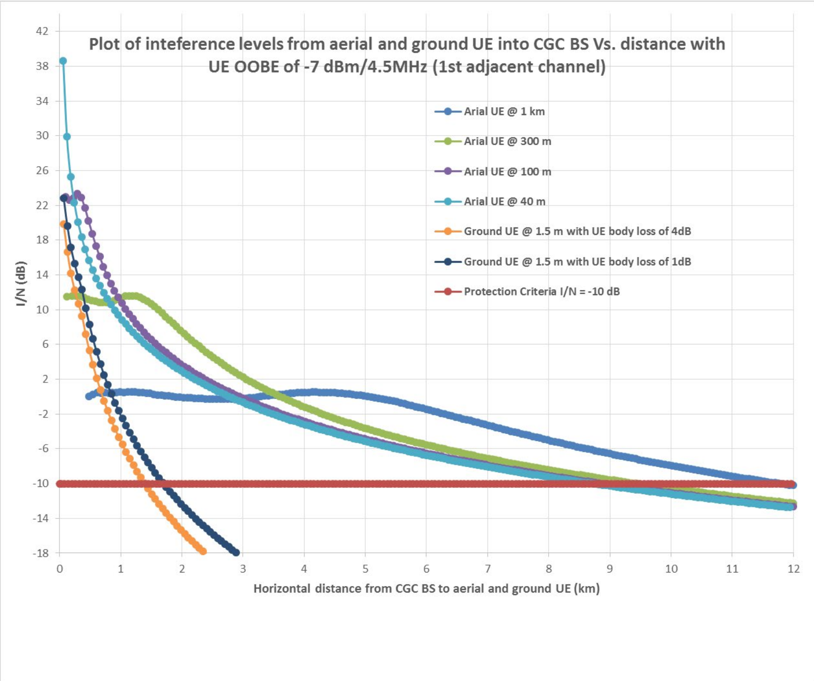

Figure 72: Plot of I/N against distance resulting from ground and aerial UEs

The above plot shows that the interference levels from aerial UEs into CGC BS with aerial UE flying below 1000 m and without any OOBE level reduction would be higher than the interference caused by ground UEs with the same OOBE levels.

A further comparison study, similar to the MetSat comparison study that was done in Annex 5, was carried out, where the interference levels received by the CGC BS from an aerial UE with a reduced OOBE level (-30 dBm/MHz, equivalent to -23.5 dBm/(4.5 MHz)) was compared to the interference levels received from ordinary ground UE without any reduction in OOBE level (-7 dBm/(4.5 MHz)). The results of this comparison study is shown in the below figure.

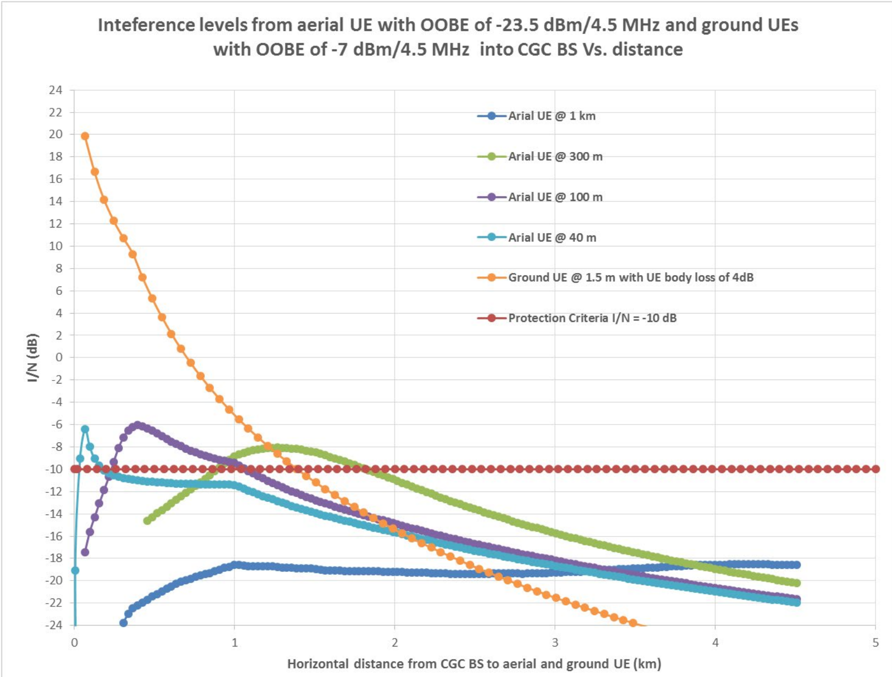

Figure 73: Plot of I/N against distance resulting from ground UE (OOBE=-23.5 dBm/4.5 MHz) and aerial UE (OOBE=-7 dBm/4.5 MHz)

The above plots are the interference levels from aerial UEs into CGC BS with aerial UE flying at different altitudes and with aerial UE OOBE level reduced to -23.5 dBm/(4.5 MHz) (i.e., a reduction of 16.5 dB from -7 dBm/(4.5 MHz)), as well as interference levels from ground UE into CGC BS without any reduction in OOBE levels.

The results show that at horizontal distances less than approximately 1.3 km from the CGC BS, while there are some interference from aerial UEs, the interference is lower than the interference from ground UEs. At horizontal distances close to the CGC BS, there is some interference from ground UE, however, currently, there is no interference experienced from ground UEs into CGC BS, this could be because:

- CGC BS are typically co-located with terrestrial rural base stations, and therefore when the ground UE is close to the serving BS, the power control of the UE will be deployed reducing the OOBE of the UE significantly than the value assumed in this study;
- CGC BS actual antennas typically have lower side lobes towards the ground compared to the mask assumed in the study, as they are designed to direct the energy upwards to optimise coverage to aircrafts and to minimise gain in the direction of the ground. This could have significant impact on the interference received from ground UEs into CGC BS.

With aerial UE OOBE level reduced to -23.5 dBm/(4.5 MHz) (-30 dBm/MHz), the interference from ground UE located close (approximately 1.3 km) to the CGC BS would be lower than the interference from aerial UEs. Interference would however be higher for an aerial UA operating at 300m altitude. Note that this unwanted emission level, -30 dBm/MHz, is the same as the spurious emission of the aerial UE assumed in the studies done in section A12.1.1.5, and as indicated in Table 70 and in the conclusion table below, the separation distance required to protect CGC BS from aerial UEs with spurious emission of -30 dBm/MHz is 2.5 km. Therefore, while aerial UEs with an unwanted emission level of -30 dBm/MHz coupled with separation distance of 2.5 km would provide 100% protection of CGC BSs, if administrations choose to apply CGC BS protection measures relative to the interference caused by ground UEs, then this would mean limiting the OOBE of aerial UEs to -30 dBm/MHz but without needing any separation distances; this protection measure doesn't provide 100% protection as there is some interference above the criterion if the aerial UE is permitted to operate within around 2.5 km of the CGC base station.

In summary, the different protection measures are shown in the table below in the conclusion section.

A12.1.1.7Conclusion

Table 72: Conclusions on protection measures

UAS UE OOBE/spurious level	Required separation distance	Protection of CGC BSs
-7 dBm/5 MHz (first adjacent channel)	15 km	100%
-30 dBm/MHz	2.5 km	100%
-30 dBm/MHz	No separation distance	There is a risk of interference which is comparable to that of ground UEs.

A12.1.2 Study 1B: Monte Carlo simulation

In this Report, in ANNEX 13:, a comparative analysis of the interference received by CGC base stations (BS) from ground UEs and aerial UEs was studied. The analysis was done for rural and urban deployment scenarios based on Monte Carlo simulation. As is stated in the executive summary, 3GPP performed extensive studies on aerial UEs using MFCN networks. 3GPP studies (3GPP TR 36.777 [1]) used a number of parameters and assumptions, such as:

- Typical aerial UE application data include video streaming, images with data rates of up to 100Mbps;
- Aerial UE heights above ground of 50 m, 100 m, 200 m and 300 m;
- Five cases of aerial UE to the total UEs ratios were considered (Case 1: 0%, this is used as baseline, Case 2: 0.67%, Case 3: 7.1%, Case 4: 25% and Case 5: 50%).

With regards to the percentage of aerial UEs to the total UEs, 3GPP stated that the impact of aerial UEs on network performance remain modest when the percentile of aerial UEs remain low and 3GPP concluded that no more than 33% of the UEs per cell should be aerial UEs with current technology to avoid self-interference.

It should be noted that some of the assumptions and parameters used in the studies in ANNEX 13:, are different from the above listed 3GPP parameters and assumptions. As well as this, the study in ANNEX 13: assumes in all the scenarios that the CGC BS to be co-located with terrestrial BS. This is a critical assumption and has an impact on the level of interference received by CGC BS when compared to the interference levels received by the CGC BS when it is not co-located with a terrestrial BS.

In this study, a Monte Carlo simulation was carried out using parameters and assumptions consistent with the 3GPP report on the aerial UEs using MFCN networks in order to analyse the interference levels received by the CGC BS from aerial UEs in both rural and urban deployment scenarios, and to analyse the impact on interference received by CGC BS when it is co-located with a terrestrial BS and when it is not co-located. An MFCN network was modelled using the Visualyse modelling tool to implement Monte Carlo simulation by following the parameters and assumptions in Report ITU-R M.2292 [25] and Recommendation ITU-R M.2101 [51] for the implementation of the topology of MFCN deployment and UE power control as well as other assumptions.

A12.1.2.1Simulation parameters and assumptions

The parameters and assumptions for the different systems and characteristics were as follows:

- MFCN Mobile Network topology in the 2 GHz band for uplink was as shown in Table 82 of this Report;
- Ground and aerial UE parameters are as shown in Table 83 of this Report;
- MFCN BS characteristics in the 2 GHz band are as shown in Table 84 of this Report;
- Propagation assumptions for the scenario of ground UE into CGC BS is based P.1546-5 [49] and aerial UEs into CGC BS interference is based on free space loss as given in Table 85 of this Report;
- CGC base station parameters are given in Table 86 of this Report;
- The parameters from 3GPP listed in section 1 of this study are also considered.

As well as the above, the following are assumed in this study:

- Ratio of aerial UEs to ground UEs as 33% as per 3GPP recommendation than no more that 33% is used;
- Aerial UEs altitudes of 40 m to 10 km and 40 to 300 m as per 3GPP, see Figure 74 below from (3GPP TS 22.125 [7]);
- One case of CGC BS co-located with terrestrial BS and another case when CGC BS is not co-located;
- A range of target C/N at the BS to reflect the range of data rates shown in Figure 74 below from (3GPP TS 22.125)

Table 7.1-1 KPIs for services provided to the UAV applications

Use case	Services	Data rate	End to end Latency	Altitude AGL	service area (note 4)
1	8K video live broadcast	100Mbps UAV originated	200 ms	<100 m	Urban, scenic area
		600Kbps UAV terminated	20 ms	<100 m	
2	Laser mapping/ HD patrol Note 7	120Mbps UAV originated Note 1	200 ms	30-300 m	Urban, rural area, scenic area
		300Kbps UAV terminated	20 ms	30-300 m	
3	4*4K AI surveillance	120Mbps UAV originated	20 ms	<200 m	Urban, rural area
		50Mbps UAV terminated	20 ms	<200 m	
4	Remote UAV controller through HD video	>=25Mbps UAV originated (Note 3)	100 ms	<300 m	Urban, rural area
		300Kbps UAV terminated	20 ms	<300 m	
5	Real-Time Video	0.06 Mbps w/o video UAV originated	100 ms	-	Urban, rural, countryside
6	Video streaming	4 Mbps for 720p video 9 Mbps for 1080p video UAV originated	100 ms	-	Urban, rural, countryside
7	Periodic still photos	1Mbps UAV originated 1S 0.1m	1s	<120 m	Urban, rural, countryside

NOTE 1: The flight average speed is 60km/h. The KPI is referring to [5].
NOTE 2: The latency is the time of the 5G system provide higher accuracy location information of a UAV to a third party.
NOTE 3: Referring to clause 5.2.2, the absolute flying speed of UAV in this service can be up to 160km/h.
NOTE 4: The density of active UAV is $10/200km^2$. The maximum altitude is 300m. The flight average speed is 60km/h.

Figure 74: A table from (3GGP 22.125 [7]) showing a range of data rates and aerial altitudes with maximum of 300 m

A12.1.2.2Modelling of the MFCN Network

The MFCN network was modelled based on the topology given in Recommendation M.2101 [51]. The base stations are deployed using the geometry for a 3-sector deployment shown below as a hexagon, with the parameters cell radius and inter-site distance as given in M.2101, and shown in Figure 75 below.

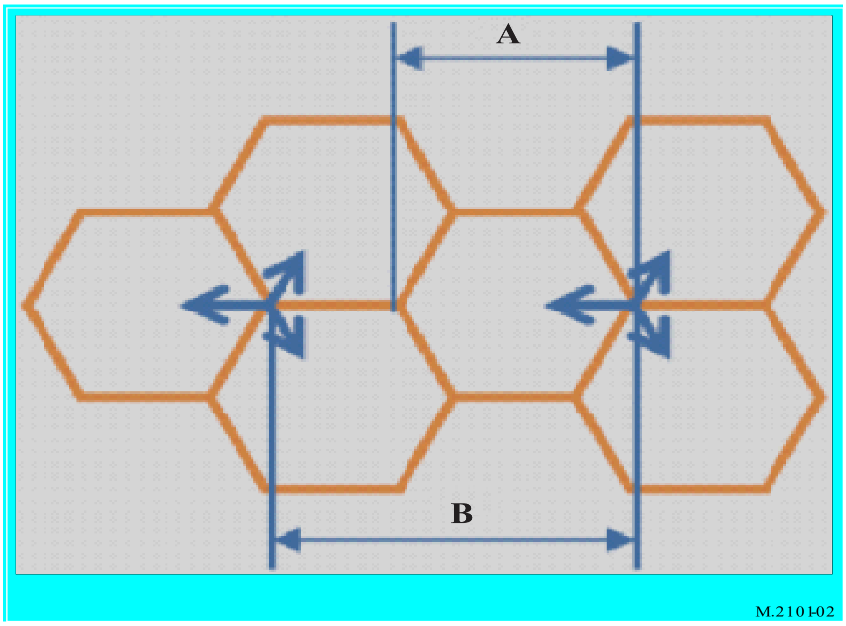

Figure 75: Macro cell geometry

A12.1.2.3Urban deployment scenario

Using the above geometry in Figure 75, for the urban deployment scenario, an MFCN network topology was generated consisting of a cluster of 19 base stations with three sectors using the Visualyse simulation tool as shown in Figure 76 below.

Figure 76: MFCN base stations in urban deployment scenario

The above set up was for interference from ground and aerial UEs into the CGC BS. For the aerial UE interference into CGC BS, one aerial UE per base station was assumed giving 19 aerial UEs as shown in the Figure 77 below.

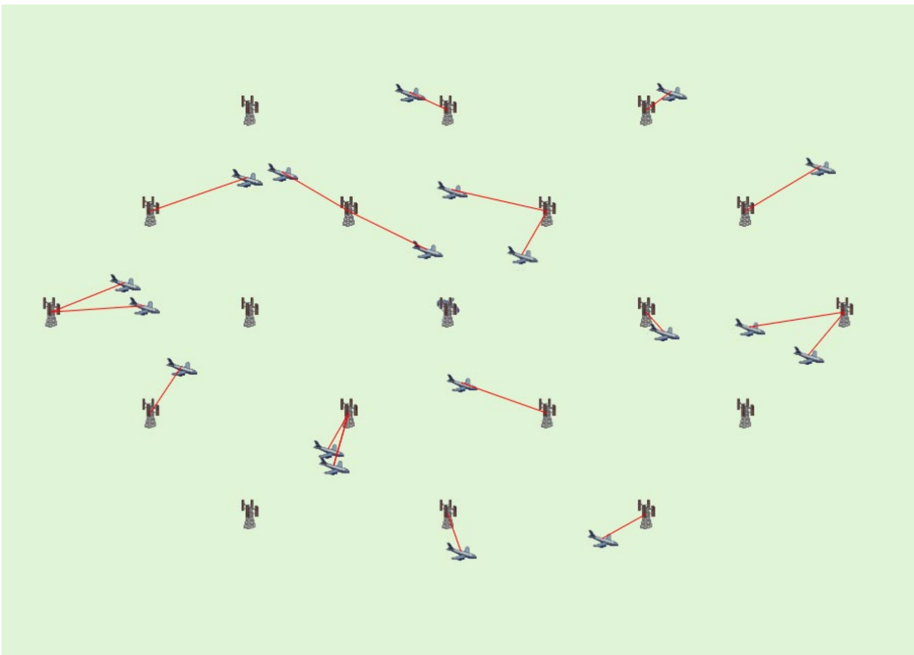

Figure 77: MFCN base stations and aerial UEs in urban deployment scenario

A12.1.2.4Rural deployment scenario

For the rural scenario, a simulation area of 341 km^2 was considered. This area corresponds to an area covered by 21 cells/sectors for the rural scenario. Using the density of UEs given in M.2292 [25] for rural deployment scenario, 0.17/km^2, the number of UEs are calculated as 57, as shown Figure 78 below. As was described above, 3GPP stated that the ration of aerial UEs should be no more than 33% of all the UEs, so using 33% value, this would give 19 drones in the deployment area of 341 km^2, as shown in Figure 79 below.

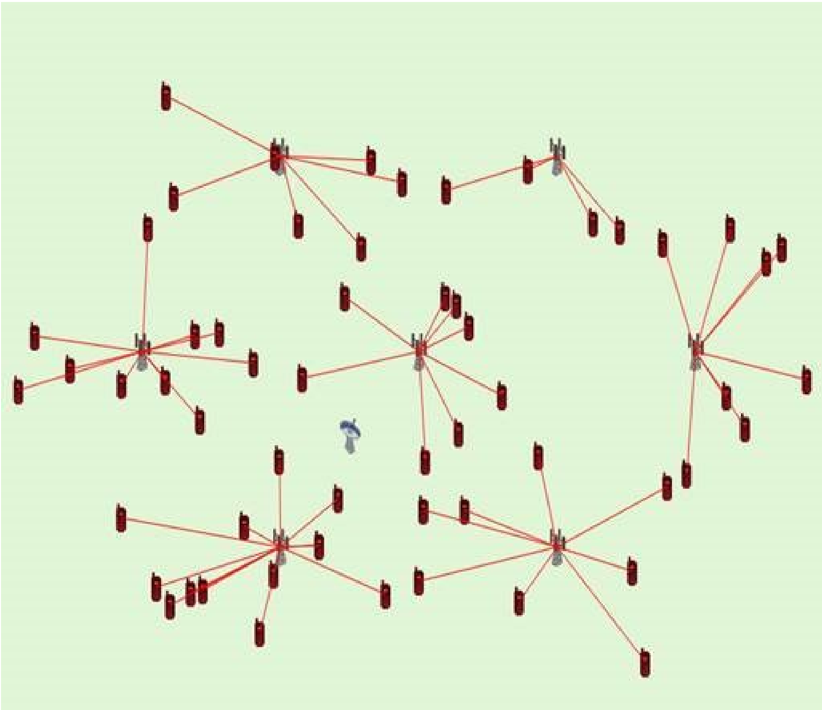

Figure 78: 57 ground UEs in a rural scenario of area of 341 km^2 with 21 cells

Figure 79: 19 aerial UEs in a rural scenario of area of 341 km^2 with 21 cells

A12.1.2.5Monte Carlo simulation set up

Using the Visualyse simulation tool, the Monte Carlo simulation was configured as follows:

The required base stations are generated in line with the geometry described above, with the inter-site distance and cells size as per M.2292 [25] for the given deployment scenario (rural and urban)

The ground UE is randomly located within the cell of the nearest BS and the highest BS antenna beam gain. The aerial UE is also randomly located within a cell to the nearest BS, their altitude is also randomly varied within the range

UE power control: Where the ground/aerial UE transmit power levels between the maximum and minimum depending on the propagation loss, the BS relative receive gain and the target signal level at the BS corresponding to the target C/N.

A12.1.2.6 Interference results and analysis

Rural deployment scenario results

For the rural deployment scenario, the interference probability from ground UE and aerial UEs were determined and compared.

Arial UEs interference into CGC BS results

For the rural scenario of interference from aerial UEs into CGC BS, analysis was done for:

- Range of aerial UEs altitudes, 40 m to 300 m which was based on 3GGP TS 22.125 [7], see Figure 74 and 40 m to 10000;
- For C/N of 20 dB and 15 dB;
- For CGC BS co-located with terrestrial and not co-located.

The results are shown in Table 73 below.

Table 73: Arial UEs interference into CGC base stations for rural scenario

Aerial UE altitude a.g.l	C/N (dB)	20		15	
	CGC BS location	Co-located	Not co-located	Co-located	Not co-located
40-300 m	% of probability of interference	80	82	52	58
40-10000 m	% of probability of interference	9.8	10.5	3.8	7.3

As the results in Table 73 show, the interference is higher when the target C/N set is higher, this is because the aerial UE will have to transmitter higher to achieve the higher C/N and hence causing more interference. Similarly, when the altitude of the aerial UE is higher the aerial UE will have to transmit higher to meet the required target signal level at the BS. Finally, the results show then the CGC BS is co-located, the interference is lower than when it is not collocated.

Ground UEs interference into CGC BS results

For the rural scenario of interference from ground UEs into CGC BS, analysis was done for two values of C/N and with the CGC BS co-located and not co-located, and the results are shown in Table 74.

Table 74: Ground UEs interference into CGC base stations for rural scenario

C/N (dB)	20		15	
CGC BS location	Co-located	Not co-located	Co-located	Not co-located
% of probability of interference	0.75	1.4	0.4	0.6

Looking at the results in Table 74 and comparing them to the interference from aerial UEs, the interference from aerial UEs into CGC BS is much higher than the interference from ground UEs.

While the interference from ground UEs is very small, the results show that the interference is higher when the CGC BS is not co-located with a terrestrial BS.

In summary, the interference from aerial UEs into CGC BS is much higher than the interference from ground UEs, also the interference into CGC BS is higher when the CGC BS is not co-located.

Urban deployment scenario results

For the urban deployment scenario, the simulation was as depicted in Figure 77, where 19 aerial UEs with altitude range of 40 m to 10 km are randomly located in the network coverage area and within the altitude range. Two case of interference into CGC BS were considered. The first case is aerial UEs interference into CGC BS when the CGC base station is co-located with terrestrial BS, and the second case was for the CGC base station not co-located with terrestrial BS.

The interference received in both cases was presented as the cumulative distribution function (cdf) of I/N as shown in the plot in Figure 80 below.

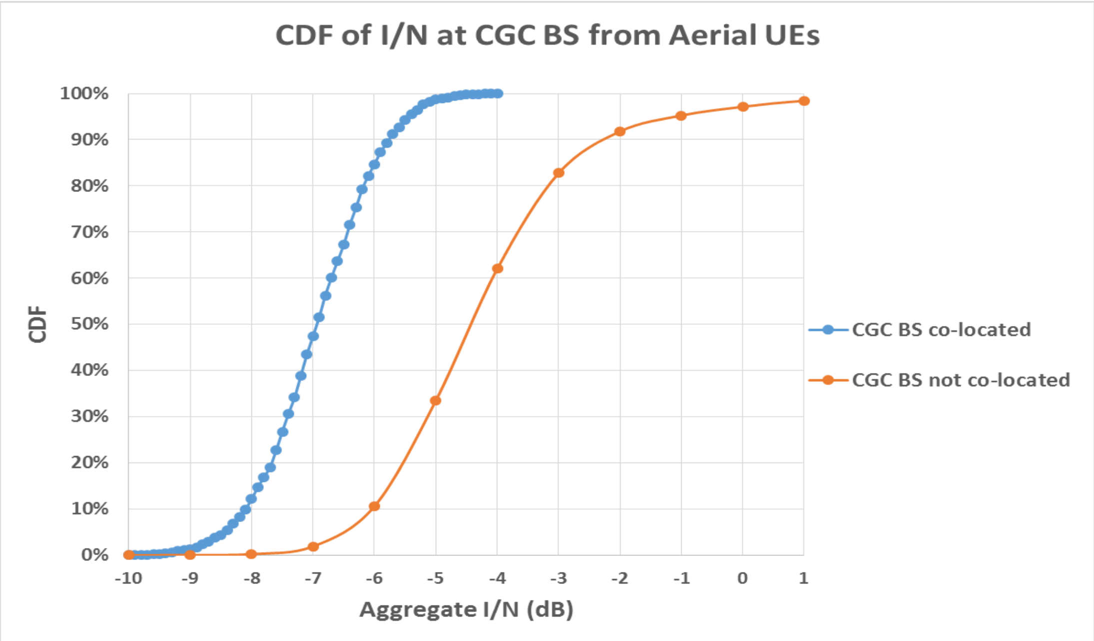

Figure 80: Results of interference from aerial UES when the CGC BS is co-located and not co-located with terrestrial BS

The above results show clearly the impact of the location of the CGC BS when consider interference into the CGC BS. From the above plot, considering I/N of -6 dB, when the CGC BS is co-located the probability of the interference exceeding I/N= -6 dB is less than 17% while when the CGC BS is not co-located, the probability of the interference exceeding I/N = 6 dB is 90%, this is a significant difference with major impact on the results of interference analysis into CGC BS.

A12.1.2.7Additional Monte Carlo Study with different size of simulation area

According to Table 20, the parameters used in the analysis of MetSat stations, aerial UE altitudes of up 10 km above ground level are able to see an area of 535,858.32 km^2. This simulation area was used in the aggregate study of aerial UEs interference into MetSat. Additional studies have been carried out using different simulation area sizes for the rural scenario in order to analyse the impact of simulation area size on the aggregate interference from aerial UEs into CGC BS. The analysis with different simulation area was done starting with 990 km^2 and then gradually increasing the simulation area size. For this additional study, the other assumptions and parameters were kept the same: aerial altitude 40 m to 10 km, SNR of was 10 dB, I/N = -6 dB and keeping the same density of aerial UEs, i.e. 1 aerial UE/cell. The ratio of aerial UEs to total number of UEs assumed was 7%, which is much lower than that assumed in 3GPP (up to 33%).

The below table shows the results of probability of aggregate interference from aerial UEs into CGC BS with different simulation area sizes, the results clearly show that with increased size of the simulation area, the aggregate interference from aerial UEs into CGC is increased. These results show fact that using only 990 km^2 area underestimates the aggregate interference from aerial UEs into CGC BS when compared to the visible area by aerial UEs at 10 km altitude.

It should be noted that the largest simulation area considered in Table 75 was 5026 km^2 resulting in almost 100% of probability of aggregate interference but this areas is still much smaller than the visible area (535,858.32 km^2) by aerial UEs at an altitude of 10 km.

Table 75: Probability of aggregate interference from aerial UEs into CGC BS with different sizes of simulation areas

Simulation area size (km2)	% of probability of interference
990	8.0
1520	17.4
1962	28.9
2463	50.0
3019	68.5
3421	79.8
3848	87.6
4300	93.3
5026	98.5

The above results in Table 75 show that for the aggregate interference from aerial UEs into CGC BS, the size of the simulation area used in the analysis is critical and has huge impact on the received aggregate interference into CGC BS, as the size of the simulation area determines the number of aerial UEs for the aggregate interference. The above results in Table 75 show a significant increase in aggregate interference level as the simulation areas is increased.

A12.1.2.8Conclusions

In this study, the interference received by CGC BS from ground and aerial UEs in the rural and urban deployment scenarios were considered and the results showed that the interference from aerial UEs in to CGC BS is much higher than the interference from ground UEs.

Therefore, in conclusion, administrations need to consider protection measures for CGC BS from aerial UE interference by applying, either an exclusion zone or aerial UE OOBE limit as given in Table 76 below.

Table 76: Results from this study

Minimum separation distance required	Regulatory limit required of aerial UE OOBE above 1980 MHz to protect CGC BS at the required separation distance
15 km	-7 dBm/4.5 MHz (ACLR1)
2.5 km	-30 dBm/MHz (Spurious)
0 km	-30 dBm/MHz, there is a risk of interference which is comparable to that of ground UEs, based on single interference worst-case scenario where aerial UE operates up to 1 km altitude a.g.l. Based on Monte Carlo study-1B, considering aerial UE altitude of up to 300 m or 10,000 m (Annex 13.2), no OOBE limit would lead to interference greater than that experienced from ground UEs, hence an OOBE limit of -30 dBm/MHz is determined.

A12.2 STUDY 2

Study 2 considers interference from an aerial UE operating in a 2 GHz MFCN network with respect to an MSS CGC aeronautical system operating in the band 1980-2010 MHz. In this study, reference is made to interference between two aeronautical CGC systems operating in the band 1980-2010 MHz on adjacent frequencies, with characteristics based on the ETSI harmonised standard. While referring to the study, the following facts should be taken into account:

- There is currently one MSS CGC aeronautical system operator (Inmarsat) providing service to passenger aircraft in the band 1980-1995 MHz;
- The second MSS operator (EchoStar), which may use the band 1995–2010 MHz, does not operate an MSS CGC aeronautical system, and hence the interference analysis in study 2 is based on theoretical assumptions and not an actually deployed network;
- If the second operator was to deploy an MSS CGC aeronautical system in the band 1995–2010 MHz, interference between the systems can be mitigated co-locating the base stations, which is a method identified in ECC Report 233 [83] to mitigate interference to a DA2GC system. In addition, bilateral coordination requirements means that there is the possibility to require constraints on the second operator additional to those provided by operation under the ETSI standards, if that was necessary. Such assumptions cannot be made for an aerial UE operating in a 2 GHz MFCN network. Therefore, the comparison made in study 2 may not be realistic;
- Study 2 is only valid for aerial UEs operating at altitude above 1000 m a.g.l, this is the minimum altitude mandated by the ETSI standard for MSS CGC aeronautical terminal.

A12.2.1 Introduction

This study examines the potential interference of an aerial UE operating within 1920-1980 MHz into the MSS CGC aeronautical system operating in 1980-2010 MHz.

Figure 81 presents the potential interference scenarios

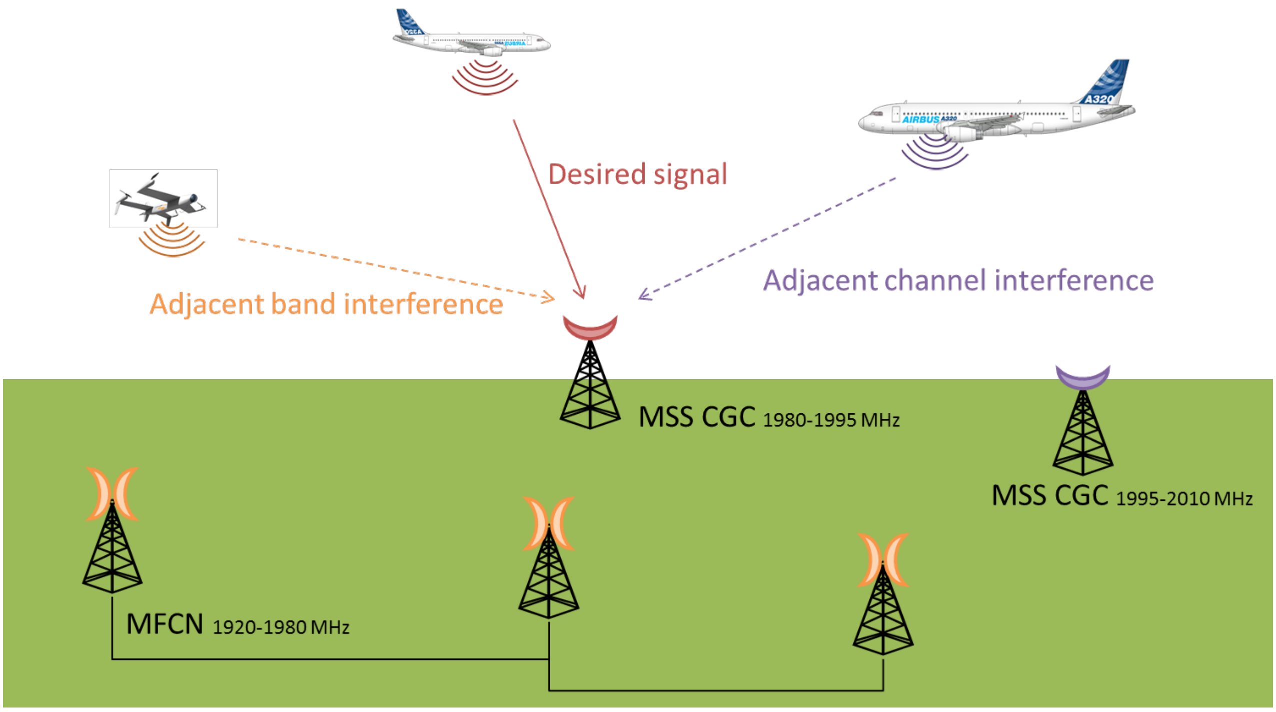

Figure 81: Potential interference scenarios to MSS CGC aeronautical around 1980 MHz

A12.2.2 Analysis based on MSS CGC Adjacent Channel interference

ETSI EN 302 574-2 [84] provides the transmit parameters for Aeronautical Terminals (MSS CGC UE mounted on aircrafts), see Table 77. The actual measured performance of the adjacent channel leakage ratio (ACLR) of the aeronautical terminal communicating with the CGC BS is 9.7 dB better than ACLR in the ETSI standard, see Table 77 below. The same ETSI standard also specifies the minimum altitude that MSS CGC aeronautical terminal operates is limited to 1000 m.

Table 77: Aeronautical Terminals Parameters

Parameter	Value	Reference
Transmitter Maximum Output Power	37 dBm	ETSI EN 302 574-2 [84]
Adjacent Channel Leakage Ratio	44 dB	ETSI EN 302 574-2 [84]
Adjacent Channel Leakage Ratio	53.7 dB	Actual measured performance

Based on ETSI EN 302 574-2, MSS CGC aeronautical terminals operating in adjacent channels from the desired MSS CGC channel transmit with up to -7 dBm/(4.5 MHz) in the adjacent channel,.

Considering that MSS CGC aeronautical terminals and MFCN aerial UE operate with the same interference scenario geometry MFCN aerial UEs MSS CGC BS operating in adjacent band. MFCN aerial UE operate with a maximum transmitter output power of 23 dBm with ACLR of 30 dB corresponding precisely to -7 dBm/(4.5 MHz) for a 5 MHz aerial UE and -7 dBm/(9 MHz) for a 10 MHz aerial UE.

Therefore, no specific measures are required to protect MSS CGC BS from interference from aerial UEs.

A12.2.3 Analysis based on MSS Aeronautical CGC BS selectivity

ETSI EN 302 574-1 [85] provides the receive parameters for MSS Aeronautical CGC base stations, see Table 78.

Table 78: MSS Aeronautical CGC base stations parameters

Parameter	Value	Reference
Reference Sensitivity (RefSens)	-101.5 dBm	ETSI EN 302 574-1 [85]
Adjacent Channel Selectivity	-52 dBm @ RefSens + 6 dB	ETSI EN 302 574-1 [85]
Noise Level	-174 dBm/Hz	
Bandwidth	5 MHz	
Noise Figure	3 dB	

From the parameters in Table 78:

- The Receiver_Noise can be deduced as Noise Level +10xlog10(Bandwidth)+Noise Figure = -104 dBm
- The noise and interference level corresponding to the ACS test level is therefore Receiver_Noise+6 dB=-98 dBm, corresponding to an interference of -99.3 dBm.
- The MSS Aeronautical CGC base stations therefore filter an input signal of -52 dBm to a resulting interference of no more than -99.3 dBm, corresponding to an attenuation of 47 dB.

Comparing the ACLR of terminals (see Table 77) to the MSS Aeronautical CGC base stations adjacent channel filtering (47 dB), it is clear that the adjacent channel interference will be dominated by the adjacent channel leakage of terminals, when considering standard ACLR.

Improving the ACLR of aerial UE would improve the coexistence situation as long as the aerial UE emissions in 1980-2010 MHz are above 23-47=-24 dBm/(5 MHz). This level corresponds more or less to the aerial UE spurious emission level (-30 dBm/MHz = -23 dBm/(5 MHz)).

Below this emission limit, the aerial UE emission in the 1980-2010 MHz is not the dominant factor, and the interference will be dominated by the lack of MSS Aeronautical CGC Base Station selectivity.

A12.2.4 Conclusion

Taking into account the adjacent channel interference situation within the MSS band, it can be concluded that aerial UEs operating in 1920-1980 MHz will not create more interference than MSS aeronautical terminal in adjacent channels For administrations wishing to provide more protection to MSS Aeronautical CGC base stations, additional protection can be achieved by ensuring the aerial UE operates only in frequency channels ensuring that MSS Aeronautical CGC base stations operates in the second adjacent channel or spurious domain. This can be achieved by limiting the authorisation of aerial UEs to the lower channels of the 1920-1980 MHz band.

A12.3 STUDY 3

A12.3.1 Introduction

The band 1980–2010 MHz is designated for MSS in CEPT and is used in Europe by two MSS operators. One operator has an operational network, European Aviation Network which uses a complimentary ground component (CGC) with base stations on the ground to provide passenger communications within an aircraft. The aircrafts communicate with the CGC base stations (uplink) in the 1980-2010 MHz band, which are located across Europe. The base stations are generally up-tilted to enhance coverage to the aircraft.

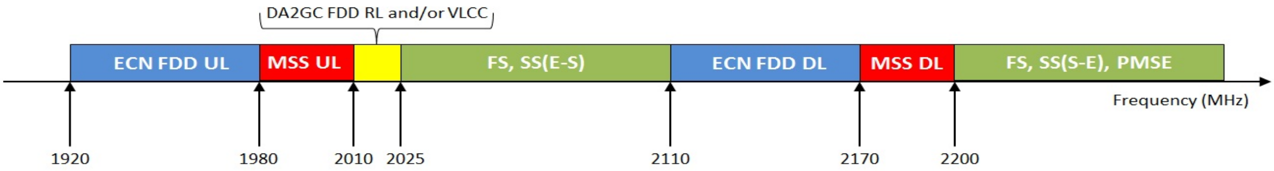

Figure 82: Different services in the 2 GHz band indicating MSS UL adjacent to Band 1 Uplink [83]

A12.3.2 Simulation assumptions

The table below lists the simulation assumptions for the CGC base station and Table 80 lists the parameters for the aerial UE. The study assumes free space propagation between the aerial UE and the CGC base station.

Table 79: CGC base station parameters

Parameter	Value	Source
CGC Base station type	Macro	ECC Report 233 [83]
Cell radius	70–150 km	ECC Report 233 [83]
Maximum Antenna Gain	15 dBi	ECC Report 233 [83]
Channel bandwidth CGC system	2 X 10 MHz FDD	ECC Report 233 [83]
Antenna vertical radiation pattern	Figure 5, ECC Report 233	ECC Report 233 [83]
Antenna height	30 m	ECC Report 233 [83]
No. of sectors/ site	3	ECC Report 233 [83]
Antenna up-tilt	10°	ECC Report 233 [83]
Noise figure	3 dB	
I/N protection criteria	-6 dB	ITU-R M.2292 [25]
Permissible interference level/MHz	-117 dBm/MHz	

Table 80: Aerial UE parameters

Parameter	Value	Source
Max. transmit power	23 dBm	
Antenna	Isotropic	
Channel bandwidth (LTE system)	5 MHz	
Aerial UE height	40 m, 100 m, 300 m, 1 km, 5 km and 10 km	

Table 81: Aerial UE OOB emissions for 5 MHz channel BW (Table 6.6.2.1.1-1, 3GPP 36.101 Error! Reference source not found.)

ΔfOOB (MHz)	Spectrum emission limit	Measurement BW
± 0-1	-15 dBm	30 kHz
± 1-2.5	-10 dBm	1 MHz
± 2.5-2.8	-10 dBm	1 MHz
± 2.8-5	-10 dBm	1 MHz
± 5-6	-13 dBm	1 MHz
± 6-10	-25 dBm	1 MHz

A12.3.3 Emission masks

The below figure illustrates the emission masks based on the above table for the aerial UEs operating in Band 1. When the CGC base station is operating adjacent to the Band 1 aerial UE, the maximum emission is 0.2 dBm/MHz while with 1 MHz guard band, the maximum emission is -10 dBm/MHz.

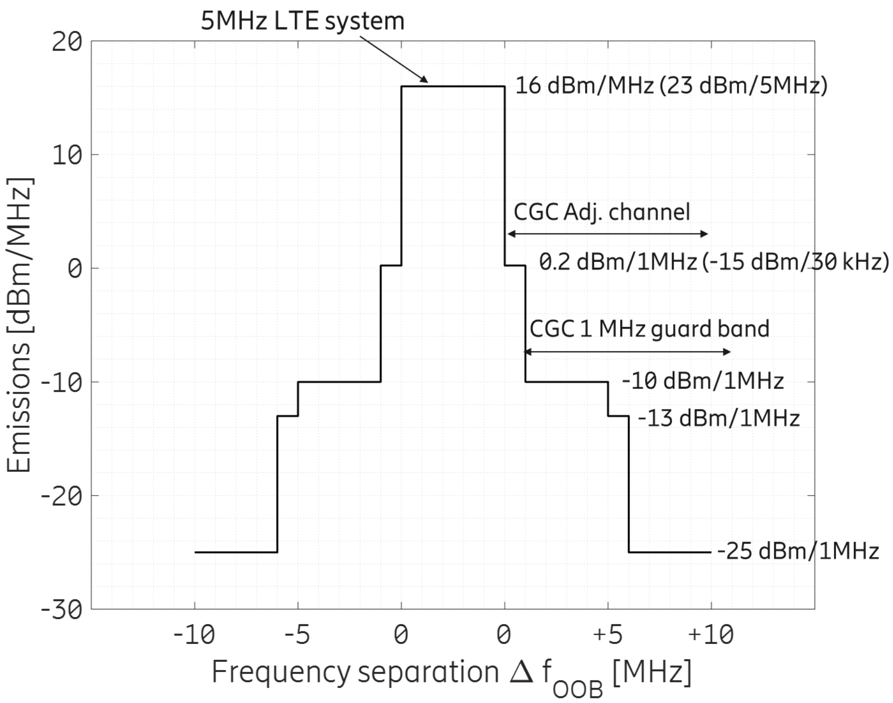

Figure 83: Out of band emission for UEs in Band 1 indicating emissions in CGC band (Adjacent channel and with 1 MHz guard band)

A12.3.4 Results

A12.3.4.1 Emission limits according to specifications

Figure 83-Figure 86 illustrate the separation distances required to achieve a selected I/N with different guard bands. Figure 83 shows the required separation distances for fulfilling the required I/N criterion when the aerial UE operates in the adjacent channel to the CGC uplink without any guard band indicating 38 km

separation distance required for the operation of drones without any additional restrictions. For drones flying up to 1 km altitude, the required separation distance can be reduced to 15 km.

Figure 84 shows the required separation distances if there is 1 MHz guard band between the aerial UEs and the CGC uplink band. The maximum required separation distance is 9 km to fulfil the required I/N criteria, while the separation distance can be reduced further to 4.5 km if the aerial UEs operate with a maximum altitude of 300 m.

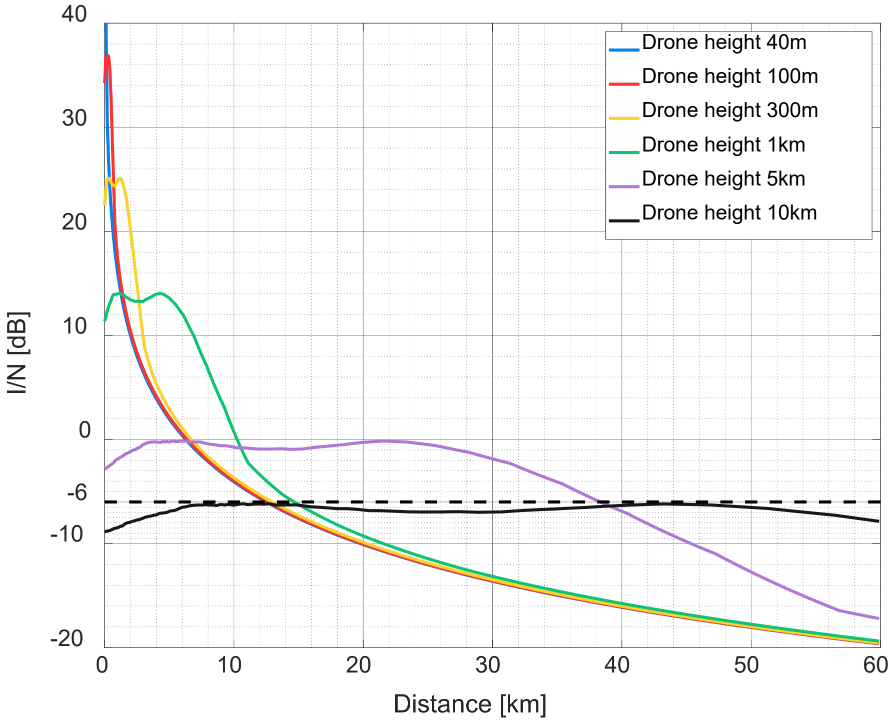

Figure 84: I/N vs Separation distance with no guard band

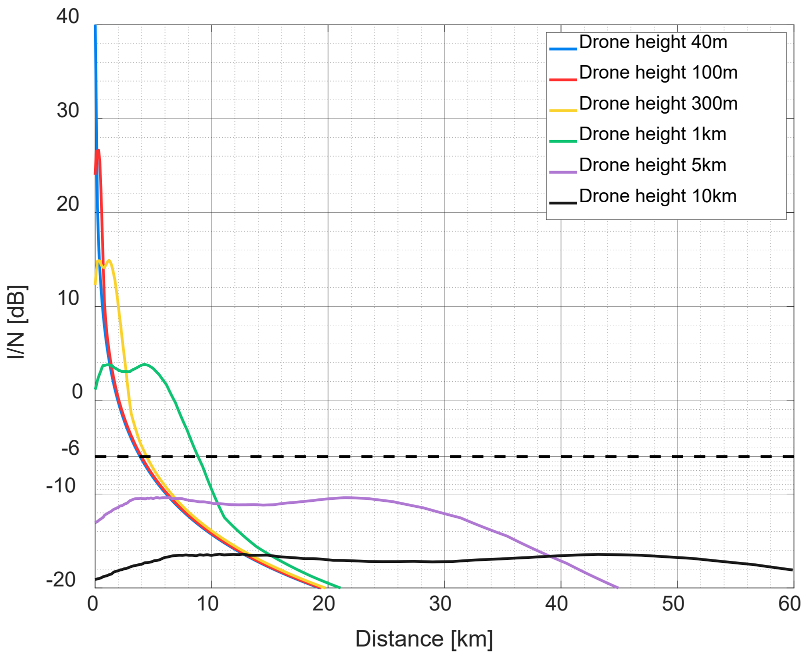

Figure 85: I/N vs Separation distance with 1 MHz guard band

A12.3.4.2Restricting aerial UE emission limits

Figure 85 shows the required emission limit to fulfil -6 dB I/N protection criteria at different separation distances from the CGC base station considering different heights of the aerial UE. At 600 m separation distance, the required emission limit is -38 dBm/MHz. Considering 1 MHz guard band, this requires additional 28 dB reduction in the OoB emission from the aerial UE.

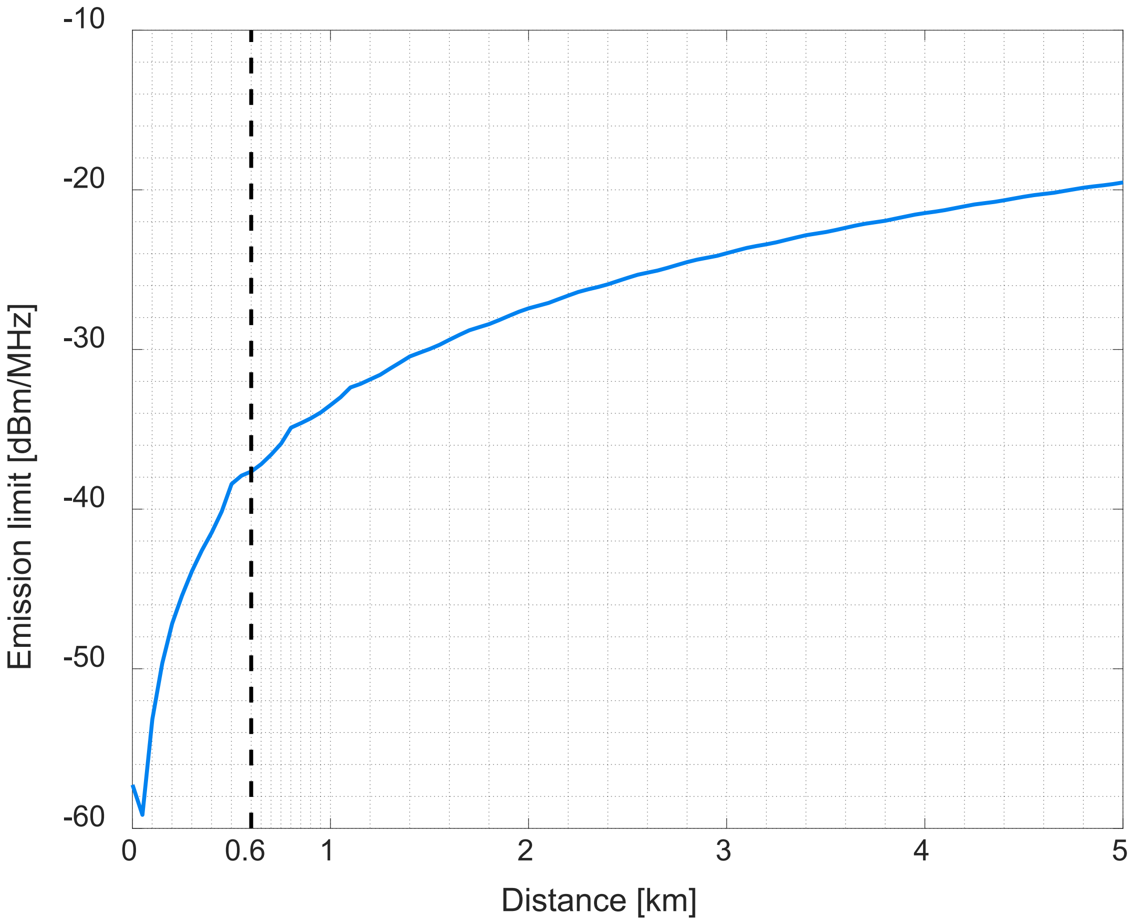

Figure 86: Required emission limits to fulfil -6 dB I/N vs separation distance

A12.3.5 Conclusions

The study shows that it is possible for Band 1 (1920-1980 MHz) aerial UEs to operate in adjacent channel with CGC with large separation distances. The aerial UEs can operate with 600 m separation distance with 38 dBm/MHz restricted OoB emission limit, corresponding to an additional 28 dB reduction in OoB emissions with at least 1 MHz guard band.

ANNEX 13: STUDY ON COEXISTENCE OF AERIAL UES IN BAND (1920-1980 MHZ) WITH CGC GROUND STATIONS

The band 1980-2010 MHz is designated for MSS in CEPT and is used in Europe by two MSS operators. One operator has an operational network, European Aviation Network which uses a complimentary ground component (CGC) with base stations (BS) on the ground to provide passenger communications within an aircraft. The aircrafts communicate with the CGC base stations (uplink) in the 1980-2010 MHz band, which are located across Europe. The base stations are generally up-tilted to enhance coverage to the aircraft.

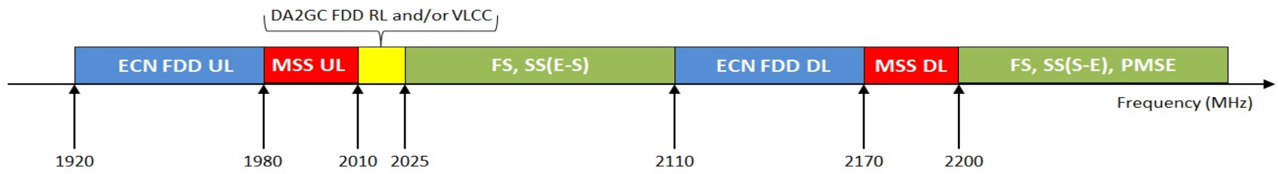

Figure 87: Difference services in the 2 GHz band indicating MSS UL adjacent to Band 1 Uplink [83]

Different studies were carried out, several of them performing a single entry baseline analysis with drones operating at different altitudes for different frequency separations, other analysing the current situation with the compatibility in adjacent block within the same MSS band. As they draw diverging conclusions regarding the conditions of existence, there is a need to further investigate the sharing between CGC BS and aerial UEs by considering both existing situation and modelling the interference affecting the ground BS receiver.

Another analysis was performed which accounts the current situation on the operation of typical UEs (generally ground UEs) in the adjacent band 1920-1980 MHz without geographical restriction.

A13.1 SIMULATION ASSUMPTIONS

Report ITU-R M.2292 [25] and Recommendation ITU-R M.2101 [51] provide the methodology to describe the radio interference behaviour coming from user terminals (operating within a terrestrial IMT mobile network), in particular values for the parameters driving the MFCN in different environments (rural, urban). Further consideration on parameters related to the user deployment (including the power control algorithm) is available in A13.8 and A13.9.

Table 82: MFCN Mobile Network structure in 1920-1980 MHz UL Band

Parameter	Value	Source
Cell range (for aerial and typical UEs)	500 m (urban), 5 km (rural)	ITU-R Report M.2292 [25]
Cell radius (for aerial and typical UEs)	250 m (urban), 2.5 km (rural)	
Inter-site distance	750 m (urban), 7.5 km (rural)	
Site structure	3 adjacent sectors	ITU-R Report M.2292 [25]
Number of active sectors in the MFCN mobile network	19, 37, 61	ITU-R Report M.2292 [25]
MFCN Base Station (BS) category	Macro BS for rural and urban	

Regarding Table 83, the difference between the aerial and typical UE antenna gain comes from different references (ITU-R for the typical UE and the external organisation for the aerial UE).

Although one single value is referred in Report ITU-R M.2292 (4 dB), different body loss values are assumed for the typical UE in this analysis simply because of the variability of the situation the body could absorb a part of the emissions e.g. speech position (head + hand-loss), browsing position (hand-loss). Moreover, the apportionment of the usage between data/voice relates to a traffic asymmetry in favour of the data over the voice. Finally, aerial UE is not subject to any body loss conditions.

Table 83: Ground and aerial UE parameters in 1920-1980 MHz UL Band

Parameter	Value	Source
Ground and aerial UE Min. and Max. transmit power	-40.23 dBm	Minimum and maximum output power from 3GPP TS 36.101 **Error! Reference source not found.**
Ground and aerial UE Antenna	Isotropic	
Ground UE antenna gain	-3 dBi	ITU-R Report M.2292 [25]
Aerial UE antenna gain	0 dBi	
Ground Body Loss	4 dB for voice and 1 dB for data	
Apportionment voice-data usage (Ground UE)	20%-80%	
Ground and aerial Channel bandwidth	5 MHz	
Typical UE Power control	Yes ▪ $SNIR_{min}$=15 dB (following CL-95th percentile) ▪ γ=1 (good channel balancing factor) ▪ MCL[38]=70 dB	3GPP TR 36.942 [48] for the values (for typical UEs) Recommendation ITU-R M.2101 [51] for the output power formula.
Aerial UE Power control	Yes ▪ $SNIR_{min}$=10 dB ▪ γ=1 (good channel balancing factor) ▪ MCL=70 dB	See A13.9 for the values Recommendation ITU-R M.2101 [51] for the output power formula.
MFCN BS serving (aerial and typical) UE	MFCN BS located at the centre of the three sectors	
Frequency resource allocation per used	25 RBs split between 15 users (rounded to 1RB per typical user and 2-4[39] RBs per aerial user) within the cell	See A13.9for the values related to the aerial UEs.
Indoor terminal usage	70% for urban, 50% for rural	Report ITU-R M.2292 [25]
Indoor UE height	1.5+k×3 m, k=0..{7 (urban), 9 (rural)} (kth floor of the building)	
Outdoor UE height	1.5 m	Report ITU-R M.2292 [25]
Aerial UE height	40..10000 m	

[38] Minimum Coupling Loss in signal between serving BS and UE

[39] 4 RBs scenario is set as a sensitivity analysis and would in practice correspond to a 1 Mbps data rate for aerial UE although this is considered outside to the proposed maximum value applied to 61 active cells

Parameter	Value	Source
Simultaneously UEs transmitting Density	15 users/ sector apportioned between 1 aerial and 14 typical UEs.	See A13.8 and A13.9

In addition, characteristics related to the base station (BS) are provided below, in order to compute the UE output power in UL from the radio link budget perspective.

Table 84: MFCN BS characteristics in 1920-1980 MHz UL Band

Parameter	Value	Source
BS antenna height	25 m for urban, 30 m for rural	ITU-R Report M.2292 [25]
BS antenna mechanical downtilt	-10° for urban, -3° for rural	ITU-R Report M.2292 [25]
BS antenna pattern model	Recommendation ITU-R F-1336-4 (Rec 3.1) [45] kp = 0.7 kh = 0.7 kv = 0.3 φ3 dB=65°	ITU-R Report M.2292 [25]
BS antenna peak gain	16 dBi for urban, 18 dBi for rural	ITU-R Report M.2292 [25]
BS antenna radiation pattern sidelobes model	Peak sidelobes (in UE-BS radio link budget)	Recommendation ITU-R F-1336-4 [45]
BS noise figure	5 dB	ITU-R Report M.2292 [25]
BS system bandwidth	5, 10, 15 MHz (5 MHz assumed)	
BS Effective Bandwidth	4.5 MHz assumed (25 RBs[40])	

The choice of the peak sidelobes for the BS antenna pattern reflects the performance objective and not the interference situation when computing the radio link budget between UE and BS because the interference from MFCN is assessed at UL (meaning that Macro BS does not behave as source of interference with respect to the CGC BS receiver).

Moreover, assumptions related to the:

- propagation were also modified for the sake of accuracy and coherence with other parameters and are summarised in Table 85. More information on the justification of these changes is available in A13.7;
- Out-of-Band (OoB) level from typical and aerial UEs is adjusted in accordance with the application of the power control to the user terminal. More information is available in A13.10.

Table 85: Propagation assumptions for different radio links

Transmitter/ Receiver	Indoor UEs	Outdoor UEs	Aerial UEs
MFCN BS	Recommendation ITU-R P.1546-6 [49] 90% location variability + Recommendation ITU-R P.2109-1 (Building Entry Loss) [87]	Recommendation ITU-R P.1546-6 90% location variability	Recommendation ITU-R P.525-4 [76] (Free Space Loss)

[40] Resource Blocks (180 kHz size).

Transmitter/ Receiver	Indoor UEs	Outdoor UEs	Aerial UEs
CGC BS	Recommendation ITU-R P.1546-6 90% location variability + Recommendation ITU-R P.2109-1 (Building Entry Loss) [87]	Recommendation ITU-R P.1546-6 1..99% location variability	Recommendation ITU-R P.525-4 [76] (free-space loss)

The below table lists the simulation assumptions for the CGC base station.

Table 86: CGC base station parameters

Parameter	Value	Source
CGC Base station type	Macro	
Cell radius	70-150 km	ECC Report 233 [83]
Maximum Antenna Gain	13.8 dBi	ANNEX 12:
Channel bandwidth CGC system	5 MHz	
Channel effective bandwidth CGC system	4.5 MHz (25 RBs)[41]	
Antenna height	30 m	ECC Report 233 [83]
No. of sectors/ site for the MFCN	3	ECC Report 233 [83]
Antenna up-tilt	10°	ECC Report 233 [83]
Noise figure (NF)	3 dB	ANNEX 12:
Antenna Noise temperature	100K	
Ground Noise Temperature T0	290K	
Receiver Equivalent Noise temperature	(10NF/10-1) T0 =288.6K	
Equivalent System (Receiver + Antenna) Noise	388.6K	
I/N protection criteria	-6 dB, -10 dB[42]	Report ITU-R M.2292 [25]
Permissible interference level / Effective bandwidth	-112.2 dBm/ MHz	

As can be seen from the above table, one could notice that the antenna noise temperature is lower (100 K) than those used for typical BS (generally 290 K)

This is simply due to the fact that the antenna uptilts to the sky known for having a lower noise temperature. Recommendation ITU-R P.372-4 [88] provides insight on the way to calculate the antenna noise temperature depending on the antenna elevation angle.

41 Assuming CGC BS operates under IMT-Advanced technology (based on ECC Report 233 [83]) .90% of the system bandwidth is effectively used, corresponding to 25 Resource Blocks (RBs), i.e. 5×90%=4.5 MHz.

42 Added in ANNEX 12:

The CGC base station antenna pattern (vertical and horizontal) is extracted from ANNEX 12:.

The protection criterion of CGC BS (-10 dB) proposed by input contributions ECC/PT1/226 and 236 was not retained, mainly because MFCN Macro BS having similar characteristics as CGC BS and that in accordance with the technology used (IMT-Advanced), the protection criterion should be I/N=-6 dB (based on Report ITU-R M.2292-0 [25]). Additional information on this assumption is available in Annex A7.5.

the protection is not related to any percentage (of time or of case)

Unlike the protection of RAS or MetSat, no percentage is related to the protection criterion of the CGC BS (and more generally to any system under the Mobile Service). Keeping in mind the idea of comparing the current situation with typical UEs already deployed in 1920-1980 MHz UL and the new one with aerial UEs, it is proposed to assess this percentage in accordance with the ground UEs deployment in various environments e.g. in rural or urban areas. More precisely, due to the mobile nature of the ground UEs, the analysis would be performed on a statistical manner with Monte Carlo simulations computing the interference generated by a set of UEs simultaneously transmitting in their serving cells. In such a case, the percentage linked to the exceedance of the CGC BS protection criterion would correspond to a percentage of case/event achieved when the generated interference exceeds this threshold. Once this percentage is assessed, it can be applied to the scenario involving aerial UEs and the unwanted emissions levels of the aerial UEs could be adjusted in order to meet the same requirement (i.e. to meet the same percentage as for the typical UEs).

A13.2 METHODOLOGY

A13.2.1 Deployment of typical and aerial UEs around the CGC BS

Whatever environment (rural, urban), a CGC cell is much larger than a MFCN cell, meaning that the area where to perform the compatibility study could be a portion of a CGC cell. In this logic, the exact location of the CGC BS within a MFCN sector has no influence in the resulting interference, that's why CGC and MFCN BSs are assumed to be collocated in the coexistence analysis. Moreover, a number of active cells from the mobile network has to be simulated to evaluate the aggregate UEs interference affecting the CGC receiver. The below figure illustrates as an example the deployment of 61 cells rural MFCN and CGC cell.

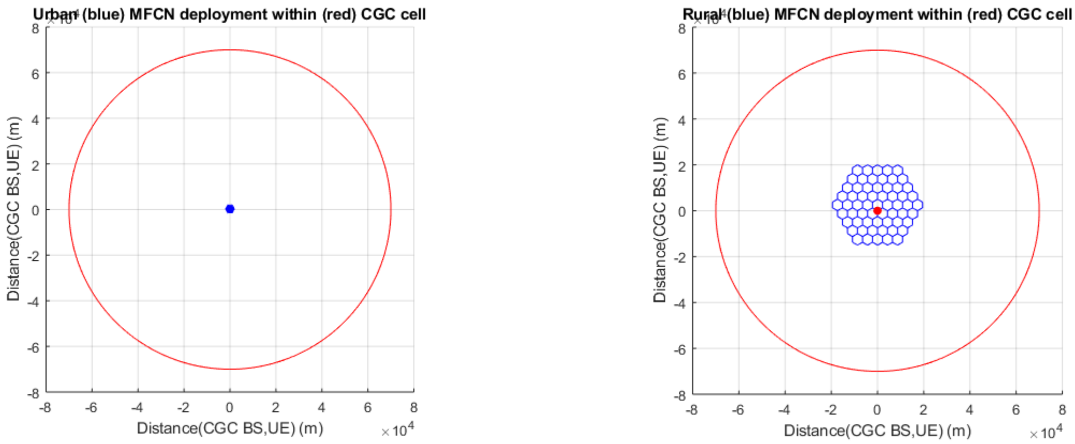

Figure 88: Location of 61 active cells of MFCN within a CGC cell

It is understood that due to multiple UEs transmitting at the same time, the interference affecting the CGC BS has to be assessed on an aggregate basis.

A13.2.2 interim results on the coexistence study

In accordance to Recommendation ITU-R M.2101 [51], some intermediate results on MFCN modelling are provided in order to understand the differences between the addressed scenarios (indoor/outdoor/aerial UEs, urban/rural): transmit power distribution, path coupling loss distribution (including Tx and Rx antenna gains, propagation loss and fading, etc.). Details on these results can be found in A13.11.

In addition, as the compatibility analysis deals with the protection of the CGC BS, interim result on the CGC BS antenna pattern is also provided (see A13.13) to facilitate the understanding of the aggregation interference simulated at the CGC receiver.

A13.2.3 Calculation of the aggregate interference

The interference received by the CGC BS is assumed to be generated by a number of typical or aerial UEs N simultaneously transmitting in the unwanted emissions domain. It can be expressed as follows:

$$I_{aggregate} \text{ received (dBm/MHz)} = \sum_{i=1}^{N} oob\ level(dBm) - PathLoss_{CGC\ BS-UE_i} - G_{CGC\ BS-UE_i}(\varphi_i, \theta_i) \qquad (22)$$

Where:

- PathLoss results from the computation of the propagation models between CGC BS and the sources of interference, namely:
  - a terrestrial path when the interferers are typical UEs: P.1546-6 [49] model for urban and rural areas is assumed;
  - aerial UEs for an aeronautical path: Recommendation ITU-R P.525-4 (Free Space Loss) [76];
  - GCGC BS- UE (φ,θ) relates to the CGC BS antenna gain in the direction (φ,θ) of the source of interference UE.

Due to the mobility of the (aerial and typical) UEs and the fact that transmitting UEs over the active UEs are not necessarily the same at any time, this aggregate interference can be considered as a random variable

$$I_{aggregate\ received} \triangleq I_{aggregate\ received}(t, \omega) \qquad (23)$$

Its assessment needs to be performed over a Monte Carlo simulation with M runs as follows:

$$I_{aggregate\ received}(t, \omega) = I_{aggregate\ received}(k), k = 1..M. \qquad (24)$$

The computation of this interference $I_{aggregate\ received}(k)$ is performed over M=1000 events in order to get a satisfactory reliable statistic of the probability of exceeding the protection criterion. At each event k (k=1..M), a number of simultaneously transmitting aerial or typical UEs (N=15) is generated within each serving MFCN sector. A total of P=61 cells compose the simulation area and the cumulative effect of interference produced by them is calculated. The rationale for this value is further detailed in A13.9.

A13.3 ANALYSIS OF THE RESULTS

A13.3.1 Compatibility studies between CGC BS and typical UEs

As indicated in the previous section, the compatibility study in adjacent band starts with the analysis on the condition of protecting CGC BS receiver from unwanted emissions levels caused by typical (ground) UEs. Figure below depicts the distribution of this aggregate interference for an urban area, expressed in terms of cumulative density function (cdf) resulting from the Monte Carlo simulation run. The green vertical line relates to the I/N=-6 dB (from Report ITU-R M.2292 [25]) while red dot lines reflect relaxed protection criteria retained for the sharing analysis.

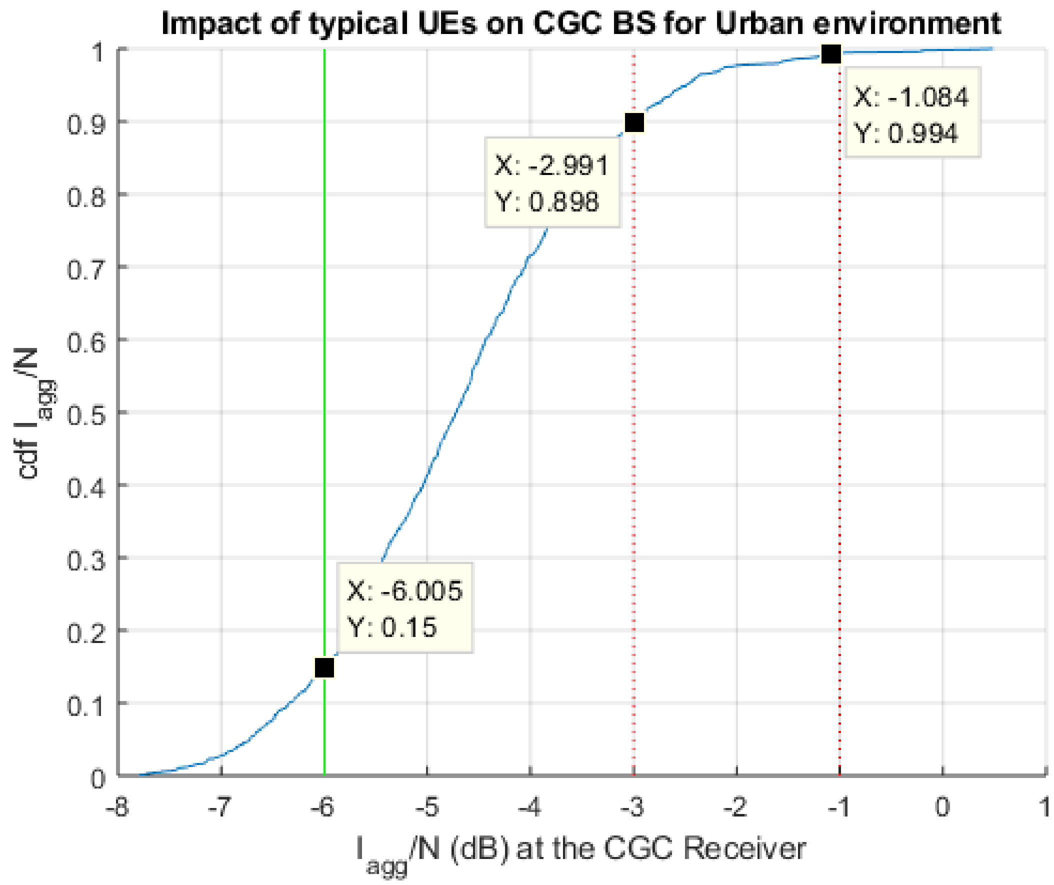

Figure 89: Aggregate interference at CGC BS from ground UEs

Portions of the cdf curves located at the left side of the vertical line (green or red depending on the assumed protection criterion) is understood as cases (among all samples) where the aggregate interference received at the CGC BS does not exceed the protection threshold. On the contrary, points of the curves situated at the right side of the vertical line refer to an exceedance of the protection criterion.

A first glance at the results shows that a very low percentage of cases ensures the I/N=-6 dB (only 15%), meaning that for 85% of case, the protection criterion is exceeded. Recalling that this criterion cannot be considered as a short-term because it does not relate to any percentage of time that a fade depth is exceeded but a percentage of case, a so low percentage for which the protection threshold is met would lead to conclude that CGC BS should not be deployed in Urban environment[43] or that I/N=-6 dB is irrelevant for urban environment. Since a high percentage of case is seeked to meet the protection criterion (e.g. 90%, 95%, 99%), other values than -6 dB are proposed to draw the comparison between interference from typical UES and aerial UEs for urban environment: -3 dB and -1 dB.

Results for the urban case are summarised in below table and also cover the rural scenario. For this one, as it is observed that I/N=-6 dB ensures a high percentage of case (100%), there is no need to investigate for any other values of I/N.

[43] Otherwise it would be a risk of interference for more than 80% of the case.

Table 87: Protection criteria of the CGC BS Receiver from aggregate interference from typical UEs

Environment/ Protection criterion	Urban			Rural
I/N	-6 dB	-3 dB	-1 dB	-6 dB
cases ensuring I/N	15%	90%	99%	100%

It can be concluded that based on the current deployment of typical UEs in 1 920 – 1 980 MHz, the protection criterion of the CGC BS Rx under study is:

- I/N=-3 dB 90% of the case and -1 dB and 99% of the case for the urban environment,
- I/N=-6 dB 100% of the case.

A13.4 COMPATIBILITY STUDIES BETWEEN CGC BS AND AERIAL UES

Similar calculation is performed on the scenario involving aerial UEs as a portion of active UEs in the mobile network. The figures below respectively depict for the Urban case the cdf of the aggregate interference for different out-of-band (OoB) emissions levels depending on the number of RBs allocated to the aerial UEs (while OoB levels from typical UEs have not been reduced) among a total of 15 users per cell over 61 active cells.

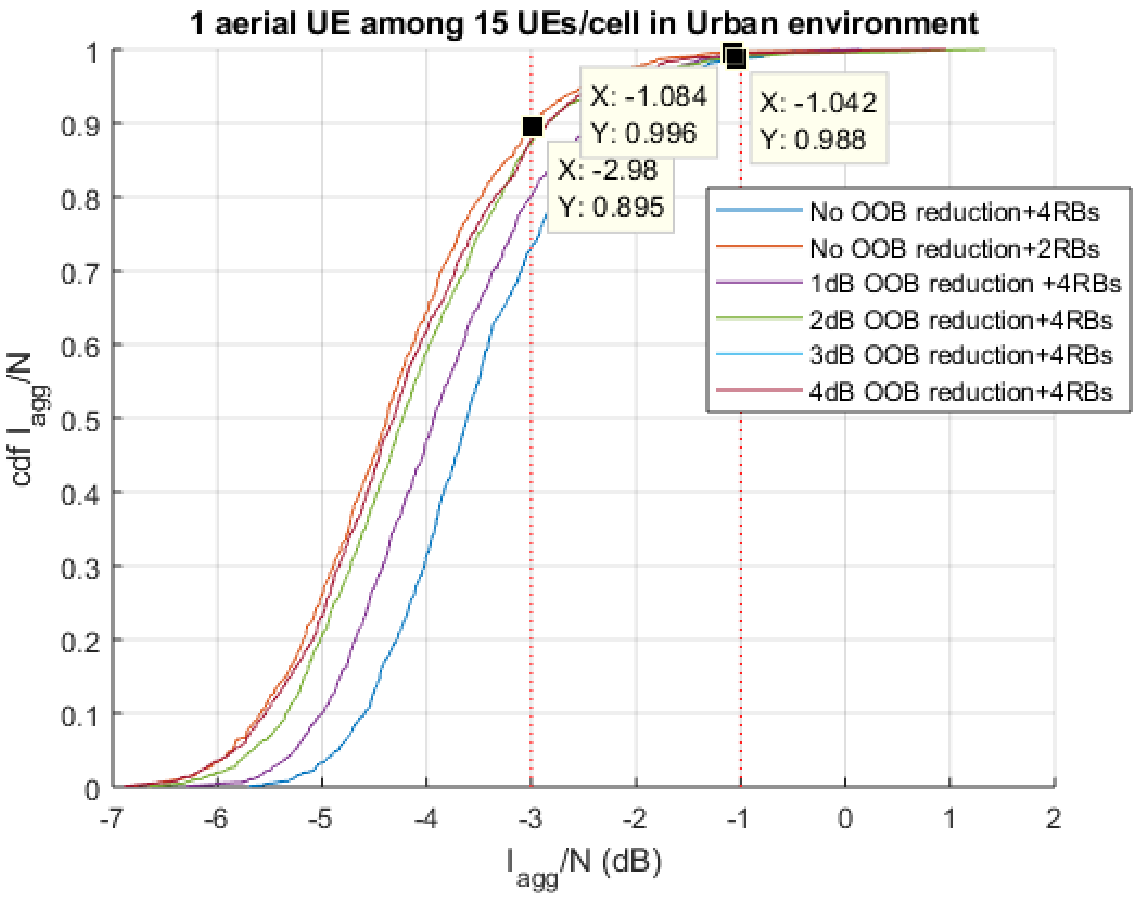

Figure 90:Impact of 6.7% aerial UE Oob levels reduction for urban environment

The lower unwanted emissions levels, the bigger probability of ensuring the protection threshold. The reduction of unwanted emissions levels is not reflected in the above graph by a constant shift over the entire cdf curve in the left side of the vertical line, simply because this OoB reduction only applies to aerial UEs as a portion of all transmitting UEs (using 8% or 16% of the available RBs). Moreover, the results show that whatever the resource of the aerial UE is reduced, the mitigation of the aggregate interference is pretty similar (3 dB OoB level reduction from blue curve to magenta curve or reduction by 2 of the RBs amount from red curve to blue curve). When considering the protection criterion of the CGC BS:

- For 1 aerial UE/15 total UEs per cell using 2 RBs, i.e. 8% of the available frequency resources:
  - I/N=-1 dB is met for more than 99% of the case when no OoB reduction is applied to aerial UEs;
  - I/N=-3 dB is met for more than 90% of the case when no OoB reduction is applied to aerial UEs.
- For 1 aerial UE/15 total UEs per cell using 4 RBs, i.e. 16% of the available frequency resources:
  - I/N=-1 dB is met for more than 99% of the case when no OoB reduction is applied to aerial UEs;
  - I/N=-3 dB is met for more than 90% of the case when 4 dB OoB reduction is applied to aerial UEs.

Results for rural scenario are displayed in the below figure in addition with the protection criterion (I/N=6 dB green vertical line) and shows that when aerial UEs use 8 or 16% of the frequency resources (2 or 4 RBs), the protection criterion (I/N=-6 dB 100% of the case) is met for the same percentage of case => no additional OoB reduction on them is needed

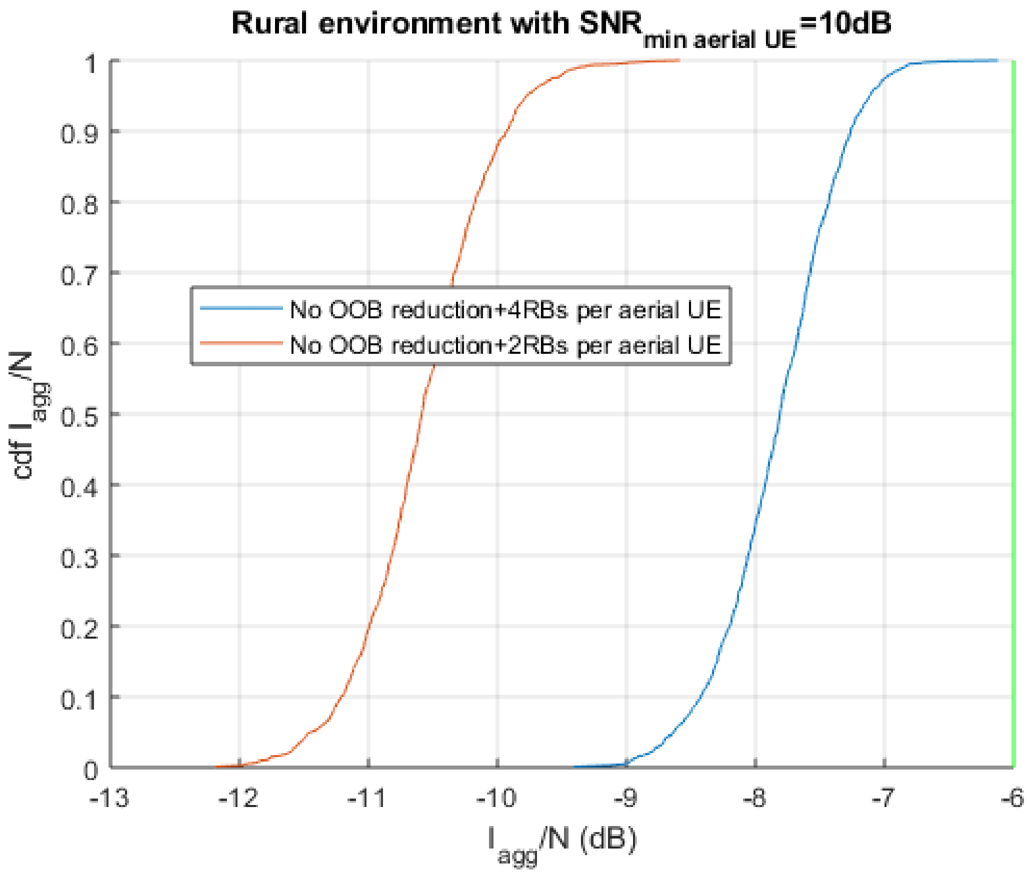

Figure 91: Impact of 1 aerial UE/cell OoB levels at Rural environment

As indicated in A13.9, an average of 6.7% of aerial UEs (1 aerial UE/15 UEs) per cell over 61 active cells can be seen as an high ratio as it applies to a large number of sectors. If the aerial UE activity was limited to few cells, the aerial user density would be significantly higher (from 33% to 100%) as highlighted in the below example for a full aerial UEs deployment over 4 cells (15 aerial UEs and 0 typical UEs) with almost 2 RBs used per UE.

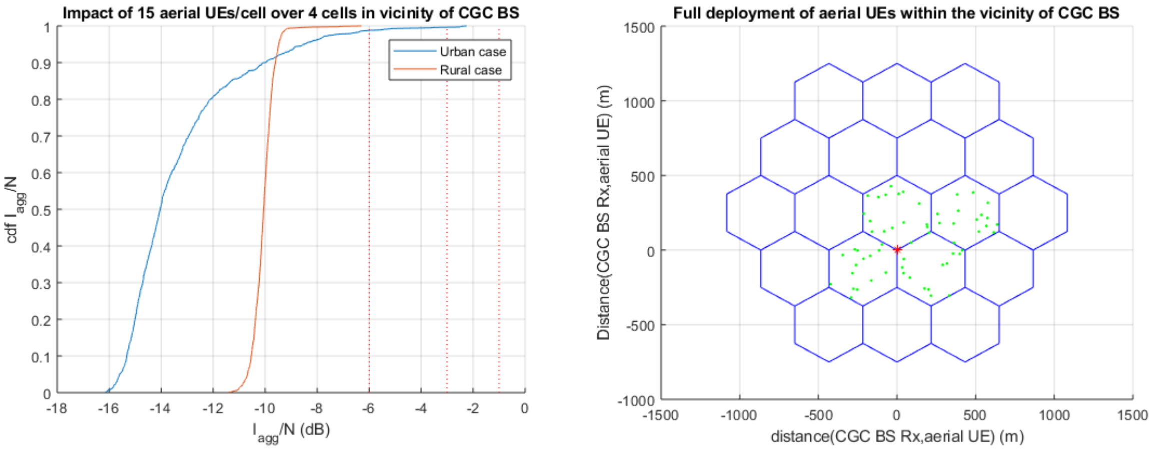

Figure 92: Impact of local full deployment of aerial UEs in MFCN the vicinity of CGC BS

The coexistence between CGC BS Rx and aerial UEs does not require reduction of their OoB emissions levels in such a case.

A13.5 RESULTING LEAST RESTRICTIVE TECHNICAL CONDITIONS FOR AERIAL UES

Based on results from Section A13.3, in order to ensure the coexistence with CGC BS when 1 aerial UE per cell operate over 61 active cells in the MFCN:

- with 2 RBs, no additional OoB reduction applied to drones is needed for any rural and urban environments;
- with 4 RBs:
  - no additional OoB reduction is needed for rural (based on protection criterion I/N=-6 dB 100% of the case) and for urban (based on protection criterion I/N=-1 dB 99% of the case);
  - 4 dB additional OoB reduction applied to drones is needed for urban (based on protection criterion I/N=-3 dB 90% of the case).

A13.6 CONCLUSIONS

The study shows that it is possible for 1 aerial UE/cell using up to 2 RBs (8% of the available frequency resources) within 61 active cells over 1920-1980 MHz to operate in adjacent channel with CGC without any geographical restrictions and without any OoB reduction level whatever deployment environment of the MFCN (urban or rural).

For a higher frequency resources usage of the aerial UEs (e.g. 4 RBs) and a specific protection criterion (I/N=-3 dB 90% of the case), a 4 dB OoB reduction level is needed to ensure the same level of coexistence as for the typical UEs. However, this configuration goes beyond the worst-case scenario (2 RBs per aerial UE) for the aerial UE RBs usage within a large area of the MFCN, that's why France considers that no specific measure is necessary to be applied to the aerial UEs for the protection of CGC BS receiver.

A13.7 INTERIM RESULTS OF THE COMPATIBILITY STUDIES

A13.7.1 preliminary thoughts on propagation models between terrestrial stations

It is important to note that the path loss needs to account the reduced effect of the clutter loss when UEs are in high heights (indoor users in high floors of the building) which Hata model may not be able to reflect. That's why it is proposed to use Recommendation ITU-R P.1546-5 [49] to cover these issues, noting that the method, a point-to-area model is suitable when one of the radio device is subject to mobility. One could advocate that ITU-R P.1546 was designed based on measurements for the transmitting station being on a broadcast tower and is in principle not reciprocal. However, in order to make this Recommendation useable for the case where the transmitting station height is smaller than the receiving station height e.g. UL for MFCN, the options a), b), and c) in Paragraph 1.1 of Annex 5 were introduced, leading to conclude that P.1546-6 is suitable to model path between (CGC and MFCN) BS and typical (outdoor and indoor) UE. The computation of this propagation point-to-area propagation requires the input of one key parameter : the location variability which aims at capturing the variation in excess of the path loss over the entire service area of a transmitter, thus including all terrain effects, in particular shadowing loss. It should be noted that a constant value like median differs from a random usage within a set of Monte Carlo simulation as there is a deviation between average and median value of the path loss for such distribution. Finally, the application of this parameter should account the different objectives achieved in coverage prediction and for interference assessment:

- For the sake of network planning, the operator generally aims at predicting the path loss with a high confidence level expressed through « fading margin », i.e. a target path loss value Xo is set so that the probability of exceeding Xo is very low (5%, 1%). High value of location variability contributes to achieve this aim;
- for the interference assessment, a real value is desired. Random value of the location variability looks suitable.

Consequently, to these changes in the simulation setting, in order to appreciate the deviation resulting from different uses of propagation in the sharing studies, a plot of the aggregate interference received at the CGC BS under different path loss configurations is drawn for different use cases.

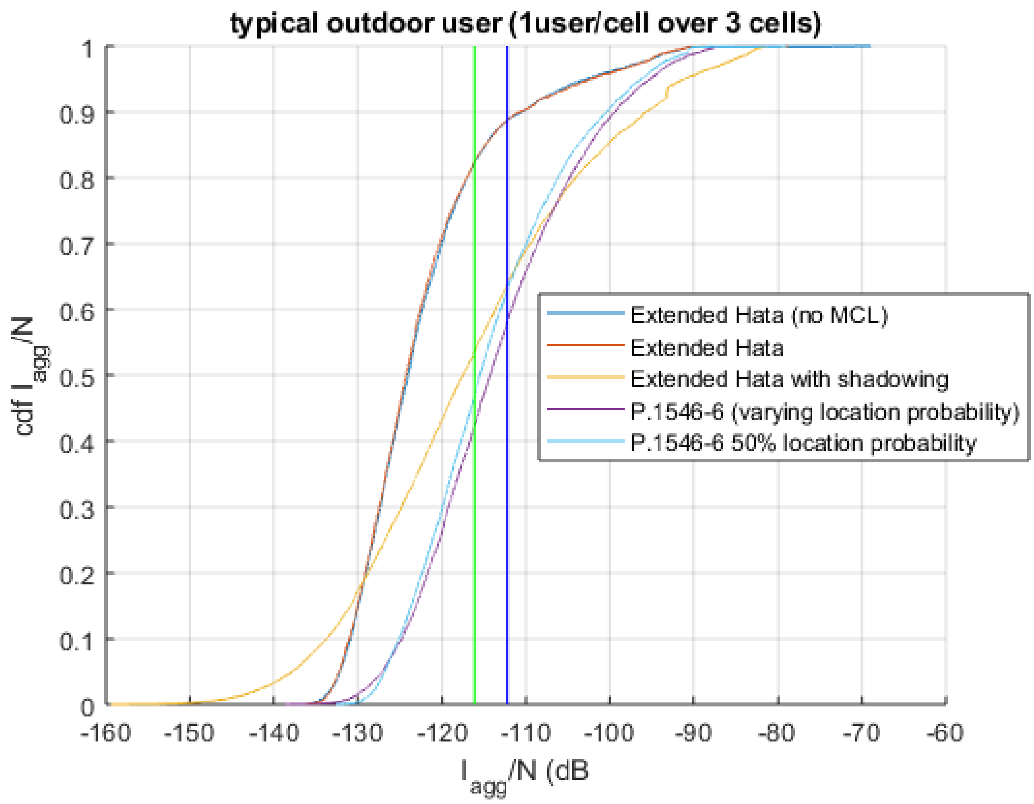

Figure 93: Aggregate interference received at the CGC BS under different path loss configurations

The main outstanding observation relates to the contribution of the shadowing loss (in both Extended Hata and P.1546 models) in the aggregate interference by significantly increasing this figure : this is due to the spreading effect of the shadowing into the cdf aggregate interference curve as adding the extreme cases (lower and higher interference). Although not displayed on the curve, the influence of taking two different location variability values in the path loss prediction for planning purpose between MFCN UE and BS and between CGC BS and MFCN UE for interference link is only visible if power control to user equipment is applied in the cellular network (which is not the case in the above figure but which is the case in the current compatibility analysis).

A13.8 ASSUMPTIONS RELATED TO THE TYPICAL USER DEPLOYMENT AND LINK PERFORMANCE

Subscribers deployed within the mobile network consist in a set of typical and aerial users. Typical user terminals operate indoor (in different floors of the building) or outdoor within a cell/sector connected to a MFCN base station (BS). Unlike the previous study submitted by France, power control is applied to terminal by BS when transmitting. In order to account the target Quality of Service (QoS) for each user (assumed to be the same for all users for sake of simplicity) in the computation of the output power, it's recommended for 5G NR to refer to series 38 (3GPP TS 38.213, section 7.1.1 [74]) or in a more synthetic way and to be more general to Recommendation ITU-R M.2101, section 4.1 [51] which describes a generic formula applicable for both IMT-Advanced (LTE-Advanced) and IMT-2020 (5G NR). That is why this analysis calculates a coupling loss percentile (dB) in line with a SNR_{min} and a number of resource blocks allocated to the (aerial or typical) UE.

The Coupling Loss Percentile is given by the following formula:

$$CL(p\%) = P_{max} - P_{O\_PUSCH} - 10\log_{10}(M_{PUSCH}) \quad (25)$$

Where:

- P_{max} is the maximum transmit power by UE
- M_{PUSCH} depicts the number of Resource Blocks dividing the (occupied) channel bandwidth under Physical Uplink Shared CHannel (PUSCH),
- P_{O_PUSCH} denotes the minimum received power per resource block (assuming 180 kHz here[44]) that can be processed by the radio link receiver to process the data stream in accordance with a given QoS and is equal to:

$$P_{O\_PUSCH} = -114\ \text{dBm/MHz} + 10\log_{10}\left(\frac{180\ \text{kHz}}{1\ \text{MHz}}\right) + \text{NoiseFigure}_{\text{BS}} + \text{SNR}_{\min} \quad (26)$$

The choice of SNR_{min} in the calibration of the cellular network is important as it drives the value of the transmitted power as indicated by the formula above. From the performance perspective, A good SNR_{min} value seeks at achieving high data rate in order to avoid concealing the reduction in network/cell/user throughput with low data rates (which explains why several 3GPP deliverables do not only consider throughput loss but also provides average throughput for sake of efficiency of the mobile network). From the interference perspective, if underestimation of interference is to be avoided, the transmitted power should be assumed on the maximum (but variable) basis, i.e. with a high SNIR. This is why SNR_{min}=15 dB is assumed to approximate what was analysed in 3GPP TR.36.942 [48] when comparing the assumed CL 95th percentile (115 dB for 5 MHz bandwidth).

Since aerial UEs operate with existing cellular mobile network, cell radius for the aerial UE is the same as for typical UEs (500 m for urban and 5 km for rural environment).

The number of simultaneous transmitting UEs within a cell is also important to set as outlined in 3GPP TR 36.942. For uplink, the number of UEs per sub-frame might affect the simulation results, because the total transmission power for the system would depend on the number of UEs per sub-frame. Favouring the possibility to assess in a flexible way (% of used Resource Blocks RBs) the effect of the operation of aerial UE per cell, it is relevant to assume a sufficiently high number of UEs per cell/sector like in 3GPP TR.36.777 [1], i.e. 15 users/cell.

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44 Which may be a different value for other frequency ranges because of propagation conditions as well as channel bandwidth of the system).

A13.9 ASSUMPTIONS RELATED TO THE AERIAL USER DEPLOYMENT AND LINK PERFORMANCE

If the apportionment between outdoor/indoor for different environments within typical UE is given on ITU-R reference and that further information on link performance can be found in 3GPP deliverables (in the coexistence framework), the aerial UEs case is questionable. If the data type supported by aerial vehicles includes video (streaming), images, other sensors data, range of low and high data rates would be in few tens kbps (60) to tens of Mbps (50) for UL, according to 3GG TR 36.777 [1]. This could suggest that allocated RBs to aerial UEs may be higher than for typical UEs, but this trend would be limited to one or few cells as the existing MFCN would (in overall) not change from the planning perspective (similar BS downtilting, similar cell size) to take benefit the flight of the drone over specific locations (e.g. lake, hill, park, castle), noting that several areas may be subject to exclusion zone from the relevant national authorities. For that reason, it is important to define the maximum number of aerial UEs in accordance with the number of active cells assumed in the coexistence analysis. If the study was limited to few cells e.g. 3 sectors, it would be relevant to deal with a high deployment of aerial UEs e.g. 33% up-to 100% aerial UEs/cell. On the contrary, if the assessment of the aggregate interference generated by OoB emissions from aerial UEs is performed over a high number of cells (e.g. 61), the “average” ratio of drones per cell would be much lower in order to account cells without any aerial UE activity.

Based on that rationale, the “average” aerial UEs ratio as an upper-bound could be derived based on the maximum number of aerial UEs/RBs used by aerial UEs over few cells (i.e. 3 or 4).

For 4 cells/sectors, the maximum number of

- aerial UEs would be 15 per cell × number of cells=60 aerial UEs,
- RBs allocated to aerial UEs would be 25 per cell × number of cells=100 RBs,

which would be equivalent to have 1 aerial UE/cell over 60 cells and 1.7 RB allocated to aerial UE over 60 cells. The aerial user density should then be associated with the aerial user RBs occupancy rate as well as the target Quality of Service (QoS) of the application run by the subscriber, expressed in terms of minimum Signal to Noise Ratio (SNR_{min}) as a complete feature of the offered MFCN cell traffic. This means that aerial user density is 1 aerial UE per cell with (average over 61 active cells) 2 RBs per aerial UE.

SNR_{min} link level performance and aerial user RBs occupancy are driven by the selected application. SNR_{min} relates to the minimum SNR that handles for the receiver a minimum data rate at a given application. 3GPP TR 36.942 [48] and 38.803 [91] describe through equations how to derive the (cell, user) throughput over a channel with a given SNIR.

If streaming video is likely to be the most used application by the aerial user and since the required minimum data rate for having access to streaming video is about 500 kbps, the corresponding target SNR_{min} for this application would be 10 dB[45] when 4 RBs[46] are allocated to the aerial user for LTE/LTE-A and 5G (3GPP TR 38.803 Section 5.2.7[47]).

It can be concluded that the proposed upper-bound is 1 aerial UE/cell over 61 cells, each of them using 2 RBs under $SNIR_{min}$=10 dB performance objective. Typical UEs (14 UEs/cell) remain operating with 1 RB under $SNIR_{min}$=15 dB QoS objective.

A13.10 ASSUMPTIONS RELATED TO THE OUT-OF-BAND LEVELS FROM UES

Any terminal transmitting within a given number of RBs behaves outside its allocated frequency resources with reduced power in adjacent channel called ACLR. This ACLR is scaled with the number of RBs separating the (interferer) transmitter from the (victim) receiver. 3GPP TR 36.942 (see table 5.1) [48] assumes for the

[45] Because SNIR=10 dB gives 1.3838 bps/Hz in UL based on TR 36.942 [48] (Annex A.1) resulting in 1.3838×2 RBs(1 RB=180 kHz)=498 kbps≈500 kbps.

[46] 1 RB under SNR=10 dB would give 249 kbps 2 RBs => 498 kbps 4 RBs => 1 Mbps (SNR=10 dB)

[47] although it was carried out for mmWave frequencies

coexistence studies two stairs ACLR function with 30 dBc as a first step (less than 4 RBs away from the victim e.g. directly adjacent to the channel used by the victim) and 43 dBc as a second step (at least 4 RBs away from the channel edge of the victim).

The Out-of-Band (OoB) emissions level mainly depends of two parameters : the frequency separation from the receiver where the level is measured and the In-band power of the UE. In the vicinity of the In-band component, it’s relevant to consider linear behaviour of OoB with In-band power value provided this level does not fall below a lower bound level. The choice of this lower bound should rely on practical and realistic values, based on real measurements or existing requirements from the standard. 3GPP TS.36.101 [36] relates to the User Equipment and specifies a requirement for the minimum power to be -40 dBm/effective bandwidth. The effective bandwidth can be calculated from the system bandwidth from the number of RBs as well as the size of RB. If 5 MHz is the system bandwidth, there are 25 RBs, each RB has a 180 kHz bandwidth, which leads to 4.5 MHz effective bandwidth.

The minimum power requirement for a UE operating at 5 MHz system bandwidth is -40 dBm/4.5 MHz. This minimum value will be taken in this study as the lower bound of the OoB level.

A13.11 ASSUMPTIONS ON THE CGC BS PROTECTION CRITERION

Although there is an ECC/CEPT reference of sharing and compatibility studies between CGC BS and other services (ECC Report 233 [83]), no characteristics related to the CGC BS receiver is available. This means that there is a need to assess the protection criterion for the CGC BS receiver, which could be based on other applications/services presenting similarities with the CGC ground station.

MFCN Macro BSs pretty have similar characteristics from the technology perspective i.e. LTE/LTE-Advanced (as outlined in section 5.1 of this Report) which leads to consider protection criterion in Report ITU-R M.2292 [25] dealing with IMT-Advanced (I/N=-6 dB). One could advocate that a more stringent protection criterion is available in another Report ITU-R M.2039 [92] but the proposed I/N=-10 dB:

- only applies for IMT-2000 technology and not IMT-Advanced, the difference standing on the fact that the multiplexing resources for IMT-2000 are the spreading codes bringing all UEs served within the same cell using the same bandwidth to behave as co-channel interference sources resulting in increasing the cell (intra-) interference environment;
- is not suitable for IMT-2000 when interference affects one or a few cells corresponds to I/N = -6 dB which is the case in the current analysis.

Fixed Links do consider I/N=-10 dB protection criterion (for the long-term) but on Point-to-Point/Point-Multipoint basis with another (or more) fixed station(s) where there is no mitigation technique to accommodate the management of interference between these two fixed stations (making a fixed protection criterion I/N relevant compared which is not the case for CGC BS communicating with aeronautical (mobile) terminals).

Based on rationale provided above, it could be concluded that I/N=-10 dB is not relevant for the protection of CGC BS.

As previously highlighted, the protection criterion of fixed BS in communication with mobile stations (aeronautical terminals) should consider the existing and variable interference environment. This is illustrated through Report ITU-R M.2324-0 [93] indicating that for a transient source of interference (aeronautical mobile transmitter) affecting a portion of the cellular network the protection criterion over I/N = –6 dB could be relaxed. Prerequisites for such a relaxed protection criterion is that the average (long-term) throughput per cell should not be reduced with a significant amount (e.g. no more than 1%), and for no cell shall there be a (short-term) severe degradation of the service.

A13.12 INTERIM RESULTS ON UE OUTPUT POWER IN MFCN

As highlighted, (aerial and typical) UEs operate under power control in UL which means that the output power is driven by the coupling loss (Loss+Gain of the radio-link budget) between MFCN BS and UE within the serving cell. Below left figure draws for the urban environment the statistical behaviour of the coupling loss (between MFCN BS and UEs) in one cell closer than the CGC BS receiver.

Recalling that Coupling Loss covers:

- Body Loss (only for indoor and outdoor UEs) randomly distributed around voice and data application;
- Building Entry Loss (only for indoor UEs) following Recommendation ITU-R P.2109-1 [87]
- UE antenna gain (-3 dBi for indoor/outdoor UEs, 0 dBi for aerial UEs);
- MFCN BS Antenna gain towards the serving UE, accounting for its downtilt.

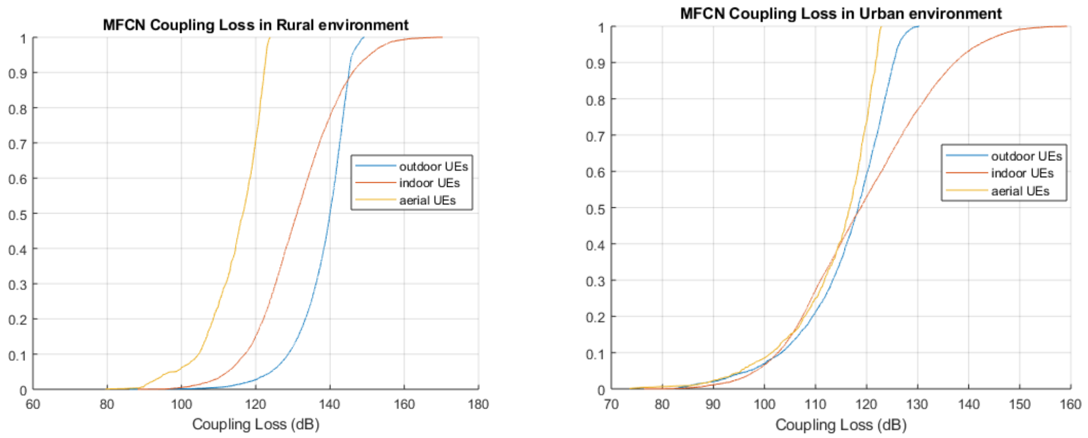


Figure 94: MFCN coupling loss in rural and urban environments

It can be observed similarly in rural and urban environments:

- A higher coupling loss results for indoor UEs (achieving values higher than 160 dB) due to the effect of the building entry loss parameter (achieving values up-to 40 dB) although a higher MFCN BS antenna gain (see below right side Figure) compared to the outdoor and aerial UEs case may a little mitigate the overall gap in the coupling loss cdf; A lower coupling loss results for aerial UEs because path loss is higher for outdoor UEs despite of the higher distance (BS,aerial UE)[48] than for (BS,typical UE) and lower MFCN BS Antenna Gain for aerial UEs (because of the mechanical downtilt that creates more discrimination in angle for the aerial UEs, generally operating above 30 m) (see above figures).

[48] which may be higher than for distance(BS,typical UE) because of very higher altitude

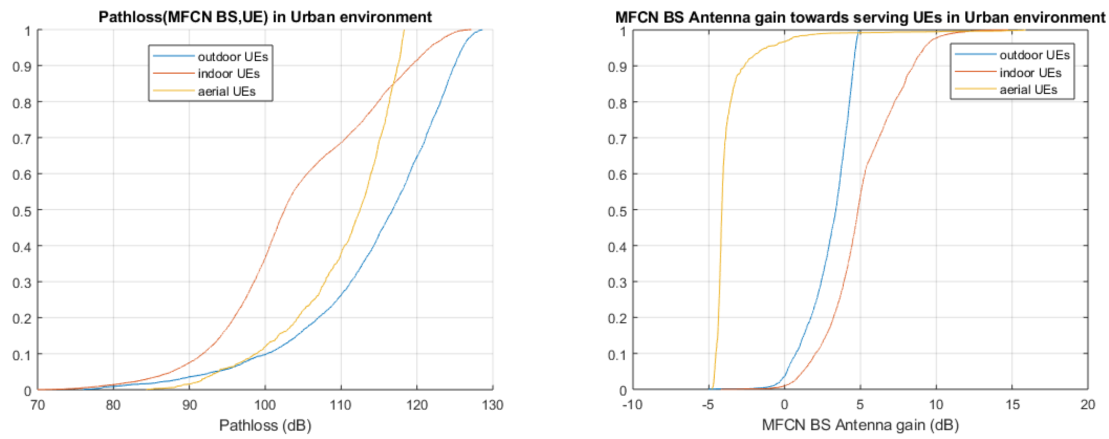


Figure 95: Path loss and antenna in urban environment

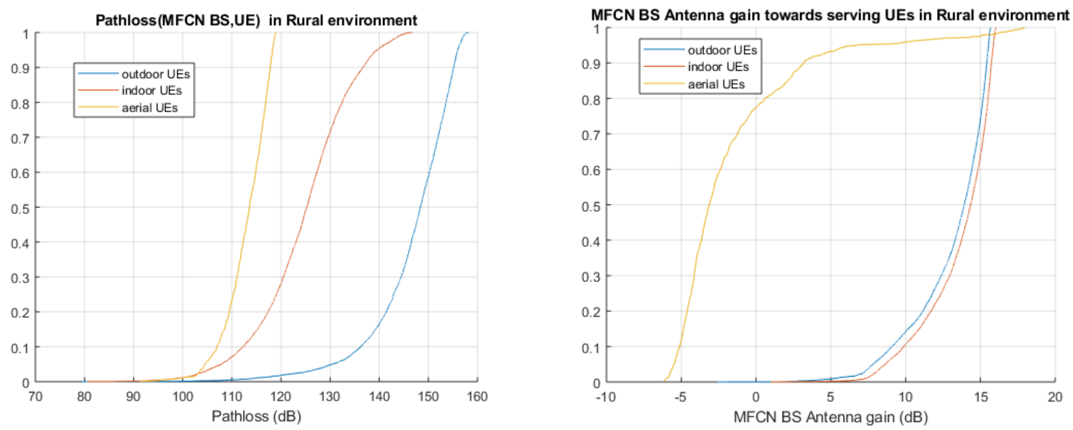


Figure 96: Path loss and antenna in rural environment

Differences between urban and rural environments:

- The gap (for the Coupling Loss) in rural environment between outdoor and aerial cases is bigger (around 30 dB) compared to the urban environment scenario mainly because a larger distance(MFCN,UE) (several kms) results in much higher path loss for typical than for aerial UEs due to a numerous occurrence of the non-line of sight situations (around 40 dB for the path loss at the upper edge of the cdf curve) although there is an overall mitigating effect due to the lower MFCN BS antenna UE antenna gain towards an aerial UE (compared to typical UEs);
- Coupling loss for indoor and outdoor UEs are closer in rural despite of the active building entry loss phenomenon for user terminals located inside buildings simply because the direct path loss (MFCN BS - indoor users) decreases when mobile terminals transmit at higher floors and become lower than for outdoor (ground) UEs.

Based on these facts, the distribution of output power for aerial and typical UEs is displayed in the below figures for urban and rural environments:

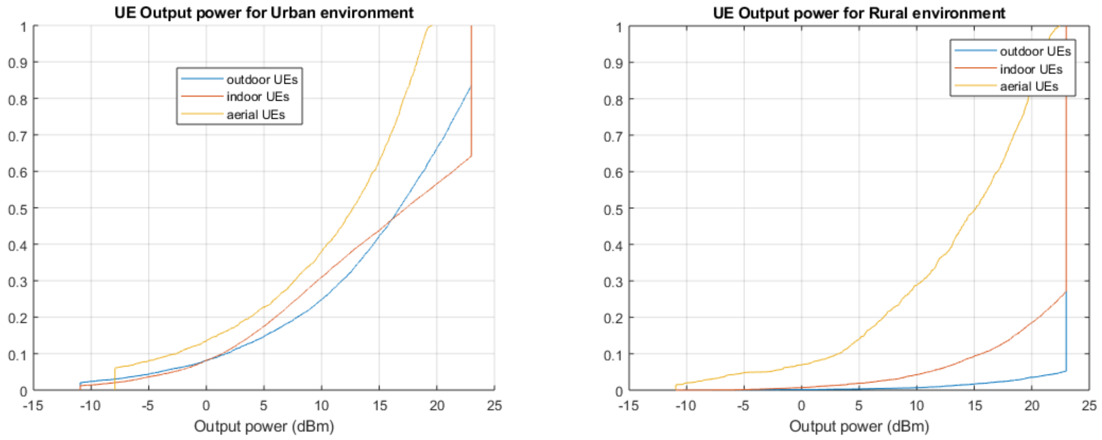


Figure 97: UE output power for urban and rural environments

As expected from the results on Coupling Loss (CL) cdf, a lower value for the CL results in a lower output power, e.g. in Urban environment for outdoor UEs (PIn-band=23 dBm)>10% or for aerial UEs (Proba(PIn-band aerial<20 dBm)=100% while a higher CL value leads to higher UE output power for the indoor and outdoor scenario (Proba(PIn-band aerial=23 dBm)>90% for outdoor and >70% for indoor).

A13.13 DISTRIBUTION OF CGC BS ANTENNA GAIN TOWARDS UES

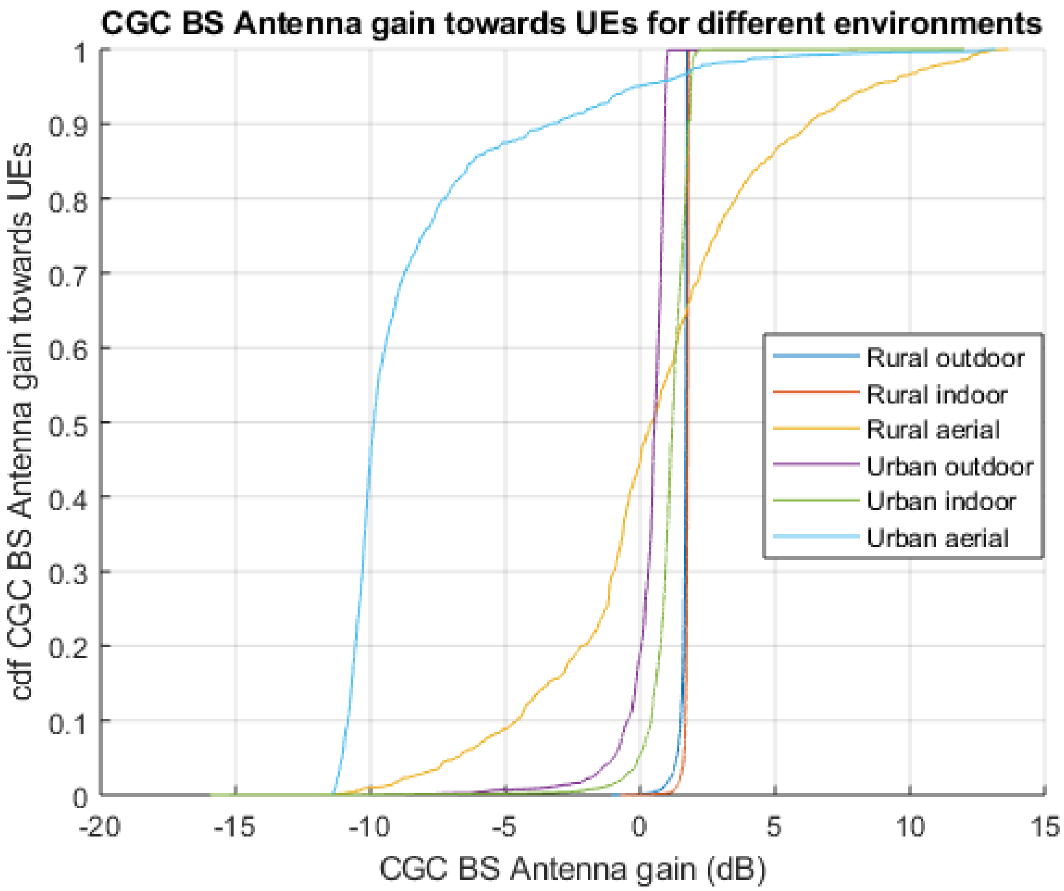


Figure 98: CGC BS antenna gain towards UEs for different environments

At a first glance, one could notice:

- The CGC BS antenna gain towards the aerial UEs is higher than towards typical UEs: because of the (10°) up-tilt of the CGC BS, the discrimination angle towards the typical UEs is bigger than for the aerial UEs (that are located above the CGC BS), explaining why the CGC BS antenna gain towards the ground UEs is lower than for the drones. For example, the probability that CGC BS antenna gain is higher than 5 dBi is respectively 13% and 1% for Rural and Urban aeras for the aerial UEs while it is less than 0.1% for the (urban and rural) typical UEs,
- A smaller dynamic of BS antenna gain values for the typical UEs because the discrimination angle is generally higher than 10°, typical UEs being below the horizon.

The CGC BS antenna gain towards typical UEs is higher for rural than for urban: since rural case assumes larger cell size than for urban ones, the proportion of terminals at the horizon is larger for rural case than for urban ones. Hence, the discrimination angle between the CGC BS antenna pointing with the ground UEs is in proportion higher for the urban area where more terminals are below the horizon in comparison with rural ones, bringing the antenna gain to be lower for the urban scenario.

A13.14 ASSUMPTIONS RELATED TO THE NUMBER OF CELLS WITHIN THE MOBILE NETWORK

The cumulative effect of interference level from UEs increases with the number of active cells from the cellular network up-to an upper-bound depending on the nature of the terminals.

For any given cellular mobile network, it is important to indicate the number of active cells, i.e. cells where aerial and typical UEs are transmitting in UL in order to calculate the aggregate interference produced by user terminals in their respective cells onto the CGC BS receiver. If the CGC BS receiver is assumed to be located at the centre of the network, the below figures illustrates scenarios with a different number of active cells within the mobile network (15 users per cell: 4 outdoor, 10 indoor, 1 aerial).

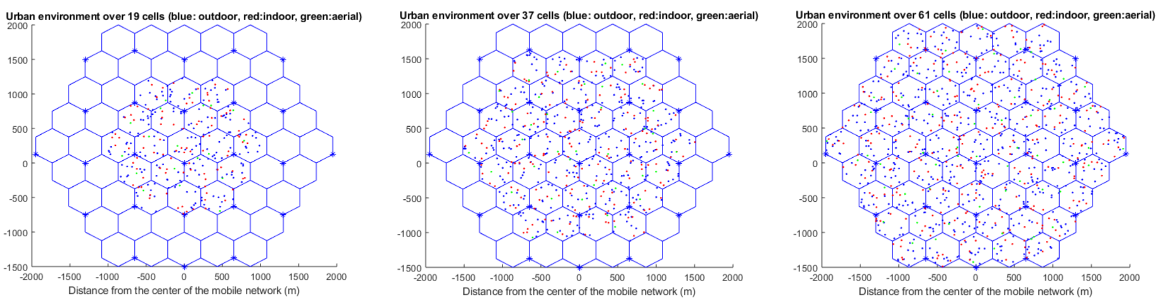


Figure 99: Scenarios with a different number of active cells within the mobile network

The below figure depicts for the urban case the saturation of the aggregate interference over the noise received by the CGC receiver I_{agg}/N achieved at 19 cells when no transmitting user terminal is aerial, i.e. being typical (indoor and outdoor).

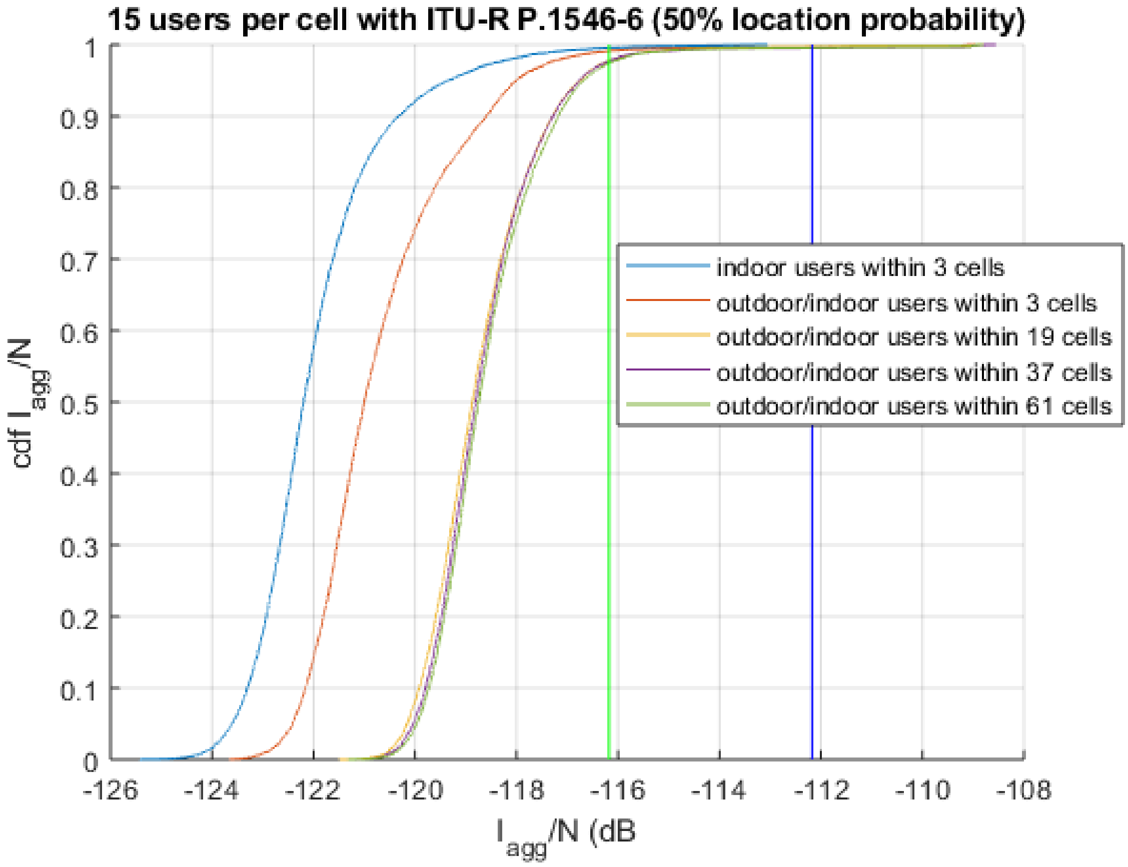


Figure 100: Saturation of the aggregate interference over the noise received by the CGC receiver

The situation differs in case of RBs occupancy by aerial UEs mainly because of the slower mitigating effect of free space loss over several cells in the calculation of the single received interference that explains why the cumulative effect of multiple UEs should be computed on more than 19 cells, 61 cells in this analysis.

ANNEX 14: AERIAL UES IN BAND 3.4 TO 3.8 GHZ CO-CHANNEL INTEREFERENCE INTO FSS EARTH STATIONS OPERATING IN 3400-3800 MHZ

Several mobile-satellite operators use the lower end of the 3400-3800 MHz band for their feeder links. A very high degree of availability is required because of the nature of the service. This band is also used by other FSS services, such as very small aperture terminal (VSAT) networks, internet providers, point-to-multipoint links, satellite news gathering, TV and data broadcasting to satellite master antenna television (SMATV), direct-to-home (DTH) receivers, and disaster relief.

The band 3400-3800 MHz is used for receiving earth stations in the FSS and aerial UEs could be a source of interference to FSS earth stations.

This Annex deals with the potential co-channel from UAS UEs transmitting in the band below 3400 -3800 MHz into FSS earth stations receiving in the same band.

The UAS UE operating in the band 3400-3800 MHz is assumed to be non-AAS.

A14.1 SYSTEM PARAMETERS

This section provides the key FSS earth station and UAS ES technical and operational parameters used for these studies.

Table 88 below provides typical MSS feeder link receiving earth station parameters used in the interference analysis (source Report ITU-R S.2368-0 [94]).

Table 88: Representative feeder link earth station characteristics used in in these studies

FSS system parameters	
Frequency Band	3400-3800 MHz
Channel Bandwidth	5 MHz
Earth station antenna radiation pattern	Recommendation ITU-R S.580 [95]
Maximum earth station gain	48.7 dBi
Antenna diameters (m)	9 m
Noise temperature (including the contributions of the antenna, feed and LNA/LNB referred to the input of the LNA/LNB receiver)	70 K
Antenna elevation angle	5-85°
Antenna height	10 m

The antenna elevation angle is relative to local horizontal at 0° of elevation. 5° is considered as the minimum operational elevation angle.

Table 89 below provides the UAS UE parameters assumed in the interference analysis for the 3.4 to 3.8 GHz band. The reference for these parameters is this ECC Report.

In these studies, it is assumed that the UAS UE transmitting in the band 3.4 to 3.8 GHz band is a non-AAS UE, i.e. the UAS UE antenna gain is assumed to be 0 dBi (Omni).

Table 89: Representative UAS UE characteristics used in these studies

Parameter	Value	Unit
Frequency band	3.4-3.8	GHz
Frequency centre	3.6	GHz
Channel bandwidth	5	MHz
Transmitted power	23	dBm
Antenna gain	0	dBi
Altitude	10000, 5000, 2000, 1000, 300, 100, 40 a.g.l	m

A14.2 INTERFERENCE PROTECTION CRITERIA

In these studies, the potential interference into a FSS earth station is evaluated based on protection criteria of I/N = -12.2 dB, in accordance with Recommendation ITU-R S.1432 [96].

A14.3 PROPAGATION MODEL

The UAS UEs are assumed to operate above the horizon with respect to the FSS earth station, and therefore the ITU-R P.528-3 [86] propagation model for aeronautical mobile is used in these studies. The percentage of time associated with the propagation variations is set to 50%.

A14.4 METHODOLOGY

Assuming one UAS UE interfering with an FSS earth station, the received interference power level at the earth station is calculated according to the equation:

$$I_{UAS} = P_{UAS} + G_{UAS} + G_{FSS}(\varphi) - L \tag{27}$$

Where:

- I_{UAS}: Received interference power level at the earth station (dBm);
- P_{UAS}: Transmitted power of the UA (dBm);
- G_{UAS}: Antenna gain of UA (dBi);
- $G_{FSS}(\varphi)$: Receive antenna gain of FSS earth station (dBi);
- L: Path loss (dB);
- (φ) The off- axis angle of the interference signal.

A14.5 TECHNICAL STUDIES AND RESULTS

This is section evaluates a baseline single entry interference analysis. The interference analysis conducted is co-channel interference from UAS UE into FSS earth station operating in the band 3.4 to 3.8 GHz.

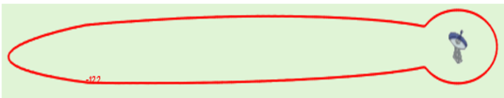
The results in Table 90 below show the required geographic separation distance with respect to FSS earth stations for example cases of UAS UEs operating in the band 3400-3800 MHz at an altitude of 300 m. The size of the geographic separation distance varies depending on the elevation angle of the FSS ES.

Table 90: Required isolation and the corresponding separation distance (UA at altitude of 300 m)

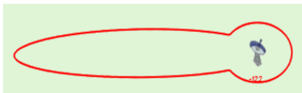
Parameter	5 deg elevation	10 deg elevation	25 deg elevation	40 deg elevation	85 deg elevation	Unit
Frequency	3600	3600.0	3600.0	3600.0	3600.0	MHz
UAS UE Bandwidth	5.0	5.0	5.0	5.0	5.0	MHz
UAS UE Transmit (dBm)	23.0	23.0	23.0	23.0	23.0	dBm
UAS UE Omni antenna gain	0.0	0.0	0.0	0.0	0.0	dBi
UAS UE EIRP Spectral Density	-44.0	-44.0	-44.0	-44.0	-44.0	dBm/Hz
UAS height	300.0	300.0	300.0	300.0	300.0	m
Polarisation Loss and FSS ES feeder loss	6.0	6.0	6.0	6.0	6.0	dB
FSS ES peak antenna gain	48.8	48.8	48.8	48.8	48.8	dBi
FSS relative gain at a given elevation angle	-37.4	-44.9	-54.6	-58.8	-58.8	deg
FSS ES gain @ a given elevation angle	11.4	3.9	-5.8	-10.0	-10.0	dBi
Interference received at FSS ES	-38.6	-46.1	-55.8	-60.0	-60.0	dBm/Hz
FSS ES receiver noise temperature	70.0	70.0	70.0	70.0	70.0	K
FSS ES receiver noise temperature	18.5	18.5	18.5	18.5	18.5	dBK
FSS ES Noise PSD	-180.2	-180.2	-180.2	-180.2	-180.2	dBm/Hz
I/N Protection Criteria	-12.2	-12.2	-12.2	-12.2	-12.2	dB
Allowable interference PSD	-192.4	-192.4	-192.4	-192.4	-192.4	dBm/Hz
Link Loss required to meet protection criterion	153.8	146.3	136.6	132.4	132.4	dB
Separation distance assuming ITU-R P.528 model	**135.3**	**103.8**	**42.6**	**26.7**	**26.7**	**km**

The above results show the required geographic separation distance with respect to FSS earth station corresponding to the worst-case interference at a given elevation of the FSS earth stations when the UAS is flying towards the main beam the FSS earth station antenna at an altitude of 300 m a.g.l.

Protection contours have also been calculated in order to evaluate the impact of UAS flying towards the FSS earth station in all directions and results are obtained for I/N criteria assumed in this study using propagation model Recommendation ITU-R P.528-3. The protection contour results for different FSS ES elevation angles and different UAS flying altitudes are shown below.



a) Distance separation of 26.7 to 290.4 km



b) Distance separation of 26.7 to 179.8 km

c) Distance separation of 26.7 to 69.3 km

d) Distance separation 26.7 to 41.0 km

e) Distance separation 26.7 km

Figure 101: Protection distance contour to mitigate interference for the receiving FSS earth station operating at an elevation angle of a) 5 deg, b) 10 deg, c) 25 deg, d) 40 deg and e) 85 deg with the UAS UE altitude of 10 km, showing different distance separations depending on direction

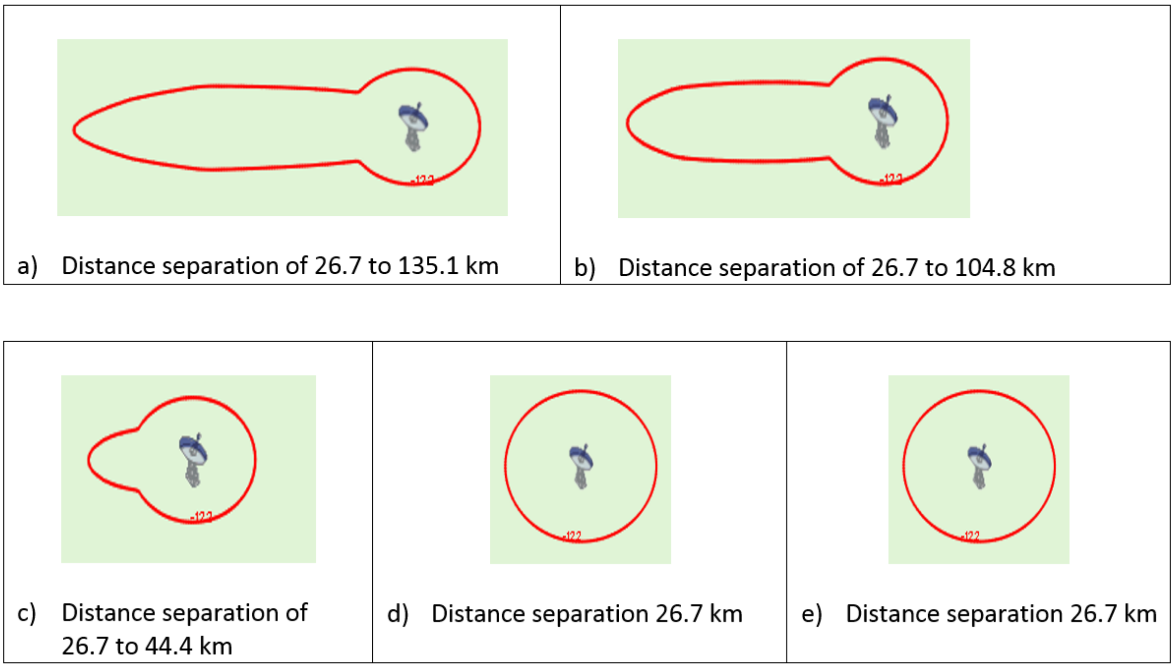


Figure 102: Protection distance contour to mitigate interference for the receiving FSS earth station operating at an elevation angle of a) 5 deg, b) 10 deg, c) 25 deg, d) 40 deg and e) 85 deg with the UAS UE altitude of 1 km, showing different distance separations depending on direction

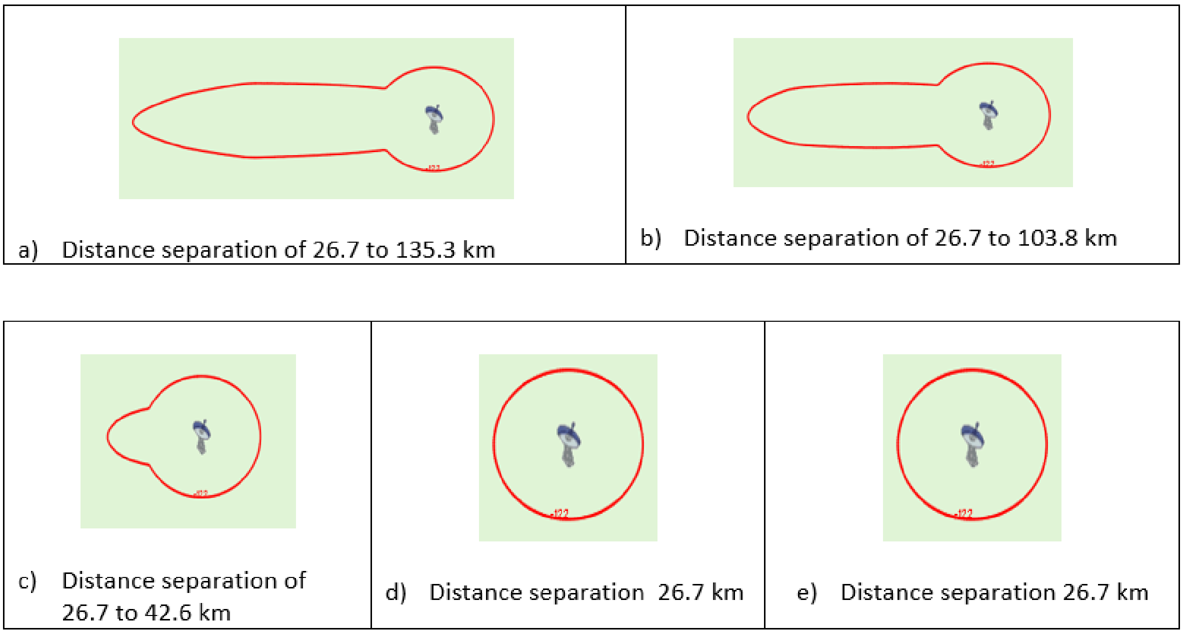


Figure 103: Protection distance contour to mitigate interference for the receiving FSS earth station operating at an elevation angle of a) 5 deg, b) 10 deg, c) 25 deg, d) 40 deg and e) 85 deg with the UAS UE altitude of 300 m, showing different distance separations depending on direction

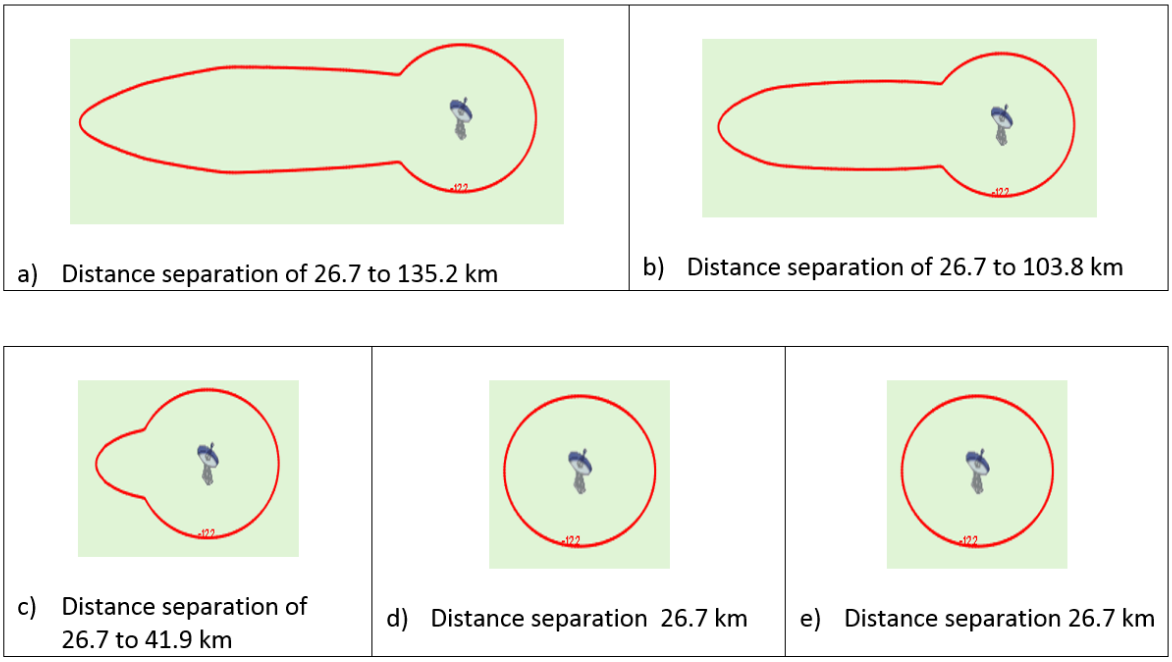


Figure 104: Protection distance contour to mitigate interference for the receiving FSS earth station operating at an elevation angle of a) 5 deg, b) 10 deg, c) 25 deg, d) 40 deg and e) 85 deg with the UAS UE altitude of 100 m, showing different distance separations depending on direction

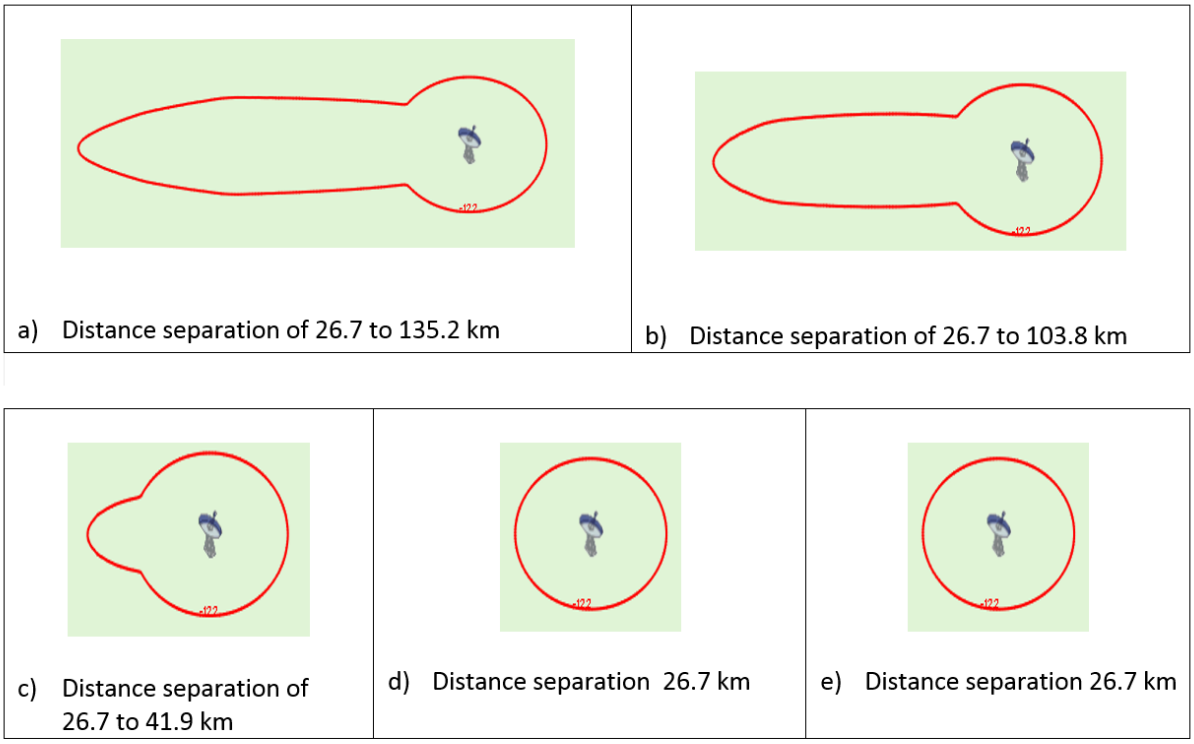


Figure 105: Protection distance contour to mitigate interference for the receiving FSS earth station operating at an elevation angle of a) 5 deg, b) 10 deg, c) 25 deg, d) 40 deg and e) 85 deg with the UAS UE altitude of 40 m, showing different distance separations depending on direction

A14.6 ANALYSIS AND MITIGATION

Table 91 below summarises the protection distances required to mitigate interference for the receiving FSS earth station operating at different elevation angles and the UAS flying at different altitude a.g.l. The size of the geographic separation distance varies depending on the elevation angle of the FSS earth station and the flight altitude of the UAS UE as shown in below.

Table 91: Protection distances between FSS earth station and UAS UEs with FSS ES at different elevations angle and UAS at different flight altitudes depending on direction

FSS ES elevation / UAS Altitude	5 degree	10 degree	25 degree	40 degree	85 degree
10 km	26.7 to 290.4 km	26.7 to 179.8 km	26.7 to 69.3 km	26.7 to 41.0 km	26.7 km
1 km	26.7 to 135.1 km	26.7 to 104.8 km	26.7 to 44.4 km	26.7 km	26.7 km
300 m	26.7 to 135.3 km	26.7 to 103.8 km	26.7 to 42.6 km	26.7 km	26.7 km
100 m	26.7 to 135.2 km	26.7 to 103.8 km	26.7 to 41.9 km	26.7 km	26.7 km
40 m	26.7 to 135.2 km	26.7 to 103.8 km	26.7 to 41.9 km	26.7 km	26.7 km

Based on the above results of analysis, a range of protection distances of 26.7 km to 290 km would be required to ensure protection of FSS earth stations operating in the band 3400-3800 MHz from UAS UEs operating in the same band.

Sharing between FSS earth stations and MFCN base stations generally requires exclusion areas to be established (see ECC Report 100 [97] and ECC Report 254 [98]). However, normally, the determination of the exclusion area considers interference from the base station only, and not potential interference from the UAS UE. Therefore, when implementing the required measures to ensure coexistence of UAS UEs with FSS earth stations, administrations could consider two cases:

- Case 1: For deployment of new base stations in the band 3.4-3.8 GHz, administrations should take into account the above minimum separation distances required to ensure coexistence of UAS UEs with FSS earth stations, when implementing exclusion zones around FSS earth stations. Figure 106 below depicts an example of case 1, where D1 is the minimum separation distance required with respect terrestrial base station and D2 is the minimum separation distance required with respect UAS UE. D2 could be greater than D1.

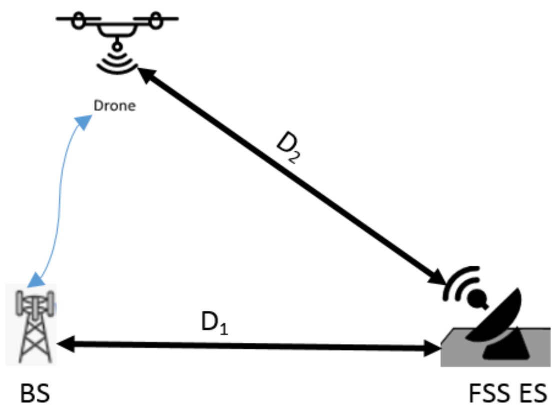


Figure 106: UAS UE communicating with a terrestrial base station with potential interference into FSS earth station

- Case 2: where there are already existing exclusion zones around FSS earth stations with respect to terrestrial base stations operating in the band 3.4 to 3.8 GHz, it needs to be checked whether the exclusion zone is sufficient to ensure that any UAS UE transmitting to/communicating with a terrestrial base station is sufficiently distant from the earth station (i.e. the distance to any drone is greater than D2). If the base station is not sufficiently distant, in order to ensure the protection of FSS earth stations from UAS UEs interference, the UAS should be required to implement a mechanism that prohibits it from using these base stations.

It should be noted that given the size of the minimum separation distances (290 km in the worst case), cross-border coordination may be necessary to ensure that earth stations do not suffer interference from UAS UEs operating in other countries.

ANNEX 15: STUDY FOR FSS 3800-4200 MHZ

Adjacent band compatibility study between IMT aerial UEs in 3.4-3.8 GHz and FSS earth stations in 3.8-4.2 GHz

A15.1 SUMMARY

This study has investigated the mitigations necessary for successful compatibility between IMT user equipment (UEs) on unmanned aircraft (UAs) (IMT aerial UEs) and FSS earth stations operating in an adjacent frequency band. This study considers a situation where the IMT aerial UEs operate in the 3.4 to 3.8 GHz frequency band and FSS earth stations (ESs) operate in the adjacent 3.8 to 4.2 GHz band. However, the results presented in this Report are applicable to other boundaries between IMT and FSS operating in C-Band.

Since this is an adjacent band compatibility problem, we model the frequency separation between wanted and unwanted systems. This model takes account of the Net Filter Discrimination (NFD) available between an IMT system and an FSS system both tuned to carrier centre frequencies close to the 3.8 GHz boundary, including a baseline scenario where frequency separation is minimum. Results where the IMT and FSS carriers have greater frequency separation are also presented. It is found that a few MHz separation of the FSS channel lower bound from the IMT band edge makes a dramatic difference to the NFD and that an assumption of such separation is strongly supported by representative data for FSS frequency assignments. These NFD calculations make use of established specifications for IMT spectrum masks and some simple assumptions with regards to the characterisation of the FSS ES receiver spectrum mask.

This study presents I/N contours and results for the maximum distance required between IMT aerial UEs and an FSS earth station. These contours can help inform the shape of no-fly zones around the earth station. This study considers some alternative I/N thresholds and reductions in maximum distance when real-world practical frequency assignment data is considered. The baseline case and low-elevation case require maximum distances of 3.7 km and 19.7 km respectively when a minimum separation between IMT and FSS carriers is considered. These maximum distances reduce to 0.5 km and 5.5 km when including a small frequency separation to take account of practical frequency assignment data for FSS systems closest to the 3.8 GHz boundary.

A15.2 INTRODUCTION

In this study, a spectrum compatibility problem where IMT operates in a frequency band adjacent to that used by FSS is investigated. Specifically, it considers interference sourced from IMT user equipment (UEs) on unmanned aircraft (UAs) operating in the frequency band 3.4-3.8 GHz, incident to FSS earth station (ES) receivers operating in the 3.8-4.2 GHz frequency band.

A practical engineering approach is taken with focus on the conditions required in order for compatibility to be viable. Specifically, for any particular scenario, the I/N threshold contours and the largest distance between the FSS earth station receiver and specific I/N contours are calculated. These contours can help inform the shape of no-fly zones around the earth station.

A range of FSS protection criteria are considered but these are relatively small adjustments within the bounds of a noise-limited approach; that is, all of the criteria constrain interference to thresholds below the wanted system's noise level.

The FSS parameters used are based on actual data for licences in the UK published by Ofcom. The Ofcom data is the basis for an alternative to the approach that simply searches for the worst case.

The simulations (performed using Visualyse software) deliver calculated I/N values at the earth station receivers. The modelling assumptions are such that it is expected that there is a minimum separation distance at each azimuth around the FSS stations - any point closer than this distance will exceed the I/N threshold, any point further than this will be below the I/N threshold.

A15.3 INTERFERENCE MODELLING

Using Visualyse software, I/N contours where interference sourced from a UAS UE is incident to an FSS earth station receiver have been calculated. Free space path loss on all interference paths is assumed with no clutter loss included. Each pixel in the area analysis is a potential location for the UE. These pixels are then used to extract contours at a particular I/N level - that level being the FSS protection criterion.

A15.3.1 FSS parameters

Two sources of data were used to investigate the FSS earth station parameters:

- Firstly, Ofcom published data relating to their earth station licences in this band [99] as part of a geographical sharing study [101].
- Secondly, Arqiva publish a summary of their teleport data in the UK, including dish size and pointing details [101].

Some observations about the Ofcom data are:

- The 5 MHz FSS carrier used in Annex 12 is not representative of the majority of the assignments and in fact does not appear in the data at all.
- 62% of all assignments are 36 MHz emissions.
- 86% of all assignments are 9 MHz and above, 9 MHz represents 17.4% of the total.
- Low elevation angles are not the typical case, only 23.4% of assignments operate below 10 degrees, 67.4% operate above 20 degrees. Only 2.8% operate <=5 degrees.

Generally, there is no correlation between dish size and elevation angle, but there is a set of very high gain links with low elevation angles.

The majority of FSS assignments do not extend to the lower end of the 3.8-4.2 GHz band. Of around 1300 assignments only 8 are closer than 5 MHz to the band edge.

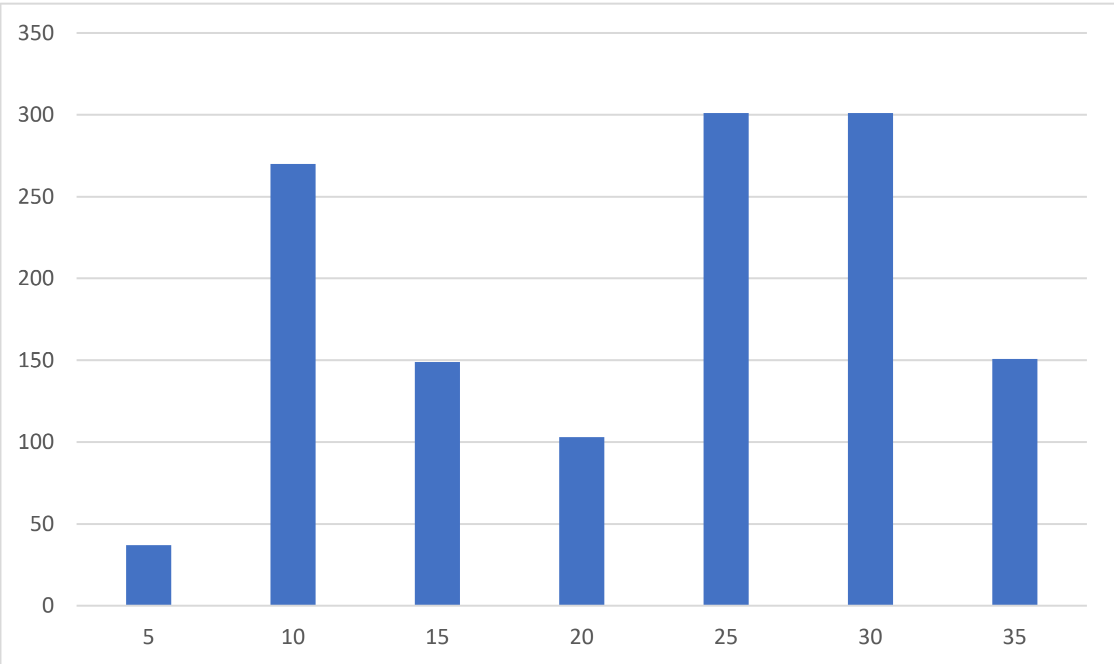


Figure 107: Distribution of elevation angles from the Ofcom data. The X axis labels bins in a 5 degree quantisation (0-5, 5-10 degrees, etc.) and the Y axis is the relative count over the data set

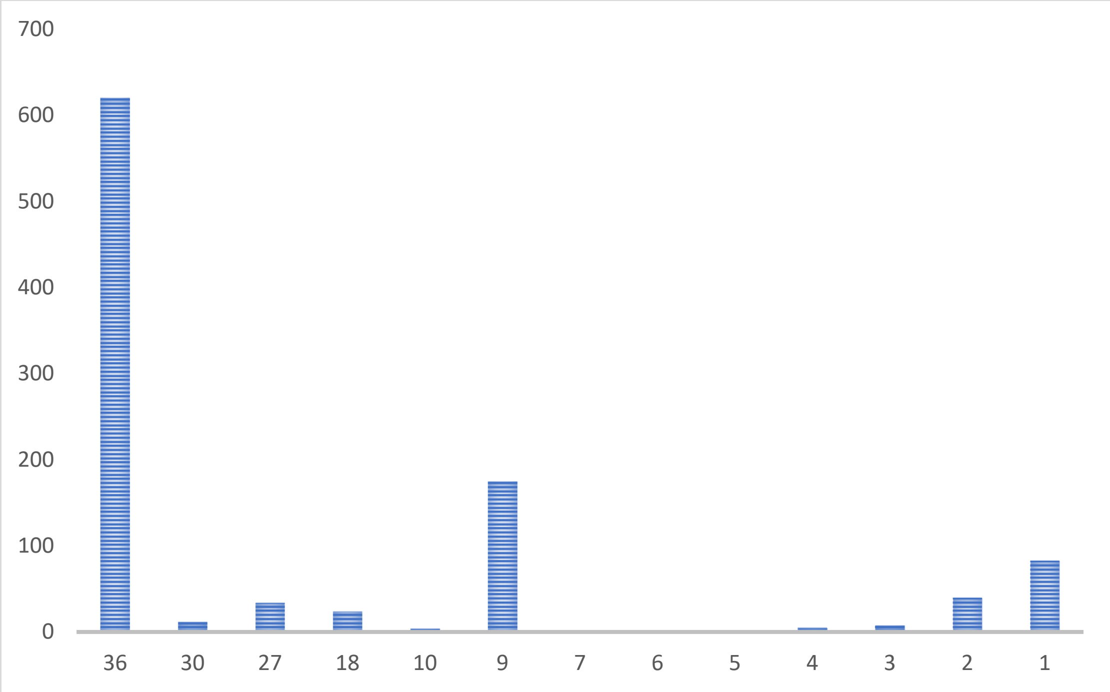


Figure 108: Distribution of bandwidths from the Ofcom data. The X axis labels bins by the integer part of the carrier bandwidth (in MHz) and the Y axis is the relative count over the data set

In the baseline study data has been used which is contained in [101] but is also more representative of the Ofcom dataset [99].

Ofcom licence ES0018088/18 corresponds to CHA 02 in the Arqiva data. This is a 9.3 m dish at Chalfont Grove operating to Intelsat 10-2 at 1° West.

The FSS parameters used in the baseline scenario are given in the below table.

Table 92: FSS baseline parameters

FSS baseline parameters	
Frequency of operation	3818 MHz
Channel bandwidth	36 MHz
Earth station antenna radiation pattern	Recommendation ITU-R S.580 [95]
Earth station antenna gain (dBi)	48.8 dBi
Antenna diameter (m)	9.3 m
Noise temperature	70 K
Antenna elevation angle	30.1° (pointed to Intelsat 10-02 at 1° West from Chalfont Grove)
Antenna height	17 m (from the Ofcom data)

A15.3.2 IMT parameters

For this study, the parameters are summarised in the below table.

Table 93: IMT parameters

IMT parameters	
Frequency of operation	3795 MHz
Channel Bandwidth	10 MHz
Antenna radiation pattern	Omni directional
Spectrum mask	ETSI TS 136 101 **Error! Reference source not found.**
Antenna gain (dBi)	0 dBi
UE altitude	150 m above local terrain
UE e.i.r.p.	23 dBm

A 10 MHz bandwidth for the IMT system is assumed and a spectrum mask derived from ETSI TS 136 101 V14.5.0 (2017-11), table 6.6.2.1.1-1 **Error! Reference source not found.**.

A15.3.3 Further modelling assumptions and variations

The baseline case assumes that the IMT carrier is at the top of its band with the upper edge of the channel residing at 3800 MHz, and the FSS carrier is at the bottom of its band with the lower edge of the channel also residing at 3800 MHz - as a result there is minimum separation between the two carriers.

The Ofcom data, which is assumed to reflect best practice in professional frequency assignment work, shows that very few assignments for 36 MHz FSS systems reside at the lowest possible frequency of 3818 MHz (with the lower bound of the channel at 3800 MHz). Hence, the typical case has at least some separation between the lower bound of the FSS channel and the 3800 MHz boundary and therefore some extra separation between FSS and IMT carriers beyond the minimum separation given in equation (29) below.

Based on an investigation of [99], results are presented for the cases where there is an additional {1,2,3,…,7} MHz frequency separation between IMT and FSS carriers over and above that given by equation 2.

An extreme case where the FSS system uses a very low elevation angle and a very large dish is also considered.

A15.3.4 Net Filter Discrimination

This study investigates a compatibility problem where a frequency offset between interferer and victim receiver always exists. Therefore, we calculate NFD using the well-established method specified by ETSI [102], an approach widely used in sharing studies, academic investigations and practical frequency assignment work[103], [104] and [105].

The ETSI method rests on an integration of transmitter and receiver spectrum masks in the frequency domain at discrete frequency offsets. NFD is calculated and expressed in decibels using:

$$\mathrm{NFD} = 10 \cdot \mathrm{Log}\left(\left[\int_{f_0-\Delta_-}^{f_0+\Delta_+} 10^{\left(\frac{Tc+Rc}{10}\right)} \cdot df\right] \Big/ \left[\int_{f_0-\Delta_-}^{f_0+\Delta_+} 10^{\left(\frac{To+Rc}{10}\right)} \cdot df\right]\right) \tag{28}$$

Where:

- Tc is the transmitter spectrum mask sampled co-frequency;
- Rc is the receiver spectrum mask sampled co-frequency;
- To is the transmitter spectrum mask sampled at some frequency offset from the receiver;
- f_0 is the receiver centre frequency;

- Δ_- is the delta required for a suitable lower frequency bound on the spectrum masks;
- Δ_+ is the delta required for a suitable upper frequency bound on the spectrum masks.

In scenarios where the interfering transmitter's bandwidth b_{tx} is greater than that of the victim receiver's b_{rx} not all of the interferer's power can be incident to the victim receiver and the NFD procedure includes a bandwidth correction factor. However, in this study, $b_{tx} < b_{rx}$ and so bandwidth correction is not applied.

For this procedure, a radio spectrum transmit mask for the 10 MHz IMT UAS UE was sourced from **Error! Reference source not found.**. FSS receiver spectrum masks are difficult to source and this is a persistent problem in sharing and compatibility studies as well as in practical frequency assignment and coordination work. However, theoretical spectrum masks are often utilised, and default masks are a feature of practical frequency assignment and coordination work in cases where spectrum mask data is unavailable [103]. In this study, for the FSS system, we make use of a Gaussian mask that extends two times channel bandwidth with attenuation of -60 dB specified at the end-points of the Gaussian distribution.

In this compatibility study, the minimum frequency separation between the carrier centre frequencies of an IMT UAS and FSS system is given by:

$$\Delta f_{min} = \frac{b_{FSS}}{2} + \frac{b_{IMT}}{2} \tag{29}$$

where b_{FSS} and b_{IMT} are the channel bandwidths of the FSS receiver and IMT transmitter, respectively. In this study, the IMT system operates in a 10 MHz channel and the FSS system in a 36 MHz channel, hence Δf_{min} = 23 MHz. the below figure shows the relative position of the two transmitter masks in the frequency domain when modelled in Visualyse. The NFD obtained = 20.49 dB.

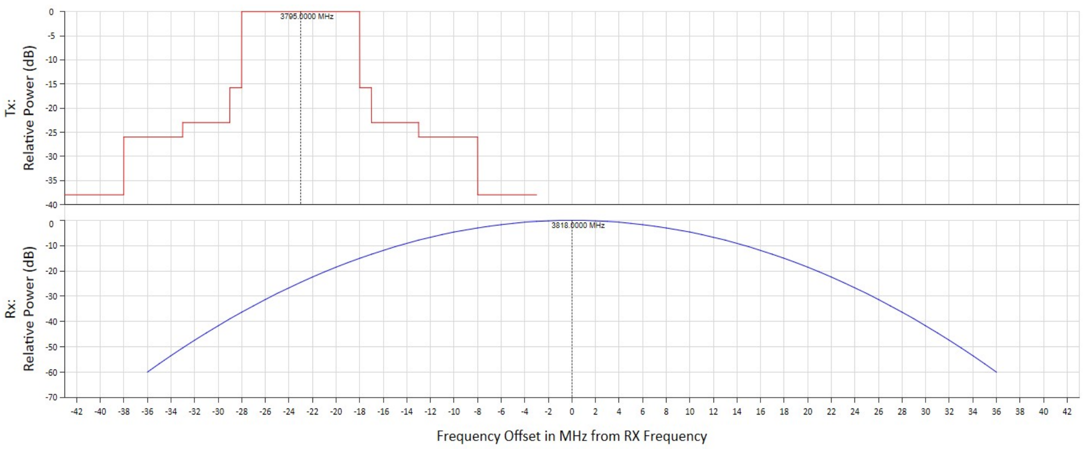


Figure 109:Spectrum masks in Visualyse software

Having determined NFD, a revised interfering signal power incident to the victim receiver is calculated.

The below table shows the NFD results obtained for the minimum frequency offset between the carrier centre frequencies of the IMT and FSS carriers and for additional offsets where the minimum offset is increased by {1, 2,…, 7} MHz.

Table 94: Net Filter Discrimination

FSS frequency (MHz)	IMT frequency (MHz)	NFD (dB)
3818	3795	20.49

FSS frequency (MHz)	IMT frequency (MHz)	NFD (dB)
3819	3795	22.25
3820	3795	24.05
3821	3795	25.86
3822	3795	27.64
3823	3795	29.32
3824	3795	30.85
3825	3795	32.16

A15.3.5 Results

The below figure shows the results from the baseline case at Chalfont Grove. The outer contour is for I/N = -12.2 dB, the middle contour is for I/N = -10 dB, and the inner contour is for I/N = -6 dB. In this case, the largest distance between the earth station receiver and the -12.2 dB contour is 3.7 km.

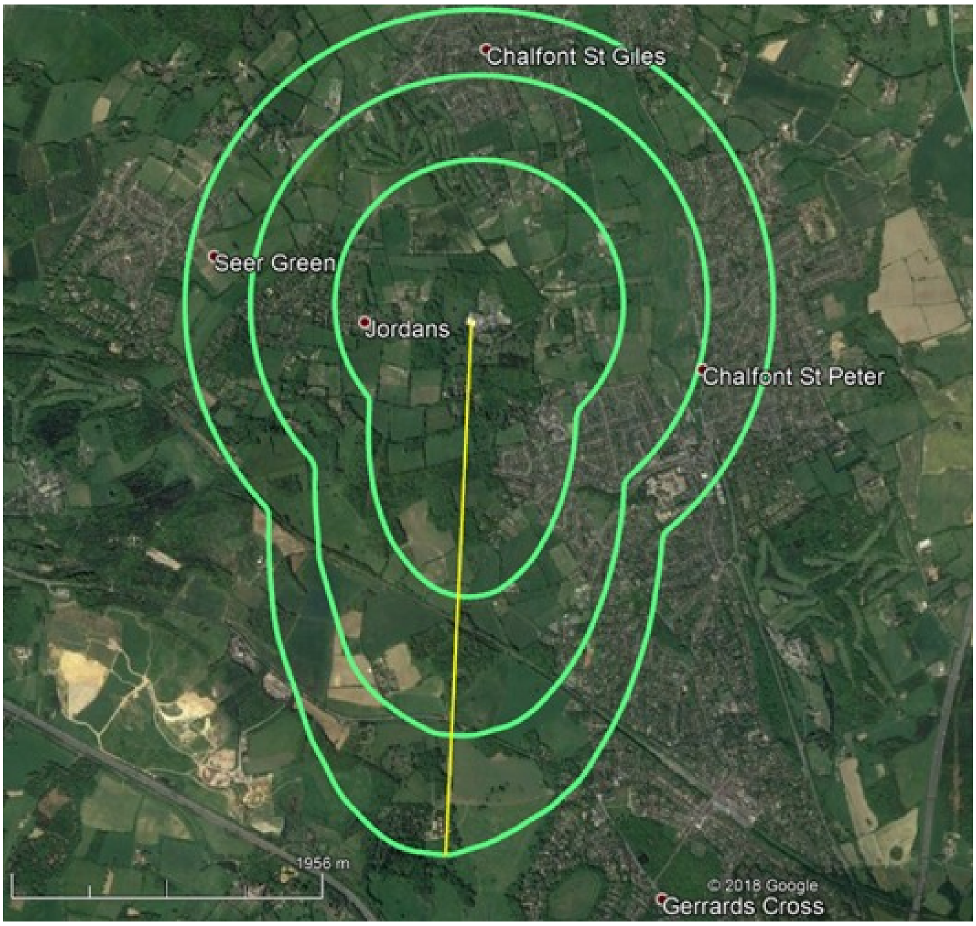


Figure 110: I/N = -12.2 dB, -10 dB and -6 dB I/N contours around Chalfont Grove; 9.3 m dish, 30.1 degrees elevation. The yellow line represents a great circle distance of 3.7 km

The below figure shows the case for a 25 m dish pointing at 5.6 degrees elevation. Again, contours are shown for I/N thresholds of -12.2 dB, -10 dB and -6 dB. The largest distance between the earth station receiver and the -12.2 dB contour is 19.7 km.

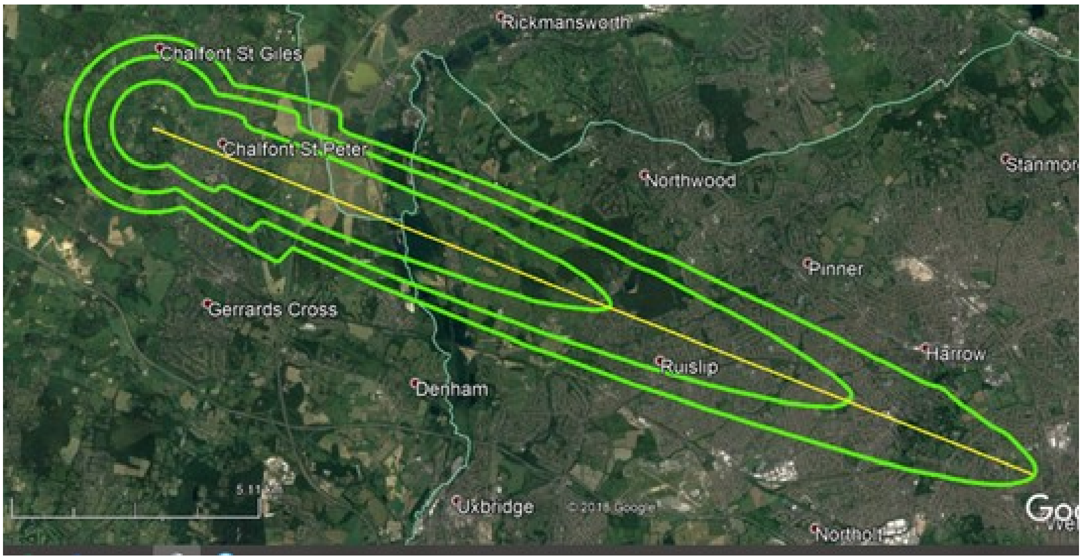


Figure 111: I/N = -12.2 dB, -10 dB and -6 dB I/N contours around Chalfont Grove, 25 m dish, 5.6 degrees elevation. The yellow line represents a great circle distance of 19.7 km

It is also instructive to see the impact of relatively small increases in frequency separation between the IMT and FSS carriers as depicted in the two following figures. Here, each of the contours represents the I/N threshold of -12.2 dB with each of the frequency separations in Table 94 considered. The smallest contour represents the frequency assignments in the final row of Table 94 that is, with 7 MHz frequency separation between the edges of the IMT and FSS carriers and 32.16 dB of NFD accounted for.

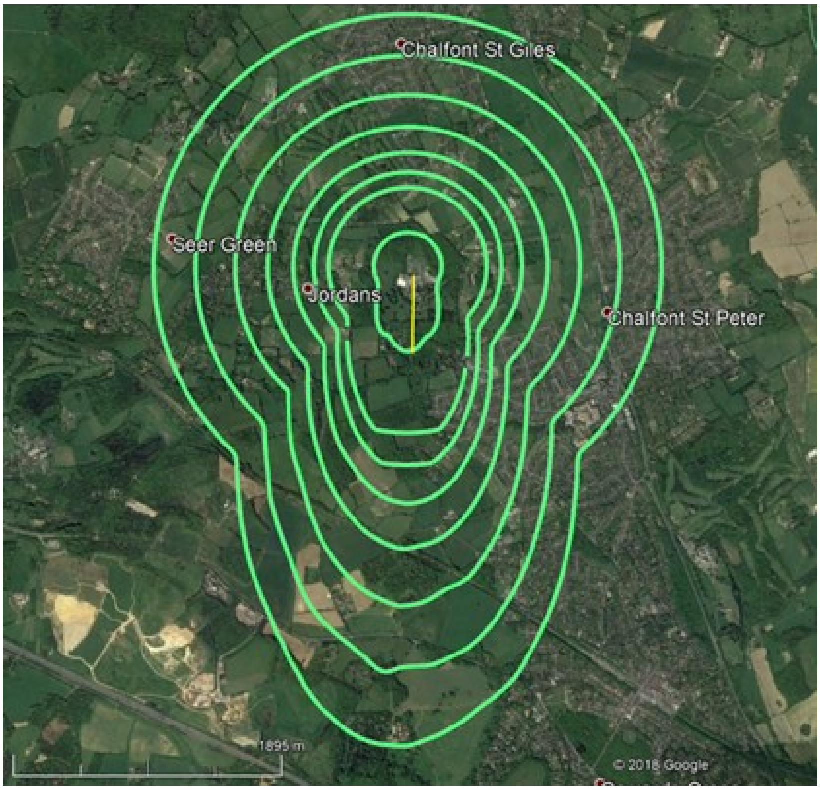


Figure 112: I/N = -12.2 dB, with contours at 1 MHz additional frequency separation around Chalfont Grove; 9.3 m dish, 30.1 degrees elevation. The yellow line represents a great circle distance of 0.5 km

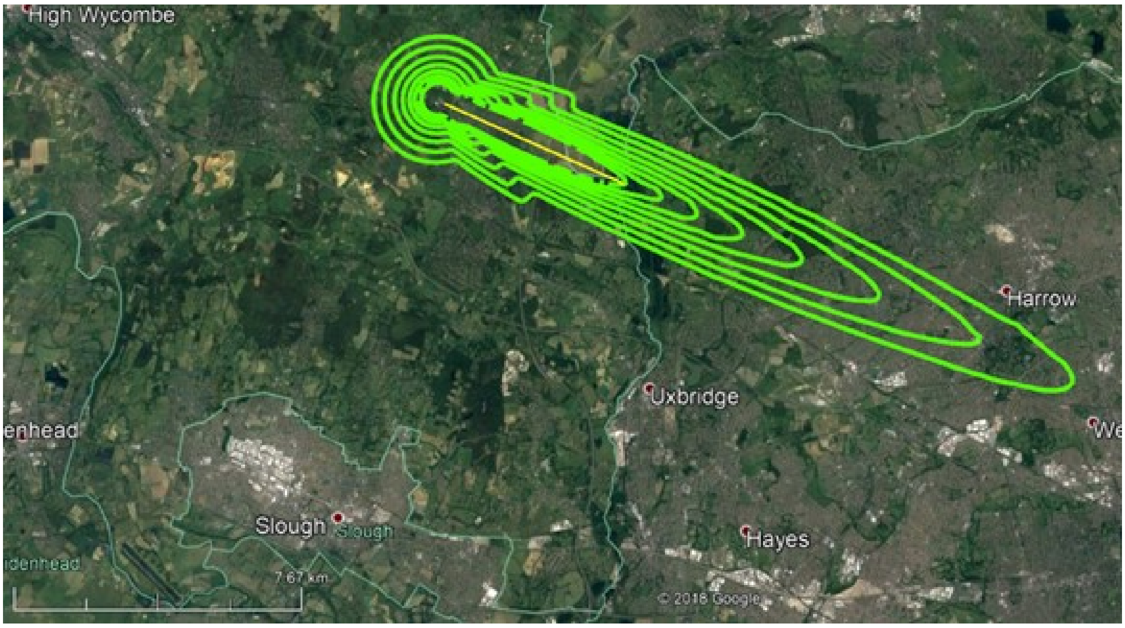


Figure 113: I/N = -12.2 dB, with contours at 1 MHz additional frequency separation around Chalfont Grove; 25 m dish, 5.6 degrees elevation. The yellow line represents a great circle distance of 5.5 km

These results show maximum distances of 3.7 km and 19.7 km for the baseline case (Figure 110) and the low elevation case (Figure 111) respectively. The maximum distances for these two cases are subject to substantial reductions when we take account of the Ofcom frequency assignment data for FSS earth stations. Assuming an additional 7 MHz frequency separation between IMT and FSS carriers reduces the maximum distance to 0.5 km and 5.5 km for the baseline and low elevation cases respectively.

A15.4 CONCLUSIONS

In this study, we calculate contours for specific I/N thresholds around FSS ES receivers such that IMT UAS UEs operating beyond these contours do not cause excess interference at the ES receiver.

Making some assumptions, we take account of the Net Filter Discrimination available when the frequency separation between wanted and unwanted systems is at a minimum.

Further, a range of protection criteria are considered for the FSS ES receiver and a range of frequency offsets between the IMT and FSS carriers based on investigation of some real-world data. This study has worked with actual licence data from Ofcom. The results indicate that maximum distances between the earth station and I/N contour are sensitive to several assumptions. The assumption of minimum frequency separation, which has been made in ANNEX 11:, bears particular examination. The vast majority of Ofcom's assignments imply a frequency separation greater than 30 MHz between IMT and FSS carriers and this results in a significant reduction in the required separation distances.

ANNEX 16: IN-BAND ADJACENT CHANNEL CO-EXISTENCE SIMULATION FOR AERIAL UE OPERATION IN THE 3.4-3.8 GHZ BAND

A16.1 INTRODUCTION

The purpose of this study is to examine the potential UL interference from aerial UEs in interfering network B to victim network A, operating in the adjacent channel. This is done by comparing the throughput loss caused in a victim network from ground UEs with the throughput loss caused by aerial UEs. As ground UEs are already ubiquitously deployed, a realistic assessment for the interference of aerial UEs can be made.

In this study, it is assumed that the base station is able to use beam steering to increase its gain towards the UE. Furthermore, it is assumed that both networks are synchronised which means that at the same time, both networks are either operating in UL or DL.

A16.2 SCENARIO

The considered scenario assumes an uncoordinated case, which means that the sectors of network A and B are overlapping and shifted. The base stations of network A are depicted in black, whereas the base stations of network B are depicted in red. In this study, network B is the interfering network, which is why the colour red has been chosen for it. The figure below illustrates this scenario.

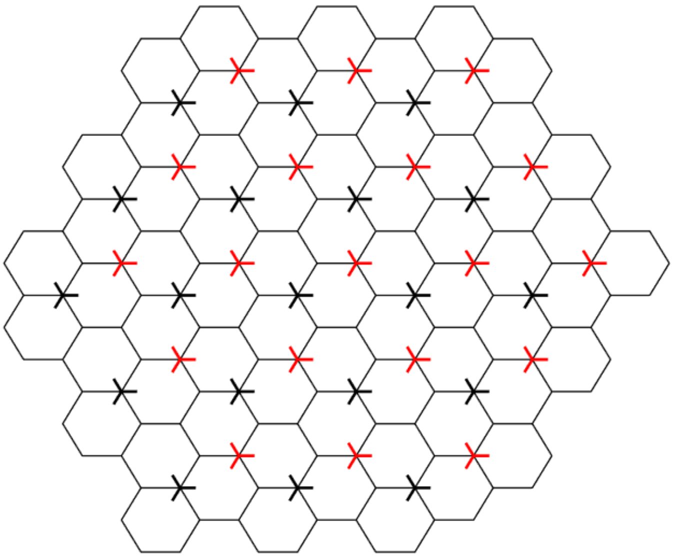


Figure 114: Networks A and B (BS only)

To achieve a perfect shift of the sector the network B with the red BS has been shifted by the following formulas:

$$X_{Shift} = Cellradius * (1 + \cos(60)) \quad (30)$$

$$Y_{Shift} = Cellradius * \sin(60) \quad (31)$$

Each sector is then populated with an UE which connects to the corresponding base station. Note that overlapping sectors are populated with two UEs, so that one UE connects to network A and the other connects to network B. The figure below illustrates this, where the UEs are depicted with small points. The altitude of the UEs depends on whether ground or aerial UEs are considered. The details can be found in the table of parameters.

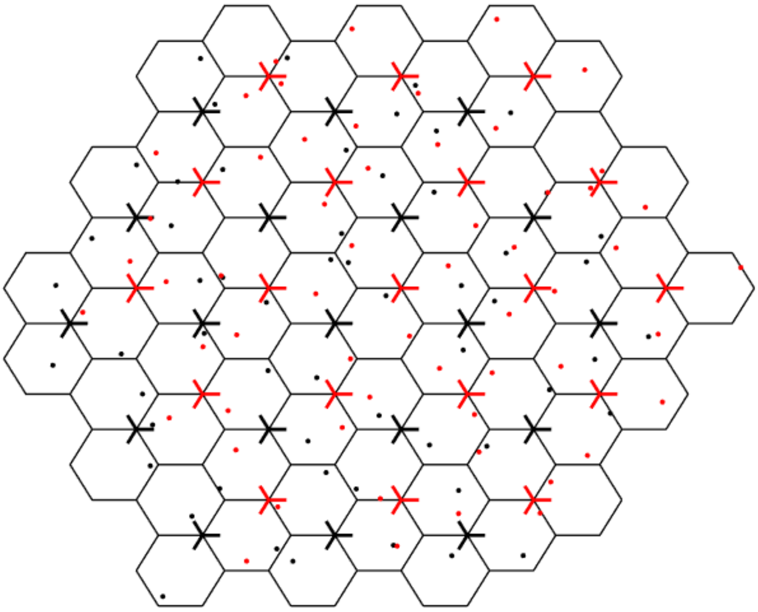


Figure 115: Networks with deployed UEs

This deployment scenario sets the basis for the calculation of the throughput loss, which is explained in the methodology section.

A16.3 PARAMETERS

Table 95:Network parameters

Parameter	Value	Reference
Frequency Band	3400-3800 MHz	
Duplex Mode	TDD	3GPP TS 38.101-1 **Error! Reference source not found.**
Technology	5G NR	3GPP TS 38.101-1 **Error! Reference source not found.**
Bandwidth	10 MHz	3GPP TS 38.101-1 **Error! Reference source not found.**

Parameter	Value	Reference
Considered Centre Frequency	3405 MHz	
Deployment Scenario	Macro Urban (UMa)	
Cell Range	300 m	ITU-R M.2292, table 4 [25]
Inter Site Distance	450 m	Linked to cell range
Propagation Model	Ground UE: 3GPP TR 38.901 UMa scenario Aerial UE: Free Space Path Loss	3GPP TR 38.901, table 7.4.1-1
Minimum Coupling Loss (MCL)	70 dB	
Base stations per network	19 base stations / 57 sectors per network	
Antenna height	20 m	ITU-R M.2292 [25]
Mechanical down tilt	10°	ITU-R M.2292 [25]
Sectors per station	3 sectors - 120° shifted	ITU-R M.2292 [25]
Thermal Noise	290°K	
Noise Figure	5 dB	ITU-R M.2292 [25]
Noise Floor	-98.977 dBm	Derived value
Antenna	▪ AAS according to 3GPP TR 37.840 ▪ 1 AAS per sector with 8x8 Elements ▪ Element Peak Gain: 5 dBi ▪ Signal Correlation Factor: 1 ▪ Horizontal Element Spacing: 0.9λ ▪ Vertical Element Spacing: 0.6 λ ▪ 3 dB vertical beamwidth: 65° ▪ 3 dB horizontal beamwidth: 80° ▪ Front to back radio: 30 dB ▪ Side lobe level limit: 30 dB ▪ Array gain normalisation factor: +3.35 dB	ECC Report 281 [38]
Bitrate mapping	$Bitrate = Spectral_{Eff} * Bandwidth$ with ▪ $Spectral_{Eff} = 0$ for $SNIR < -10dB$ ▪ $Spectral_{Eff} = 0.4\log_2(1 + 10^{\frac{SNIR_{db}}{10}})$ for $-10dB \leq SNIR < 22$ ▪ $Spectral_{Eff} = 2.9269$ for $22 \leq SNIR$	3GPP TR 38.803 Chapter 5.2.7 [91]

Table 96: Base station parameters

Parameter	Value	Reference
Antenna height	Ground UE: 1.5 m Aerial UE: 30, 300, 3000, 6000, 10000	

Parameter	Value	Reference
Transmit power	-40 to 23 dBm	3GPP TS 38.101-1 **Error! Reference source not found.**
ACLR	30 dB	3GPP 38.101-1 **Error! Reference source not found.**
Target SNIR	10 dB	
Number of UEs	1 per BS sector	

A16.4 METHODOLOGY

A16.4.1 General

The methodology used is in principle identical with Recommendation ITU-R M.2101 [51] but further elaborated below.

This study assesses the interference by the network throughput loss in a victim network B caused by the UL interference in an interfering network A. This throughput loss is determined for two different cases.

The first cases are the reference cases, where only ground UEs are deployed in the interfering network. Based on that, the network throughput loss in the victim network caused by the UL interference of the ground UEs is calibrated.

In the second case, only aerial UEs are deployed in the interfering network. Afterwards, the network throughput loss in in the victim network caused by the UL interference of aerial UEs is calculated.

Based on the results, the throughput loss on victim network B caused by aerial UEs (from network A) can be compared with the network that is interfered by ground UEs (from network A) and a fair assessment can be made.

The following steps explain how the network throughput loss is calculated. The steps apply for both cases, as they are essentially the same with the only difference of the UE altitude.

A16.4.2 Throughput Loss Calculation

A16.4.2.1 Step 1: Deploy the networks and place randomly UEs

To calculate the throughput loss, consider the scenario previously described. Here, both networks are deployed, and each base station sector serves a randomly deployed UE.

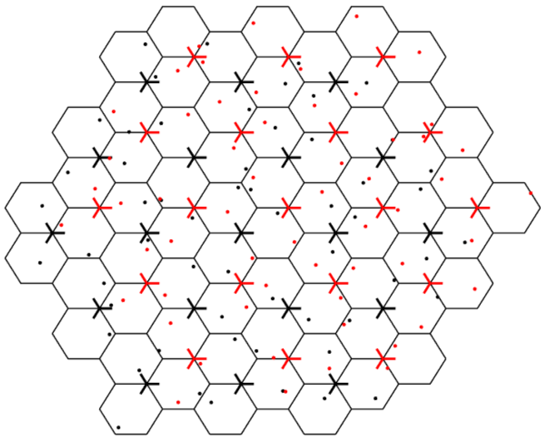


Figure 116: Networks with deployed UEs

A16.4.2.2Step 2: Determine the UE transmit power of the UEs in the victim network

The UEs in the victim network need to determine their transmit power by a power control algorithm to achieve the desired SNIR at the serving base station sector. Here an idealized power control algorithm is used, which assumes that the UE knows the gain of the base station, the noise floor and the propagation loss. Using this formula, the UE can determine the precise transmit power which is required to achieve the SNIR in an interference free environment (no intra network interference).

$$UE_{TXpower} = SNIR_{Target} + BS_{NoiseFloor} - BS_{GainToTarget} - UE_{Gain} + PropagationLoss \quad (32)$$

Where:

- $UE_{TXpower}$: UE transmit power;
- $SNIR_{Target}$: Target value for the Signal-to-Interference-Noise ratio;
- $BS_{NoiseFloor}$: Noise floor of the base station;
- $BS_{GainToTarget}$: AAS gain of the base station towards the UE it is serving;
- UE_{Gain}: Gain of the UE towards the serving BS;
- $PropagationLoss$: Propagation loss from the UE to the base station;
- P_{Max}: Maximum output power.

*A16.4.2.3**Step 3: Determine the desired received signal strength in the victim network***

Determine the desired received signal strength at the serving base station for each UE. This is done by a simple and well known link budget calculation

$$dRSS = UE_{TXPower} + BS_{Gain} + UE_{Gain} - PropagationLoss \quad (33)$$

Where:

- $dRSS$: Desired received signal strength;
- $UE_{TXpower}$: UE transmit power;
- BS_{Gain}: AAS gain of the base station towards the UE it is serving;
- UE_{Gain}: Gain of the UE;
- $PropagationLoss$: Propagation loss from the UE to the base station.

A16.4.2.4 Step 4: Determine the aggregate intra system interference in the victim network

It is assumed that all UEs within the same network operate in the same frequency band. Hence, it is necessary to consider the interference of other UEs, operating in the other cells of the same network (as they are using the same RBs), which are causing interference to a base station sector. This is done by calculating the interfering received signal strength from each UE and summing them up. This step needs to be done for all base station sectors. Remember that the signal strength from the UE that is located in the sector served by the base station is not considered as unwanted interference, but as wanted signal.

Firstly, determine the (intra system) interfered received signal strength at each base station sector from each UE in the own network.

$$iRSS_{k,i} = UE_{TXPower_i} + BS_{GainToTarge_{k,i}} + UE_{Gain_i} - PropagationLoss_{k,i} \quad (34)$$

Note: $k \,!= i$, as the k-th base station sector serves the i-th UE.

Where:

- $iRSS_{k,i}$: Interfered received signal strength from the i-th UE received at the k-th base station sector;
- $UE_{TXPower_i}$: Transmit power of the i-th UE;
- $BS_{Gain_{k,i}}$: Gain from the k-th base station sector towards the i-th UE;
- $PropagationLoss_{k,i}$: Propagation loss from the i-th UE to the k-th base station sector.

Afterwards, sum up the (intra system) interference at the k-th base station sector to determine the aggregate intra network interference. Calculate this value for each base station sector.

$$IaggIntra_k = 10\log_{10}\Big(\sum_{\substack{i=1\\ i\,!=k}}^{N_{intra_{UE}}} 10^{\frac{iRSS_{k,i}}{10}}\Big) \quad (35)$$

Where:

- $IaggIntra_k$: Aggregated intra system interference at the k-th base station sector;
- $N_{intra_{UE}}$: Total number of UEs in the same network;
- $iRSS_{k,i}$: Interfered received signal strength from the i-th UE received at the k-th base station sector.

A16.4.2.5 **Step 5: Determine the SNIR with intra system interference**

With the values previously obtained, SNIR can be calculated when taking into account the intra system interference for each base station sector.

$$SNIR_{Intra_k} = dRSS_k - 10\log_{10}\big(10^{\frac{IaggIntra_k}{10}} + 10^{\frac{NoiseFloor}{10}}\big) \quad (36)$$

Where:

- $SNIR_{Intra_k}$: Signal to noise plus interference ratio at the k-th base station, taking into account the intra system interference;
- $dRSS_k$: Desired received signal strength at the k-th base station sector;
- $IaggIntra_k$: Aggregated intra system interference at the k-th base station sector;
- $NoiseFloor$: Noise floor of the k-th base station sector, which equal for all sectors.

A16.4.2.6 Step 6: Determine the non-interfered throughput in the victim network

With the SNIR just calculated, we are able to calculate the throughput for each base station sector. Firstly, the spectral efficiency needs to be calculated corresponding to the SINR.

$$SpectralEff = \begin{cases} 0 & \text{for} \quad SNIR < -10\,dB \\ 0.4\log_2(1+10^{\frac{SNIR_{db}}{10}}) & \text{for } -10\,dB \le SNIR < 22\,db \\ 2.9269 & \text{for} \quad 22\text{ db} \le SNIR \end{cases} \tag{37}$$

With:

- $SpectralEff$: Spectral efficiency;
- $SNIR$: Signal to noise plus interference ratio.

The figure below illustrates the relationship between the spectral efficiency and the SNIR.

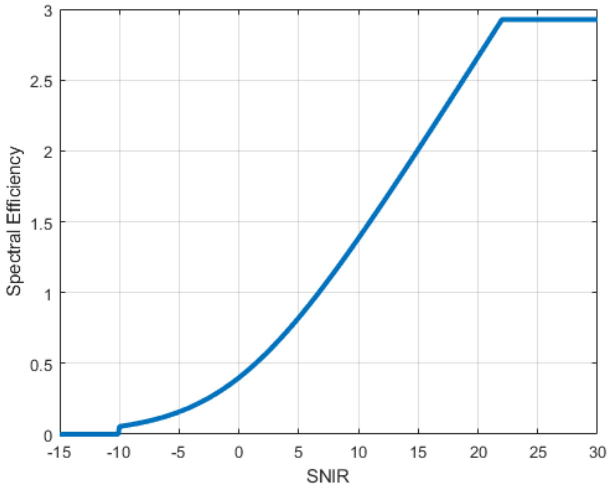


Figure 117: SNIR and spectral efficiency relation

Multiplying the bandwidth with the spectral efficiency, the non-interfered throughput for each base station sector is obtained.

$$Throughput_k = SpectralEff_k * Bandwidth \tag{38}$$

With:

- $Throughput_k$: Throughput at the k-th base station sector for the non-interfered case;
- $SpectralEff_k$: Spectral efficiency achieved at the k-th band for the non-interfered case;
- $Bandwidth$: Bandwidth.

A16.4.2.7Step 7: Determine the inter system interference from the interfering network

To determine the throughput loss, we first need to calculate the interference received from the interfering network. Afterwards, we can calculate the interfered SNIR taking into account both intra and inter network interference and obtain the interfered throughput. Afterwards, we can compare this interfered throughput with the non-interfered throughput to obtain the throughput loss.

To obtain the interference received from the interfering network, we need to perform a basic link budget calculation and sum up the received interference for each base station sector. The interfering UEs determine their transmission power in a similar way as described here for the victim network, using AAS towards the aerial UE. Based on the ACLR, the emissions into the adjacent channel (victim network) can be determined for the UE.

In this study, the adjacent channel selectivity is neglected because the adjacent channel interference is usually dominated by the adjacent band emissions and not by selectivity of the base station.

$$iRSS_{k,j} = UE_{ACLR_j} + BS_{Gain_{k,j}} + UE_{Gain_j} - PropagationLoss_{j,k} \quad (39)$$

Where:

- $iRSS_{k,j}$: at — Interfered received signal strength from the j-th UE (interfering network) received the k-th base station sector
- UE_{ACLR_j}: Adjacent channel emissions from the j-th UE
- UE_{Gain_j}: Gain from the j-th UE
- $BS_{Gain_{k,i}}$: Gain from the k-th base station sector towards the j-th UE
- $PropagationLoss_{\mathrm{j,k}}$: Propagation loss from the j-th UE to the k-th base station sector

A16.4.2.8 Step 8: Determine the aggregate inter system interference from the interfering network

Afterwards, sum up the interfered received signal to obtain the aggregate interference from the interfering network. Perform this step for every base station.

$$IaggInter_k = 10\log_{10}\left(\sum_{j=1}^{N_{Interfering_{UE}}} 10^{\frac{iRSS_{k,j}}{10}}\right) \quad (40)$$

Where:

- $IaggInter_k$: Aggregate inter system interference at the k-th base station sector caused by the interfering network;
- $N_{Interfering_{UE}}$: Number of UEs in the interfering network;
- $iRSS_{k,j}$: Interfered received signal strength from the j-th UE (interfering network) received at the k-th base station sector.

A16.4.2.9 Step 9: Determine the interfered SNIR (intra and inter system interference)

Knowing the aggregate intra system interference and aggregate inter system interference at a given base station sector, it is possible to obtain the SNIR for the interfered case.

$$SNIR_{Intra_k} = dRSS_k - 10\log_{10}\left(10^{\frac{IaggIntra_k}{10}} + 10^{\frac{IaggInter_k}{10}} + 10^{\frac{NoiseFloor}{10}}\right) \quad (41)$$

Where:

- $SNIR_{Intra_k}$: Signal to noise plus interference ratio at the k-th base station, taking into account the intra system interference;
- $dRSS_k$: Desired received signal strength at the k-th base station sector;
- $IaggIntra_k$: Aggregate intra system interference at the k-th base station sector;
- $IaggInter_k$: Aggregate inter system interference at the k-th base station sector caused by the interfering network;
- $NoiseFloor$: Noise floor of the k-th base station sector, which equal for all sectors.

A16.4.2.10 Step 10: Determine the interfered throughput in the victim network

With the interfered SNIR just calculated, it is possible to calculate the interfered throughput for each base station sector. First, it is necessary to calculate the interfered spectral efficiency which corresponds to the interfered SINR. The steps to obtain the spectral efficiency corresponding to an SINR value are described in step 6. After obtaining the interfered SINR, the interfered throughput at a given base station can be determined.

$$IThroughput_k = SpectralEff_k * Bandwidth \tag{42}$$

Where:

- $ITroughput_k$: Throughput at the k-th base station sector for the interfered case;
- $SpectralEff_k$: Spectral efficiency achieved at the k-th band for the interfered case;
- $Bandwidth$: Bandwidth.

A16.4.2.11 Step 11: Determine the throughput loss

After obtaining the interfered throughput and the non-interfered throughput, it is possible to determine the relative throughput loss for each base station sector.

$$ThroughputLoss_k = \frac{Throughput_k - IThroughput_k}{Throughput_k} \tag{43}$$

Where:

- $ThroughputLoss_k$: The throughput loss at the k-th base station sector;
- $Troughput_k$: The non-interfered throughput at the k-th base station sector;
- $ITroughput_k$: The interfered throughput at the k-th base station sector.

A16.4.2.12 Step 12: Determine the average network throughput loss

After determining the throughput loss for each base station, the average network throughput loss caused by the interfering network can be determined:

$$ThroughputLoss_{\mathrm{Avg}} = \frac{\sum_{k=1}^{\mathrm{N_{sectors}}} ThroughputLoss_k}{N_{sectors}} \tag{44}$$

Where:

- $\mathrm{ThroughputLoss_{Avg}}$: Average cell throughput loss caused by the interfering network;
- $\mathrm{N_{sectors}}$: Number of base station sectors in the victim network;
- $ThroughputLoss_k$: The throughput loss at the k-th base station sector.

A16.4.2.13 Collect Statistics

Repeat the calculation of the average cell throughput loss sufficiently often for

- Scenario 1: Ground UEs in the interfering network;
- Scenario 2: Aerial UEs in the interfering network (Separately for each altitude level););););
- Afterwards, plot the empirical cumulative density function of the snapshot average throughput loss for both cases;
- Also plot the snapshot average throughput loss.

A16.5 RESULTS

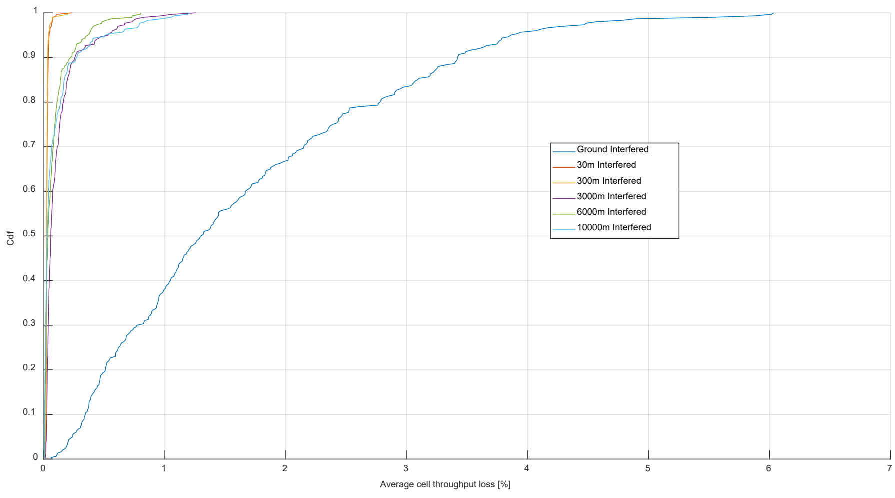


Figure 118: Full results for average network throughput loss

For ground UEs, the average cell throughput degradation is usually less than 5%. For the most of the aerial UEs, the average cell throughput loss is below 1%. Hence, the interference to the network in the adjacent channel is practically negligible for aerial UEs.

The figures below show the interim results of the average cell throughput for the non-interfered and interfered cases respectively. The dashed lines indicate the average over all snapshots.

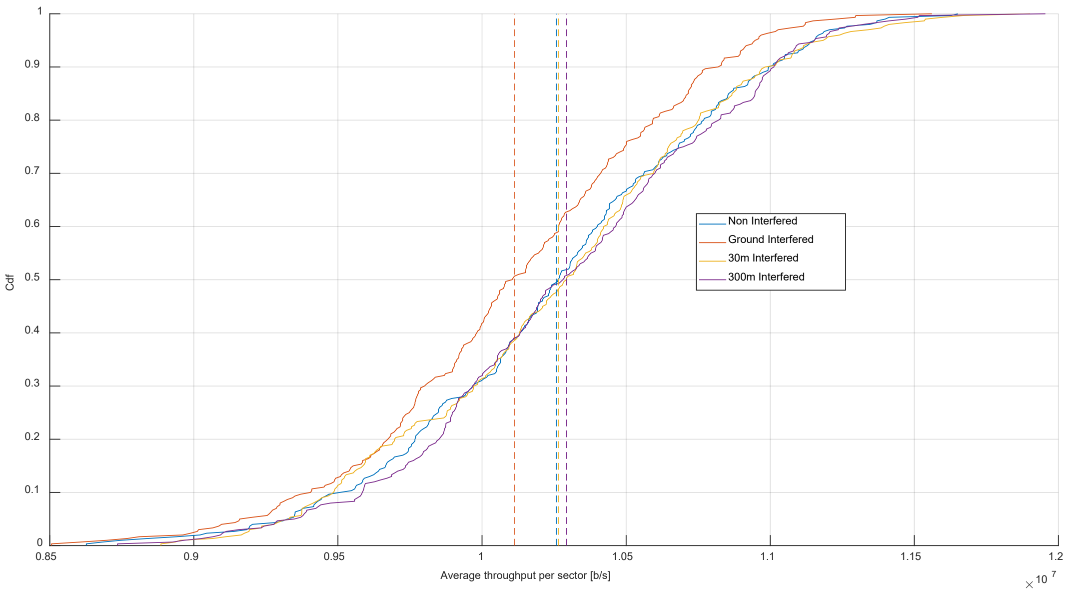


Figure 119:Average throughput for scenarios below 300 m

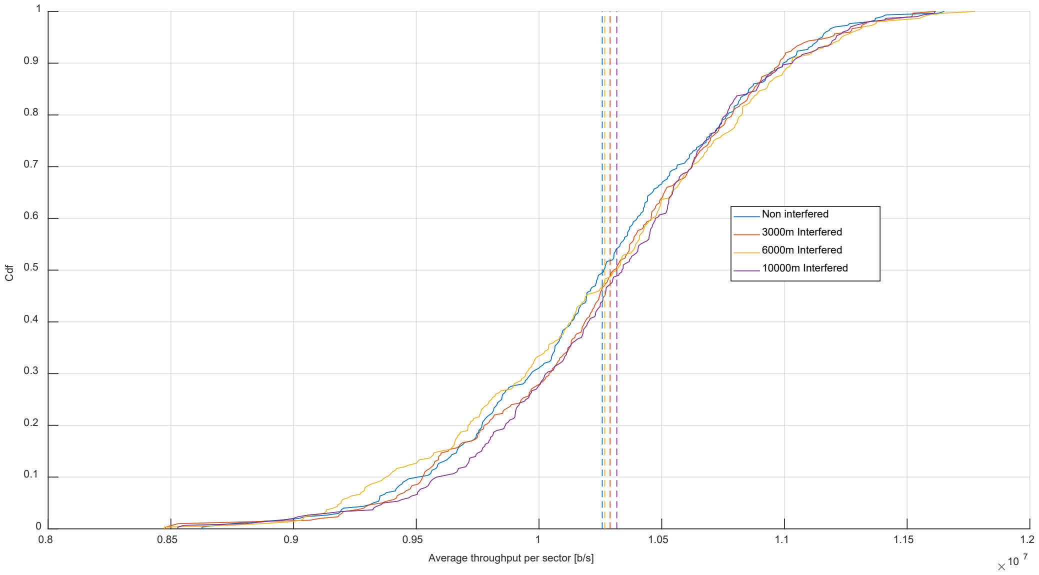


Figure 120: Average throughput for scenarios above 3000 m

As the figures indicate, the average cell throughput per sector does not depend very much on the adjacent channel interference. Only a small impact by ground UEs can be observed. The small differences for the aerial UEs in the results are most likely related to statistical variations and can therefore be neglected.

The difference between the impact of aerial UEs and ground UEs can be explained by the additional gain discrimination towards the sky and lower transmission power of aerial UEs as they experience LOS propagation conditions.

The table below summarises the results.

Table 97:Summary of throughput results by altitude

Interferer Altitude	Average throughput per cell over all snapshots	Average cell throughput loss over all snapshots
1.5 m (ground UE)	10.11 Mbps	1.58%
30 m	10.26 Mbps	<0.1%
300 m	10.29 Mbps	<0.1%
3000 m	10.29 Mbps	<0.1%
6000 m	10.26 Mbps	<0.1%
10000 m	10.31 Mbps	<0.1%

A16.6 CONCLUSION

The results suggest that for the simulated scenario, the interference of aerial UEs to the network of an adjacent operator is negligible (often <1%) and less than the interference caused by ground UEs. This is in line with the results of ANNEX 2:, studying the aerial UE interference for networks in lower frequency bands with passive antennas.

ANNEX 17: ANALYSIS OF THE PROTECTION OF RADAR OPERATING ABOVE 2700 MHZ

The frequency band 2700-3100 MHz is used by several different types of radars on land-based fixed and transportable platforms. One particular use is terminal approach/airport surveillance radars for air traffic control (ATC).

Interference from 2.6 GHz MFCN UEs[49] into ATC radars operating in above 2700 MHz may occur for the following reasons:

- Unwanted emissions from the UEs occurring in the frequency range above 2700 MHz used by the radars.
- The radars receiving the UE transmissions below 2700 MHz, resulting in interference or blocking.

There may be an increased risk of interference from aerial UEs, compared to ground-based UEs, because an aerial UE could enter the main beam of an ATC radar.

This study analyses the impact of the unwanted emissions from aerial UEs in the 2.6 GHz MFCN band to ATC radars operating above 2700 MHz.

A17.1 CHARACTERISTICS AND PROTECTION OF RADARS

To ensure the unwanted emissions from aerial UEs operating in the 2.6 GHz MFCN band do not impact on the performance of ATC radars operating in the frequency band 2700-3100 MHz, the protection criteria defined in Recommendation ITU-R M.1464-2 [71] must be met. This recommendation states that the radars should be protected with the threshold I/N = −10.

The ATC radar parameters required for this study are given in Table 98. The parameters for thermal noise, antenna gain, and feeder loss have been taken from a study commissioned by Ofcom [107], and are based on Watchman Radar testing at RAF Honington.

Table 98: ATC Radar Parameters

Parameter	Value	Unit
I/N protection threshold	−10	dB
Thermal noise	−110.5 = −112.8	dBm / 1.7 MHz dBm / MHz
Antenna gain	28	dBi
Feeder loss	2	dB

A17.2 CHARACTERISTICS OF AERIAL UES

Aerial UEs operating in the 2.6 GHz MFCN band have a frequency separation of at least 80 MHz from the radars operating above 2700 MHz. Therefore, the unwanted emissions in the radar band correspond to spurious emission from the aerial UEs. As defined in ETSI TS 136 101 V14.5.0 (2017-11) [36], the spurious emissions limit of LTE UEs is −30 dBm/MHz.

In practice aerial UE emissions may be below the defined limit:

[49] Although 2.6 GHz UEs (operating in 2500-2570 MHz uplink and 2570-2620 MHz TDD) operate with greater frequency separation compared to 2.6 GHz (operating in 2570-2620 MHz TDD and 2620-2690 MHz downlink), there are a number of differences which mean that coexistence with 2.6 GHz UEs could be more complex than coexistence with 2.6 GHz BSs. These include: (1) coordination with moving UEs is more difficult than coordination with static BSs; and (2) unlike BSs, as UEs are mass market products they do not have access to other mitigations such as filtering.

- TS 36.101 **Error! Reference source not found.** defines spurious emission limits for 2.6 GHz TDD emissions into 2645-2690 MHz as −40 dBm / MHz, and defines spurious emission limits for 2.6 GHz FDD emissions into 2620-2690 MHz as −50 dBm / MHz. Therefore, it may be expected that emissions into 2700-3100 MHz may also meet these requirements.
- ECC Report 249 [26] gives measurements of out-of-band and spurious for LTE 2300 MHz UE, showing spurious emissions in the range −70 dBm/MHz to −50 dBm/MHz. Therefore, it may be expected that 2.6 GHz UEs have similar spurious emissions.

Therefore, as evidence shows that emissions may be lower than −30 dBm/MHz, this analysis is also carried out with an alternative value of −50 dBm/MHz.

Additionally, it is assumed that the aerial UE transmission is omni-directional with 0 dB antenna gain.

A17.3 ANALYSIS OF THE COEXISTENCE

The interference power at the ATC radar is calculated as follows:

$$RxP_{Radar} = TxSpurP_{UE} + G_{UE} - PL + G_{Radar} - FL_{Radar} \quad (45)$$

- RxP_{Radar} is the power received at the ATC radar receiver, coming from aerial UE;
- $TxSpurP_{UE}$ is the spurrious emission power from the aerial UE;
- G_{UE} is the aerial UE antenna gain;
- PL is the path loss between the aerial UE and the ATC radar;
- G_{Radar} is the ATC radar antenna gain;
- FL_{Radar} is the ATC radar feeder loss.

Replacing the receive power with the protection threshold, this equation becomes:

$$TherN_{Radar} + I/N_{Radar} < TxSpurP_{UE} + G_{UE} - PL + G_{Radar} - FL_{Radar} \quad (46)$$

Where:

- $TherN_{Radar}$ is ATC radar thermal noise;
- I/N_{Radar} is the I/N protection threshold.

This formula can be used to determine the required path loss between the aerial UE and the ATC radar that must be exceeded to maintain the expected radar protection. Assuming free-space path loss, and assuming that the aerial UE is in the main beam of the ATC radar, Table 99 gives the separation distance required to protect the radar.

Table 99: Separation distance required to protect ATC radar based on the two alternative spurious emission levels

UE Spurious Emission Level	Required Path Loss	Separation Distance
−50 dBm/MHz	98.8 dB	0.8 km
−30 dBm/MHz	118.8 dB	7.7 km

A17.4 CONCLUSION

Based on the results in Table 53, additional regulatory measures are likely to be needed to protect ATC radars from aerial UEs operating in the 2.6 GHz MFCN band, especially if the UEs spurious emissions are at or near to the emission limit. As ATC radars are deployed at aerodromes, the geofencing implemented by aviation authorities may be sufficient to protect ATC radars. However, as this Report is not considering civil aviation regulation, no conclusion can be drawn on whether the geofencing is sufficient. Therefore, administrations should coordinate with their national aviation authorities to ensure that 2700-3100 MHz radars are protected from interference, through the implementation of no-fly zones or alternative measures.

ANNEX 18: COEXISTENCE OF AERIAL UES IN BAND (1920-1980 MHZ) WITH FRMCS RECEIVER

A18.1 INTRODUCTION

In 2012, the UIC has launched a project called Future Railway Mobile Communication System (FRMCS), which aims to find a new Radio Access Technology (RAT) for RMR. Possible candidates are 4G Long Term Evolution (LTE) or 5G New Radio (NR)[50], both being commercial technologies developed at 3GPP. At CEPT level, the work related to the introduction of FRMCS is focusing on different bands, in particular the possibility of introducing a 10 MHz TDD channel in the 1900-1910 MHz band using either 4G LTE or 5G NR technology.

Similarly to the work undertaken in ECC Report 314 [109], the interference from MFCN is to be studied onto the cab-radio receiver. Section 4.1 of ECC Report 314 draws an overall picture of the different interference mechanisms affecting any cab-radio receivers from the train and concludes that the dominant mechanism by which LTE UE interfere with cab-radios are the unwanted emissions falling into the FRMCS receiving bandwidth. This is due to the relatively low output power of these UEs (interference from MFCN base stations would involve intermodulation distortion effects as an additional). The same rationale can be applied to UAS interferers as they also share the same low output power feature as the typical UE that's why it is proposed to focus the compatibility studies over the unwanted emission levels from aerial UEs.

A18.2 SIMULATION ASSUMPTIONS

A18.2.1 FRMCS characteristics

FRMCS link needs to be described, from the (cab-radio) receiver perspective, corresponding to the Downlink (DL) in TDD 1900-1910 MHz band. Its performance can be expressed in terms of Signal-to-Noise Ratio degradation with Interference. The cab-radio receiver noise level N, the wanted signal C radiated from the serving FRMCS single base station cell and the intra-interference $\boldsymbol{I_{intra}}$ caused by FRMCS base stations together located in the two adjacent cells are described in ECC Report 314:

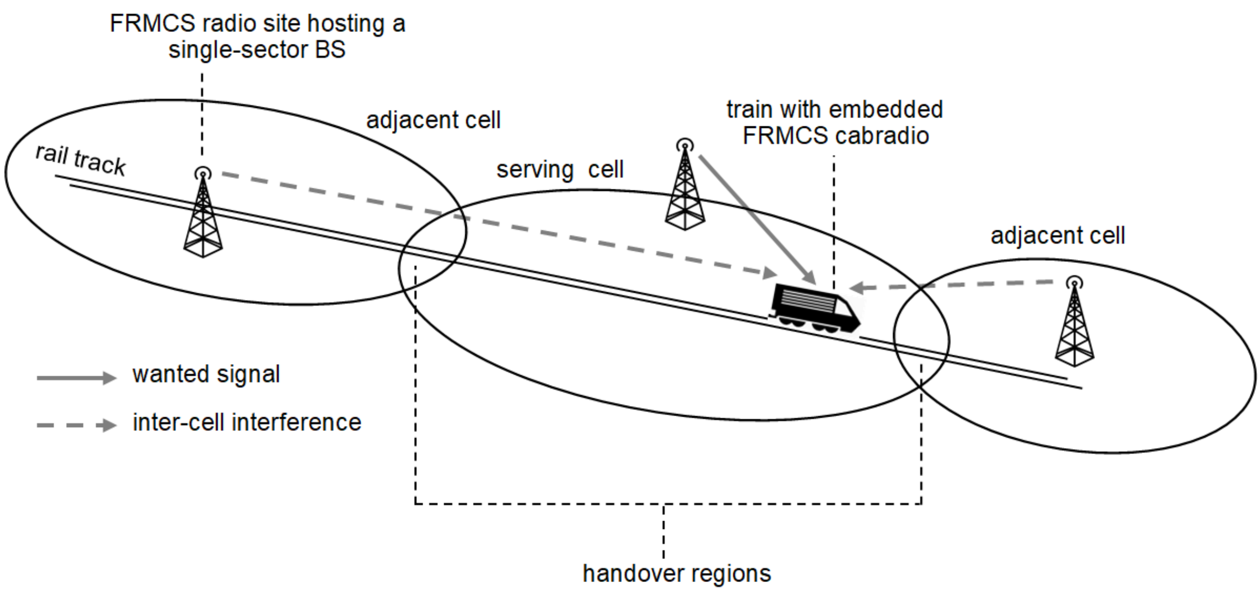


Figure 121: FRMCS intra-cell interference from ECC Report 314

[50] Source : ETSI TR 103 333 [108]

It is then important to know the geographical location of the FRMCS radio sites (as well as their transmission characteristics) in order to compute the wanted signal C and $\boldsymbol{I_{intra}}$.

For the sake of coexistence with a cellular mobile network, three different environments may be considered: rural, urban, and suburban areas, corresponding respectively for the railway network to: high-speed lines, low-density[51] lines and high-density lines[52]. Their respective characteristics are shown in Table 100 below[53].

Table 100: Characteristics of the three railway segments

Railway environment	Corresponding MFCN environment	Average train speed	Number of trains per cell P	Example
High-speed	macro rural	300 km/h	4	see ECC Report 314 Figure 8 [109]
Low-density		100 km/h	3	see ECC Report 314 Figure 9 [109]
High-density	macro urban	50 km/h	5	see ECC Report 314 Figure 10 [109]

$\boldsymbol{I_{intra}}$ refers to the interference caused from the 2 FRMCS sites in adjacent cells and from the FRMC site of the serving cell covering the other segment of the cell. 2 of them operate in adjacent blocks which suggests that only 1 component needs to be modelled in the interference assessment, e.g. FRMCS site from cell #2 for the first segment of the serving cell or FRMCS site from cell #1 for the second segment of the serving cell

C and N are computed keeping in mind that the power transmitted from FRMCS site is set to constant value but shared among the P trains within the serving cell which means that the available bandwidth for each train is effective FRMCS bandwidth/NbTrainsPerCell, e.g.. 9/4=2.25 MHz for the High Density scenario.

Regarding to their transmission characteristics, the below table summarizes the needed information for assessing the distribution of C/$\boldsymbol{I_{intra}}$ over the rail track:

Table 101: FRMCS system parameters

Parameter	Value	Reference
Operating band	E-UTRA TDD operating band n°33	ECC Report 314, Table 3 [109]
Carrier centre frequency	1905 MHz	
Channel bandwidth	10 MHz	
Maximum number of RBs	50	ECC Report 314 Table 3 [109]
Occupied bandwidth	9 MHz	ECC Report 314 Table 3 [109]
FRMCS BS		
Maximum output power per antenna connector	46 dBm	ECC Report 314 Table 3 [109]

[51] understood as the density of trains.

[52] See ECC Report 314, section 2.5 [109]

[53] A detailed description of these railway segments is provided in ECC Report 294 §3 (“Assessment of the spectrum needs”) [110].

Unwanted emissions	Given in TS 36.104 [44] Table 6.6.3.2.1-6 (OBUE for Category B Option 1 BS) and Table 6.6.4.2.1-1 (spurious emissions)	ECC Report 314 Table 3 [109]
FRMCS on-board equipment		
Noise Figure (NF)	5 dB	ECC Report 314, table 3 [109]
Protection Criterion C/I_{intra}	13 dB 95% of the time over each 100 m	ECC Report 314, figure 51 [109]
Protection Criterion C/(N+I[54])	4 dB 95% of the time over each 100 m railway segment	ECC Report 313, annex 2 (value) [27] Eirene SRS v16.0.0 (percentage of the time) [111]

As indicated in ECC Report 314 [109], when calculating the wanted signal received by the cab-radio from the FRMCS site in the serving cell short distances situation is typical. Moreover, given the terrain path profile as well as the clutter data in the close vicinity of the rail track, it is then possible to perform accurate prediction of the path loss with consideration of the free space and the diffraction loss. National terrain and buildings database from ”Institut National de l’Information Géographique et Forestière” (IGN), with a precision of 5 m are used in the close vicinity of the railway segment to compute the path loss between the FRMCS BS and Cab-radio.

One important point dealing with the selection of the FRMCS serving BS is given below (from ECC Report 314):

Table 102: FRMCS deployment-related parameters

Parameter	Value
FRMCS radio sites	Same sites as for GSM-R coverage
Parameters of FRMCS BS	
Feeder loss	4 dB
Antenna height, azimuth and tilt	Two antennas per FRMCS site. 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 [112] clause 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°

[54] I=I_{intra}+I_{ext}

Parameters of on-board equipment	
Hardware losses	3 dB
Antenna pattern	HUBER+SUHNER 1399.99.0121 See ECC Report 314 [109]
Antenna height above the rail track	4 m

The antenna mounted on the cab-radio is supposed not to be mechanically tractable i.e. that the antenna orientation with respect its location on the train is assumed to be fixed.

A18.2.2 MFCN characteristics

The table below is mainly based on the ECC Report 314 [109] and summarises the system parameters of LTE 2100 uplink that is used in the coexistence study with FRMCS. Since some information related to MFCN came from real data base, it's important to note that most recorded radio sites at this frequency range relate to UMTS technology because this band has been made available for decades to 3G although LTE usage was recently authorised in 1920-1980 MHz. However it is expected that UMTS radio sites within this band may be refarmed for LTE or 5G technology, this is why all macro BS sites recorded within this band starting at 1920 MHz are considered in the vicinity of each rail track (whether they are UMTS or LTE).

Table 103: LTE 2100 uplink system parameters

Parameter	Value
Operating band	E-UTRA FDD operating band n°1
Carrier centre frequency	1922.5, 1930 MHz
Channel bandwidth	5, 20 MHz
Maximum number of RBs	25, 100
Occupied bandwidth	4.5,18 MHz
Parameters of LTE aerial UEs	
Maximum output power	23 dBm
Unwanted emissions	Given by TS 36.101 **Error! Reference source not found.** Table 6.6.2.1.1-1 (SEM) and Table 6.6.3.1-2 (spurious emissions)

Several parameters deserve some comments:

- Channel bandwidth: Among the numerous system bandwidth options available for MFCN to operate above 1920 MHz (5 MHz, 10 MHz, 15 MHz, 20 MHz), it is important to note that ECC Report 314 dealt with 20 MHz between FRMCS and MFCN with typical UEs while this ECC Report considers the same MFCN Band (1920-1980 MHz) but with another service (CGC BS above 1980 MHz) with 5 MHz system bandwidth. For that reason, it is proposed to address the coexistence analysis with the highest and the lowest system bandwidth (20 and 5 MHz).

- Unwanted emissions: due to the frequency separation between the edge of FRCMS (1910 MHz) and MFCN (1920 MHz), the unwanted emissions from aerial UEs fall in the cab-radio receiver bandwidth respectively in its out-of-band (OoB) and in the spurious domains for 20 and 5 MHz channel bandwidth. The nature of the aerial UEs unwanted emissions within the cab-radio receiver bandwidth matters in the sense that the power control may affect the OoB as a domain close to the In-band region, but not in the spurious domain. This is why different assumptions are taken in this study regarding the unwanted emissions levels from aerial UEs, e.g. -30 dBm/MHz for 5 MHz channel bandwidth and range of values for 20 MHz channel bandwidth (See Section A18.6.2 for more details).
- Aerial UE output power: although the maximum power is given in the above table, power control is assumed in this analysis in order to account the varying nature of the power radiated by the aerial UE in MFCN UL, depending on the coupling loss with its serving BS and the target SNIR (See Section A18.6.1 for more details).

Information related to the theoretical MFCN deployment consists in providing the cell characteristics (hexagonal structure, inter-site distance) as well as the amount of UEs simultaneously served (transmitting) over each cell/sector.

Table 104: MFCN Mobile Network structure in 1920-1980 MHz UL Band

Parameter	Value	Source
Cell range	500 m (urban), 5 km (rural)	ITU-R Report M.2292 [25]
Cell radius	250 m (urban), 2.5 km (rural)	
Inter-site distance	750 m (urban), 7.5 km (rural)	
Site structure	3 adjacent sectors	ITU-R Report M.2292 [25]
Number of active sectors in the MFCN mobile network	61	
MFCN base station (BS) category	Macro BS for rural and urban	

Although this study is performed using real information on macro BSs from a national data base (geographical locations, azimuth and tilt pointing of BS antenna…), it is important to keep in mind the theoretical topology of the cellular mobile because of a lack of knowledge of the user’s density (used to determine the number of aerial UEs simultaneously transmitting). One could advocate that user density values are available in ITU-R Report M.2292-0 [25] however they relate to active users, which are not necessarily simultaneously transmitting. If the aggregate interference caused by aerial UEs is assessed on the basis of multiple UEs simultaneously radiating, these values cannot be used. For that reason, one way to solve this issue would be to rely on a number of UEs per cell and multiply this one by the number of cells composing the simulation area. Such approach requires the cell size to be assessed. When extracting real data from radio sites recorded in the database, it is observed that:

- the number of sectors declared by the mobile operator in any site is not necessarily 3 (ranging from 1 to 4) nor the pointing of each transceiver is regularly spaced (e.g. 120°);
- the spacing between radio sites is not constant, making the inter-site distance assessment challenging.

which makes the derivation of a “real” cell size challenging. For that reason, it is important for each environment scenario to evaluate the consistency between the theoretical cell size and the simulation area by comparing the theoretical number of sites with the real number of sites.

Characteristics of aerial UEs and Macro BS are given in the below table in order to compute the radiated power in UL from the radio link budget perspective.

Table 105: Aerial UE parameters in 1920-1980 MHz UL Band

Parameter	Value	Source/Rationale
Ground and aerial UE minimum and maximum transmit power	-40..23 dBm	Minimum and maximum output power from 3GPP TS 36.101 [36]
Aerial UE antenna gain	0 dBi	
Aerial UE Power control	Yes - $SNIR_{min}$=10 dB - γ=1 (good channel balancing factor) - MCL=70 dB	See Study from A13.4[55] for the values Recommendation ITU-R M.2101 [51] for the output power formula.
MFCN BS serving for aerial UE	MFCN BS with lowest coupling loss if available RBs	
Frequency resource allocation per used	2 RBs[56] per aerial UE in 5, 20 MHz	See study from A13.4[57]
Aerial UE height above the ground	40..10000 m	
Simultaneously aerial UEs transmitting per cell/sector N	12 in 5 MHz, 50 in 20 MHz	$N = \left\lfloor \frac{NbTotalRBs}{NbRBsPerUE} \right\rfloor$

Table 106: MFCN BS characteristics in 1920-1980 MHz UL Band

Parameter	Value	Source
BS antenna height above the ground	3..59m	Real data
BS antenna mechanical downtilt	-6° for urban, -3° for rural	Real data (averaged)
BS antenna pattern model	Recommendation ITU-R F-1336-4 (Rec 3.1) [45] k_p = 0.7 k_h = 0.7 k_v = 0.3 φ_{3dB}=65°	ITU-R Report M.2292 [25]
BS antenna peak gain	16 dBi for urban and rural	Real data (averaged)
BS antenna radiation pattern sidelobes model	Peak sidelobes (in UE-BS radio link budget)	Recommendation ITU-R F-1336-5 [112]
BS noise figure	5 dB	ITU-R Report M.2292 [25]
BS system bandwidth	5, 20 MHz	
BS Effective Bandwidth	4.5, 18 MHz assumed (25 and 100 RBs[58])	

[55] On coexistence between MFCN aerial UEs in 1920-1980 MHz and CGC BS in 1980-2010 MHz.

[56] Considered in study from A13.4.

[57] On coexistence between MFCN aerial UEs in 1920-1980 MHz and CGC BS in 1980-2010 MHz.

[58] Resource Blocks (180 kHz size)

The choice of the peak sidelobes for the BS antenna pattern reflects the performance objective and not the interference situation when computing the radio link budget between UE and BS because the interference from MFCN is assessed at UL (meaning that Macro BS does not behave as source of interference with respect to the CGC BS receiver).

Moreover, due to the Macro BS antenna height (whose median value exceeds 24m for all three scenarios as depicted by the below figure) and the altitude of the aerial UE, it is assumed that the propagation between these two radio devices is of free space nature (Recommendation ITU-R P.525-4 [76]).

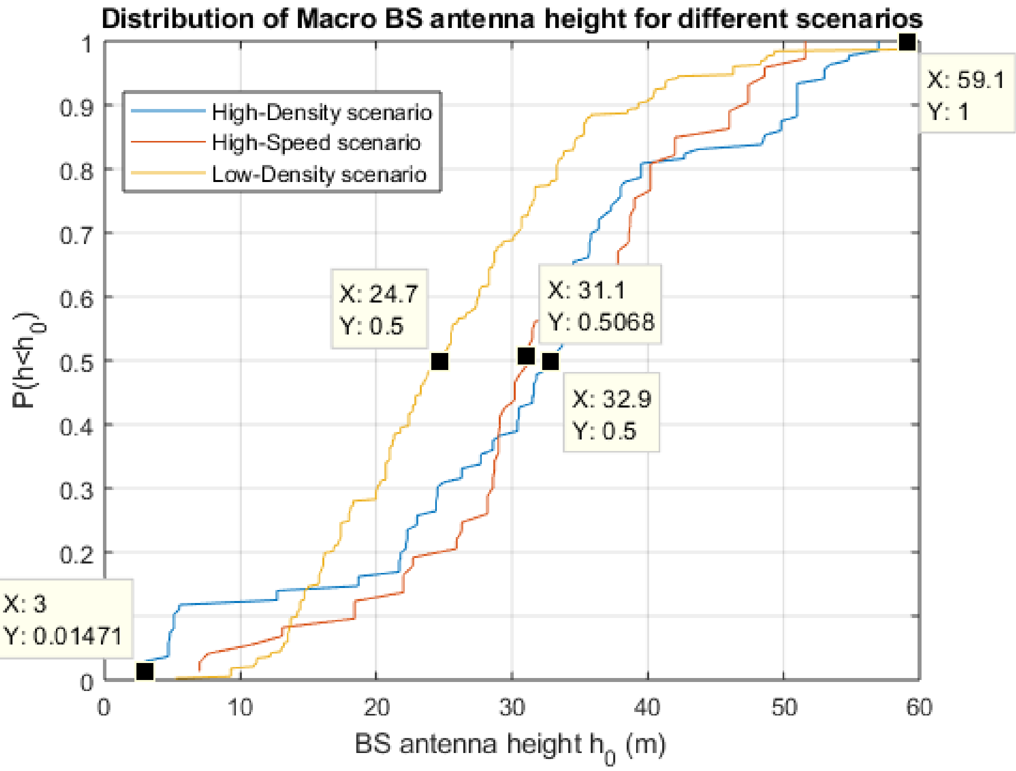


Figure 122: Distribution of Macro BS antenna heights used in the study

BS activity factor was not accounted in the study due to the limited time for computing the coexistence study. This means that the current analysis assumes all Macro BSs recorded in the simulation are active (from reception perspective) but may not use all RBs depending on its coupling loss figures with aerial UEs (because the number of simultaneously transmitting aerial UEs is derived from a simulation area and the theoretical cell size). In practice, the amount of aerial UEs simultaneously transmitting should be capped by the number of active BSs (e.g. 50% of the total amount).

A18.3 METHODOLOGY FOR THE COEXISTENCE STUDY

A18.3.1 generation of the simulation area

Whatever environment (rural, urban) is considered, the simulation area S is set to cover the selected railway segment for interference assessment. As shortly introduced in the previous section, the size of S is determined based on the cell size of the considered environment (rural or urban) and the number of cells

(61), i.e. around 10 km² for urban[59] and 1000 km² for rural[60]. Afterwards, S is drawn to cover the rail track at this centre and macro BS sites recorded in the national database (from one mobile operator using the frequency block directly starting at 1 920 MHz) located inside S are extracted and used for this analysis. For example, Figure 123 illustrates the location of the macro BSs (in red) closer to the rail-track (in green) in S (depicted in blue).

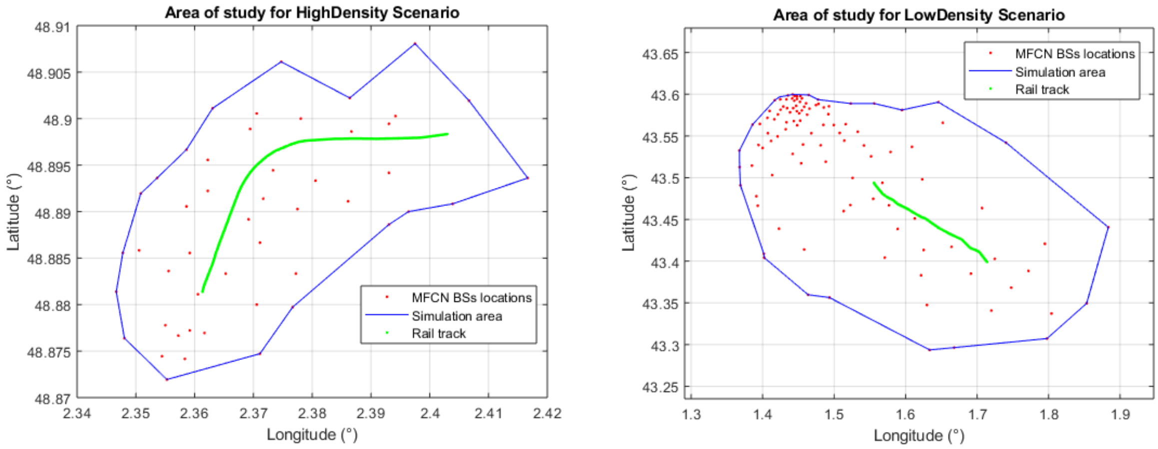


Figure 123: Examples of locations of MFCN Macro BSs around rail track

As can be seen in the above figures, MFCN macro BSs are not deployed uniformly within S. Their amount is provided in the below Table for each studied scenario. It could be noted that the number of sectors recorded inside S is not necessarily a multiple of 3 (featuring the three sectors radio site structure) as several sites do not have 3 sectors.

Table 107: Distribution of macro BSs within simulation area for different scenarios

Scenario	Simulation Area S size	Number of cells/sectors recorded inside S
high-speed	1029 km²	73
low-density	1007 km²	300
high-density	10 km²	136

A sharp comparison between the number of recorded sectors and the theoretical number of cells within S (61) shows for:

- High-speed scenario: that the number of cells recorded within S (73) is pretty close to the theoretical value (61) leading to conclude that the environment related to the high-speed scenario is compliant with a rural one; the fact that the real amount of sectors is higher than the theoretical one can be explained by indicating that the cell/sectors defined by macro BSs located inside S but at the very edge of S are not entirely contained within S;
- Low-density: there is huge gap between the expected number (61) and the real one (300) although this use case was initially considered as a rural one. The reason for such difference can be explained by noticing that a portion of S is overlapping an urban environment (overlapping with Toulouse city- centred at 43.6044°N 1.4439°E-), resulting in concluding that S in low-density scenario should be then considered as an apportionment of Rural (20% of the total BSs) and Urban areas (≈80% of the total BSs);
- High-density: the number of cells recorded is roughly twice the theoretical value, due to the dense-urban nature of the area partially covering Paris (centred at 48.8567°N, 2.3519°E).

59 $\frac{3\sqrt{3}}{2}0.25^2 \times 61 = 9.9052km^2$

60 $\frac{3\sqrt{3}}{2}2.5^2 \times 61 = 990.52km^2$

A18.3.2 FRMCS inter-cell interference and wanted signal

As described in Section A18.2.1, C, N and $\boldsymbol{I_{intra}}$ can be regularly computed at each successive position of the train over the railway, leading to represent a timely varying $\boldsymbol{SNIR_{intra}}$ over the path segment. In order to compute the C and $\boldsymbol{I_{intra}}$ from an adjacent cell that is responsible for Inter-Cell Interference (ICI), the following power levels are introduced:

$C_{serving,1}$	Wanted signal mean power when the train is in the first half of the serving cell. This signal occupies $^{50}/_{N}$ RBs among RB #1 to RB #25.
$C_{serving,2}$	Wanted signal mean power when the train is in the second half of the serving cell. This signal occupies $^{50}/_{N}$ RBs among RB #26 to RB #50.
$I_{adj,1}$	ICI mean power when the train is in the first half of the serving cell. This signal originates from the second adjacent cell and occupies the same RBs as $C_{serving,1}$.
$I_{adj,2}$	ICI mean power when the train is in the second half of the serving cell. This signal originates from the first adjacent cell and occupies the same RBs as $C_{serving,2}$.

Afterwards, it is then possible to derive SNIR and the high-speed scenario is illustrated in the below figure:

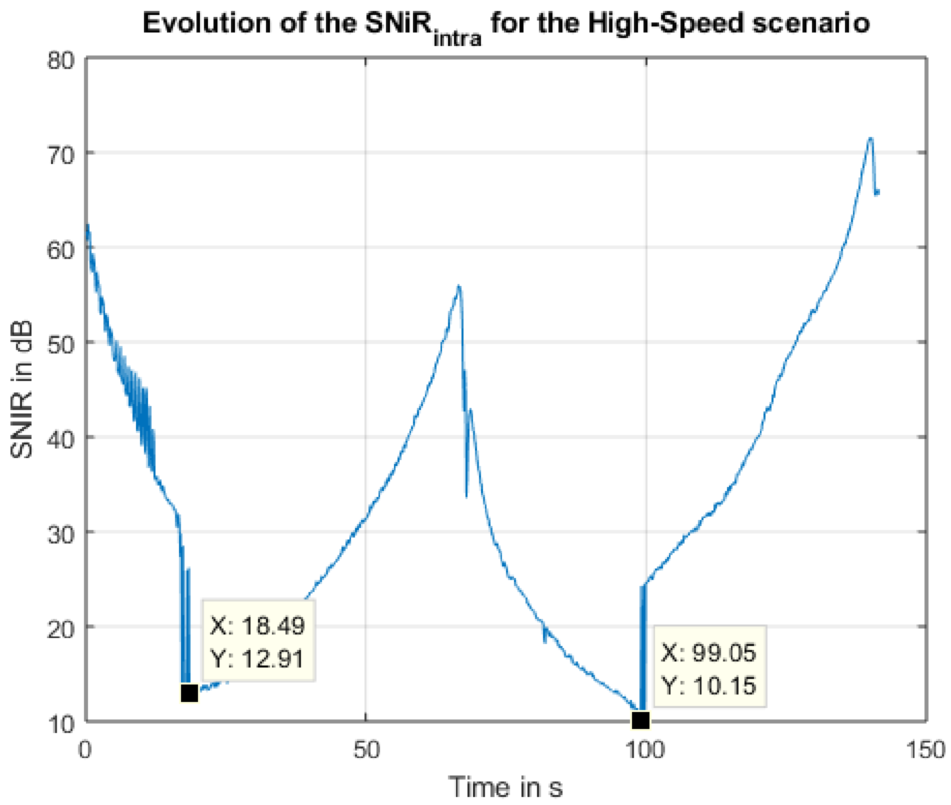


Figure 124: Evolution of the SNIR for the high-speed scenario

SNIR values for each position of the train within the railway segment are depicted in ordinates while abscissa refers to the time axis, based on the assumption that the train is at its initial position at t = 0s and considering that its average speed is 300 km/h (see Table 100). The handover procedures occur when $C_{serving,1} \approx I_{adj,2}$ (before this point, the wanted signal was $I_{adj,2}$) at t=18.49 s and when $C_{serving,2} \approx I_{adj,1}$ (after this point, the useful signal becomes $I_{adj,1}$) at t=99.05 s. Therefore, the train stays in the serving cell for about 81s. Moreover, $\boldsymbol{SNIR_{intra}}$ is about 12.9 dB and 10.1 dB at the handover points.

$\boldsymbol{SNIR_{intra}}$ time evolution for the other scenarios (low-density and high-density) is provided in the below figures and are consistent with results presented in ECC Report 314.

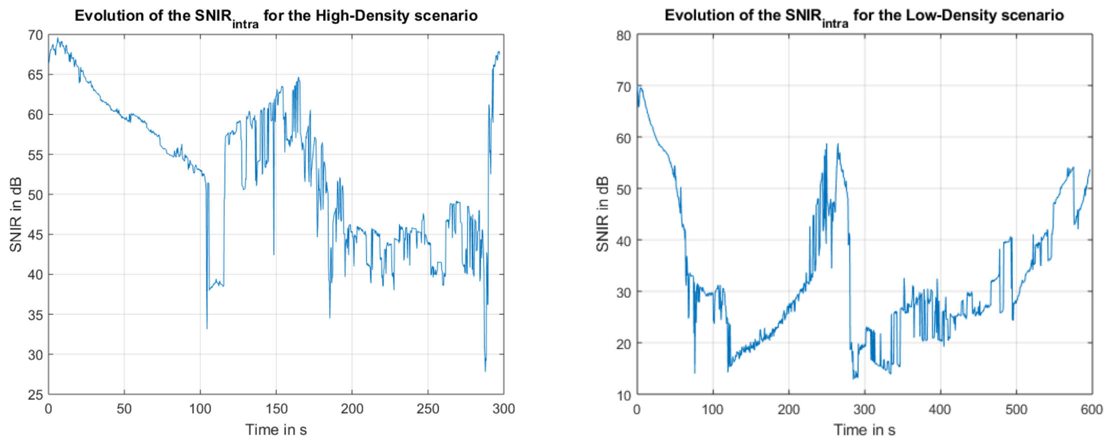


Figure 125: Evolution of the SNIR for the Low and high-density scenarios

With comparison to the results from ECC Report 314 [109] (See Section A18.4.2), it can be observed that the shape of the $\boldsymbol{SNIR_{intra}}$ curves offer a good matching in time and SNIR values for the three scenarios[61].

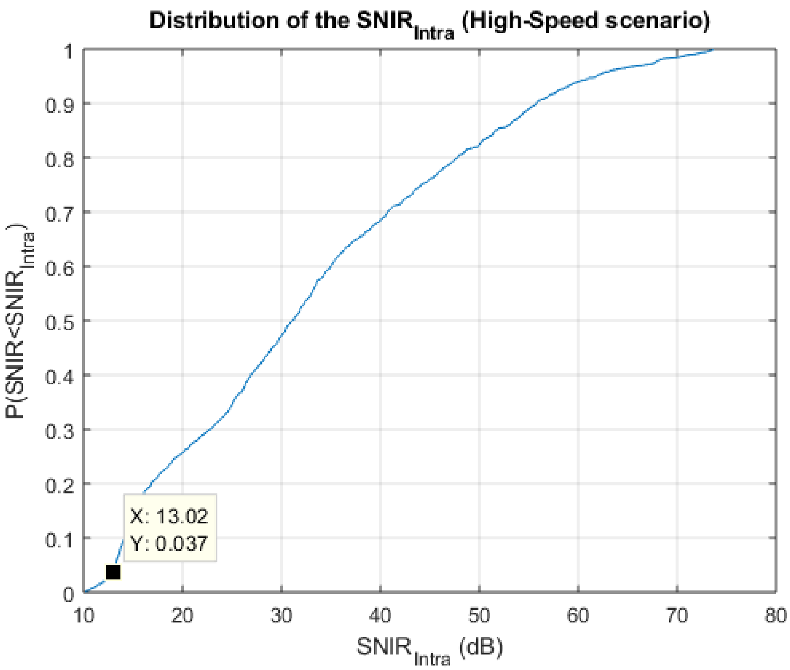


Figure 126: Deriving $SNIR_{Intra}$ for the high-speed scenario

[61] Although some mismatching is noticed for high-density scenario where the railway segment is not a direct line but a curve one (which may create a bias in the time axis of the evolution of the SNIR curve over the time).

Finally, the $SNIR_{intra}$95th percentile (corresponding to the worst scenario of ICI for FRMCS Cab-radio: high-speed) also matches with the value suggested in ECC Report 314[62].

A18.3.3 Deployment of aerial UEs in the simulation area

Aerial UEs locations are randomly generated in the convex envelope of the simulation area S with altitude distributed in the range given by Table 105, as exhibited in the below figure.

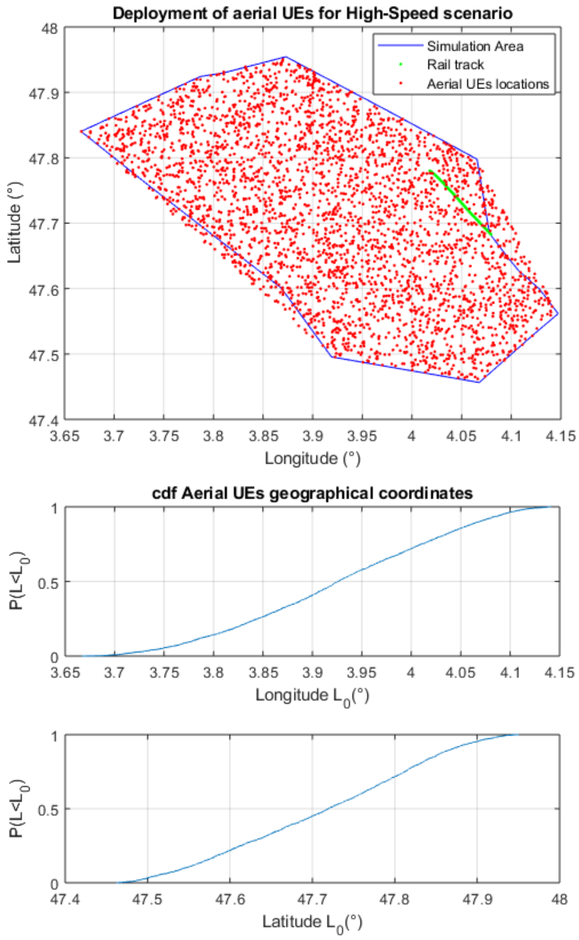


Figure 127: Uniform distribution of aerial UEs locations within Simulation Area

Cumulative distribution functions (cdf) of aerial UEs geographical coordinates (longitude, latitude) (right side figure above) show a good matching to uniform distribution of their positions in the vicinity of the rail track.

A18.3.4 Radiated power from aerial UEs

As aerial UEs and Macro BSs locations are generated within S through the previous steps, it is possible to compute the output power of aerial UE (towards its serving Macro BS) in MFCN UL block using power control algorithm (see section 6.1 for details on its computation). In any Macro cellular network, the selection of the serving BS for each aerial UE is generally based on the lowest coupling loss characteristics, which would correspond to the BS radiating the cell containing the UE for regular hexagonal meshed network. However, in real case, the network topology is scarcely matching with hexagonal cells because of heterogeneous clutter

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[62] ECC Report 314: *the SINR value exceeded 95% of the time has also been shown, and equals 13 dB, 14 dB and 40 dB in the high-speed, the low-density and the high-density scenario, respectively.*

and terrain path profiles but also due to the non-uniform distribution of the subscribers within an environment. That is why it is important to consider both lowest coupling loss (optimization criterion) and available RBs (the constrains) to set the resources allocations from each BS to its served aerial UEs. Coupling loss refers to the summation of losses (path loss between Macro BS (Free Space) and aerial UE) and gains (aerial UE and serving BS antenna gains towards each other). Simple assumptions such like full buffer traffic and round Robin scheduling are assumed in the study, i.e. the selection of priority for each aerial UE to be served by the Macro BS (with the lowest coupling loss) is random at each snapshot and the RBs usage rate for the Macro BS in the simulation area S is always higher than 50%. This results in having for several aerial UEs a connection with its serving Macro BS not based on the lowest coupling loss.

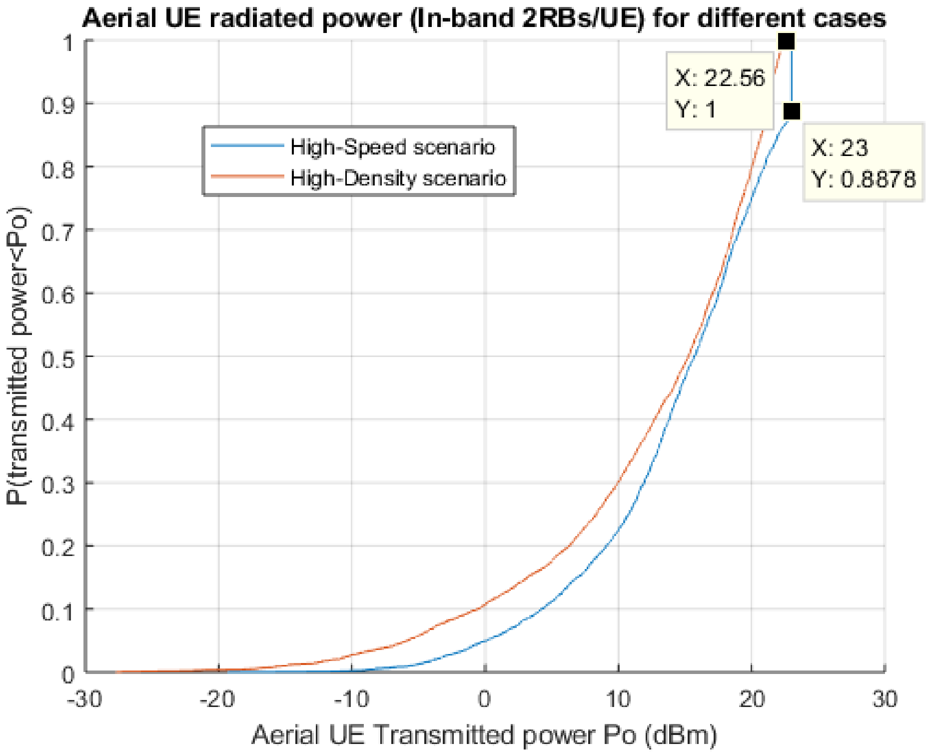


Figure 128: cdf of aerial UEs radiated power on two scenarios (20 MHz channel bandwidth)

Figure 128 shows the influence of the environment in the distribution of the aerial UE radiated[63] power (for one snapshot): a little more than 11% of the aerial UEs are transmitting with full power for high-speed environment (blue curve) while none of them reaches the peak value for the high-density case (red curve max value 22.56 dBm is achieved). This difference is mainly due to lower distance between the terminal and the serving BS in high-density scenario (resulting in lower coupling loss, i.e. giving lower output power).

A18.3.5 single interference from aerial UE to cab-radio receiver

The interference from an aerial UE (In-band above 1920 MHz) at the Cab-radio receiver bandwidth (1900-1910 MHz) falls in the unwanted emissions domain, i.e. OoB for 20 MHz channel bandwidth, spurious emissions for 5 MHz channel bandwidth. It depends on both the aerial UE output power as well as its coupling loss. Recalling the isotropic nature of the aerial UE antenna, the single interference from aerial UE#i can be expressed as follows:

$$\mathrm{I}_{\mathrm{Aerial\ UEi}}\ (\mathrm{dBm}) = P_i(dBm) - PL_{Cabradio-Aerial\ UE_i}(dB) - G_{FRMCS\ Cabradio-Aerial\ UE_i}(\varphi_i,\theta_i)(dBi), \quad (47)$$

[63] As aerial UE operates with isotropic antenna, radiating and transmitted powers are identical

Where:

- P_i relates to the output power of aerial UE #i within the Cab-radio receiver bandwidth;
- $PL_{Cabradio-Aerial\ UE_i}$ results from the computation of the path loss between Cab-radio and the sources of interference, namely aerial UEs for an aeronautical path: Recommendation ITU-R P.525-4 (Free Space Loss);
- $G_{FRMCS\ Cabradio-Aerial\ UE_i}(\varphi_i, \theta_i)$ relates to the FRCMS Cab-radio antenna gain in the direction (φi,θi) of the source of interference UE.

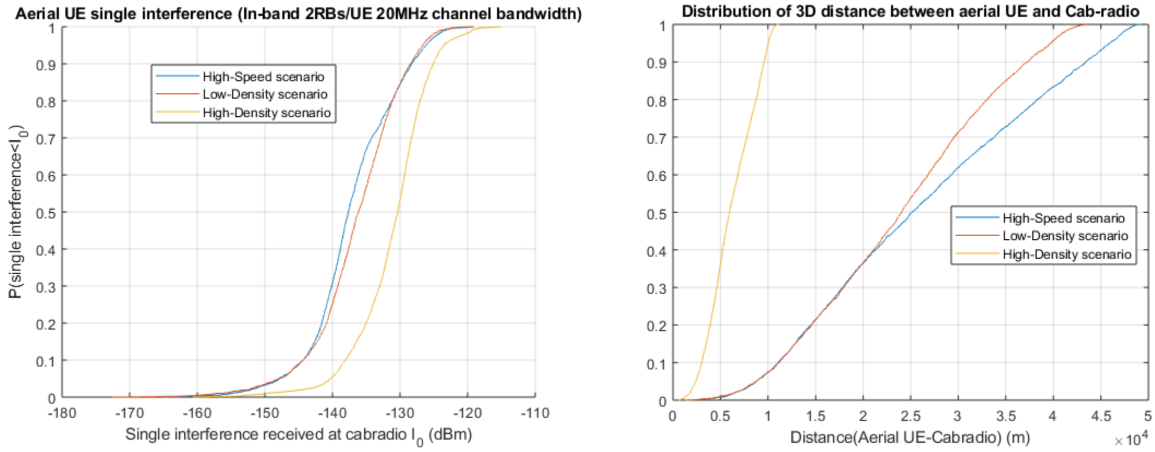


Figure 129: Distribution of aerial single interference at cab-radio receiver

Although the previous section showed that radiated In-band power of aerial UEs may be, from a statistical point, a little lower in urban than in rural environment, the single-interference received by the cab-radio (Figure 129 left side) is higher for the urban environment (high-density) compared to the other one (low-density and high-speed), simply because the aerial UEs are (geographically) statistically closer to the rail track in a urban (high-density) than in a rural case (high-speed and low-density), given their distance (Figure 129 right side).

A18.3.6 Calculation of the aggregate interference

The interference received by the Cab-radio is assumed to be generated by a number of aerial UEs simultaneously transmitting in the unwanted emissions domain. It can be expressed as follows:

$$=I_{aggregate\ received}\ (\mathrm{dBm/MHz}) = 10log_{10}(\textstyle\sum_{i=1}^{N} I_{aerial\ UEi}(mW)) \qquad (48)$$

Due to the mobility of the aerial UEs and the fact that transmitting UEs over the active UEs are not necessarily simultaneously transmitting, this aggregate interference can be considered as a random variable:

$$I_{aggregate\ received} \triangleq I_{aggregate\ received}(t, \omega) \qquad (49)$$

Its assessment needs to be performed over a Monte Carlo simulation with M runs as follows:

$$I_{aggregate\ received}(t, \omega) = I_{aggregate\ received}(k), k = 1..M \qquad (50)$$

This aggregate interference will be denoted $\boldsymbol{I_{ext}}$ in order to distinguish it from the intra-interference caused within the FRCMS network $\boldsymbol{I_{Intra}}$ (due to FRMCS cells adjacent to the FMRCS serving cell). If it is expected that this aggregate interference depends on the environment scenario (high-Speed, low-Density, high-density) similarly to the single interference, it's worth noticing that the channel bandwidth also influences the cumulative effect of interference from aerial UEs as a larger spectrum block results in getting more aerial UEs simultaneously transmitting (for the same amount of RBs per terminal) as outlined below:

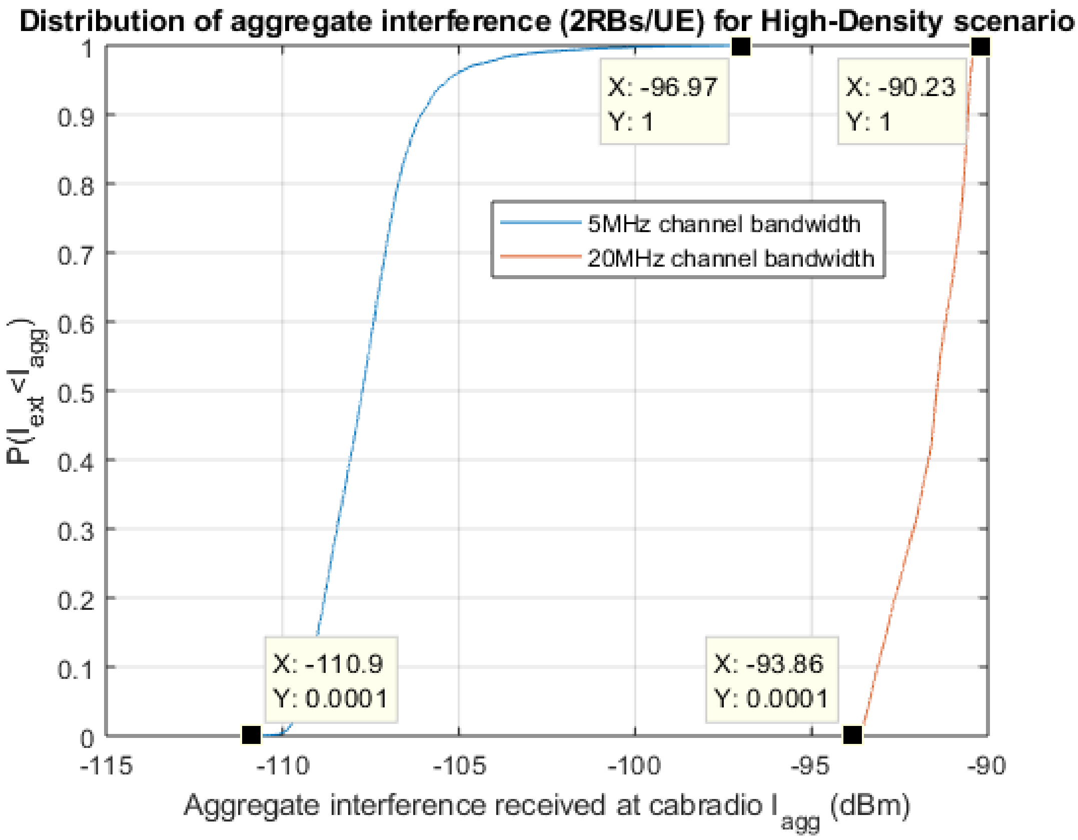


Figure 130: Effect of the channel bandwidth on I_{ext} at Cab-radio receiver

Reminding that every UE is assumed to use 2 RBs whether it is 5 MHz and 20 MHz channel bandwidth, the amount of simultaneously transmitting terminals for the 20 MHz is then 4 times higher (4=20 MHz/5 MHz) than for 5 MHz per cell. This figure can be easily checked when comparing upper tail of the cdf curves (blue and red) and noticing the gap is roughly 10log10(4)=6 dB[64].

Moreover, when comparing the shape of the two cdf curves, one could deduce that the aggregation factor (when it increases) reduces the dynamic of the cdf (respectively 3.7 dB and 14 dB for red and blue curves), mainly due to the effect of integration of random variables (as illustrated by the central limit theorem).

A18.3.7 modelling in coexistence studies

As described in ECC Report 314, the coexistence studies aims at analysing the evolution in time and space of the SNIR by tracking the train over the rail segment selected for each scenario: high-speed, low-density and high-density. This monitoring consists in performing the SNIR assessment (I_{ext}, I_{intra}, C and N) for every position. Assuming a constant speed of train, it is then possible to sample the railway segment into sub-segments whose edge feature a train position. Giving the complexity of the simulation, it is proposed to provide the flowchart of coexistence modelling:

[64] -90.23-(-96.97)=6.7 dB

for scenario ∈ {high-speed, low-density, high-density}

for i = 1 to number of snapshots

position FRMCS base stations as shown in ECC Report 314 (See Section 2.5 [109]) and install two panel antennas per FRMCS site with the characteristics described in Table 102.

position aerial UEs.

for j = 1 to number of successive train positions considered in the serving cell

Compute the wanted signal power C (step 2).

Compute the Cab-radio noise floor N.

Compute the inter-cell interference $\boldsymbol{I_{Intra}}$ generated by one of the two adjacent cells,

Compute the external interference level $\boldsymbol{I_{ext}}$, depending upon the interferer considered (step 5).

Compute the SINR value at the considered position of the train.

end

Store the SNIR values measured at each successive position of the train

end

end

The number of events to be run generally depends on the expected accuracy in the results (expressed in terms of smoothness of the SNIR cdf, SNIR time evolution curves). Interference to the FRMCS downlink is not dominated by a single interferer as the coupling loss (including the free space propagation) between the cab-radio and the aerial UE can involve many terminals not located in the close vicinity of the rail track; thus aggregation effects needs to be accounted for accordingly. Moreover, for the case of the aerial UEs exclusive (and worst case scenario) deployment in MFCN, the density of devices to consider is so high (e.g. 1088 and 3200 aerial UEs respectively for 5 and 20 MHz, with 2 RBs per UE) that the aggregate situation does not significantly change from a snapshot to another, i.e. when “re-deploying” all the devices. Therefore only 10 events have been considered and are assumed to be sufficient in this case for the sake of computational effort and accuracy of the results.

A18.4 ANALYSIS OF THE RESULTS

A18.4.1 evolution of the SNIR within the rail-track

A18.4.1.1 Overview of the results of the simulation

For each of the three scenarios (high-speed, low-density, high-density), the computation of SNIR with/without extern interference due to multiple aerial UEs is performed over the rail-track at each sampling position of the train within each segment. Two channelisations for the MFCN block are considered in the interference assessment: 5 and 20 MHz. As this process is reiterated for a number of snapshots and because the SNIR values vary from an event to another event, the results presented in the below figures correspond for each curve (blue, red and magenta) to the event for which lowest SNIR value has been achieved within the railway segment. The minimum value for each curve has been ticked in the graph for facilitate the analysis of the curves, e.g. for the high-density scenario, the lowest SNIR is respectively 27.8 dB for $\boldsymbol{SNIR_{intra}}$, 27.66 dB for $\boldsymbol{SNIR_{intra+ext}}$ (5 MHz channel bandwidth) and 20.44 dB for $\boldsymbol{SNIR_{intra+ext}}$ (20 MHz channel bandwidth). Other values may be given as a matter of comparison if the minimum is not achieved for the same position of the train in the railway segment.

A18.4.1.2Analysis of the high-density scenario

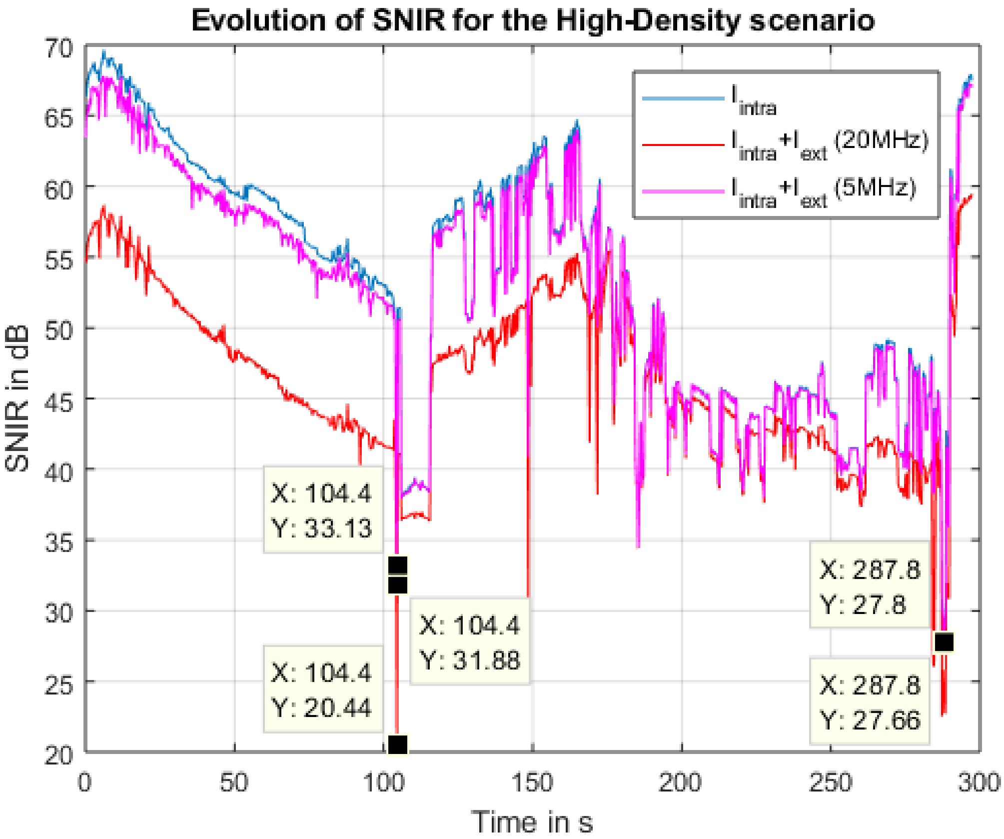


Figure 131: Evolution of the SNIR for different MFCN channel bandwidth (high-density)

The high-density case scenario is the one for which I_{ext} has the highest degradation of the SNIR because the aerial UEs are (geographically) statistically closer to the rail track in a urban (high-density) than in a rural case (high-speed and low-density) (see section A18.3.5 for more details). More precisely, the SNIR reduction is higher for 20 MHz channel bandwidth (up to 13 dB) in some points of the segment than for a smaller one (5 MHz): up to 1.3 dB probably because of a higher aggregation factor for 20 MHz (50 aerial UEs simultaneously transmitting per cell) than for 5 MHz (12 aerial UEs simultaneously transmitting). However, SNIR remains much higher (above 20 dB) than the protection threshold (C/(N+I)=4 dB described in Table 101).

A18.4.1.3Analysis of the low-density scenario

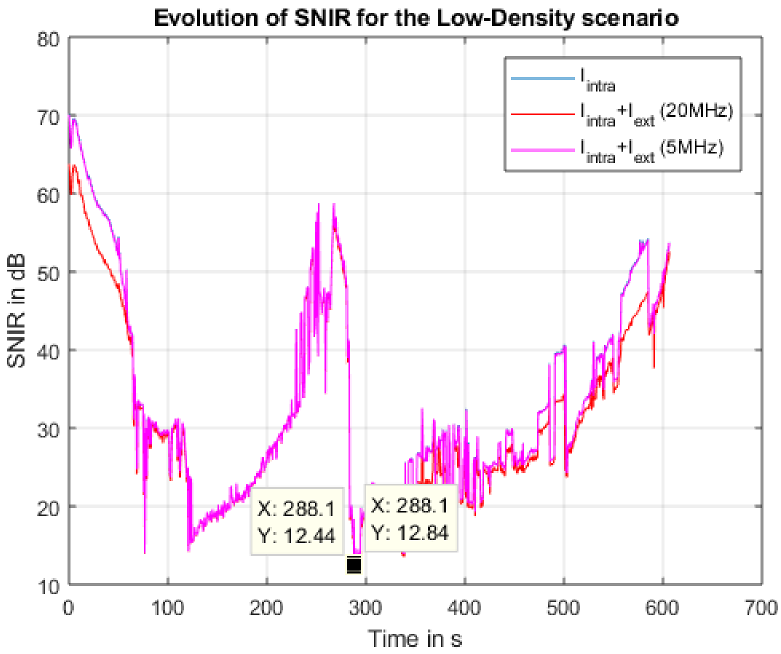


Figure 132: Evolution of the SNIR for different MFCN channel bandwidth (low-density)

Results from the curves on the low-density scenario show few effects on SNIR due to I_{ext},

- except for several peak SNIR values in the case of 20 MHz channel bandwidth;
- with almost no SNIR degradation for 5 MHz channel bandwidth (blue and magenta curves are overlapped).

This is mainly due to the fact that I_{intra} is higher in rural environment compared to the urban scenario (i.e. high-density). Again, SNIR remains much higher (above 12 dB) than the protection threshold (4 dB).

A18.4.1.4 Analysis of the high-speed scenario

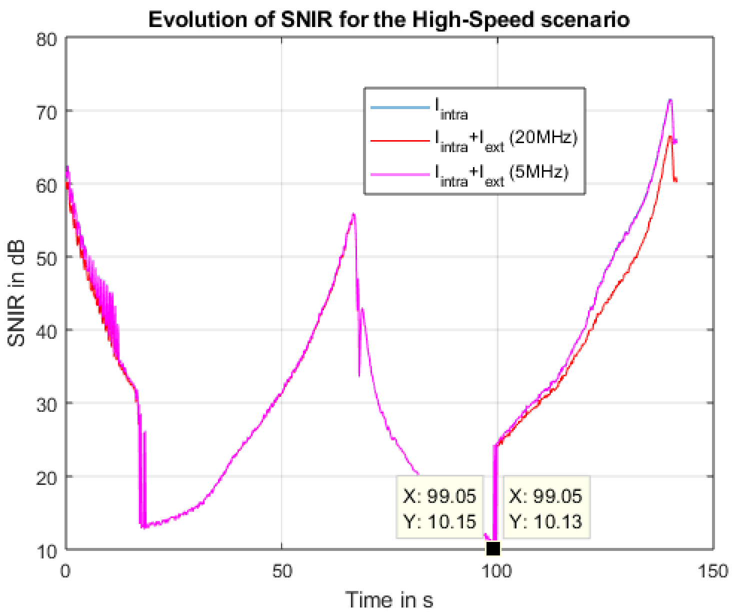


Figure 133: Evolution of the SNIR for different MFCN channel bandwidth (high-speed)

As expected from the results presented in Section A18.3.2 (related to the FRMCS network with inter-cell interference component I_{intra}), the high-speed scenario is the one achieving the lowest SNIR, but the influence of I_{ext} is generally negligible because of the dominance of I_{intra} over I_{ext} (in particular $SNIR_{intra+ext} \approx SNIR_{intra}$).

SNIR remains much higher (above 10 dB) than the protection threshold (4 dB).

A18.4.2 Conclusion on the studies

As observed in section A18.4.1, the evolution of SNIR within the rail-track shows that $SNIR_{intra+ext}$ is higher than 4 dB protection criterion for the three considered scenarios (high-speed, low-density and high-density). This is further corroborated when plotting the cdf over all snapshots and positions of the train within the railway segment of the scenario achieving the smallest SNIR value (high-speed) as seen in the following graph.

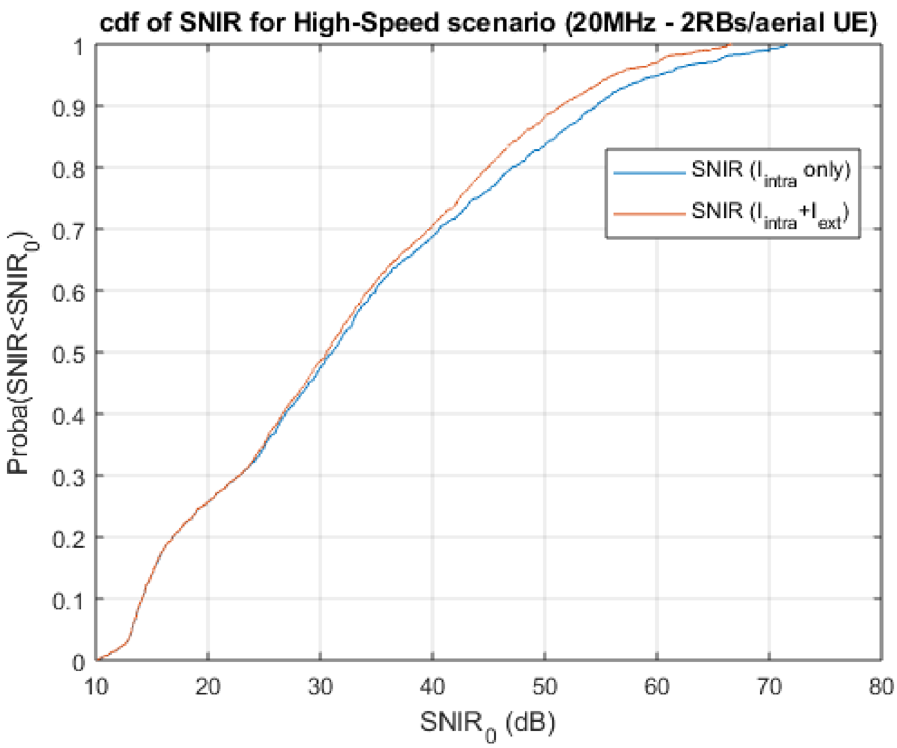


Figure 134: Distribution of SNIR with and without MFCN interference in the high-speed scenario

It can be concluded that

- the coexistence between aerial UEs and FRMCS cab-radio was conducted under pessimistic (i.e. overestimation of the aggregate interference affecting the FRMCS receiver) assumptions regarding aerial UEs deployment i.e.:
  - Aerial UEs deployed in more than 60 cells in the vicinity of the rail track;
  - Aerial UEs using almost all resources (RBs) from Macro serving BSs for each cell in high amount (up to 3200 aerial UEs simultaneously transmitting for 20 MHz channel bandwidth);
  - Free-space loss propagation between cab-radio and aerial UE (although it may not be the case for high-density scenario with clutter affecting the interference from aerial UEs).
- Under such conditions, the protection criterion (C/(N+I)>4 dB 95% of the time) is always met with a high margin (the “worst case” scenario in those studies would correspond to the high-speed environment under MHz channel bandwidth: dB margin can be achieved.

In practice, the coexistence environment will be by far better than those assumed in this study for different considered environments (high-speed, low-density, high-density) and MFCN channel bandwidth (5 and 20 MHz).

A18.5 CONCLUSIONS

This compatibility study between FRMCS Cab-radio receiver and aerial UEs shows that the protection of the cab-radio is ensured (with a margin) for different environments (high-speed, low-density, high-density) even for worst conditions of aerial UEs deployment within the MFCN (i.e. with a high traffic load: from 12 to 50 aerial UEs per cell simultaneously transmitting over more than 60 cells in the vicinity of the railway). Therefore, it can be concluded that no specific measure is necessary to be applied to the aerial UEs operating above 1920 MHz for the protection of FRMCS cab-radio receiver at 1900-1910 MHz.

A18.6 APPENDIX: INTERIM RESULTS OF THE COMPATIBILITY STUDIES

A18.6.1 Assumptions related to the power control algorithm

Subscribers deployed within the mobile network generally consist in a set of typical and aerial users. Typical user terminals operate indoor (in different floors of the building) or outdoor within a cell/sector connected to a MFCN base station (BS). In order to account the target Quality of Service (QoS) for each user (assumed to be the same for all users for sake of simplicity) in the computation of the output power, it’s recommended for 5G NR to refer to series 38 (3GPP TS 38.213 Section 7.1.1 [74]) or in a more synthetic way and to be more general to Recommendation ITU-R M.2101 (Section 4.1) [51] which describes a generic formula applicable for both IMT-Advanced (LTE-Advanced) and IMT-2020 (5G NR). This is why this analysis calculates a coupling loss percentile (dB) in line with a SNR_{min} and a number of resource blocks allocated to the aerial UE.

The Coupling Loss Percentile is given by the formula in A2.4.1: Since aerial UEs operate with existing cellular mobile network, cell radius for the aerial UE is the same as for typical UEs (250m for urban and 2.5km for rural environment).

The number of simultaneous transmitting UEs within a cell is also important to set as outlined in 3GPP TR 36.942 [48]. For uplink, the number of UEs per sub-frame might affect the simulation results, because the total transmission power for the system would depend on the number of UEs per sub-frame. Favouring the possibility to assess in a flexible way (% of used Resource Blocks RBs) the effect of the operation of aerial UE per cell, it is relevant to assume a sufficiently high number of UEs per cell/sector like in 3GPP TR.36.777 [1], e.g. 12 users/cell for 5 MHz channel bandwidth and 50 users/cell for 20 MHz channel bandwidth (each aerial UE using 2 RBs).

A18.6.2 Assumptions related to the unwanted emission levels from aerial UEs

Any terminal transmitting within a given number of RBs behaves outside its allocated frequency resources with reduced power in adjacent channels called ACLR. This ACLR is scaled with the number of RBs separating the (interferer) transmitter from the (victim) receiver. 3GPP TR 36.942 (See Table 5.1) [48] assumes for the coexistence studies two stairs ACLR function with 30 dBc as a first step (less than 4 RBs away from the victim e.g. directly adjacent to the channel used by the victim) and 43 dBc as a second step (at least 4 RBs away from the channel edge of the victim).

The Out-of-Band (OoB) emissions level mainly depends of two parameters: the frequency separation from the receiver where the level is measured and the In-band power of the UE. In the vicinity of the In-band component, it’s relevant to consider linear behaviour of OoB with In-band power value provided this level does not fall below a lower bound level. The choice of this lower bound should rely on practical and realistic values, based on real measurements or existing requirements from the standard. 3GPP TS.36.101 [29]**Error! Reference source not found.** relates to the User Equipment and specifies a requirement for the minimum power to be -40 dBm/effective bandwidth (See 3GPP TS 36.101, Section 6.3.2.1). The occupied bandwidth can be calculated from the channel bandwidth from the number of RBs as well as the size of RB. If 20 MHz is the channel bandwidth, there are 100 RBs, each RB has a 180kHz bandwidth, which leads to 18 MHz effective bandwidth.

The minimum power requirement for a UE operating at 20 MHz system bandwidth is assumed for the OoB domain to be -40 dBm/(18 MHz). This minimum value will be taken in this study as the lower bound of the OoB level, noting that OoB levels shall vary among the aerial UEs.

The maximum value relies on the requirement applied to the spectrum emission mask (see 3GPP TS 36.101 Table 6.6.2.1.1-1) when using 20 MHz channel bandwidth with 10 MHz frequency separation from FRMCS cab-radio receiver bandwidth edge and corresponds to -13 dBm/MHz≈-8.2 dBm/(3 MHz).

Figure below gives an idea of the range of variation concerning the OoB levels in the cab-radio receiver bandwidth (=3 MHz[65] for low-density scenario). It is noticeable that the minimum (-40 dBm/(18 MHz)≈-47.8 dBm/3 MHz) theoretical OoB value are not achieved for this scenario because the minimum output power is not achieved while maximum (-8.2 dBm/(3 MHz)) is.

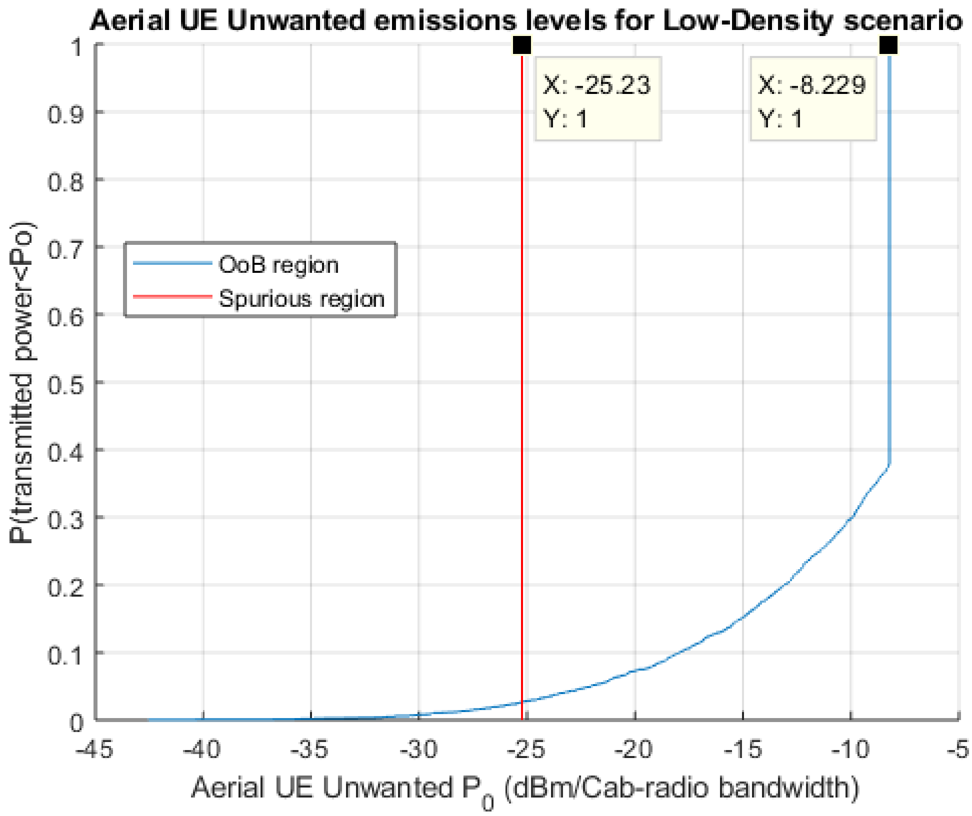


Figure 135: Distribution of aerial UE unwanted emissions levels

The situation is different regarding the Spurious emissions levels as there is no similar power control from the device beyond its OoB domain, that’s why the common rule of thumb is to use spurious emissions level to be -30 dBm/MHz for aerial UE in accordance with Recommendation ITU-R SM.329-12 [33] for Category B equipment (commonly used in CEPT countries) above 1 GHz[66] and corresponding roughly to -25.2 dBm/(3 MHz).

[65] =FRMCS Efficient bandwidth/NbTrainsCoveredByOneCell=9/3=3.

[66] see Recommendation ITU-R SM.329-12, table 3

Recalling that for 5 MHz channel bandwidth, unwanted emissions are limited to spurious levels within the cab-radio receiver bandwidth and that for 20 MHz channel bandwidth there are only OoB emissions in the cab-radio channel, it can be concluded that for:

- 20 MHz channel bandwidth, the unwanted (OoB) emissions vary
- 5 MHz channel bandwidth, the unwanted (spurious) emissions are assumed to be constant.

A18.6.3 Distribution of cab-radio antenna gain towards aerial UEs

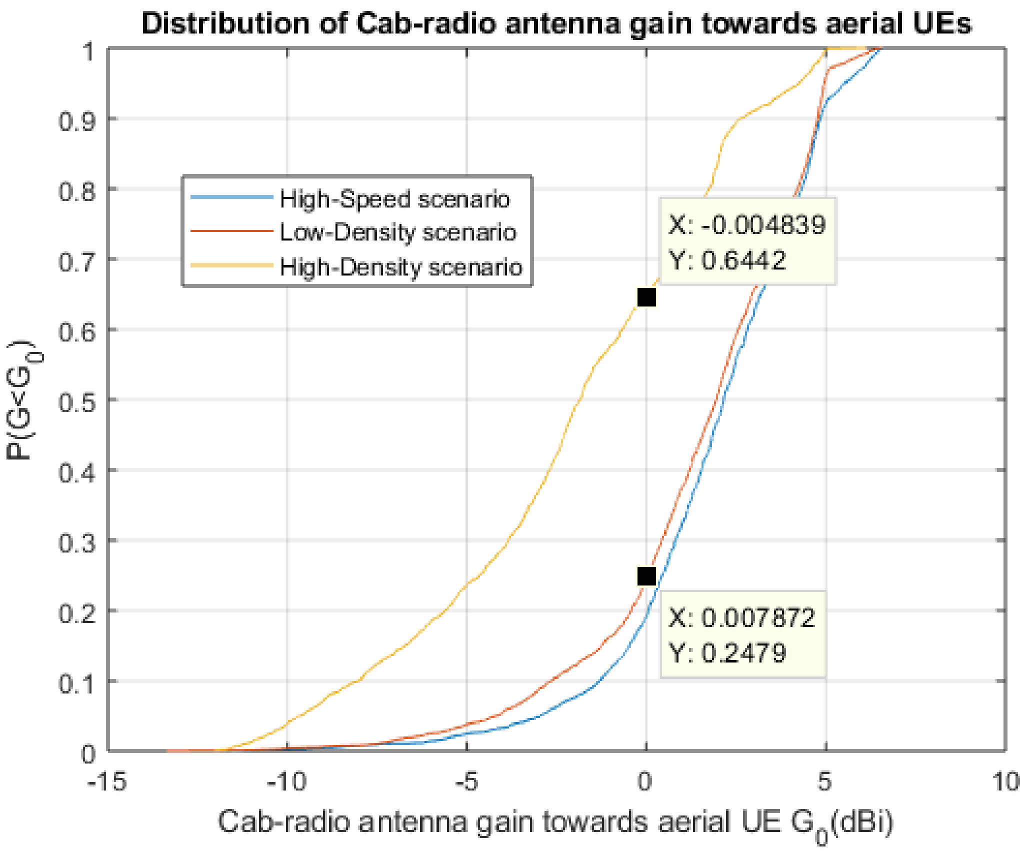


Figure 136: Distribution of cab-radio antenna gain towards aerial UEs for different scenarios

At a first glance, one could notice that the cab-radio antenna gain towards aerial UEs is higher for rural (high-speed and low-density scenarios) than for urban (high-density): more than 60% of the case relates to cab-radio antenna gain <0 dBi for high-density scenario (orange curve) while it is less than 25% for the two other rural cases (red and blue curves). This can be explained by recalling that rural case assumes larger cell size (0.25 km) than for urban ones (2.5 km), the proportion of terminals at the horizon is larger for rural case than for urban ones. Hence, the discrimination angle between the FRMCS cab-radio antenna pointing with the aerial UEs is in proportion higher for the urban area where more terminals are above the horizon in comparison with rural ones, bringing the antenna gain to be lower for the urban scenario.

ANNEX 19: AAS BS ISSUE: COEXISTENCE BETWEEN DRONES ABOVE 3400 MHZ AND RADARS BELOW 3400 MHZ

A19.1 INTRODUCTION

ECC has published ECC Decision (11)06 [40] on unwanted emissions levels of BS (AAS) based on a use of 5G UE at a height of 1.5 m. However, UE could be used like aeronautical application, that implies UE heights larger than 1.5 m, and so, different BS antenna beams directions.

More specifically, this document addresses the protection of radar in adjacent band scenario by introducing "aeronautical " UE : the aim is to check that unwanted emissions defined in ECC Decision (11)06 is sufficient to protect radiolocation service in 3100-3400 MHz, under these new conditions.

A19.2 CHARACTERISTICS OF RADARS

Radars considered for the study are:

- airborne systems A-A as described in Recommendation ITU-R M.1465-3 [75];
- land based system I and L-D as described respectively in Recommendation ITU-R M.1464-2 [71] and Recommendation ITU-R M.1465-3 [75].

whose characteristics used in this document are provided in the table below:

Table 108: General characteristics of IMT BS

Parameters	Unit	A-A	I	L-D
3 dB azimuth beamwidth	degree	1.2	1.5	1 to 4.5°
3 dB elevation beamwidth	degree	6	4.8°	Not available
Antenna polarization	N/A[67]	Not Available	Linear or circular	V
Typical peak antenna gain	dBi	40	33.5	40
Altitude/height	m	9000	4 to 30 (10)	10
Noise Factor (NF)	dB	3.0	3.0	4.0
Protection criterion (I/N)	dB	-6	-6	-6
Maximum acceptable interference	dBm/MHz	-117[68]	-118[2]	-116[2]
Vertical scan range	degree	-60..+60	Max 90°	Max 90°
Horizontal scan type	degree	Mechanical Rotating	Mechanical Rotating	Mechanical Rotating
Horizontal scan range	degree	0..360	0..360	0..360

[67] Not Applicable

[68] Noting that the noise (including the noise factor) level N is equal to -114+NF = -111 dBm/MHz and Imax=I/N+N

Radar A-A: Such airborne systems are used for long-range surveillance or target tracking and typically operate at about 9000 m in altitude. The location of the antenna (atop of the airframe but not in front because of its large size) explains why it is not possible for the radar antenna to perform a vertical scanning to the nadir (leading to -60° lower bound). In the study, the antenna is assumed to scan the area up to 5°.

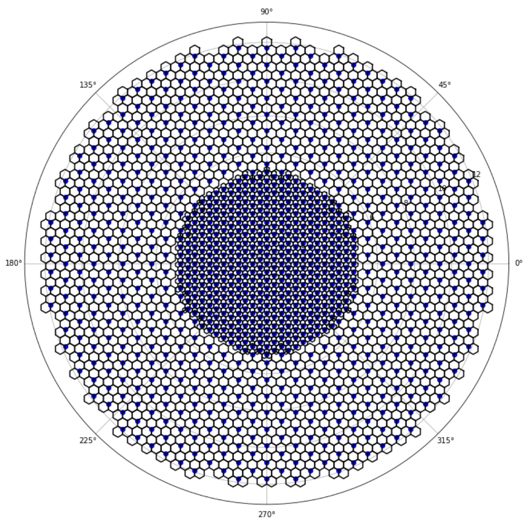
Radar I and L-D: land based radar. Concerning radar L-D, since there is a range of values for azimuth beamwidth (1..4.5°) and no values specified for the 3 dB elevation beamwidth, the following assumptions are taken for:

- 3 dB azimuth beamwidth: 1.5° and 4°;
- 3 dB elevation beamwidth: 40°.

A19.3 CHARACTERISTICS OF IMT SYSTEM IN MFCN

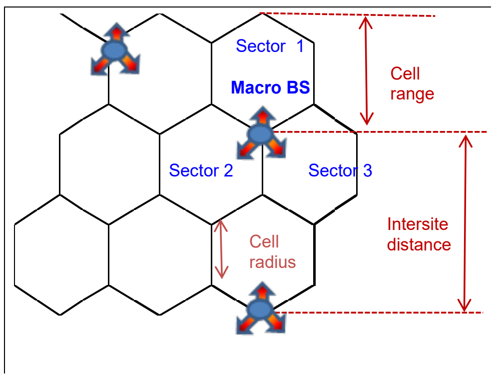
A19.3.1 IMT network

IMT network



IMT network in a town defined with

- an urban radius of 5 km
- a sub-urban radius of 12 km



Reference: doc. 3GPP TR25.816

Inter site distance

- Urban: 450 m
- Suburban: 900 m

- Urban cell range: 300 m
- Suburban cell range: 600 m

: macro BS (3 sectors)

: transmitter

Figure 137: IMT network

A19.3.2 IMT base stations

A19.3.2.1Deployment of IMT base stations

The amount of Macro BSs spread within the ring is derived following the mathematical formula:

$$NbBSs = BS\ density\ \times\ TDD\ Factor \times Network\ load \tag{51}$$

Where:

- BS TDD Factor (%) corresponds to the DL activity factor
- Network load (%) refers to the percentage of BSs simultaneously transmitting at full power
- BS density provides the number of BSs per km^2.

TDD factor: 80% is used for downlink and 20% for uplink

Network load: when simulations involve small areas, 50% is used; when simulations involve large areas (1/3 of the world, for example), 20% is used

BS density: (calculated with cell radius available in report ITU-R M.2292 [25]→ Inter Site Distance).

Micro base stations are not taken into account in this study.

<u>Characteristics of IMT BS</u>

Table 109: General characteristics of IMT BS

Macro BS	Polar	e.i.r.p./sector 5/10/20 MHz	Antenna	Mechanical Down Tilt	Height	Cell range / deployment density
Urban	Linear ± 45 °	58/61/61*	AAS	-10°	20 m	0.15-0.62 km (typical 0.3 km)
Suburban	Linear ± 45 °	58/61/61*	AAS	-6°	25 m	0.3-2 km (typical 0.6 km)

Unwanted emissions levels: ECC Decision (11)06 [40] defines a TRP limit of -52 dBm/MHz for AAS BS.

Table 110: General characteristics of AAS (IMT BS)

AAS: Antenna array 8x8	Value
Maximum element gain	8 dBi
H/V 3 dB beamwidth	80°/65°
Am and SLA	30 dB for both
Horizontal and Vertical element spacing	0.6λ for horizontal 0.9λ for vertical
Feeder loss	3 dB
Maximum composite antenna Gain	23.4 dB

A19.3.3 IMT UE in mobile network

Unwanted emissions levels of BS (AAS) in ECC Decision 11(06) has been defined taking into account the coverage of “terrestrial” UEs (h=1.5 m).

However, UEs could be used in aeronautical applications that implies heights larger than 1.5 m. These different result in performing up-tilt of the AAS antenna beam when serving the aerial UE. This is why this study aims at evaluating the impact of the use of 5G drone on the unwanted emission level to protect radiolocation service below 3400 MHz.

In this study:

- User equipment used as terrestrial application is named "ground" UE (typical height 1.5 m);
- User equipment on drone is named "drone" UE (typical altitude from 10 m to 150 m, and an example with altitude from 10 m to 10000 m).

A19.4 ASSUMPTIONS AND SCENARIO OF COEXISTENCE

A19.4.1 Analysis of the interference from base stations in adjacent band

A19.4.1.1 Modelling of the e.i.r.p. of multiple sources of interference

<u>BSs simultaneously transmitting load and traffic factors</u>

In practice, all BSs within the network do not simultaneously transmit that’s why it is important to define the network load (Average base station activity) to be 0.5. This means that half of the BSs are simultaneously radiating with full conducted power, but not necessarily the same BSs all the time. Consequently, it is important to determine at each trial which BSs are active to know the orientation of the antenna panel when determining the direction (towards the victim) of the e.i.r.p. assessment.

Moreover a TDD factor needs also to be considered in regard to the traffic asymmetry of a terrestrial mobile network. This factor can be accounted for in the Monte Carlo trials by multiplying all radiated powers by the same single binary random variable x (0 or 1), where Pr{x = 1} = ratio of DL transmissions to total frame duration. A DL ratio of 0.7 will be assumed.

<u>Statistics of the BS antenna beam-steering within the cell</u>

For each IMT BS sector, a single beam of the antenna with a mechanical tilt is steered in phi-scan and electrical tilt toward a UE which is dropped randomly within the sector.

Ground UEs are assumed to be only outdoor, and 1.5 metres above ground. Random with Rayleigh law for UE (h =1.5 m) and uniform random between -60° to +60° (azimuth) (see A6.3).

Drone UEs are assumed to be only outdoor, and maximum 150 metres above ground, i.e. for UEs with uniform random distribution between -30° to +30° (elevation) and uniform random distribution between -60° to +60° (azimuth)

These different uses lead to different orientation of the AAS antenna beam, as shown in the figure below.

ground UE	BS H = 20/25m	drone UE

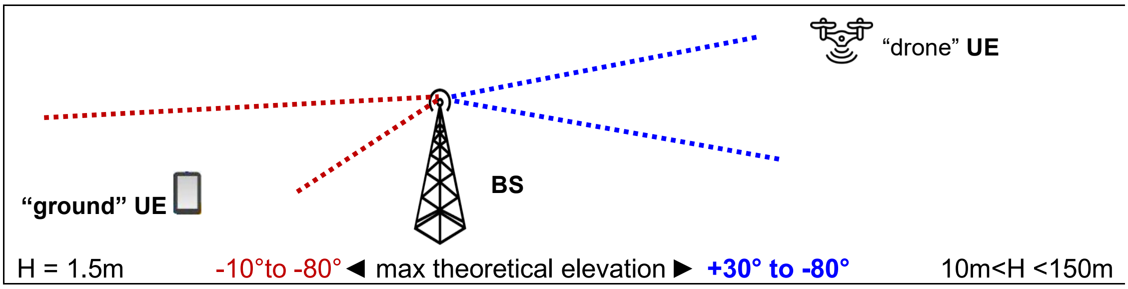


Figure 138: link between BS and UE

When BS-UE angle exceeds [-10°to-80°or +30° to -80°] values, then this BS is not selected and another random run is launched.

Calculation of the antenna gain of the BSs within the IMT network in the direction of radar receiver

Use of the 3GPP LTE-Advanced AAS model (correlation coefficient =1 ‘antenna pattern beamformed’).

A19.4.1.2Propagation of the radiated unwanted emissions from BSs

Description of the physical phenomena involved in the propagation

As indicated previously, at each trial the active BSs may change (which makes the distance (active BS, radar) vary at each event) which requires modelling the BS index as a random variable, e.g. discrete uniform. Moreover, as a generic analysis on the aggregate interference caused by BSs, the path profile between the Radar and each BS is assumed to be not specific, i.e. with a flat terrain with buildings (featuring urban and suburban areas). Considered phenomena involved in the losses of the link budget between the radar and the BSs for distance lower than the horizon distance are:

- the free space loss,
- losses due to clutter in the vicinity of the BSs area (suburban and urban) which are modelled in a statistical way. It has to be noted that not all BSs are subject to clutter loss depending on the nature of the area where the BS is located:
  - No clutter is assumed for suburban area because each BS antenna is set above the roof
  - Half of BSs are not subject to clutter for urban environment (as indicated in Rep. ITU-R M.2292).

Models used to describe these phenomena

Recommendation ITU-R P.2108-0 [115] is selected to describe the clutter loss in the vicinity of the BS (according to the nature of UE (ground or aero)). Two key parameters of this Recommendation are the percentage of locations and the distance between the interferer and the receiver. In MonteCarlo simulations, the percentage of locations is assumed to vary within all actives BSs at each trial, that’s why a uniform random value within the range 1-99%) is generated for each active BS at each event. In addition, the distance between the radar and the BS also varies for each trial because the active BSs change at each event.

Recommendation ITU-R P.525 [76] is used to describe the free space loss.

Polarisation discrimination phenomena

Difference of polarisation (BS: linear ± 45°, radar vertical or horizontal or circular) leads to a use a discrimination value of 3 dB in the link budget, in the configuration main lobe to main lobe.

A19.4.1.3 Cumulative effect of the BS unwanted emissions levels at the radar receiver

Direction of interest concerning the radiated interference

Although the antenna of the radar rotates within the horizon plane, the study focuses on the impact of the BSs for a given orientation of the antenna, when the radar receiver is pointing its beam towards the centre of the town.

Choice of the metric featuring the aggregate interference

The calculation of the aggregate interference at the receiver level can be computed over 100,000 trials using Monte Carlo methods. The cumulative distribution function (cdf) of the aggregate received interference level (as a random variable[69]) is computed from these trials and a 99th percentile of the cdf is selected to be compared to the maximum acceptable interference level I_{max}.

Any exceedance of the maximum acceptable level I_{max} (by Δ=99th percentile(cdf)- I_{max} >0) is balanced by reducing the conducted power/Total Radiated Power (TRP) of the BS by Δ dB.

A19.4.1.4 Details and assumptions on simulations

1 Town (urban radius=5 km and suburban radius= 12 km)

2 5G network is only composed of macro BS,

3 Random for

- a) active BS (with a TDD factor equal to 0.8)
- b) UE (max one per sector)

4 Radar "looks at" centre of the town, and is placed at a distance A of the centre of the town

5 The computation of the received interference is performed over 105 samples in order to get a satisfactory reliable statistic of the probability of exceeding the protection criterion

6 Determination of distances and angles take into account earth roundness.

A19.4.2 Analysis of the scenario of coexistence

A19.4.2.1 Aggregate statistical analysis of the impact of BS spurious onto radiolocation service when drone UE are used

The mobility of the drone, the use of AAS BS leads to consider from a statistical point of view the impact of the use of 5G drone on AAS electronic beamwidth of BS and consequently the impact on the radar receiver. In addition, several drones can operate simultaneously in the town, this is why the cumulative effect of multiple BS in link with aerial UEs is investigated in this section.

The radar is in the vicinity of the town (at horizontal distance equal to 1 km for land-based system, at an altitude of 9000 m for airborne system).

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69 This random variable results from the generation of multiple random variables such as: UE statistic distribution (for AAS electronic beam orientation), clutter loss and location /orientation of active BS antenna sector

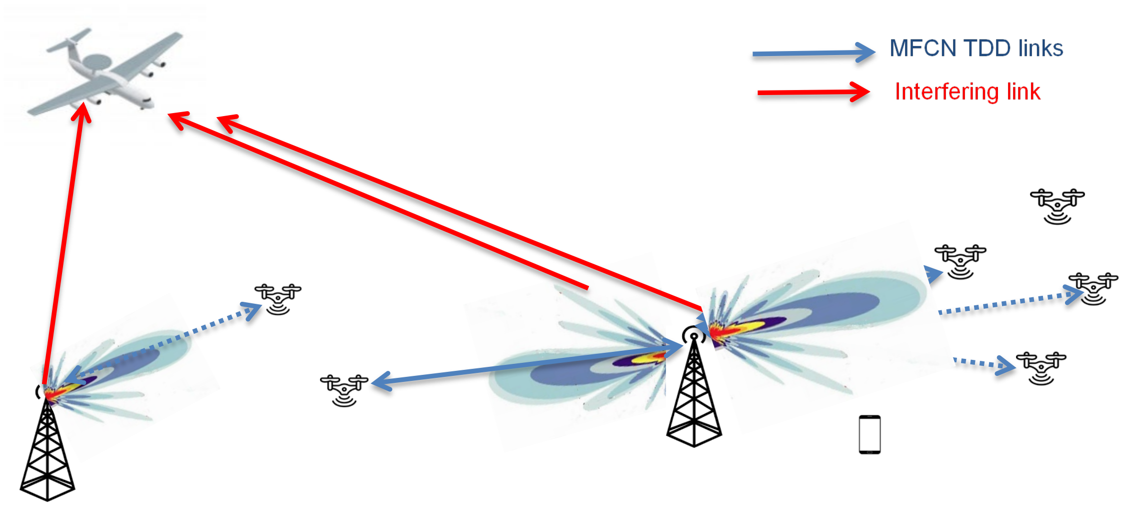


Figure 139: Radio link multiple transmitting drone UE

Reminding that the band under study is dedicated for 5G, the density of UEs within a cell is assessed on the basis of the following information:

1 the UE density given in ITU-R Report M.2412-0 on Guidelines for evaluation of radio interface technologies for IMT-2020 [78] for this frequency range on Rural eMBB: 10 simultaneous UEs per BS,

2 the density of aerial UEs is expected to be lower than the one for the ground UEs for different reasons:

   a) physical separation between two drones is needed to avoid collisions during the flight

   b) cell area for drone is larger than for ground UEs because lower (due to free-space) path loss.

For this study, an assumption of 1 UE per sector (i.e. 3 UE per BS) is used to evaluate the necessary TRP level of 5G BS:

The 3 following cases are under analysis:

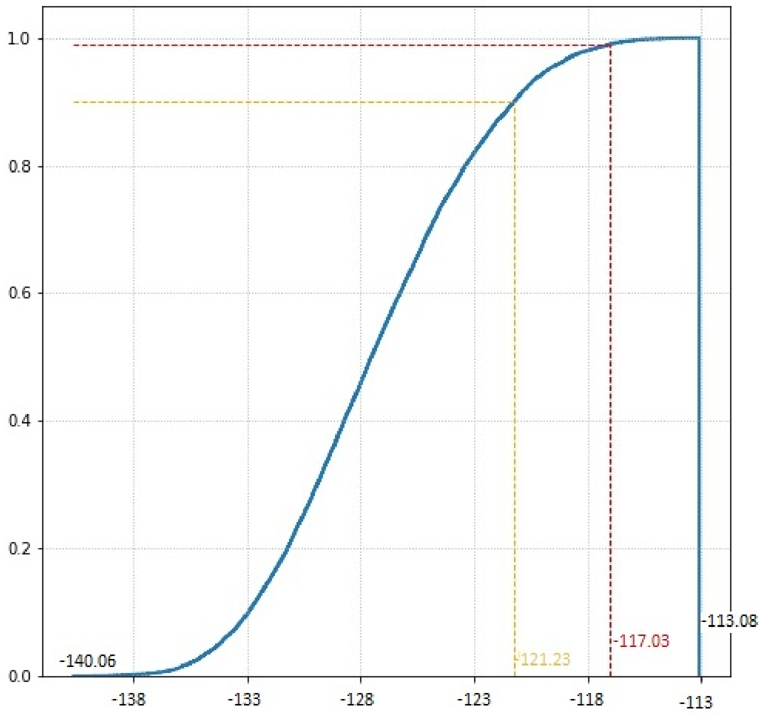
1 100% ground UEs, at a height of 1.5 m: this analysis has been realised to determine necessary TRP level to insure protection of radiolocation service (results lead to ECC Decision (11)06 [40] and a limit of -52 dBm/MHz per cell;

2 50% ground UEs at a height of 1.5 m and 50% of drone UEs;

3 100% of drone UEs.

A19.4.3 Analysis of the results

Distribution of received interference from multiple BS (as cdf) is plotted in the figure below. The maximum acceptable interference level is also displayed in the graph through a red vertical dotted line in order to evaluate the probability of interfering the airborne radar (A-A). Below an example for radar (A-A) at 50 km is provided to illustrate how to select the TRP based on the given percentage of exceedance of the (aggregate) interference threshold. Note that this example does not reflect the value set in ECC Decision (11)06 or EC Decision 2019/235 **Error! Reference source not found.** (i.e. -52 dBm/MHz TRP).



- X axis: (aggregate) interference level at radar receiver for a TRP level = -43.7 Bm/MHz applied to each BS
- Y axis: probability that received level of interference is equal or lower than the x-axis value:
  - Red dotted line: received level at 99%;
  - Yellow dotted line: 90%;

For this scenario (depicted by a coloured curve), the exceedance of the protection criterion can be read by looking at the intersection of the curve with a (yellow and red in this graph) vertical dotted line. For the sake of readability, these intersections are tagged. This means that for the part at the right side of each vertical line corresponds to the cases of interference threshold exceedance (for different percentages of exceedance).

Figure 140: Example of results - cdf of aggregate interference received at the radar receiver from UEs

A19.4.4 Results

Necessary TRP limit has been calculated for three different radars and for different horizontal distances accounting for the spherical nature of the Earth. Results are summarised in the table below.

Table 111: Results

Radar parameters					Necessary TRP limit (dBm/MHz) for 99%		
RADAR (Recommendation ITU-R)	G_{ant} (dBi)	Threshold (dBm)	α°	ϴ°	A= 13 km	A= 50 km	A= 150 km
Distribution between aerial and typical UEs: 100% ground UEs							
I (M.1464-2) [71]	33.5	-118	40°	1.5°	-50.4		
L-D (M.1465-3)	40	-116	40°	1.5°	-54.8		
				4°	-59.3		
A-A (M.1465-3)	40	-117	6°	1.2°	-37.5	-37.1	-34.6
Distribution between aerial and typical UEs: 100% aerial UEs							
I (M.1464-2) [71]	33.5	-118	40°	1.5°	-50.1		
L-D (M.1465-3) [75]	40	-116		1.5°	-54.5		

Radar parameters					Necessary TRP limit (dBm/MHz) for 99%		
			40°	4°	-58.4		
A-A (M.1465-3) [75]	40	-117	6°	1.2°	-44.6	-43.7	-37.2
Distribution between aerial and typical UEs: 50% aerial UEs and 50% ground UEs							
I (M.1464-2) [71]	33.5	-118	40°	1.5°	-49.9		
L-D (M.1465-3) [75]	40	-116	40°	1.5°	-54.4		
				4°	-59.1		
A-A (M.1465-3) [75]	40	-117	6°	1.2°	-43.1 (note 1)*	-42.2	-35.6
Note 1: A5.3 gives result for an altitude (of aerial UEs) up to 10000 m							

A19.5 CONCLUSIONS

Compatibility studies between radar and base stations managing drones in MFCN were carried out at 3400 MHz. Analysis of the cumulative effect of multiple sources of interference was carried out on a statistical basis because of the variability of several parameters (e.g. the positioning of the drones : distance/altitude and the airborne radar: orientation of the beam radar antenna).

From these results, it appears that level of unwanted emissions defined in ECC Decision 11(06) (in terms of TRP (-52 dBm/MHz)) is sufficient to ensure protection of radars I and AA (probability of interference ≤0.01%), However, according to the radar operating knowledge, it is considered that radar L-D operates mainly below 3.3 GHz. It is assumed that these unwanted emissions fall down below -59.3 dBm/MHz below 3.3 GHz.

It is noted that results are dependent of numerous factors, such as:

- Type of radar;
- Size of town;
- Clutter loss (Recommendation ITU-R P.2108 [115]);
- Altitude and density of aerial UEs.

A19.6 APPENDIX

A19.6.1 Extract of ECC Decision (11)06 [40]

Table 112: Base station additional baseline power limits below 3400 MHz for country specific cases, for non-AAS and AAS base stations (1) cases (Table 5 of ECC Decision (11)06)

Case		BEM element	Frequency range	Non AAS e.i.r.p. limit dBm/MHz per antenna	AAS TRP limit dBm/MHz per cell (2)
A	CEPT countries with radiolocation systems below 3400 MHz	Additional baseline	Below 3400 MHz (3)	-59 dBm	-52
B	CEPT countries with radiolocation systems below 3400 MHz	Additional baseline	Below 3400 MHz(3)	-50 dBm	
C	CEPT countries without adjacent band usage or with usage that does not need extra protection	Additional baseline	Below 3400 MHz(3)	Not applicable	Not applicable

(1) Alternative measures may be required on a case by case basis for indoor AAS BSs on a national basis.

(2) In a multi-sector base station, the radiated power limit applies to each one of the individual sectors

(3) In cases where CEPT administrations have already implemented a guard band when issuing licences for MFCN before the adoption of this ECC Decision and in accordance with ECC Decision(11)06 (approved 9th December 2011, amended 14th March 2014), these CEPT administrations may apply the additional baseline only below such guard band, provided it complies with the protection of radars in the adjacent band and with cross-border obligations.

A19.6.2 Example of Distribution of antenna gain (AAS) in a simulation

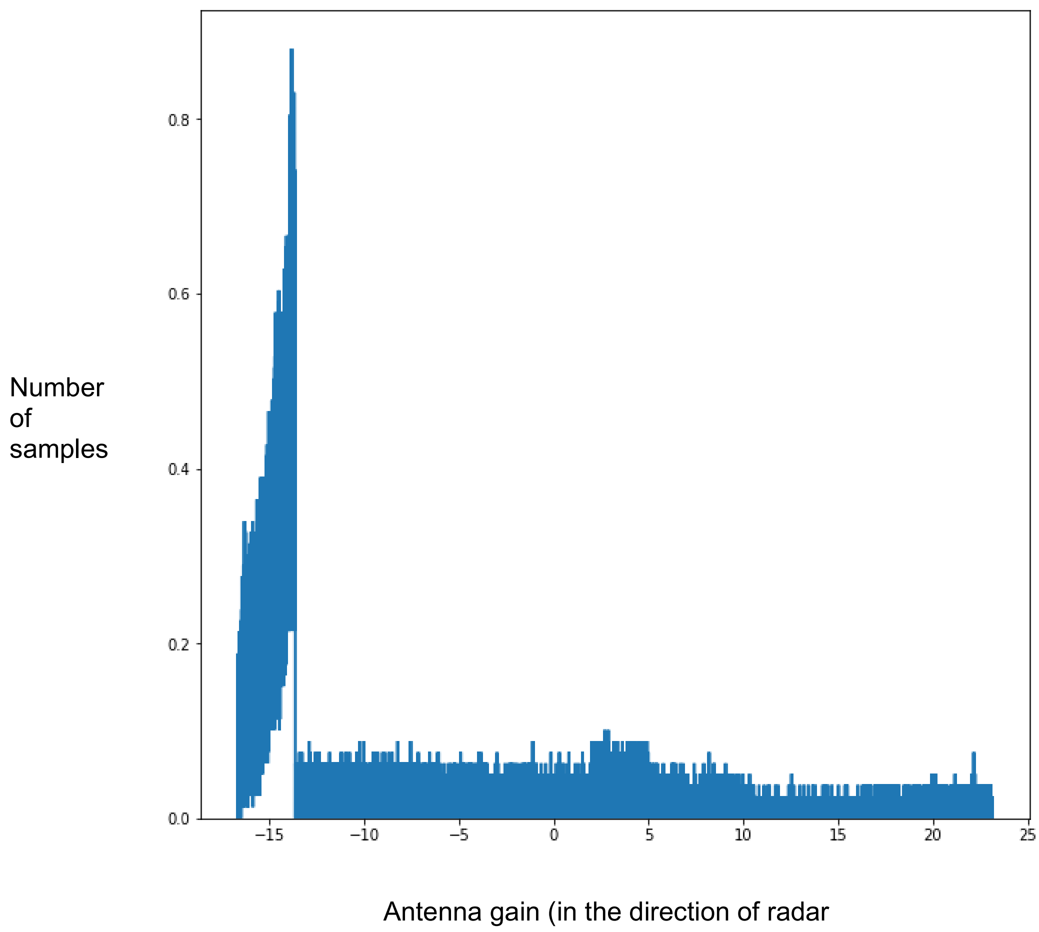


Figure 141: Distribution of antenna gain (AAS) in a simulation

A19.6.3 Example of Position of UE in a BS sector, for one simulation

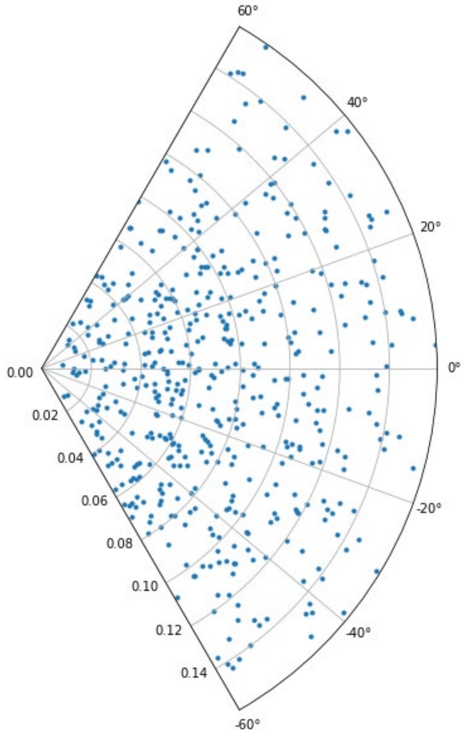


Figure 142: Position of UE in a BS sector, for one simulation

A19.6.4 Example of visualisation of active BS, when radar AA is at an altitude of 9000 m and a distance of 50 km

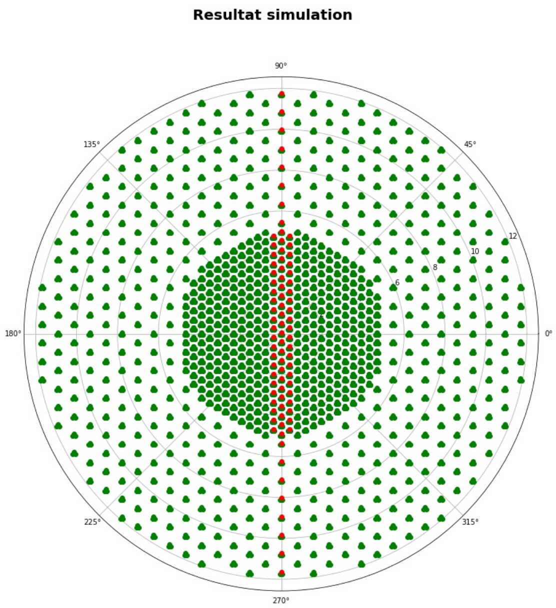


Figure 143: Example of visualisation of active BS, when radar AA is at an altitude of 9000 m and a distance of 50 km

A19.6.5 Results for drone UE at high altitude (up to 10000 m)

Calculation below is realised in the case of a use of drone UE at an altitude upper than 150 m. « drone » UE are assumed to be only outdoor, and at an altitude up to 10000 metres above ground.

For this simulation, assumptions for base station parameters are summarised in the table below:

Table 113: Assumptions for base station parameters

Macro BS	Polar	Antenna	Mechanical Down Tilt	Height
urban	Linear ± 45 °	AAS	+ 10°	20 m
suburban	Linear ± 45 °	AAS	+ 6°	25 m

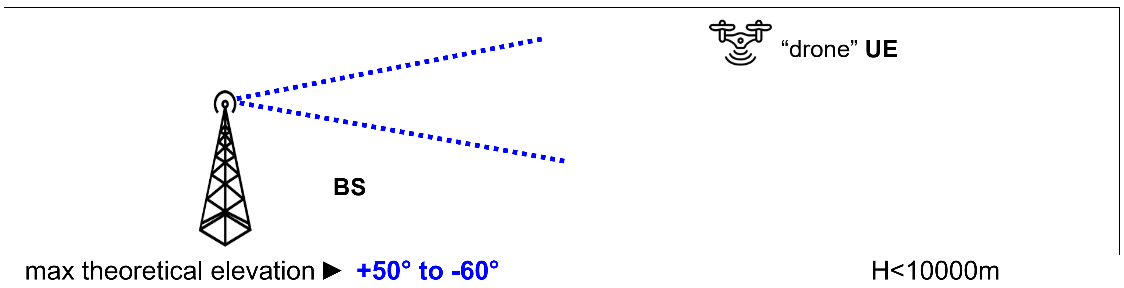


Figure 144: Link between BS and UE

When BS-UE angle exceeds [+50° to -60°] values, then this BS is not validated, and another random run is launched.

Table 114: Results

Radar parameters					Necessary TRP limit (dBm/MHz) for 99%		
RADAR (Recommendation ITU-R)	G_{ant} (dBi)	Thres hold (dBm)	α°	ϴ°	A= 13 km	A= 50 km	A= 150 km
100% "aerial" UEs							
A-A (M.1465-3) [75]	40	-117	6°	1.2°	-48.9		

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