6GNTN

D4.4 SPECTRUM REGULATION ANALYSIS FOR 6G NTN SCENARIOS

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Abstract	One of the goals of the 6G-NTN project is to combine terrestrial and non-terrestrial networks seamlessly for improved user experience, latency and availability across the globe. It is thus necessary to examine the different coexistence scenarios and offer interference mitigation solutions for each case. This deliverable focuses on the analysis of spectrum regulations for the 6G-NTN scenarios and defines the TN and NTN parameters which will be used in future coexistence simulation activities. It describes the considered frequency bands and coexistence scenarios, state-of-the-

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	art in interference mitigation and NTN networks, as well as parameters for both terrestrial and non-terrestrial components of the 6G-NTN architecture.
Keywords	6G, NTN, Interference mitigation, Coexistence scenarios, Spectrum allocation

Document Revision History

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EXECUTIVE SUMMARY

This deliverable is the first out of three planned deliverables (D4.4, D4.7, D4.8) related to spectrum regulation analysis for 6G-NTN scenarios (Task 4.3) for the 6G-NTN (6G-Non-Terrestrial Networks) project.

Launched on 1st January 2023, 6G-NTN is a project co-funded by the European Union which will study over the course of three years the different capabilities brought by 6G NTN and Terrestrial Network (TN) to propose solutions to NTN implementation challenges, such as latency, Doppler shift, smooth TN-NTN handover and global coordination, TN-NTN coexistence scenarios, interference mitigation, satellite payload limitations, etc.

Generally speaking, 6G will allow terrestrial devices to access connectivity with increased availability and decreased latency across the globe, enabling new use cases and preventing traffic congestion.

The 6G-NTN project aims to combine terrestrial and non-terrestrial networks seamlessly. It is thus necessary to examine the coexistence scenarios envisaged in novel spectrum regulations to address the 6G-NTN challenges and offer interference mitigation solutions for each case.

The present deliverable outlines preliminary coexistence scenarios and techniques to improve spectrum allocation using interference mitigation. The specific coexistence scenarios are related to the introduction of new potential bands for satellite communications (Q/V and C bands) for 6G.

This document describes considered frequency bands and coexistence scenarios, taking into account ITU-R (International Telecommunication Union Radiocommunication Sector) and regional regulation. It offers parameters for both terrestrial and non-terrestrial components of the 6G-NTN architecture, as well as an overview of the state-of-the-art on interference mitigation in NTN networks.

One of the objectives of this deliverable is to specify common parameters for the different components of the 6G-NTN architecture, such as terrestrial Base Station (BS) and User Equipment (UE), as well as NTN Satellite Access Network (SAN) and equivalent NTN UE. These parameters will be used in future simulation activities to derive interference values and their impact on the final radio access network.

The results and conclusions of the work done in spectrum regulation analysis serve as a source of input to future standardisation activities such as 3GPP (3rd Generation Partnership Project).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

3GPP	3rd Generation Partnership Project
ABS	Almost Blank Subframes
ACLR	Adjacent Channel Leakage Ratio
ACS	Adjacent Channel Selectivity
ACU	Antenna Control Unit
A-ESIM	Aeronautical-Earth Station In Motion
BF-OFDM	Block Filtered-Orthogonal Frequency Division Multiplexing
BS	Base Station
BUC	Block Up-Converter
BW	BandWidth
BWP	BandWidth Part
CA	Carrier Aggregation
CC	Carrier Components
CDF	Cumulative Distribution Function
CEPT	European Conference of Postal and Telecommunications Administrations
CFR	Code of Federal Regulations
CHO	Conditional HandOver
CIR	Carrier-to-Interference Ratio
CNIR	Carrier-to-Noise-and-Interference Ratio
CNR	Carrier-to-Noise Ratio
CoMP	Coordinated Multi-Point
CQI	Channel Quality Indicator
CS	Coordinated Scheduling
CSI	Channel State Information
DC	Down Converter
DL	Down Link
DP	Duplexer
DPS	Dynamic Point Selection
ECC	Electronic Communications Committee
eICIC	Enhanced Inter-Cell Interference Coordination
EIRP	Effective Isotropic Radiated Power
ePDCCH	enhanced Physical Downlink Control Channel
EPFD	Equivalent Power Flux Density Limit
ESIM	Earth Station In Motion
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FeICIC	Further enhanced Inter-Cell Interference Coordination
FFR	Fractionary Frequency Reuse
FR	Frequency Range
FRF	Frequency Reuse Factor
FSS	Fixed-Satellite Service
GEO	Geosynchronous Equatorial Orbit
gNB	gNodeB
GSO	Geostationary Satellite Orbit
G/T	antenna Gain to noise Temperature

HetNet	Heterogeneous Networks
HFR	Hard Frequency Reuse
HPBW	Half Power Beam Width
ICI	Inter-Cell Interference
ICIC	Inter-Cell Interference Coordination
IF	Intermediate Frequency
IM	Interference Measurement
IRC	Interference Rejection Combiner
ISD	Inter-Site Distance
ISL	Inter-Satellite Link
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication Sector
IUI	Inter-User Interference
JR	Joint Reception
JT	Joint Transmission
LA	Link Adaptation
LEO	Low Earth Orbit
L-ESIM	Land-ESIM
LHCP	Left-Handed Circular Polarisation
LNA	Low Noise Amplifier
LOS	Line Of Sight
LTE	Long Term Evolution
MAC	Medium Access Control
MBS	Multicast and Broadcast Services
MCS	Modulation and Coding Scheme
MFCN	Mobile/Fixed Communications Networks
MIMO	Multiple-Input Multiple-Output
MMSE	Minimum Mean Square Error
MS	Mobile Station
NF	Noise Figure
NGSO	Non-Geostationary Satellite Orbit
NLOS	Non-Line Of Sight
NR	New Radio
NTN	Non-Terrestrial Network
NZP CSI-RS	Non-Zero-power CSI Reference Signal
OpenAMIP	Open Antenna to Modem Interface Protocol
OpenBMIP	Open BUC Modem Interface Protocol
PA	Power Amplifier
PCC	Primary Carrier Components
PCell	Primary Cell
PDCCH	Physical Downlink Control Channel
PDSCH	Physical Downlink Shared Channel
PFD	Power Flux Density
PHY	PHYsical layer
PL	Path Loss
PRB	Physical Resource Block
PUSCH	Physical Uplink Shared CHannel
RB	Resource Block

RE	Resource Element
RF	Radio Frequency
RHCP	Right-Handed Circular Polarisation
RMa	Rural Macro
RP	Reception Point
RP-ABS	Reduced Power Almost Blank Sub frames
RRM	Radio Resource Management
RS	Reference Signal
SAN	Satellite Access Network
SCC	Secondary Carrier Components
SCell	Secondary Cell
SINR	Signal-to-Interference-plus-Noise Ratio
SNR	Signal-to-Noise Ratio
SNS	Smart Networks and Services
TAB	Transceiver Array Boundary
TDD	Time Division Duplex
TN	Terrestrial Network
TP	Transmission Point
TPC	Transmit Power Control
TSG-RAN	Technical Specification Groups-Radio Access Network
TSG-SA	Technical Specification Groups-System Aspects
UC	Up Converter
UE	User Equipment
UL	Up Link
ULA	Uniformly Distributed Array
UMa	Urban Macro
UMi	Urban Micro
URLLC	Ultra-Reliable Low Latency Communications
UT	User Terminal
UTC	Coordinated Universal Time
VMR	Vehicle Mounted Relay
VSAT	Very Small Aperture Terminal
WRC	World Radiocommunication Conferences

1 INTRODUCTION

Through the use of satellite networks, 6G-NTN will allow terrestrial devices (handheld UE, mounted UE, etc.) to access connectivity with increased availability and decreased latency across the globe, enabling new use cases and preventing traffic congestion.

6G-NTN aims to combine terrestrial and non-terrestrial networks seamlessly. It is thus necessary to examine the coexistence scenarios envisaged in novel spectrum regulations to address both 6G NTN and 6G TN challenges and implement spectrum management techniques and interference mitigation solutions for each case.

The present deliverable outlines preliminary analysis and use cases in order to identify potential novel spectrum allocation. Moreover, NTN-TN adjacent band coexistence analysis is essential for:

- Definition of Radio Frequency (RF) core requirements (Adjacent Channel Leakage Ratio (ACLR), Adjacent Channel Selectivity (ACS), etc.);
- Introduction of new NTN bands.

1.1 SCOPE AND OBJECTIVES

The objectives are:

- To propose and validate new spectrum co-existence scenarios and methods to support efficient spectrum utilisation from various incumbents;
- To evaluate the interference scenarios considered by novel spectrum regulations to address the 6G NTN challenges.

In order to fulfil these objectives, the planned work for the T4.3 task includes:

- NTN-TN coexistence scenarios identification to address specifically Q/V and C bands;
- Channel model identification;
- Simulations & evaluation of different coexistence methods;
- Identify NTN related (RF/ Radio Resource Management (RRM)) requirements, and increase the NTN end-user throughput through spectrum sharing and multiple NTN/TN access point connectivity.

This deliverable is also in line with 3GPP Rel-19 5G NR (New Radio) NTN proposed topics related to:

- TSG-RAN (Technical Specification Groups-Radio Access Network):
    - Improve the service experience
        - Coverage enhancements (DownLink (DL) and possibly UpLink (UL))
        - NTN/TN Mobility enhancement in connected mode (e.g., Conditional HandOver (CHO))

    - New Notification/Alert message for UE terminating calls with UE in poor Signal-to-Noise Ratio (SNR) conditions preventing paging message reception
  - New capabilities (band agnostic)
    - Support of Regenerative payloads (i.e., with Inter-Satellite Link (ISL))
    - Support of Multicast and Broadcast Services (MBS)
    - Asynchronous multi-connectivity (e.g., between two satellite access i.e., Non-Geostationary Satellite Orbit (NGSO) and Geostationary Satellite Orbit (GSO); possibly between NTN/TN) for above 10 GHz only
    - Support of discontinuous coverage (mitigating coverage holes during deployment/operation of constellation)
- TSG-SA (Technical Specification Groups-System Aspects)
  - Improve delay
    - Store and Forward Satellite operation for delay-tolerant communication services
    - UE-Satellite-UE communication (without going through the ground network)
  - Improve service capability
    - Dual steer NTN/TN
    - MBS via NTN
    - Vehicle Mounted Relay (VMR) in NTN

According to 3GPP roadmap for 6G, a 6G study phase is envisioned in Rel-20 and 6G normalisation phase is expected in Rel-21 assuming 18 months release plan. This 3GPP roadmap (Figure 1) is therefore aligned with 6G-NTN Smart Networks and Services (SNS) timeline (end of project end of 2025).

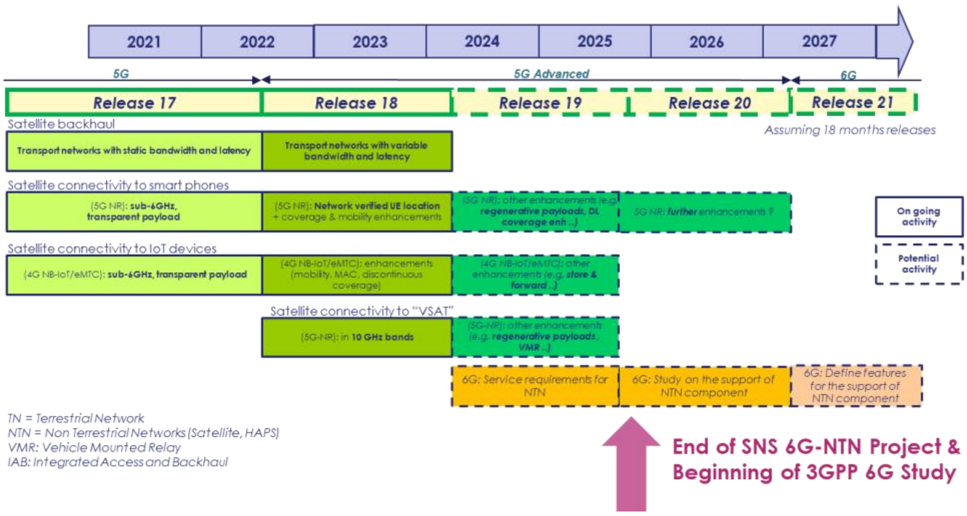

FIGURE 1: 3GPP ROADMAP FOR 6G

1.2 RELATION TO OTHER WORK PACKAGES IN 6G-NTN

The present deliverable is part of T4.3 which is one of the tasks in Work Package WP4.

The work of T4.3 is coordinated with other WPs for inputs, namely:

- WP2 D2.5 '*Report on Regulatory requirements*' (T2.5) for inputs on frequency bands and regulation
- WP3 D3.1 '*Report on 3D multi layered NTN architecture*' (T3.1) and subsequent deliverables for inputs on the 6G-NTN architecture.

1.3 STRUCTURE OF THE DOCUMENT

This deliverable is structured as follows:

- Section 2 offers an overview on channel model and spectrum allocation for both terrestrial and non-terrestrial components of the 6G-NTN architecture.
- Section 3 introduces the different frequency bands use cases and respective coexistence scenarios that will be further studied in Q/V and C bands.
- Section 4 reports the different parameters for NTN UE (User Equipment).
- Section 5 reports the different parameters for TN BS (Base Station) and UE.
- Section 6 describes the parameters for NTN SAN (Satellite Access Network).
- Section 7 reports the parameters for TN BS.
- Section 8 goes into detail about the current state-of-the-art for strategies for coexistence and interference mitigation techniques.
- Section 9 concludes this deliverable.

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2 CHANNEL MODEL AND SPECTRUM ALLOCATION

2.1 INTRODUCTION

Before starting the discussion on coexistence scenarios and related parameters, it is first necessary to define the considered frequency bands for this study. In this section, we will explain choices for frequency bands and the international regulations they may be subjected to concerning spectrum allocation.

In the sequel, an overview on relevant information concerning NTN and TN networks in 3GPP is provided.

2.2 SPECTRUM ALLOCATION, EXISTING BANDS AND STATE-OF-THE-ART

The following NTN frequency bands have been defined for the time being by 3GPP TS 38.101-5 [1] and TS 38.108 [2]. The duplex mode of all these bands is Frequency Division Duplex (FDD). Table 1 presents the NTN operating bands in Frequency Range 1 (FR1).

TABLE 1: NTN OPERATING BANDS IN FR1 FOR SATELLITE NETWORKS (REL-17)

NTN satellite operating band	UL operating band SAN receive / UE transmit $F_{UL,low}$ – $F_{UL,high}$	DL operating band SAN transmit / UE receive $F_{DL,low}$ – $F_{DL,high}$	Duplex mode
n256	1980 MHz – 2010 MHz	2170 MHz – 2200 MHz	FDD
n255	1626.5 MHz – 1660.5 MHz	1525 MHz – 1559 MHz	FDD
NOTE: NTN satellite bands are numbered in descending order from n256.			

In the figures below, the TN bands adjacent to NTN n256 and n255 are represented (TR38.863 [3]).

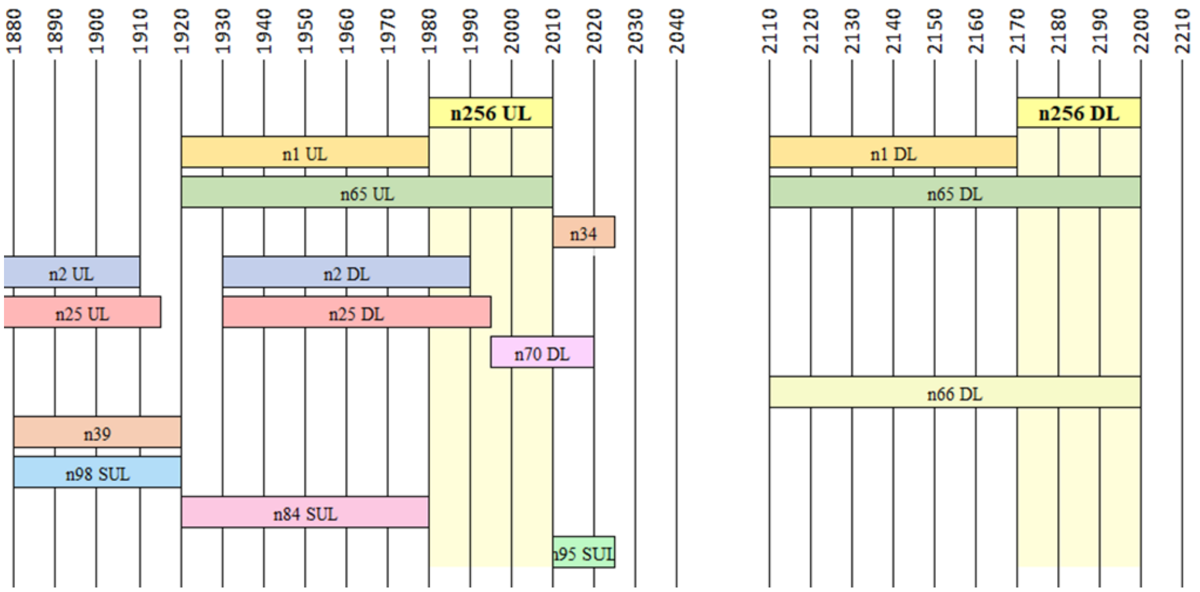

FIGURE 2: ADJACENT TN BANDS TO NTN BAND N256

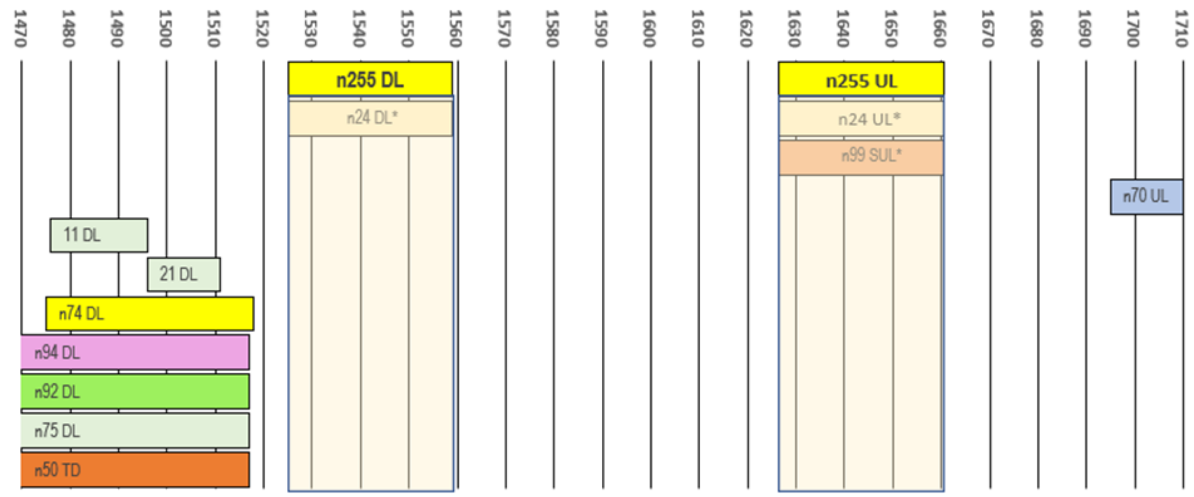

FIGURE 3: ADJACENT TN BANDS TO NTN BAND N255

NOTE: DL operation in band n24 is restricted to 1526-1536MHz and UL operation is restricted to 1627.5-1637.5MHz and 1646.5-1656.5MHz

TABLE 2: NTN OPERATING BANDS IN ABOVE 10 GHZ FOR SATELLITE NETWORKS (REL-18)

NTN satellite operating band	UL operating band SAN receive / UE transmit $F_{UL,low}$ – $F_{UL,high}$	DL operating band SAN transmit / UE receive $F_{DL,low}$ – $F_{DL,high}$	Duplex mode
n512[1]	27.5 - 30.0 GHz	17.3 - 20.2 GHz	FDD
n511[2]	28.35 - 30.0 GHz	17.3 - 20.2 GHz	FDD
n510[3]	27.5 - 28.35 GHz	17.3 - 20.2 GHz	FDD

Note 1: This band is applicable in the countries subject to CEPT (European Conference of Postal and Telecommunications Administrations) ECC (Electronic Communications Committee) Decision(05)01 and ECC Decision (13)01. **Note 2: This band is applicable in the USA subject to FCC (Federal Communications Commission) 47 CFR (Code of Federal Regulations) part 25.** **Note 3: This band is applicable for Earth Station operations in the USA subject to FCC 47 CFR part 25. FCC rules currently do not include ESIM (Earth Station In Motion) operations in this band (47 CFR 25.202).**

Figure 4 represents the adjacent TN bands to NTN bands n512, n511 and n510 [4].

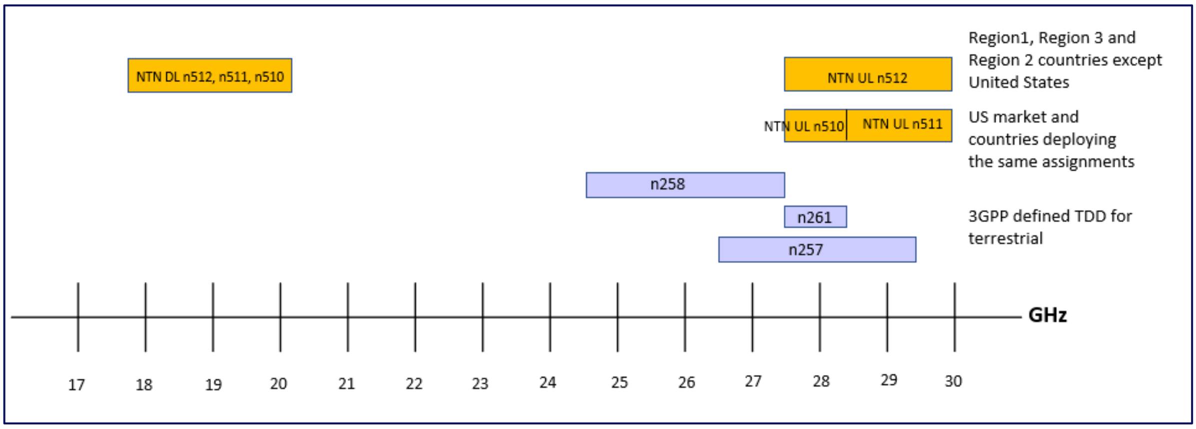

FIGURE 4: ADJACENT TN BANDS TO NTN BANDS N512, N511 AND N510

In addition, World Radiocommunication Conferences (WRC) decisions should also be taken into account [5]:

- WRC-15 authorised ESIM operations in 19.7-20.2 GHz (space-to-Earth) and 29.5-30.0 GHz (Earth-to-space) under certain conditions, and for GSO systems only.
- WRC-19 authorised ESIM operations in 17.7 19.7 GHz (space-to-Earth) and 27.5-29.5 GHz (Earth-to-space) under certain conditions, and for GSO systems only.
- WRC-23 Agenda item 1.16 on NGSO ESIM Ka Band aims to study and develop technical, operational and regulatory measures, as appropriate, to facilitate the use of the frequency bands 17.7-18.6 GHz and 18.8-19.3 GHz and 19.7-20.2 GHz (space-to-Earth) and 27.5-29.1 GHz and 29.5-30 GHz (Earth-to-space) by non-GSO Fixed-Satellite Service (FSS) ESIM, while ensuring due protection of existing services in those frequency bands, in accordance with Resolution 173 (WRC-19).

TABLE 3: OTHER RELEASE INDEPENDANT WORK ITEMS FOR OTHER NTN BAND INTRODUCTIONS (REL-INDEPENDANT)

NTN satellite operating band	UpLink (UL) operating band SAN receive / UE transmit $F_{UL,low}$ – $F_{UL,high}$	DownLink (DL) operating band SAN transmit / UE receive $F_{DL,low}$ – $F_{DL,high}$	Duplex mode
n254	1610 – 1626.5 MHz	2483.5 – 2500 MHz	FDD
NOTE: NTN satellite bands are numbered in descending order from n256.			

For the bands further investigated as part of the 6G-NTN project please refer to deliverable D2.5 '*Report on Regulatory requirements*' in the 6G-NTN project related to band regulations and current spectrum allocation.

2.3 RELEVANT 3GPP NTN INFORMATION

For relevant NTN 3GPP information, please refer to TR 38.811 [6], TR 38.821 [7] and TR 38.863 [3]. For instance, TR 38.821 describes the relationship between Signal-to-Interference-plus-Noise Ratio (SINR)/Carrier-to-noise-and-interference ratio (CNIR) and G/T (antenna Gain to noise Temperature), noise figures as well as other parameters.

Carrier-to-noise-and-interference ratio (CNIR) of transmission link between satellite and UE can be derived by carrier-to-noise ratio (CNR) and carrier-to-interference ratio (CIR) as follows:

$$\mathrm{CNIR}\ [\mathrm{dB}] = -10\log_{10}\left(10^{-0.1\mathrm{CNR}\ [\mathrm{dB}]} + 10^{-0.1\mathrm{CIR}\ [\mathrm{dB}]}\right)$$

The formula for CNR calculation is:

$$\mathrm{CNR}\ [\mathrm{dB}] = \mathrm{EIRP}\ [\mathrm{dBW}] + \frac{G}{T}[\mathrm{dB/K}] - k\ [\mathrm{dBW/K/Hz}] - PL_{FS}\ [\mathrm{dB}] - PL_{A}\ [\mathrm{dB}] - PL_{SM}\ [\mathrm{dB}] - PL_{SL}[dB] - PL_{AD}\ [\mathrm{dB}] - B\ [\mathrm{dBHz}]$$

where:

- EIRP is Effective Isotropic Radiated Power,
- G/T is antenna-gain-to-noise-temperature,
- k is Boltzmann constant and equals to -228.6 dBW/K/Hz,
- PL_{FS} is free space path loss,
- PL_{A} is atmospheric path loss due to gases and rain fades,
- PL_{SM} is shadowing margin,
- $PL_{SL}[dB]$ is scintillation loss,
- PL_{AD} is additional loss, for example degradation due to feeder links in case of non-regenerative systems,
- B is channel bandwidth.

Antenna-gain-to-noise-temperature G/T can be derived by:

$$G/T\ [\mathrm{dB}] = G_R\ [\mathrm{dBi}] - N_f\ [\mathrm{dB}] - 10\log_{10}\left(T_0\ [\mathrm{K}] + (T_a\ [\mathrm{K}] - T_0\ [\mathrm{K}])10^{-0.1N_f\ [\mathrm{dB}]}\right)$$

where G_R is receive antenna gain, N_f is noise figure, T_0 is ambient temperature and T_a is antenna temperature.

Receive antenna gain G_R can be obtained by

$$G_R\ [\mathrm{dBi}] = \begin{cases} G_{R,e}[\mathrm{dBi}] + 10\log_{10}\left(N_{R,a}\right) - L_p[\mathrm{dB}], & \text{array antenna} \\ 10\log_{10}\left(\eta \cdot \pi^2 \cdot \frac{D[m]^2}{\lambda[m]^2}\right), & \text{parabolic antenna} \end{cases}$$

where $G_{R,e}$ is receive antenna element gain, $N_{R,a}$ is the number of receive antenna elements, L_p is polarisation loss, η is the antenna aperture efficiency (a dimensionless parameter with typical values for parabolic antennas from 0.55 to 0.70), D is the equivalent antenna diameter, and λ is the wavelength.

EIRP can be calculated by

$$\text{EIRP [dBW]} = P_T \text{ [dBW]} - L_C \text{ [dB]} + G_T \text{ [dBi]}$$

where P_T is antenna transmit power, L_C is cable loss, and G_T is transmit antenna gain and can be derived by

$$G_T \text{ [dBi]} = \begin{cases} G_{T,e} \text{ [dBi]} + 10\log_{10}(N_{T,a}), & \text{array antenna} \\ 10\log_{10}\left(\eta \cdot \pi^2 \cdot \frac{D[m]^2}{\lambda[m]^2}\right), & \text{parabolic antenna} \end{cases}$$

where $G_{T,e}$ is transmit antenna element gain and $N_{T,a}$ is the number of transmit antenna elements.

CIR can be computed similarly as for CNR, but this time by taking into account the interference power instead of the useful transmitted power for wanted communication.

In this case, EIRP of the interferer depends on the transmitted power of the interferer and the antenna gain of the interferer.

Moreover, the path loss of the interferer may be different from the path loss of the useful signal, depending on the scenario. In practice, the antenna gain is a function of the direction of communication and therefore, the antenna gain of the interferer will be different from the antenna gain in the direction of the wanted communication.

With respect to link budget parameters, it is proposed that 6G-NTN project should follow similar methodology as in TR 38.863 [3], with the adaptations required for Q/V-Band with channel models/link budget parameters described in TR 38.811 [6] and TR 38.821 [7].

2.4 RELEVANT 3GPP TN INFORMATION

The relevant information from 3GPP TR 38.901 “Study on channel model for frequencies from 0.5 to 100 GHz” [8] are path loss models and Line of Sight (LOS) probability. Two deployment scenarios are considered: Rural Macro (RMa) and Urban Macro (UMa), each further differentiated between NLOS (Non-Line Of Sight) and LOS scenarios.

2.4.1 Path Loss model

The Path loss model is summarised in Table 4 and the distance definitions are indicated in Figure 5 for outdoor User Terminal (UT) and Figure 6 for indoor UT. Note that the distribution of the shadow fading is log-normal, and its standard deviation for each scenario is given in Table 4.

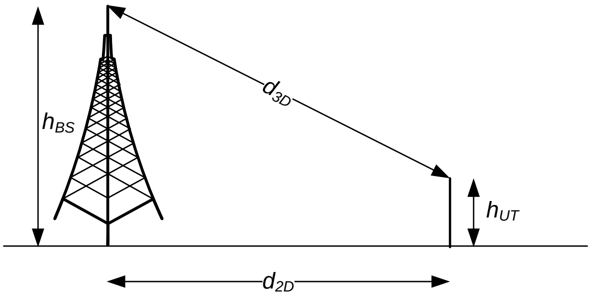

FIGURE 5: DEFINITION OF D_{2D} AND D_{3D} FOR OUTDOOR UT

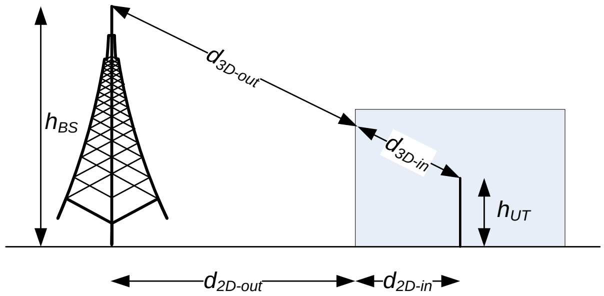

FIGURE 6: DEFINITION OF $D_{2D\text{-}OUT}$, $D_{2D\text{-}IN}$ AND $D_{3D\text{-}OUT}$, $D_{3D\text{-}IN}$ FOR INDOOR UT

TABLE 4: PATHLOSS MODELS

Scenario	Pathloss [dB], f_c is in GHz and d is in meters, see note 6	Shadow fading std [dB]	Applicability range, antenna height default values
RMa LOS	$PL_{\mathrm{RMa-LOS}} = \begin{cases} PL_1 & 10\mathrm{m} \le d_{\mathrm{2D}} \le d_{\mathrm{BP}} \\ PL_2 & d_{\mathrm{BP}} \le d_{\mathrm{2D}} \le 10\mathrm{km} \end{cases}$, see note 5 $PL_1 = 20\log_{10}(40\pi d_{\mathrm{3D}} f_c / 3) + \min(0.03h^{1.72},10)\log$ $-\min(0.044h^{1.72},14.77) + 0.002\log_{10}(h) d_{\mathrm{3D}}$ $PL_2 = PL_1(d_{\mathrm{BP}}) + 40\log_{10}(d_{\mathrm{3D}} / d_{\mathrm{BP}})$	$\sigma_{\mathrm{SF}} = 4$ $\sigma_{\mathrm{SF}} = 6$	$h_{\mathrm{BS}} = 35\mathrm{m}$ $h_{\mathrm{UT}} = 1.5\mathrm{m}$ $W = 20\mathrm{m}$ $h = 5\mathrm{m}$ *h = avg. building height* *W = avg. street width* *The applicability ranges:* $5\mathrm{m} \le h \le 50\mathrm{m}$ $5\mathrm{m} \le W \le 50\mathrm{m}$ $10\mathrm{m} \le h_{\mathrm{BS}} \le 150\mathrm{m}$ $1\mathrm{m} \le h_{\mathrm{UT}} \le 10\mathrm{m}$
RMa NLOS	$PL_{\mathrm{RMa-NLOS}} = \max(PL_{\mathrm{RMa-LOS}}, PL'_{\mathrm{RMa-NLOS}})$ for $10\mathrm{m} \le d_{\mathrm{2D}} \le 5\mathrm{km}$ $PL'_{\mathrm{RMa-NLOS}} = 161.04 - 7.1\log_{10}(W) + 7.5\log_{10}(h)$ $-(24.37 - 3.7(h/h_{\mathrm{BS}})^2)\log_{10}(h_{\mathrm{BS}})$ $+(43.42 - 3.1\log_{10}(h_{\mathrm{BS}}))(\log_{10}(d_{\mathrm{3D}}) - 3)$ $+20\log_{10}(f_c) - (3.2(\log_{10}(11.75 h_{\mathrm{UT}}))^2 - 4.97)$	$\sigma_{\mathrm{SF}} = 8$	
UMa LOS	$PL_{\mathrm{UMa-LOS}} = \begin{cases} PL_1 & 10\mathrm{m} \le d_{\mathrm{2D}} \le d'_{\mathrm{BP}} \\ PL_2 & d'_{\mathrm{BP}} \le d_{\mathrm{2D}} \le 5\mathrm{km} \end{cases}$, see note 1 $PL_1 = 28.0 + 22\log_{10}(d_{\mathrm{3D}}) + 20\log_{10}(f_c)$ $PL_2 = 28.0 + 40\log_{10}(d_{\mathrm{3D}}) + 20\log_{10}(f_c)$ $-9\log_{10}((d'_{\mathrm{BP}})^2 + (h_{\mathrm{BS}} - h_{\mathrm{UT}})^2)$	$\sigma_{\mathrm{SF}} = 4$	$1.5\mathrm{m} \le h_{\mathrm{UT}} \le 22.5\mathrm{m}$ $h_{\mathrm{BS}} = 25\mathrm{m}$
UMa NLOS	$PL_{\mathrm{UMa-NLOS}} = \max(PL_{\mathrm{UMa-LOS}}, PL'_{\mathrm{UMa-NLOS}})$ for $10\mathrm{m} \le d_{\mathrm{2D}} \le 5\mathrm{km}$ $PL'_{\mathrm{UMa-NLOS}} = 13.54 + 39.08\log_{10}(d_{\mathrm{3D}}) +$ $20\log_{10}(f_c) - 0.6(h_{\mathrm{UT}} - 1.5)$	$\sigma_{\mathrm{SF}} = 6$	$1.5\mathrm{m} \le h_{\mathrm{UT}} \le 22.5\mathrm{m}$ $h_{\mathrm{BS}} = 25\mathrm{m}$ *Explanations: see note 3*

Note 1:Breakpoint distance $d'_{BP} = 4\, h'_{BS}\, h'_{UT}\, f_c/c$, where f_c is the centre frequency in Hz, $c = 3.0\times10^8$ m/s is the propagation velocity in free space, and h'_{BS} and h'_{UT} are the effective antenna heights at the BS and the UT, respectively. The effective antenna heights h'_{BS} and h'_{UT} are computed as follows: $h'_{BS} = h_{BS} - h_E$, $h'_{UT} = h_{UT} - h_E$, where h_{BS} and h_{UT} are the actual antenna heights, and h_E is the effective environment height. For UMa h_E=1m with a probability equal to $1/(1+C(d_{2D}, h_{UT}))$ and chosen from a discrete uniform distribution uniform(12,15,…,(h_{UT}-1.5)) otherwise. With $C(d_{2D}, h_{UT})$ given by   *,*   *where*   *.*   *Note that h_E depends on d_{2D} and h_{UT} and thus needs to be independently determined for every link between BS sites and UTs. A BS site may be a single BS or multiple co-located BSs.*   *Note 2:The applicable frequency range of the Path Loss (PL) formula in this table is $0.5 < f_c < f_H$ GHz, where f_H = 30 GHz for RMa and f_H = 100 GHz for all the other scenarios. It is noted that RMa pathloss model for >7 GHz is validated based on a single measurement campaign conducted at 24 GHz.*   *Note 3:UMa NLOS pathloss is from TR36.873 with simplified format and $PL_{UMa\text{-}LOS}$ = Pathloss of UMa LOS outdoor scenario.*   *Note 4:Break point distance $d_{BP} = 2\pi\, h_{BS}\, h_{UT}\, f_c/c$, where f_c is the centre frequency in Hz, $c = 3.0 \times 10^8$ m/s is the propagation velocity in free space, and h_{BS} and h_{UT} are the antenna heights at the BS and the UT, respectively.*   *Note 5:f_c denotes the center frequency normalised by 1GHz, all distance related values are normalised by 1m, unless it is stated otherwise.*

2.4.2 LOS probability

The Line-Of-Sight (LOS) probabilities are given in Table 5.

TABLE 5: LOS PROBABILITY

Scenario	LOS probability (distance is in meters)
RMa	$$\Pr_{LOS} = \begin{cases} 1 & , d_{2D\text{-out}} \le 10\text{m} \\ \exp\left(-\dfrac{d_{2D\text{-out}} - 10}{1000}\right) & , 10\text{m} < d_{2D\text{-out}} \end{cases}$$
UMa	$$\Pr_{LOS} = \begin{cases} 1 & , d_{2D\text{-out}} \le 18\text{m} \\ \left[\dfrac{18}{d_{2D\text{-out}}} + \exp\left(-\dfrac{d_{2D\text{-out}}}{63}\right)\left(1 - \dfrac{18}{d_{2D\text{-out}}}\right)\right]\left(1 + C'(h_{UT})\dfrac{5}{4}\left(\dfrac{d_{2D\text{-out}}}{100}\right)^3 \exp\left(-\dfrac{d_{2D\text{-out}}}{150}\right)\right) & , 18\text{m} < d_{2D\text{-out}} \end{cases}$$ where $$C'(h_{UT}) = \begin{cases} 0 & , h_{UT} \le 13\text{m} \\ \left(\dfrac{h_{UT} - 13}{10}\right)^{1.5} & , 13\text{m} < h_{UT} \le 23\text{m} \end{cases}$$
Note: The LOS probability is derived with assuming antenna heights of 3m for indoor, 25m for UMa	

2.5 CHANNEL MODEL REFERENCES INCLUDING UE-UE CHANNEL MODELS IN Q/V BAND

To align with the simulation assumptions from 3GPP RAN4 as in R4-2313890 [9] and 3D multilayer architecture (WP3), the following NTN UE scenarios can be considered as in Table 6 which reflects the different antenna heights for different NTN UE types.

Deliverable D2.2 ''*User requirements'* of the 6G-NTN project separates NTN UEs into three main types: handheld (consumer or professional), drone (light or heavy) and mounted NTN UEs (First responder stationary or Vehicular Mounted Moving (e.g., trains, cars, maritime vessel, first responders)).

In terms of characteristics, these would correspond to different terminal classes in terms of transmission power, antenna gain and altitude. For these reasons, we have regrouped these different NTN UE types into three types of NTN UE according to their common altitude group: Fixed VSAT (Very Small Aperture Terminal), A-ESIM (Aeronautical-Earth Station In Motion) and L-ESIM (Land-Earth Station In Motion).

At least for first responder missions, one can identify two classes: one corresponding to a fixed VSAT and the other one corresponding to moving VSAT, mounted on a vehicle.

Drones are part of the A-ESIM category while handheld and Vehicular Mounted Moving NTN UEs can be considered part of L-ESIMs in terms of altitude. The maritime ESIM can also be associated to an altitude of 22.5m or less, depending on the height of the vessel.

TABLE 6: NTN UE SCENARIO

NTN UE scenario	**Fixed VSAT**	**A-ESIM**	**L-ESIM**
Altitude	22.5m	3-14km	1.5m

Several propagation models within TN, NTN and the cross path loss propagation between TN and NTN can be seen in Table 7.

TABLE 7: PROPAGATION MODELS WITH RESPECT TO LINK TYPE

Link	Propagation model
TN BS to Fixed VSAT on roof	Free space path loss
TN BS to L-ESIM at 1.5 m	UMa as in 3GPP TR 38.803
TN BS to TN UE	UMa as in 3GPP TR 38.803
TN UE to Fixed VSAT on roof	UMa as in 3GPP TR 38.803 (BS is to be replaced with VSAT)
TN UE to L-ESIM	UMi (Urban Micro)
Satellite to TN BS/UE	3GPP TR 38.821
Satellite to VSAT/ESIM	3GPP TR 38.821
TN BS to Satellite	3GPP TR 38.821
Note1: For the propagation models which use the 3GPP TR 38.821 [7], to use same assumptions as in [7] and consider the atmospheric losses and the scintillation losses. Note2: TN BS height is 25m	

3 FREQUENCY BANDS AND COEXISTENCE SCENARIOS

3.1 FREQUENCY BANDS

The frequency bands below will be explored during 6G-NTN project:

- **The Q/V-band** has been identified as potential candidate for the service link as part of 6G NTN, with the following frequency ranges for both NGSO and GSO satellite services:
  - DL: 37.5 – 42.5 GHz (Q-band);
  - UL: 47.2 – 50.2 GHz and 50.4 – 51.4 GHz (V-band).

  Please also note that TN mobile service allocated bands (currently) are:
  - DL & UL: 37.0 – 43.5 GHz;
  - DL/UL in some countries (e.g., Brazil): 45.5 – 47 GHz and 47.2 – 48.2 GHz.
- **The C-band** is a new NTN frequency band opportunity for direct connectivity to smartphones and cars to be considered for the 6G-NTN project:
  - DL NTN satellite communications could potentially use TN TDD (Time Division Duplex) frequency bands n77 (3,300 – 4,200 MHz) / n78 (3,300 – 3,800 MHz).
  - UL NTN satellite communications could potentially use the upper frequency spectrum (around 6 GHz) or lower frequency spectrum (e.g., UL n255 or UL n256).

Taking into account these constraints, the following operational band usage scenario has been identified for study in Q/V band:

TABLE 8: CONSIDERED BAND USAGE SCENARIO FOR Q/V BAND

Q/V band scenario #	Scenario Name	UL freq. (channel bandwidth (BW))	DL band (channel BW)	Comments
1	FR2 – Q/V	37 GHz (400 MHz)	47 GHz (400 MHz)	UE = flat panel antenna

Several operational band usage scenarios have been identified for study in C band:

TABLE 9: CONSIDERED BAND USAGE SCENARIO FOR C BAND

C band scenario #	Scenario Name	UL freq. (channel BW)	DL band (channel BW)	Comments
1	FR1 – Hybrid C FDD	2000 MHz (15 MHz) **(See Note 1, Note 3)**	3700 MHz (100 MHz)	Combination of C for DL (advantage in throughput), and lower band for UL (advantage in link budget) Anticipated challenges: availability of UL band may vary locally (could range from 1.4 GHz to 2.4 GHz)

2	FR1 – Lower C in-band TDD **(See Note 2)**	3700 MHz (100 MHz)	3700 MHz (100 MHz)	TDD implementation = in line with duplex mode of 3GPP n77/n78 Anticipated challenges: synchronisation, guard time impact on capacity
3	**FR1 – Lower C in-band FDD**	4000 MHz (100 MHz) **(See Note 4)**	3500 MHz (100 MHz) **(See Note 5)**	Representative of duplex FDD fully implemented in C band Anticipated challenges: Duplexer is needed in the UE (not the case currently in 3GPP n77/n78 TDD)
4	**FR1 – C band 6/4 GHz FDD**	6500 MHz (100 MHz) **(See Note 3, Note 6)**	3700 MHz (100 MHz)	FDD implementation matching ITU current satellite UL/DL allocations Anticipated challenges: UE UL link budget; spectrum availability TBD due to the lack of global support for 3GPP n96/n104 (TDD)
Note 1: S band has been already considered in the 3GPP coexistence scenarios. **Note 2: For satellite access, only FDD mode will be considered.** **Note 3: In the description of work, 6 GHz and 2 GHz have been considered for UL instead of C band.** **Note 4: Please note that according to ITU Radio regulation, 4 GHz band has FSS DL allocation. Thus, there is a lack of authorisation to operate UL at this frequency. One way to mitigate this issue would be for 6G-NTN UEs to operate on non-interference basis w.r.t. GSO Earth Station reception to ensure long term protection of GSO FFS DL.** **Note 5: For the coexistence simulations, we only need the carrier frequency, not the explicit band. For these reasons, we selected a 3.5 GHz carrier for DL.** **Note 6: Lack of global support for NTN due to spectrum availability.**				

Scenario 1 uses S-band that is already considered in the 3GPP coexistence scenarios. Thus, the added value gained by studying it is lower compared to other scenarios using frequency ranges that have not been studied yet in 3GPP for NTN.

Scenario 2 is a TDD band. However, for satellite access, only FDD mode will be considered.

Considering the above notes, scenarios 3 and 4 are the most promising and will be studied in priority during T4.3, as they have the advantage of being FDD and have not yet been the object of study by 3GPP for NTN.

3.2 COEXISTENCE SCENARIOS

3.2.1 Coexistence scenario 1. Aggressor and victim combination (Q/V-band) in adjacent bands

Table 10 below describes the different coexistence cases to be considered and the scope of the coexistence simulations. For instance, scenario n°1 where the NTN UL (VSAT UE transmitter in Q/V band) is the aggressor and TN UL (gNodeB (gNB) receiver in Q/V band) is the victim. Frequency carrier for this scenario has been identified at 47 GHz. For this scenario, TN gNB ACS is fixed while NTN VSAT UE ACLR is a tunable parameter.

Similar analysis can be done for different coexistence scenarios.

TABLE 10: Q/V BAND COEXISTENCE SCENARIOS IN ADJACENT BAND

No.	Combination	Aggressor	Victim	Notes	Scope of Coexistence Simulation
1	TN with NTN	NTN UL	TN UL	i1, with f_c=47GHz for simulation purposes	ACLR NTN UE to be varied/defined ACS TN gNB fixed
2	TN with NTN	TN UL	NTN UL	i2, with f_c=47GHz for simulation purposes	ACLR TN UE fixed ACS NTN SAN to be varied/defined
3	TN with NTN	NTN UL	TN DL	i3, with f_c=47GHz for simulation purposes	ACLR NTN UE to be varied/defined ACS TN UE fixed
4	TN with NTN	TN DL	NTN UL	i4, with f_c=47GHz for simulation purposes	ACLR TN gNB fixed ACS NTN SAN to be varied/defined
5	TN with NTN	TN DL	NTN DL	i5, with f_c=37GHz for simulation purposes	ACLR TN gNB fixed ACS NTN UE to be varied/defined
6	TN with NTN	NTN DL	TN DL	i6, with f_c=37GHz for simulation purposes	ACLR NTN SAN to be varied/defined ACS TN UE fixed
7	TN with NTN	NTN DL	TN UL	i7, with f_c=37GHz for simulation purposes	ACLR NTN SAN to be varied/defined ACS TN gNB fixed
8	TN with NTN	TN UL	NTN DL	i8, with f_c=37GHz for simulation purposes	ACLR TN UE fixed ACS NTN UE to be varied/defined

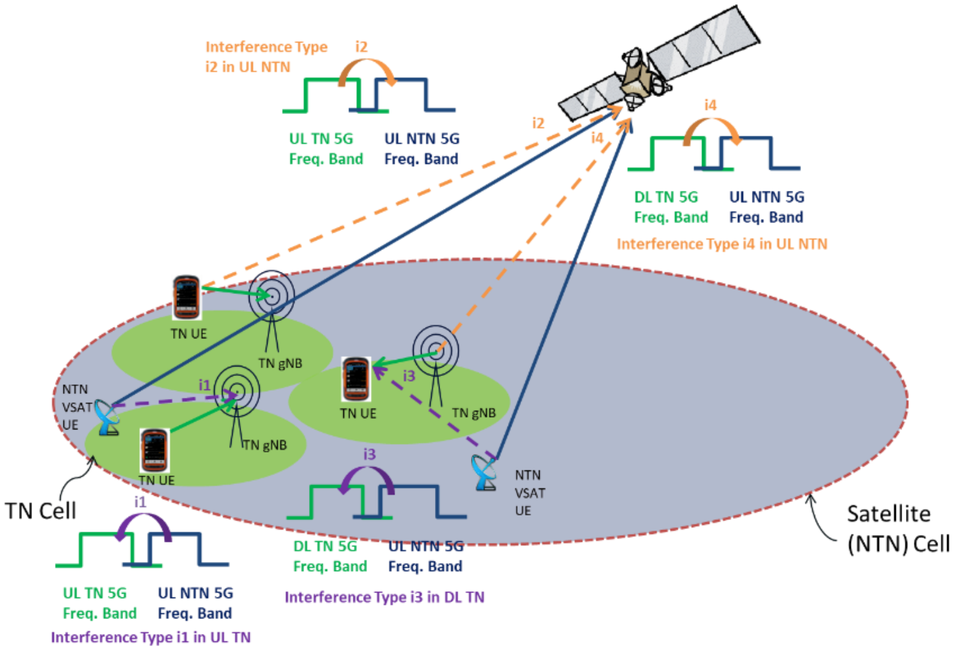

FIGURE 7: COEXISTENCE SCENARIOS 1-4 (E.G. Q/V-BAND)

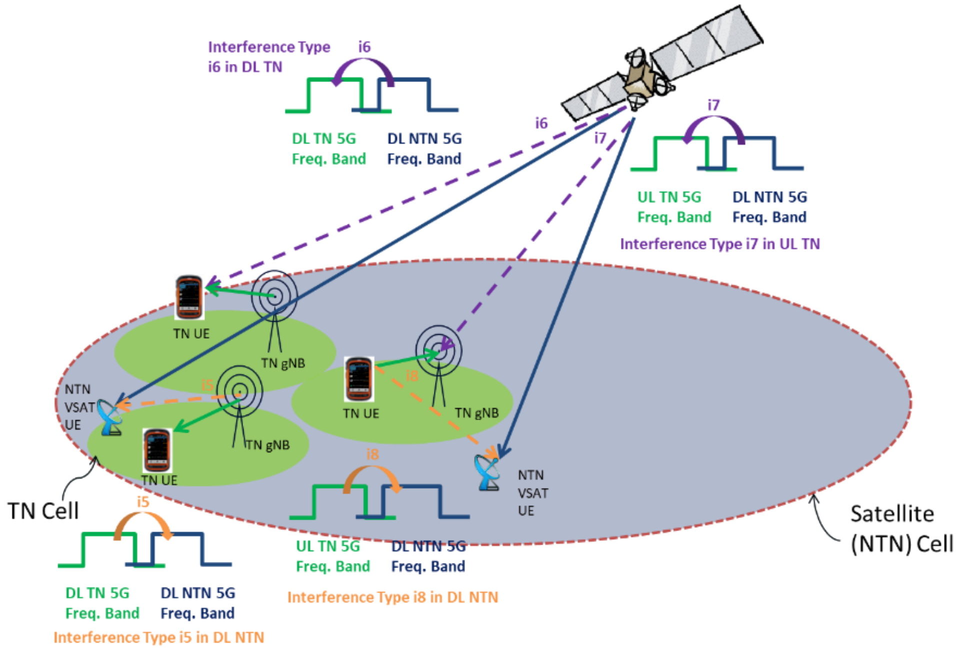

FIGURE 8: COEXISTENCE SCENARIOS 5-8 (E.G. Q/V-BAND)

3.2.2 Coexistence scenario 2. Aggressor and victim combination (C-band) in adjacent bands

As explained in Section 3.1, for C band we will continue with band usage scenarios 3 and 4 for the rest of the study.

From band usage scenario 3 (DL 3.5 GHz, UL 4 GHz) the following coexistence scenarios in Table 11 can be derived. Scenarios 7 and 8 will be studied in priority since the other scenarios are already considered by 3GPP TR38.863 [3].

TABLE 11: C BAND COEXISTENCE SCENARIOS IN ADJACENT BAND FOR FREQUENCY BAND SCENARIO 3

No	Combination	Aggressor	Victim	Notes	Scope of Coexistence Simulation	Comment
1	TN with NTN	NTN UL	TN UL	i1, with f_c=4GHz for simulation purposes	ACLR NTN UE to be varied/defined ACS TN gNB fixed	**Considered by 3GPP TR38.863. S-band requirement (ACLR) should cover this coexistence scenario**
2	TN with NTN	TN UL	NTN UL	i2, with f_c=4GHz for simulation purposes	ACLR TN UE fixed ACS NTN SAN to be varied/defined	**Considered by 3GPP TR38.863. S-band requirement (ACS) should cover this coexistence scenario**
3	TN with NTN	NTN UL	TN DL	i3, with f_c=4GHz for simulation purposes	ACLR NTN UE to be varied/defined ACS TN UE fixed	**Considered by 3GPP TR38.863. S-band requirement (ACLR) should cover this coexistence scenario**
4	TN with NTN	TN DL	NTN UL	i4, with f_c=4GHz for simulation purposes	ACLR TN gNB fixed ACS NTN SAN to be varied/defined	**Considered by 3GPP TR38.863. S-band requirement (ACS)**

						should cover this coexistence scenario
5	TN with NTN	TN DL	NTN DL	i5, with f_c=3.5GHz for simulation purposes	ACLR TN gNB fixed ACS NTN UE to be varied/defined	**Considered by 3GPP TR38.863. S-band requirement (ACS) should cover this coexistence scenario**
6	TN with NTN	NTN DL	TN DL	i6, with f_c=3.5GHz for simulation purposes	ACLR NTN SAN to be varied/defined ACS TN UE fixed	**Considered by 3GPP TR38.863. S-band requirement (ACLR) should cover this coexistence scenario**
7	**TN with NTN**	**NTN DL**	**TN UL**	**i7, with f_c=3.5GHz for simulation purposes**	**ACLR NTN SAN to be varied/defined** **ACS TN gNB fixed**	**HIGH PRIORITY**
8	**TN with NTN**	**TN UL**	**NTN DL**	**i8, with f_c=3.5GHz for simulation purposes**	**ACLR TN UE fixed** **ACS NTN UE to be varied/defined**	**HIGH PRIORITY**

The reason for excluding previous coexistence scenarios (1 to 6) is due to the fact that 3GPP already considered S-band coexistence with n1 FDD and n34 TDD. We do not expect worse coexistence scenarios and more stringent requirements for C-band as compared to S-band since the carrier frequency is higher and therefore the path loss will increase, thus decreasing the interference.

The remaining coexistence scenarios 7 & 8 have not been considered by 3GPP in previous works because the NTN DL (n256) was far away from the TN TDD UL band (n34).

From band usage scenario 4 (DL 3.7 GHz, UL 6.5 GHz), the following coexistence scenarios can be derived, with scenarios 1 2, 3 and 4 to be studied in priority:

TABLE 12: C BAND COEXISTENCE SCENARIOS IN ADJACENT BAND FOR FREQUENCY BAND SCENARIO 4

No	Combination	Aggressor	Victim	Notes	Scope of Coexistence Simulation	Comments
1	TN with NTN	NTN UL	TN UL	i1, with f_c=6.5GHz for simulation purposes	ACLR NTN UE to be varied/defined ACS TN gNB fixed	**LOWER PRIORITY**
2	TN with NTN	TN UL	NTN UL	i2, with f_c=6.5GHz for simulation purposes	ACLR TN UE fixed ACS NTN SAN to be varied/defined	**LOWER PRIORITY**
3	TN with NTN	NTN UL	TN DL	i3, with f_c=6.5GHz for simulation purposes	ACLR NTN UE to be varied/defined ACS TN UE fixed	**LOWER PRIORITY**

4	TN with NTN	TN DL	NTN UL	i4, with f_c=6.5GHz for simulation purposes	ACLR TN gNB fixed ACS NTN SAN to be varied/defined	**LOWER PRIORITY**
5	TN with NTN	TN DL	NTN DL	i5, with f_c=3.7GHz for simulation purposes	ACLR TN gNB fixed ACS NTN UE to be varied/defined	**Considered by 3GPP TR38.863. S-band requirement (ACS) should cover this coexistence scenario**
6	TN with NTN	NTN DL	TN DL	i6, with f_c=3.7GHz for simulation purposes	ACLR NTN SAN to be varied/defined ACS TN UE fixed	**Considered by 3GPP TR38.863. S-band requirement (ACLR) should cover this coexistence scenario**
7	TN with NTN	NTN DL	TN UL	i7, with f_c=3.7GHz for simulation purposes	ACLR NTN SAN to be varied/defined ACS TN gNB fixed	**Already considered in Table 11**
8	TN with NTN	TN UL	NTN DL	i8, with f_c=3.7GHz for simulation purposes	ACLR TN UE fixed ACS NTN UE to be varied/defined	**Already considered in Table 11**

Similar reasoning as previous table has been done to justify the choices of discarding scenarios 5 to 8.

4 PARAMETERS FOR NTN UE

4.1 KA & Q/V NTN UE ARCHITECTURE

A reference UE architecture for Ka and Q/V band is proposed in Figure 9, where:

- **UC:** Up-Converter;
- **PA:** Power Amplifier(s);
- **LNA:** Low Noise Amplifier(s);
- **DC:** Down-Converter;
- **DP:** Duplexer;
- **ACU:** Antenna Control Unit;
- **Antenna:** Active, Electronically or Hybrid Steered.

The UC and the Tx PA can be part of a BUC (Block Up-Converter). In this case, the BUC is part of the Transmission chain, and it includes a Tx power amplifier.

The Rx LNA and the DC can be part of an LNB (Low-Noise Block down-converter). In this case, the LNB is part of the Reception chain, and it includes a low noise amplifier.

RF represents the Radio Frequency region and IF the Intermediate Frequency region.

The interface between UE modem and BUC can be considered (for example) OpenBMIP (Open BUC Modem Interface Protocol) and could control the amplifier power and band selection. The interface between UE modem and ACU can be considered (for example) OpenAMIP (Open Antenna to Modem Interface Protocol) and could help to control the steering/switching of the antenna with respect to the satellite tracking. Parabolic/dish antenna design or active antenna design can be used. Steering can be performed electronically, mechanically or hybrid combinations of both. Other interfaces or potential implementations are not excluded.

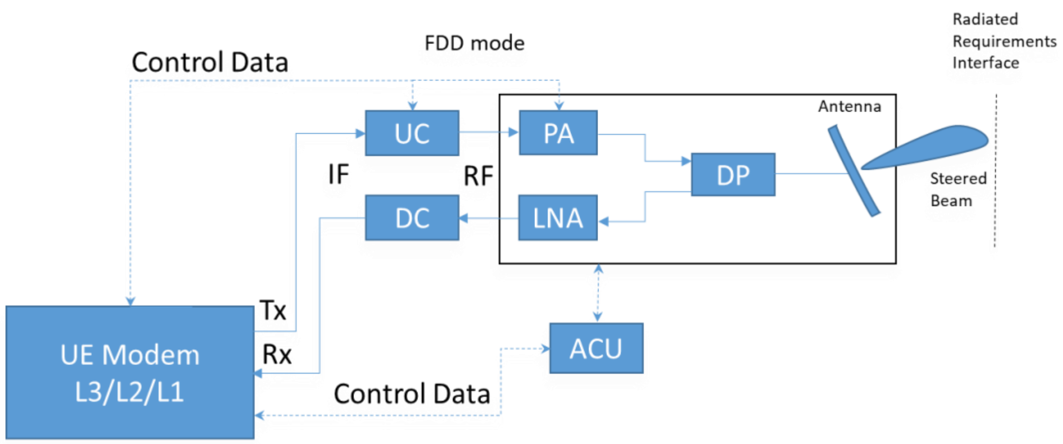

FIGURE 9: GENERALISED NTN UE TERMINAL REFERENCE ARCHITECTURE FOR ABOVE 10 GHZ

Note 1: The Up-Converter and the Tx Power Amplifier are part of the Transmission chain.

Note 2: The Rx Low-Noise Amplifier and the Down-Converter are part of the Reception chain.

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It is assumed for the NTN capable UE operating in above 10 GHz that:

- the generated Rx/Tx beams are able to track the serving satellite as well as at least another neighbouring satellite;
- the rally time of (Rx and/or Tx) beam pointing between 2 satellites is considered negligible.

4.2 NTN UE GENERAL ASPECTS

All NTN UE antenna parameters have been adapted from TR 38.821 [7] by considering the following parameters adapted to Q/V satellite band:

- Downlink frequency: 37 GHz
- Uplink frequency: 47 GHz
- 15 cm antenna aperture diameter (2*a=15cm) **

**** Antenna aperture diameter subject to change according to budget link and other constraints.**

The Technical Report TR 38.811 [6] provides typical RF parameters shown in the table below:

TABLE 13: TYPICAL MINIMUM RF CHARACTERISTICS OF NTN UE

Parameter	Very Small Aperture NTN UE Terminal (fixed or mounted on moving platforms)
Transmit Power	2 W (33 dBm)
Antenna type	15 cm equivalent aperture diameter (circular polarisation)
Antenna gain	Tx: 35.2 dBi Rx: 32.9 dBi
Noise figure	2 dB
Output loss	1.5 dB
EIRP	36.7 dBW
G/T (NOTE 1)	7.6 dB/K
Polarisation (NOTE 2)	Circular
NOTE 1: For the computation of G/T or figure of merit, following formula applies in dB: $G/T = Ga - NF - 10{*}LOG\,(T_o+(T_a-T_o)/(10^{0.1*NF}))$ **where:** - **Antenna Gain : Ga in dBi** - **Ambient Temperature : T_0 (usually 290 K)** - **Antenna temperature : T_a** - **Noise Figure: NF in dB including feeder loss**	

4.3 NTN UE ANTENNA PARAMETERS

4.3.1 Circular aperture antenna

The following normalised antenna pattern corresponding to a theoretical parabolic (reflector) antenna with circular aperture can be considered for coexistence analysis:

$$F(u) = \frac{2J_1(u)}{u}$$

where:

- $J_1(x)$ is the Bessel function of first type and first order with argument *x,*
- θ is the angle in a $(\theta;\varphi)$ spherical coordinates system,
- $u = \frac{\pi D}{\lambda}\sin(\theta)$,
- *D* is the antenna diameter,
- λ is the wavelength.

The normalised antenna pattern, expressed in decibels, is given by the following relation:

$$10\,log\big(F(u)\big)^2$$

With the linear form given by the following relation:

$$\big(F(u)\big)^2 = \left(\frac{2J_1(u)}{u}\right)^2$$

This is equivalent to (however previous equation from TR 38.811 [6] is defined on the entire range and not only from -90° to +90°):

$$\begin{cases} 1 & \text{for } \theta = 0 \\ 4\left|\frac{J_1(\mathrm{ka}\sin\theta)}{ka\sin\theta}\right|^2 & \text{for } 0 < |\theta| \le 90^\circ \\ 4\left|\frac{J_1(\mathrm{ka}\sin(\pi/2))}{ka\sin(\pi/2)}\right|^2 & \text{for } |\theta| > 90^\circ \end{cases}$$

where:

- $J_1(x)$ is the Bessel function of the first kind and first order with argument *x*;
- *a* is the radius of the antenna's circular aperture;
- *k* = 2πf/c is the wave number;
- *f* is the frequency of operation;
- *c* is the speed of light in a vacuum and θ is the angle measured from the bore sight of the antenna's main beam.

Note that $k \times a$ equals to the number of wavelengths on the circumference of the aperture and is independent of the operating frequency.

Figure 10 shows the antenna pattern of an NTN UE transmit antenna reflector 0.15 m diameter and operating at 47000 MHz. This corresponds to a circular aperture, for example parabolic or dish antenna.

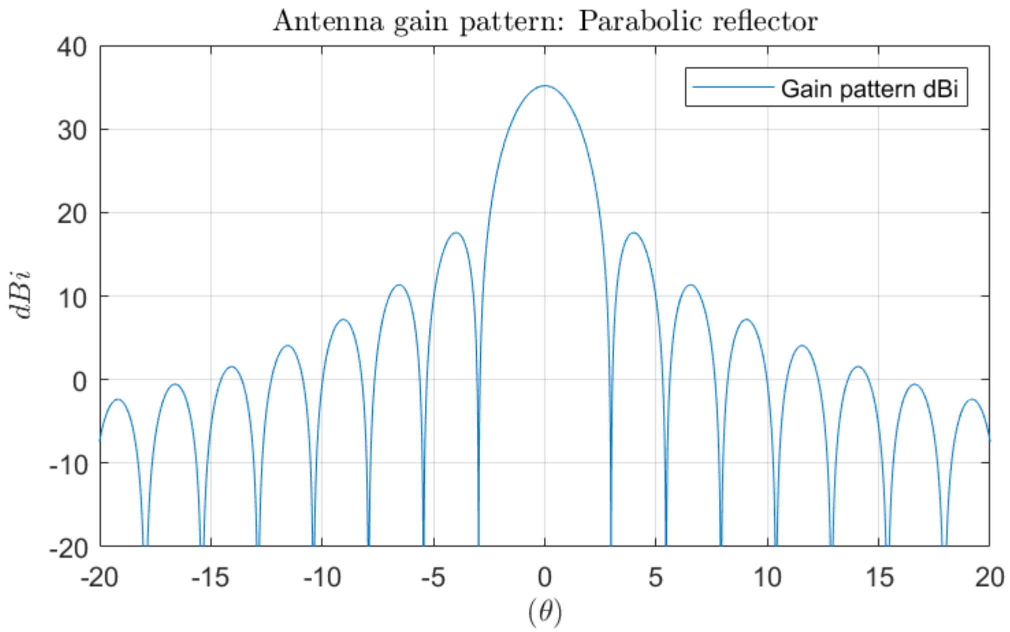

FIGURE 10: ANTENNA GAIN PATTERN OF AN NTN UE TRANSMIT PARABOLIC ANTENNA OPERATING AT 47000 MHZ

4.3.2 Phased-array antenna

A phased-array antenna with a square aperture of side length D and tapered illumination over the aperture is considered. The antenna pattern at $\phi = 0$ is described by the following relation:

$$F(u) = \left(\frac{\pi}{2}\right)^2 \frac{\cos u}{\left(\frac{\pi}{2}\right)^2 - u^2}$$

where:

- θ is the angle in a $(\theta; \phi)$ spherical coordinates system,
- $u = \frac{\pi D}{\lambda} \sin(\theta - \theta_0)$,
- θ_0 is the steering angle,
- λ is the wavelength,
- D is the side length.

The normalised antenna pattern, expressed in decibels, is given by the following relation:

$$\big(F(\theta, \phi)\big)_{dB} = 10 \, log\big(F(\theta, \phi)\big)^2$$

The antenna gain can be evaluated with the following relation:

$$G(\theta_0) = \eta \frac{4\pi \times D^2}{\lambda^2} \cos \theta_0$$

where η is the antenna efficiency.

Antenna efficiency for UE antenna was computed using the following proposed values: 60% in Tx (DL) and 57% in Rx (UL).

Figure 11 shows the antenna gain pattern of an NTN UE transmit antenna with D=0.15 m, operating at 47000 MHz.

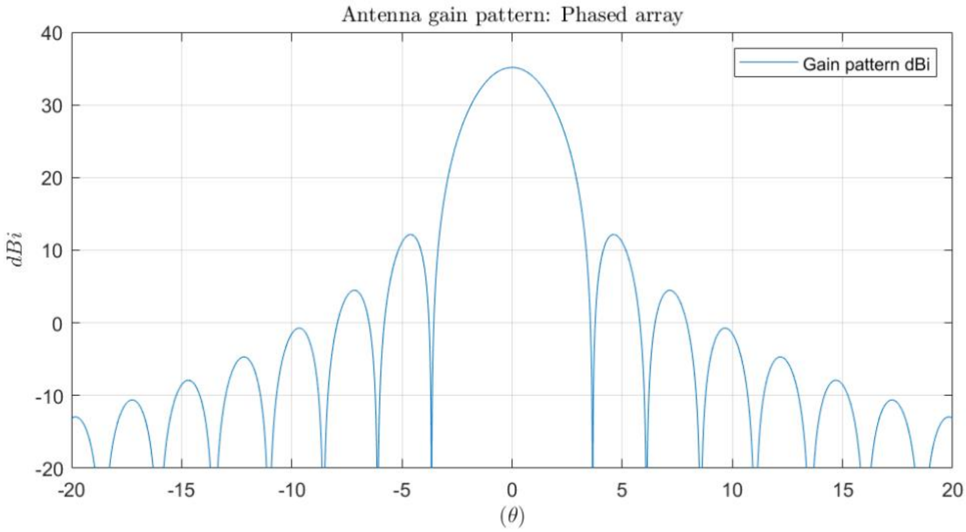

FIGURE 11: ANTENNA GAIN PATTERN OF AN NTN UE TRANSMIT PHASED ARRAY ANTENNA OPERATING AT 47000 MHZ

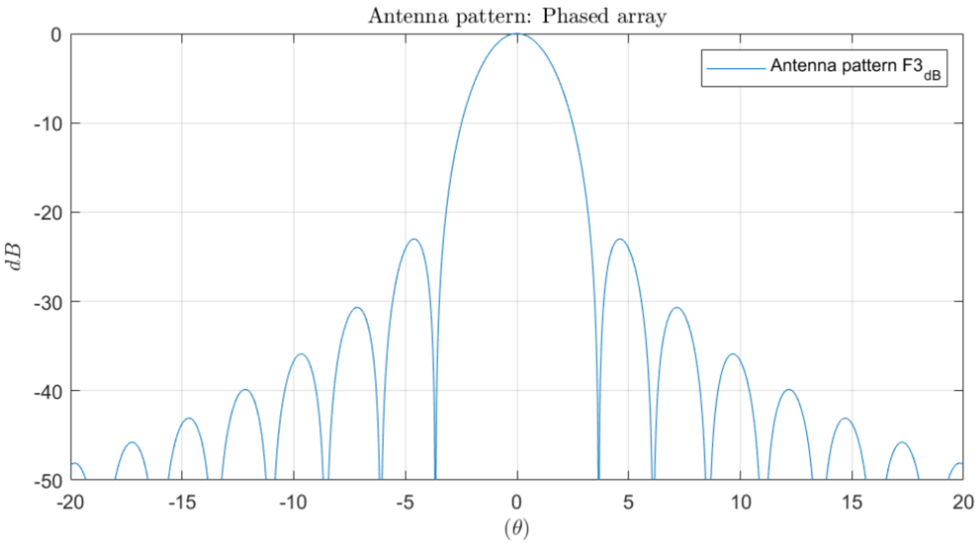

FIGURE 12: ANTENNA PATTERN OF AN NTN UE TRANSMIT PHASED ARRAY ANTENNA OPERATING AT 47000 MHZ

4.4 NTN UE TRANSMIT AND RECEIVE PERFORMANCES

The NTN UE transmit and receive performances are summarised in Table 14 considering a circular reflector antenna operating in Q/V band.

4.4.1 Option 1

In order to study the coexistence analysis in Q/V band, the following NTN UE parameters will be used:

TABLE 14: NTN UE PARAMETERS OPTION 1

NTN UE Parameters		Tx (Uplink)	Rx (Downlink)
Polarisation		Circular	Circular
Low Frequency	(MHz)	47 000	37 000
Efficiency		60%	57%
On-axis antenna gain at F_c	(dBi)	35.2	32.9
Output power	(W)	2	
Output power	(dBW)	3,0	
Output loss	(dB)	-1,5	
EIRP		**36.7**	
Receiver noise figure	(dB)		2
Feeder loss	(dB)		-1
Sky temperature	(K)		30
Ground temperature	(K)		10
Antenna temperature	(K)		40
G/T figure of merit	(dB/K)		**7.6**
NOTE1: T_a = T_Sky + T_Ground **NOTE2: The antenna temperatures are based on e.g. ITU-R Rec. P372 [10] and Rec. P618.** **NOTE3: T_sky is computed using [ITU-R Rec. P.618-14] [11] as expressed below**			

According to ITU-R Rec. P.618-14 [11], the sky noise temperature at a ground station antenna may be estimated by:

$$T_{sky} = T_{mr}\left(1 - 10^{\left(-\frac{A}{10}\right)}\right) + 2.7 \times 10^{-\frac{A}{10}}$$

where:

- T_{sky} is the sky noise temperature (K) at the ground station antenna
- A refers to the total atmospheric attenuation excluding scintillation fading (dB)
- T_{mr} is the atmospheric mean radiating temperature (K).

As attenuation increases, the emission noise also increases. For earth stations with low-noise front-ends, this increase of noise temperature may have a greater impact on the resulting signal-to-noise ratio than the attenuation itself.

In general, antenna efficiency depends on the antenna manufacturer design. Herein, the proposed values are indicative and consistent with Q/V-band definition for UL and DL respectively.

Moreover, in order to simplify the definition of NTN UE, one can compute an equivalent receiver Noise Figure (NF) at ambient temperature, and therefore the second option could be defined as below.

4.4.2 Option 2

Another way to more succinctly describe the different NTN UE parameters would be to introduce an equivalent receiver Noise Figure at ambient temperature (Table 15):

TABLE 15: NTN UE PARAMETERS OPTION 2

NTN UE Parameters		Tx (Uplink)	Rx (Downlink)
Polarisation		Circular	Circular
Frequency	(MHz)	47 000	37 000
Efficiency		60%	57%
On-axis antenna gain at F_c	(dBi)	**35.2**	**32.9**
Output power at antenna input	(W)	2	
Output power at antenna input	(dBW)	3,0	
Output loss	(dB)	-1.5	
Peak EIRP (on-axis)		**36.7**	
Equivalent Receiver Noise Figure	(dB)		**3**
Feeder loss	(dB)		-1

Moreover, the system temperature can be computed using:

$$T_{sys} = T_{sky} + T_{ground} + T_0\left(10^{-\frac{L}{10}} - 1\right) + T_0 * \left(10^{\frac{NF}{10}} - 1\right) * 10^{-\frac{L}{10}}$$

with Gain over Thermal parameter computed as:

$$\frac{\mathrm{G}}{\mathrm{T}} = \mathrm{G_{Rx}} - 10 * \log 10\left(\mathrm{T_{sky}} + \mathrm{T_{ground}} + \mathrm{T_0} * \left(10^{-\frac{\mathrm{L}}{10}} - 1\right) + \mathrm{T_0} * \frac{10^{\frac{\mathrm{NF}}{10}} - 1}{10^{\frac{\mathrm{L}}{10}}}\right)$$

The equivalent receiver NF can be then obtained with:

$$\mathrm{NF_{equivalent}} = 10 * \log_{10}\left(1 + \frac{\mathrm{T_{sys}} - \mathrm{T_{sky}} - \mathrm{T_{ground}}}{\mathrm{T_0}}\right)$$

The NF can be derived as well as a function of front-end loss and LNA as presented in 3GPP R4-2312120 [12] and R4-2309508 [13]:

$$T_s = T_a + (L-1)T_0 + LT_R + L(f-1)\frac{T_0}{G_R}$$

$$N_f\,[\mathrm{dB}] = 10\log_{10}\left(\frac{T_S - T_a}{T_0} + 1\right)$$

5 PARAMETERS FOR TN BS AND UE

5.1 Q/V BANDS

The parameters for Q/V bands TN BS and UE side can be used similarly to the TN parameters as the one used in (3GPP TR 38.803 [14]) and as highlighted below in Table 16 and Table 17 respectively.

TABLE 16: TN NR PARAMETERS FOR Q/V BANDS

TN parameters	NR
Carrier frequency in GHz	37 GHz / 47 GHz
Size of each nominal channel BW in MHz	200 MHz
Network layout	hexagonal grid, 19 macro –sites, 3 sectors per site with wrap around (57 sectors)
ISD (InterSite Distance) in m	200 m (UMa)
Minimum BS-UE distance in meter	35 m
System loading and activity	Full buffer 100%
Network location	TN as victim: Randomly generated in NTN central beam
Number of scheduled UE per cell (DL)	1
Number of scheduled UE per cell (UL)	1
UE TX power range in dBm	-40 to 23
Building penetration loss	In Pathloss model, TR 38.901 [8]
Handover margin in dB	3
UE indoor ratio	All outdoor, UE indoor ratio 0%
BS-UE path-loss model	UMa as in TR 38.803 [14]
UE distribution	Uniform
Evaluation metrics	5% Throughput loss, referring to TR 38.803 section 5.2.7 [14]

TABLE 17: TN BS (URBAN MACRO) AND UE PARAMETERS FOR Q/V BANDS

TN parameters	BS (Urban macro)	UE
Antenna height in meters	25 m	1.5 m
Antenna Pattern	For AAS, see TR 38.803 Section 5.2.3 [14]	
Element Gain in dBi	8	5
H and V 3dB beamwidth of single element in degree	65º for H 65º for V	90º for H 90º for V
H and V front-to-back ratio in dB	30 for both H/V	25 for both H/V
Antenna polarisation	Linear ±45º	Linear ±45º
Antenna array configuration (Row × Column)	8 x 16 elements	2 x 2 elements

Horizontal/Vertical radiating element spacing	0.5 of wavelength for H, 0.5 of wavelength for V	0.5 of wavelength for H, 0.5 of wavelength for V
Max TX power in dBm	43 dBm	23 dBm
Mechanical down tilt in degree	10	-
Noise Figure	11 dB	11 dB

5.2 C BAND

The parameters for the C band TN BS and UE side can be used similarly to the TN parameters as the one used in (3GPP TR 38.828 [15]) and as highlighted below in Table 18 and Table 19 respectively.

TABLE 18: TN NR PARAMETERS FOR C BAND

TN parameters	NR
Carrier frequency in GHz	4 GHz
Size of each nominal channel BW in MHz	100 MHz
Network layout	hexagonal grid, 19 macro sites, 3 sectors per site with wrap around (57 sectors)
ISD in m	450 m (UMa)
Minimum BS-UE distance in meter	35 m
System loading and activity	Full buffer 100%
Network location	TN as victim: Randomly generated in NTN central beam
Number of scheduled UE per cell (DL)	1
Number of scheduled UE per cell (UL)	1
UE TX power range in dBm	-40 to 23
Building penetration loss	In Pathloss model, TR 38.901 [8]
Cell selection margin in dB	3
UE indoor ratio	20%, All outdoor
BS-UE path-loss model	UMa as in TR 38.803 [14]
UE distribution	Uniform
Evaluation metrics	5% Throughput loss, referring to TR 38.803 section 5.2.7 [14]

TABLE 19: TN BS (URBAN MACRO) AND UE PARAMETERS FOR C BAND

TN parameters	BS	UE
Antenna height in meters	20 m	1.5 m
Antenna Pattern	For AAS, see TR 38.803 Section 5.2.3 [14]	
Element Gain in dBi	5.5	0 (omni)
H and V 3dB beamwidth of single element in degree	65º for H 65º for V	-
H and V front-to-back ratio in dB	30 for both H/V	-

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Antenna polarisation	Linear ±45º	-
Antenna array configuration (Row × Column)	16 x 8 elements	-
Horizontal/Vertical radiating element spacing	0.5 of wavelength for H, 0.5 of wavelength for V	-
Max TX power in dBm	49 dBm	23 dBm
Mechanical down tilt in degree	10	-
Noise Figure	5 dB	9 dB

For uplink scenario, TPC (Transmit Power Control) model specified in Section 9.1 TR 36.942 [16] is applied for both NTN and TN with the following power control scheme:

$$P_t = P_{\max} \times \min\left\{1, \max\left[R_{\min}, \left(\frac{CL}{CL_{x-ile}}\right)^{\gamma}\right]\right\}$$

where:

- $\mathrm{P_{max}} = \max(\mathrm{P_{UE\ Tx}})$, i.e., 23 dBm for TN UE, and 33 dBm for NTN UE.
- $\mathrm{CL_{x-ile}} = -\mathrm{SNR_{target}} + \mathrm{P_{max}} - \mathrm{ThermalNoise} - \mathrm{NF} - 10 * \log_{10}(\mathrm{BW})$, considering SNR target is 15dB and BW is actual UL BW. NF is the Noise Figure of either BS or SAN according to context.
- $\mathrm{R_{min}} = \mathit{min}\ (\mathit{Power\ reduction\ ratio})$, i.e., -63 dB for TN UE, and -63 dB by assuming NTN UE min Tx power as -30dBm as starting point for NTN UE.
- $\gamma = 1$

These parameters are to be further updated in the next deliverables based on UE type (antenna aperture, SINR target) and further service type. For the time being Tx Power of 33 dBm and SINR target of 15 dB is assumed.

6 PARAMETERS FOR NTN SAN

6.1 Q/V-BAND SATELLITE ANTENNA PATTERN

The following normalised antenna pattern, corresponding to a circular aperture theoretical antenna pattern can be considered for SAN parameterisation and related coexistence studies:

Options	Equations
Option 1	$F(\theta) = \frac{2\,J_1(u)}{u}$
Option 2	$F(\theta) = \frac{2}{3}\left[\frac{2\,J_1(u)}{u} + \frac{4\,J_2(u)}{u^2}\right]$

where:

- $J_i(x)$ is the Bessel function of first type and i^{th} order with argument *x*
- θ is the angle in a $(\theta;\varphi)$ spherical coordinates system,
- $u = \frac{\pi D}{\lambda}\sin(\theta)$
- *D* is Antenna diameter
- λ is the Wavelength

The theoretical antenna pattern can be applied to a circular aperture, either for a passive antenna or for an active antenna. Figure 13 below shows an example with the normalised antenna pattern of a satellite transmit antenna as a function of *u* parameter with D/λ=333 (corresponding to e.g., D=2.124 m and λ= 0.0064 m).

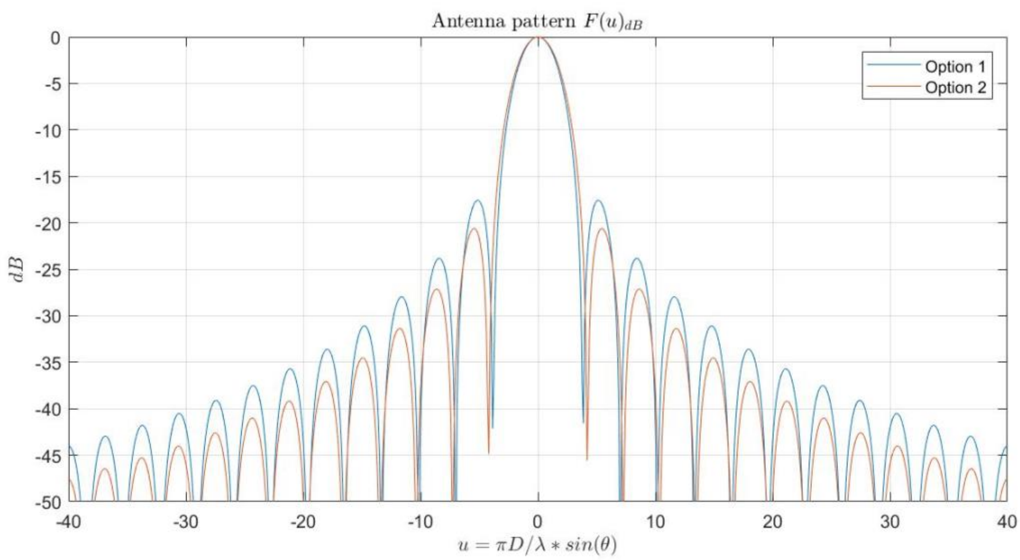

FIGURE 13: ANTENNA PATTERN AS A FUNCTION OF U PARAMETER, WITH D/λ=333

Moreover, the half-power beam-width ($2\theta_{-3dB}$) is given by the following relations:

Options	$2\theta_{-3dB}$ Value
Option 1	$2\theta_{-3dB} = 2 * Arc\sin\left(1.616 \times \frac{\lambda}{\pi D}\right)$
Option 2	$2\theta_{-3dB} = 2 * Arc\sin\left(1.720 \times \frac{\lambda}{\pi D}\right)$

which results in equivalent values. For instance:

- Option 1 results in $2\theta_{-3dB} = 0.0031$rad i.e., 0.1770 deg.
- Option 2 results in $2\theta_{-3dB} = 0.0033\ rad$, i.e., 0.1884 deg.

Based on discussion with other partners, the preferred option for subsequent simulations is option 1.

6.2 Q/V-BAND SAN TRANSMIT AND RECEIVE PARAMETERS

Satellite transmit and receive parameters with respect to satellite orbit are summarised in the tables below (Option 1 or Option 2 expressed above give similar results). Three types of satellite orbits are compared: Geosynchronous Equatorial Orbit (GEO), Low Earth Orbit (LEO) at an altitude of 1200 km and LEO at 600 km altitude.

TABLE 20: SAN PARAMETERS

SAN parameters	GEO	LEO-1200 km	LEO-600 km
Satellite altitude (km)	35786	1200	600
3 dB beamwidth (°)	0.1884 deg	1.884 deg	1.884 deg
Satellite beam diameter at nadir (km)	117.7 km	39.5 km	19.7 km

One can notice that the values from TR 38.821 [7] for Ka-band (110, 40 and 20 km beam diameter respectively) are higher than the values proposed for Q/V-band.

Moreover, the following set of SAN parameters are proposed for Q/V-Band in DL (37 GHz):

TABLE 21: Q/V-BAND DOWNLINK (I.E., ~37 GHZ FOR DL) FOR DIFFERENT SATELLITE ORBITS

SAN parameters	GEO	LEO-1200 km	LEO-600 km
Equivalent satellite antenna aperture (m)	2.7 m	0.3 m	0.3 m
Satellite EIRP density (dBW/MHz)	38	8	3
Satellite Tx max Gain (dBi)	60.4	40.4	40.4

Equivalent satellite antenna aperture is corresponding to the antenna diameter in TR 38.811 6.4.1 [6] where a = D.

The following set of SAN parameters are proposed for Q/V-Band in UL (47 GHz):

TABLE 22: Q/V-BAND UPLINK (I.E., ~47 GHZ FOR UL) FOR DIFFERENT SATELLITE ORBITS

SAN parameters	GEO	LEO-1200 km	LEO-600 km
Equivalent satellite antenna aperture (m)	2.1 m	0.2 m	0.2 m
G/T max (dB/K)	**31.8**	**11.8**	**11.8**
Satellite RX max Gain (dBi)	60.4	40.4	40.4
Earth temperature (K)	290	290	290
Satcom Repeater Noise Figure (dB)	**4**	**4**	**4**

An example of antenna pattern is shown in Figure 14 considering the following parameters:

TABLE 23: ANTENNA PARAMETERS

Parameter	Unit	Value
Frequency	[MHz]	Q/V Uplink
λ	[m]	0.0064 m
D	[m]	2.1 m
Efficiency	N/A	0,65
G_{max}	[dBi]	60.4
$2\theta_{-3dB}$	[°]	0.1770deg (Option 1) 0.1884 deg (Option 2)
D/λ	N/A	333

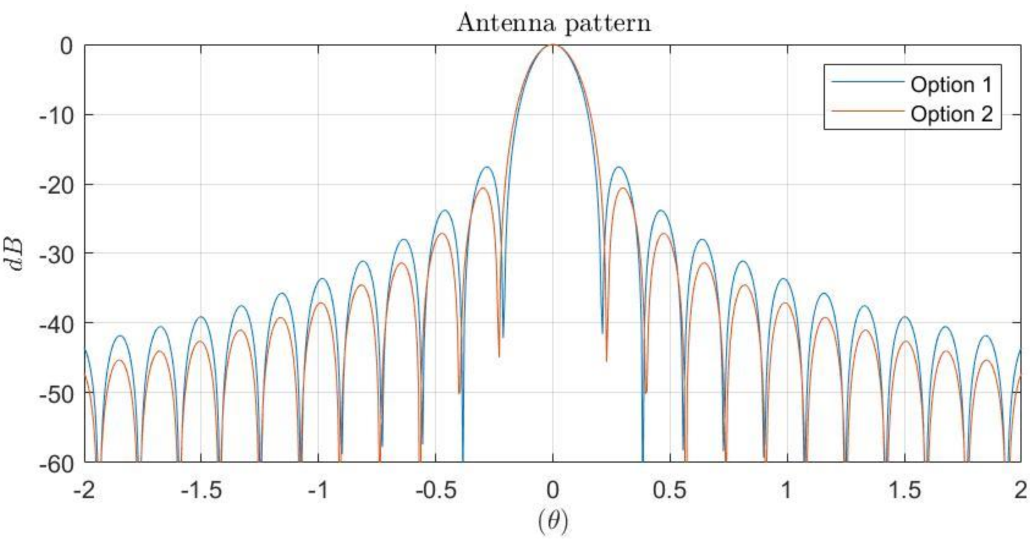

FIGURE 14: Q/V BAND TRANSMIT ANTENNA PATTERN AS A FUNCTION OF THETA ANGLE (°), WITH D/λ=333

7 TN BS ANTENNA AND BEAM FORMING PATTERN MODELLING

7.1 C-BAND

AAS antenna, patterns and parameters used follow TR 38.921 [17].

TABLE 24: PARAMETERS OF THE PARAMETERISED ARRAY ANTENNA MODEL

Parameter	Symbol	Unit
Front to back ratio	A_m	dB
Side lobe suppression	SLA_v	dB
Horizontal HPBW (Half Power Beam Width)	φ_{3dB}	Degrees
Vertical HPBW	θ_{3dB}	Degrees
Array element peak gain	$G_{E,max}$	dBi
Number of radiating elements rows and columns	(M, N)	Integer
Horizontal element separation	d_h	m
Vertical element separation	d_v	m
Electrical down-tilt angle	θ_{etilt}	Degrees
Electrical scan angle	φ_{escan}	Degrees

TABLE 25: ARRAY ANTENNA MODEL DETAILS FOR AAS (TR 38.921)

Description	Equation	Unit
Peak normalised element radiation pattern	$A(\theta,\varphi) = -\min\left[-\left(-\min\left[12\left(\frac{\varphi}{\varphi_{3dB}}\right)^2, A_m\right] - \min\left[12\left(\frac{\theta-90}{\theta_{3dB}}\right)^2, SLA_v\right]\right), A_m\right]$	dB
Peak gain normalised element radiation pattern	$A_E(\theta,\varphi) = G_{E,max} + A(\theta,\varphi)$	dBi
Composite array radiation pattern	$\boldsymbol{A_A(\theta,\varphi) = A_E(\theta,\varphi) + 10\log_{10}\left(\left\lvert\sum_{m=1}^{M}\sum_{n=1}^{N} w_{m,n} v_{m,n}\right\rvert^2\right)}$, **where** $\boldsymbol{v_{m,n} = \exp\left(j2\pi\left((m-1)\frac{d_v}{\lambda}\cos(\theta) + (n-1)\frac{d_h}{\lambda}\sin(\theta)\sin(\varphi)\right)\right)}$ $\boldsymbol{w_{m,n} = \frac{1}{\sqrt{MN}}\exp\left(j2\pi\left((m-1)\frac{d_v}{\lambda}\sin(\theta_{etilt}) - (n-1)\frac{d_h}{\lambda}\cos(\theta_{etilt})\sin(\varphi_{escan})\right)\right)}$	dBi

TABLE 26: AAS ANTENNA PARAMETERS FOR C BAND (TR 38.921)

	Urban Macro	Suburban Macro
Base Station Antenna Characteristics		
Antenna pattern	TR 38.921 [17]	
Element gain $G_{E,max}$ (dBi)	5.5	6.4
φ_{3dB} / θ_{3dB} (degree)	90º / 90º	90º / 65º
Horizontal/vertical front-to-back ratio A_m (dB)	30 for both H/V	30 for both H/V
Antenna polarisation	Linear ±45º	Linear ±45º
Antenna array configuration (M, N)	16 × 8 elements	16 × 8 elements
Horizontal /Vertical (d_h/ d_v) radiating element spacing	0.5λ / 0.5λ	0.5λ / 0.7λ
Array Ohmic loss (dB)	2	2
Conducted power (before Ohmic loss) per antenna element (dBm)	22	22
Base station maximum coverage angle in the horizontal plane (degrees)	120	120
Base station vertical coverage range (degrees)	90-120	90-100
Mechanical downtilt (degrees)	10	6

7.2 Q/V BAND

Co-existence aspects and radio frequency requirements for the new radio (5G NR) access technology with frequency up to 100 GHz are an object of study by TR 38.803 [14]. Therefore, the 6G-NTN Q/V band parameters are still applicable as part of the frequency ranges studied in TR 38.803.

TR 38.803 [14] describes a general antenna model using a uniform rectangular panel array, comprising M_gN_g panels, is illustrated in Figure 15.

- M_g is the number of panels in a column
- N_g is the number of panels in a row
- Antenna panels are uniformly spaced in the horizontal direction with a spacing of $d_{g,H}$ and in the vertical direction with a spacing of $d_{g,V}$.
- On each antenna panel, antenna elements are placed in the vertical and horizontal direction, where N is the number of columns, M is the number of antenna elements with the same polarisation in each column.
- Antenna numbering on the panel illustrated in Figure 15 assumes observation of the antenna array from the front (with x-axis pointing towards broad-side and increasing y-coordinate for increasing column number).
- The antenna elements are uniformly spaced in the horizontal direction with a spacing of d_H and in the vertical direction with a spacing of d_V.
- The antenna panel is either single polarised (P=1) or dual polarised (P=2).

The rectangular panel array antenna can be described by the following tuple (M_g, N_g, M, N, P).

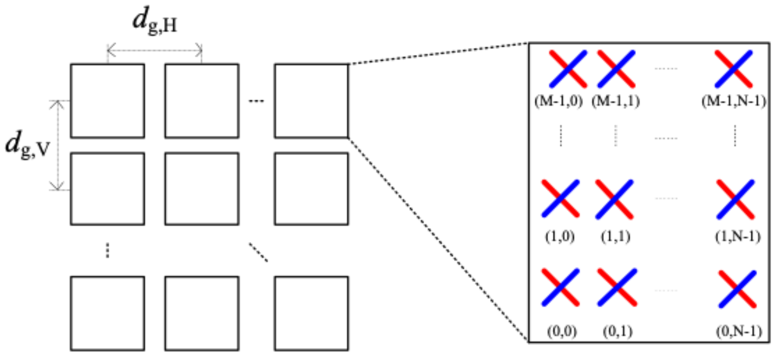

FIGURE 15: GENERAL ANTENNA MODEL

For a uniformly distributed array (ULA) antenna, as shown in Figure 16, the radiation elements are placed uniformly along the vertical **z**-axis in the Cartesian coordinate system. The **x-y** plane constructs the horizontal plane. A signal acting at the array elements is in the direction of **u**. The elevation angle of the signal direction is denoted as (defined between 0° and 180°, 90° represents perpendicular angle to the array antenna aperture) and the azimuth angle is denoted as (defined between -180° and 180°).

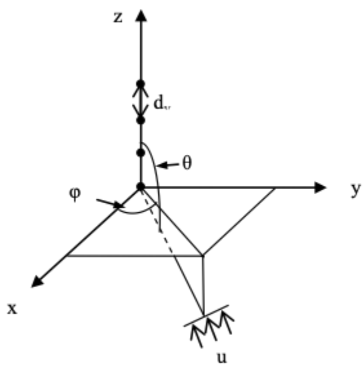

FIGURE 16: ANTENNA ARRAY GEOMETRY

The linear phase progression-based beamforming is assumed, as described in Table 27.

TABLE 27: COMPOSITE ANTENNA PATTERN

Parameter	Values
Composite Array radiation pattern in dB $A_A(\theta,\varphi)$	For beam i: $A_{A,Beami}(\theta,\varphi)=A_E(\theta,\varphi)+10\log_{10}\left(\left\lvert\sum_{m=1}^{N_H}\sum_{n=1}^{N_V} w_{i,n,m}\cdot v_{n,m}\right\rvert^2\right)$ the super position vector is given by: $v_{n,m}=\exp\left(i\cdot 2\pi\left((n-1)\cdot\frac{d_V}{\lambda}\cdot\cos(\theta)+(m-1)\cdot\frac{d_H}{\lambda}\cdot\sin(\theta)\cdot\sin(\varphi)\right)\right),$ $n=1,2,\ldots N_V;m=1,2,\ldots N_H;$ the weighting is given by: $w_{i,n,m}=\frac{1}{\sqrt{N_H N_V}}\exp\left(i\cdot 2\pi\left((n-1)\cdot\frac{d_V}{\lambda}\cdot\sin(\theta_{i,etilt})-(m-1)\cdot\frac{d_H}{\lambda}\cdot\cos(\theta_{i,etilt})\cdot\sin(\varphi_{i,escan})\right)\right)$

In this simulation, there is one beam formed using all the antenna elements. Each beam is directed to one scheduled UE.

Note the above gives the correct antenna array radiation pattern, however the correct gain is only achieved if the element pattern $A_A(\theta,\varphi)$ is selected for the exact element spacing. For other element spacings, the element pattern $A_A(\theta,\varphi)$ must be separately calculated such that it is correct for the element spacing ($d_{g,H}$ and $d_{g,V}$). If $A_A(\theta,\varphi)$ is not linked to the element spacing then the calculated absolute gain may diverge from the correct value in a manner that varies as the beam is steered.

The correct composite array radiation pattern directivity (D) is given by:

$$D_A(\theta,\varphi)=10\cdot\log\left(\frac{4\pi\left(\left|A_A(\theta,\varphi)\right|^2\right)}{\int_{-\pi}^{\pi}\int_0^{\pi}\left|P(\theta,\varphi)\right|^2\sin(\theta)d\theta d\varphi}\right),$$

The composite array radiation pattern gain can then be calculated as:

$$G_A(\theta,\varphi)=D_A(\theta,\varphi)-L$$

Where L is the Loss associated with the antenna. This is currently included in the estimate for element gain $A_E(\theta,\varphi)$, and is 1.8dB.

TABLE 28: BS ANTENNA MODELLING FOR URBAN MACRO SCENARIO

Parameter	Values
Antenna element vertical radiation pattern (dB)	$A_{E,V}(\theta'')=-\min\left\{12\left(\frac{\theta''-90°}{\theta_{3dB}}\right)^2, SLA_V\right\}, \theta_{3dB}=65°, SLA_V=30\,\text{dB}$
Antenna element horizontal radiation pattern (dB)	$A_{E,H}(\varphi'')=-\min\left\{12\left(\frac{\varphi''}{\varphi_{3dB}}\right)^2, A_m\right\}, \varphi_{3dB}=65°, A_m=30\,\text{dB}$

Combining method for 3D antenna element pattern (dB)	$A''(\theta'',\varphi'') = -\min\left\{-\left[A_{E,V}(\theta'') + A_{E,H}(\varphi'')\right], A_m\right\}$
Maximum directional gain of an antenna element $G_{E,max}$	8 dBi
(M_g, N_g, M, N, P) note	For 30GHz: (1, 1, 8, 16, 2)
(d_v, d_h)	(0.5λ, 0.5λ)
Note:	**An additional 3dB gain is added to the total beamforming gain to account for the two polarisation directions. Boresight direction is horizontal**

8 STATE OF THE ART ON STRATEGIES FOR COEXISTENCE

This section provides a literature review on strategies for coexistence of communication systems using adjacent bands. Selected techniques will be described and the coexistence scenario under consideration will be stated where relevant.

This section therefore aims to identify TN/NTN UE, TN BS & SAN algorithms and techniques for improved coexistence and interference reduction scenarios such as GSO protection, isolation of beams, side lobe power level reduction for different frequency bands (e.g., C and Q/V bands).

For instance, strategies for coexistence are needed for adjacent channel coexistence to derive NTN and/or TN core requirements (ACLR, ACS) or NTN-TN joint-optimisation techniques.

Coordination between different systems may also be considered:

- NTN-TN coordination - terrestrial systems protection/Power Flux Density limit for the satellite system, or only

- NTN-NTN coordination, such as GSO-NGSO coordination e.g., service link and/or feeder link, shut off the station if required and/or GSO protection depending on frequency bands, equivalent PFD (Power Flux Density) /EPFD (Equivalent Power Flux Density) limits.

Previous mentioned techniques may be applied at the level of PHY (Physical) layer or MAC (Medium Access Control) / RRM.

8.1 COEXISTENCE VIA COMPLIANCE TO STANDARDS

3GPP introduces as part of its standards a set of requirements for transmitters and receivers with the intent of enabling the operation in adjacent bands. The main requirements (cited from TN BS specification for FR1) are

- Adjacent Channel Leakage power Ratio (ACLR) – defined in [18] as "*the ratio of the filtered mean power centred on the assigned channel frequency to the filtered mean power centred on an adjacent channel frequency*".
- Adjacent Channel Selectivity (ACS) – defined in [18] as "*a measure of the receiver's ability to receive a wanted signal at its assigned channel frequency at the antenna connector for BS type 1-C or TAB (Transceiver Array Boundary) connector for BS type 1-H in the presence of an adjacent channel signal with a specified centre frequency offset of the interfering signal to the band edge of a victim system.*"

Implementation differences may exist with respect to FR1 or FR2 ranges for TN (for instance 2-O type is considered), or FR1 (for instance 1-C type currently not considered) and above 10 GHz ranges for NTN (for instance 2-O type is considered). However, compliance to the standard generally speaking implies that the base station and UEs abide to limits for both ACLR and ACS, and that the throughput degradation for systems operating in adjacent bands is limited to 5%.

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8.2 ISSUES RELATED TO SYNCHRONISED TDD OPERATION

While NTN systems typically operate in FDD mode, most terrestrial systems in frequencies above 3 GHz operate with TDD duplexing. With respect to NTN-related scenarios, this configuration does not occur and it might be considered only for TN-TN setup. However, the synchronised TN TDD operation may represent a difficult interference scenario for NTN since all the synchronised TN BS will transmit at the same time towards the satellite, therefore increasing the received interference from adjacent bands (if satellite and terrestrial systems use different adjacent bands).

For TN systems, special care must be taken to avoid the effects of cross-link interference. That may be thought of as the interference that occurs when two systems operate in opposite directions for the same time interval (slot).

Measurement results for the impact of misalignment of TDD slot patterns in adjacent bands are reported in [19]. The authors note that when the two adjacent systems use the same TDD format (synchronised operation), the interference impact on throughput and experienced delay is negligible. On the other hand, when the slot formats diverge (unsynchronised operation), such that cross-link interference occur, significant degradation ensues.

Coordination to avoid TDD slot format misalignment is recommended.

ECC Report 296 [20] proposes a “toolbox” with options to support Administrations and operators in identifying the most appropriate synchronisation regulatory framework at national level. The key elements from the “toolbox” regarding Synchronised operation are summarised hereafter.

Synchronised operation avoids any BS-BS and MS-MS (Mobile Station) interference therefore allowing coexistence between adjacent networks without the need for guard bands or additional filters. This operating mode simplifies network deployment because no additional interference mitigation is required. However, in order to implement this, within each deployment area/region, all MFCN (Mobile/Fixed Communications Networks) licensees operating in the same band (not limited to the licensees with adjacent blocks) should use:

- A common phase clock reference (e.g., UTC (Coordinated Universal Time)), with proper accuracy/performance constraints that depend on the underlining technology, and permanent monitoring and agreed remedies in case of accuracy loss. Those aspects and challenges are detailed in ECC Report 216 [25];
- A compatible frame structure to avoid simultaneous UL/DL transmission, which determines a specific DL/UL transmission ratio and frame length. The chosen frame structure will contribute to the network performance (e.g., latency, spectral efficiency, throughput and coverage). The feasibility and performance impacts of synchronised operation between different radio technologies have to be assessed on a case-by-case basis depending on the specific technologies. As assessed in [20], the synchronised operation of 5G-NR and LTE (Long Term Evolution)-TDD may imply a cost in terms of user plane latency and performance, especially with regards to 5G URLLC (Ultra-Reliable Low Latency Communications) latency targets. Agreements on synchronised operation between operators will be simplified when the same type of services are targeted with the associated desired user plane latency and performance targets.

8.3 INTERFERENCE MITIGATION VIA LINK ADAPTATION

Besides TDD slot format alignment, the authors in [19] suggest that a system that is suffering interference may adapt its link adaptation policies, introducing more robustness in coding to avoid retransmissions. This has the drawback of reducing peak throughput. However, there are other solutions to improve link adaptation performance.

Interference Measurement (IM) plays a significant role in Channel Quality Indicator (CQI) which is reported in Channel State Information (CSI) feedback. Thus, accurate IM can effectively improve Link Adaptation (LA) performance and further increase system capacity as well as coverage.

Two IM methods, non-zero-power CSI reference signal (NZP CSI-RS) method and CSI-IM method, are investigated and compared following 5G NR protocols in paper [21]. Besides, an interference limited scenario which particularly focuses on cell-edge users is considered in the paper. This inter-cell-interference has similarities with inter-technology interference. As a result, IM techniques are worth studying for the TN-NTN co-existence interference cancellation.

As studied in paper [21], both methods are compatible with non-pre-coded and pre-coded transmission. NZP CSI-RS method measures the interference in a residual manner, which means that IM is calculated by subtracting the product of estimated channel and transmitted RSs from the received signal.

NZP CSI-RS is allocated to the same and non-overlapped Resource Elements (REs) for serving and interfering gNBs in non-pre-coded transmission and pre-coded transmission, respectively. To the contrary, UE can measure interference directly using CSI-IM method as CSI-IM resources contain zero power REs.

Furthermore, the authors of [21] achieve higher quality channel measurement in CSI-IM method by allocating CSI-IM or ZP CSI-RS resources overlapped with NZP CSI-RS resources of interfering gNBs. Simulation results show that NZP CSI-RS method has the best throughput performance in non-pre-coded transmission scenario especially without outer loop link adaptation. On the other hand, CSI-IM method outperforms NZP CSI-RS in pre-coded interference measurement. Furthermore, NZP CSI-RS method consumes fewer overhead resources and provides relatively good performance, while CSI-IM method can estimate interference per gNB anticipated to be used for advanced receiver algorithms.

8.4 INTERFERENCE REJECTION COMBINING TECHNIQUES

With the advent of MIMO (Multiple-Input Multiple-Output), it is possible for a receiver to use additional degrees of freedom to null or mitigate interference signals. This is also called Interference Rejection Combining (IRC) technique. Paper [22] provides a study on IRC approach applied to LTE uplink transmission.

Another approach for IRC is Minimum Mean-Squared Error Interference Rejection Combining (MMSE-IRC). In [23] it is shown that MMSE-IRC performs well in the presence of interferers. It has the drawback of requiring channel estimates for the interference paths towards the victim.

MMSE-IRC addressing inter-cell interference (ICI) and intra-cell inter-user interference (IUI) is analysed for 5G NR system in [24]. Compared with conventional MMSE, MMSE-IRC shows significant performance improvement.

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8.5 TN UE TO NTN INTERFERENCE MITIGATION TECHNIQUES

The interference level from TN UE to NTN SAN or NTN UE depends on the position of the satellite or the NTN UE with respect to the TN UE. For example, if the main lobe from the TN UE is directed towards the NTN, then the NTN system can experience large amount of interference. In the below figure, one example of TN UE with main lobe beam directed towards the satellite with interference scenario and the other case with interference free scenario.

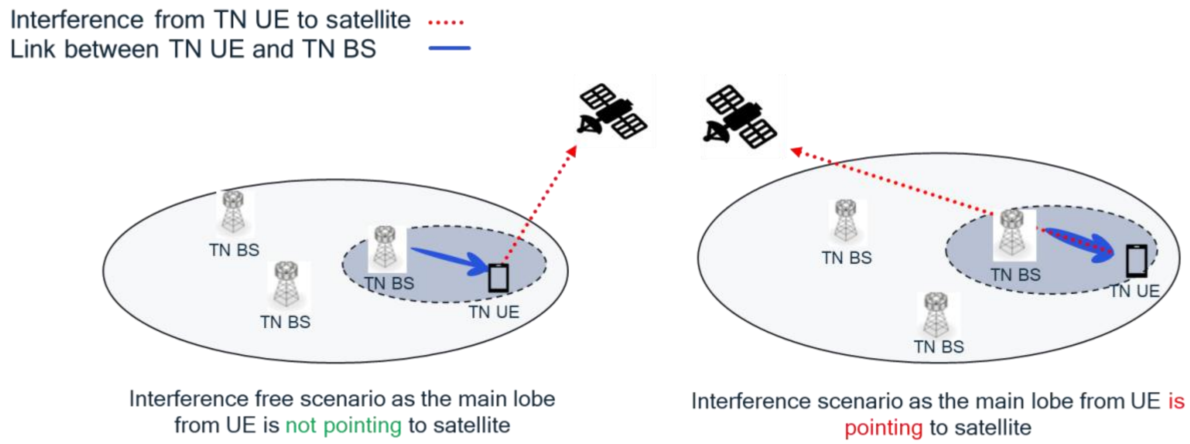

FIGURE 17: EXAMPLE OF INTERFERENCE-FREE (LEFT) AND INTERFERENCE (RIGHT) SCENARIOS FROM TN UE TO NTN SATELLITE

Different solutions can be proposed to mitigate the interference from the TN UE to the NTN, for example by using advanced receiver at baseband which can mitigate or eliminate the interference signals [26].

Furthermore, several methods can be done in the TN UE if the position of the satellite or the NTN UE is well known to the TN UE. These methods can include but not limited to:

- Power reduction method: the target here is to keep the interference lower than the threshold and that can be done by reducing the transmit power from the UE in the direction to the satellite.
- Frequency method: the target here is to apply frequency re-use or to apply different frequency allocation between TN and NTN
- Spatial method: the target here is to use the advanced beamforming techniques to reduce the unintentional interference towards the NTN. That can include reduction in the antenna gain or beam nulling towards the NTN

8.6 KNOWN TN TECHNIQUES TO BE APPLIED FOR NTN

Several techniques are discussed in the following table and the conclusions have been summarised in Section 8.7.

TABLE 29: KNOWN TN TECHNIQUES TO BE APPLIED FOR NTN

Mechanism	Overview	Comments
HFR: Hard Frequency Reuse scheme	- The whole frequency band can be partitioned into a configurable number disjoined sub-bands or BWP (Bandwidth Part) - Adjacent cells of different service areas edges are allocated with different disjointed sub-bands / BWPs -The Frequency Reuse Factor (FRF) equals the number of sub-bands / BWPs - Within a service area, an additional partitioning in (frequency, time) resource such as PRB or (sub-Carrier, sub-frames) is required. - Since these sub-bands / BWPs are allocated to cell isolated in space, they can be re-used as a configurable number of colours, pattern based -Inter-Cell Interference should be reduced between neighbouring satellite cells.	Feasible for satellite communication
CA (Carrier Aggregation) with carrier scheduling schemes	The principle of these coordination schemes is to allocate disjointed (orthogonal) Carrier Components (CCs) in FDD mode, to neighbouring cells. - <u>CA scheduling grant and resource on the same carrier</u>. In this case, the available spectrum is divided into parts, Primary Carrier Components (PCCs) and Secondary Carrier Components (SCCs). The interfering cells will use different frequency spectrum parts (either PCC or SCC). - <u>CA based Cross-carrier scheduling</u> It is an enhancement of the previous scheme. The scheduling grant and the resource allocated for data are not necessarily on the same carrier, which may keep operational the control of the scheduling grant in case of interference on the carrier associated to data. - <u>CA based HetNet (Heterogeneous Networks) using PDCCH</u> (Physical Downlink Control Channel). In this case, The PDCCH of a Secondary Cell (SCell) does not interfere with the PDCCH of the Primary Cell (PCell), since an extended PDCCH is allocated with the PRBs that the PDSCH (Physical Downlink Shared Channel) may use and not those ones of the PDCCH. - <u>CA based HetNet using ePDCCH (enhanced PDCCH) channel with ICIC (Inter-Cell</u>	May be difficult to implement for satellite purposes due to tight synchronisation and interference management between different carriers

	Interference Coordination). In this case, the extended PDCCH of the SCell cannot interfere with the extended PDCCH of the PCell, for a given frequency / band because they are not allocated on the same PRBs.	
ICIC scheme	Inter-Cell Interference Coordination scheme: The principle of this coordination scheme is to allocate disjointed (orthogonal) PRB (Physical Resource Block) to neighbouring cells. This is actually a hybrid coordination scheme in time and frequency domains. Requires Time & Frequency synchronisation between gNBs.	Feasible for satellite purposes, requires ISL(Intersatellite Link)/Xn interface between satellites
ABS based eICIC (enhanced ICIC)	Almost Blank Subframes based enhanced ICIC coordination schemes: The principle is to allocate (to schedule) disjoint (orthogonal) structures (sub-frame, sub-carrier) to neighbouring cells. It relies on transmission with Power Coordination in the time and frequency domains, per sub-frame, sub-carrier basis: - Zero Power sub frames based eICIC - RP-ABS based eICIC (Reduced Power Almost Blank Sub frames). Requires Time & Frequency synchronisation between gNBs.	Feasible for satellite purposes, requires ISL/Xn interface between satellites
CoMP (Coordinated Multi-Point) schemes and Interference nulling based CoMP	Downlink CS/CBS-CoMP (DL_CS_CoMP): Downlink Coordinated Scheduling per sub-frame, sub-carrier, potentially beam basis, with respect to JT/DPS (Joint Transmission/Dynamic Point Selection) schemes. The transmission is done from one TP (Tx Point) at once. The interfering transmission TP is steered towards the null space, for interference mitigation purposes.	May be difficult to implement for satellite purposes due to tight synchronisation and interference management between different transmission points
	Uplink CS/CBS-CoMP (UL_CS_CoMP): Uplink Coordinated Scheduling per sub-frame, sub-carrier, potentially beam basis. It relies both on scheduling & pre-coding selection decisions, per sub-frame, sub-carrier, potentially beam basis. UE data is transmitted to 1 RP (Rx point) at once. The interfering transmission UE is steered towards the null space. This technique is not suited for Handset UE with omnidirectional antenna (e.g. C band) but to UE with antenna steering and therefore VSAT type, which might be applicable for Q/V band.	
	Downlink Joint Transmission CoMP (DL_JT_CoMP). Relies on simultaneous Data Transmission from multiple TP.	

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	Downlink DPS (Dynamic Point Selection) CoMP muting (DL_DPS_CoMP): Relies on Dynamic Transmission Points Selection, per sub-frame basis. It may be combined to JT. PRB pairs are selected within sub-frame.	
	Uplink Joint Reception CoMP (UL_JR_CoMP): It relies on multiple simultaneous Reception Points (RP) of UE transmitted by the PUSCH (Physical Uplink Shared Channel) and RP selection per sub-frame basis.	
Transmitter based FeICIC (Further eICIC)	The Transmitter mutes PDSCH resource elements that experiences strong interference from other TP (Transmission Points within cells).	Is normally used together with ICIC
Receiver based FeICIC	The Receiver subtracts the dominant interferer.	Is normally used together with ICIC
MIMO techniques	Spatial diversity, as provided by MIMO, can contribute to mitigate interferences.	To be analysed with respect to diversity of satellite channel model
	MMSE-IRC: Minimum Mean Square Error (MMSE) and Interference Rejection Combiner (IRC).	Technique to be further used in next deliverables for UE
	Beamforming based.	Technique to be further used in next deliverables for both UE and satellite
Waveform Design Based	5G NR allows for any filtering technique at the transmitter side, as long as it is transparent for the receiver (TR38.802 [27]). Block Filtered-Orthogonal Frequency Division Multiplexing (BF-OFDM) as described in [28] provides several advantages, in the context of spectrum sharing: • High out-of-band rejections: each sub-band of BF-OFDM benefits from a filtering stage; therefore, the spectrum leakage in adjacent bands is very low. • Ability to create spectrum holes: BF-OFDM [28] has been designed so that entire sub-bands power can be dynamically set to zero. This enables/improves the implementation of RRM coordination schemes, dynamically allocating sub-bands to cells of different BS (gNB, eNB) sharing the same band (both NTN and TN cells). • Numerologies (frequency bands in the 5G terminology) can be set in different sub-bands, with a unique filtering stage.	Technique to be further used in the Waveform Design task (T4.1) part of WP4 in the 6G-NTN project.

8.7 NTN INTERFERENCE MITIGATION TECHNIQUES CONCLUSION

As previously mentioned, synchronisation strategies based on ICIC are not currently considered for NTN. However, the preliminary study has highlighted other potential techniques such as FFR (Fractionary Frequency Reuse), beam steering, polarisation, scheduling and MMSE-IRC.

TABLE 30: NTN INTERFERENCE MITIGATION TECHNIQUES FOR DIFFERENT EQUIPMENT TYPES AND FREQUENCY BANDS

Equipment type	Band	Interference mitigation technique	Comments
NTN SAN	C-band	FFR (Fractionary Frequency Reuse), see Figure 18 with FRF = 2 or 3 Beam steering, Side lobe limitation Beam/cell scheduling (RB, BWP, Power, Channel, MCS (Modulation and Coding Scheme), etc.), Inter-satellite scheduling	Potentially investigate: DL/UL band inversion with respect to TN, GSO/NGSO coordination
	Q/V-bands	FFR (Fractionary Frequency Reuse), see Figure 18 with FRF = 2 or 3 Beam steering, Side lobe limitation Beam/cell scheduling (RB, BWP, Power, Channel, MCS, etc.), Inter-satellite scheduling Circular polarisation (Left-Handed and Right-Handed Circular Polarisation (LHCP, RHCP))	
NTN UE	C-band	FFR (Fractionary Frequency Reuse), see Figure 18 with FRF = 2 or 3 MMSE-IRC receivers	
	Q/V-bands	FFR (Fractionary Frequency Reuse), see Figure 18 with FRF = 2 or 3 Circular polarisation (LHCP, RHCP) Pointing accuracy, Antenna off-axis limits Self-power reduction/shutdown (based on spectrum allocation/ regional requirements)	Investigate potential feasibility of MMSE-IRC receiver in Q/V band in next deliverables

Figure 18 shows different frequency reuse factors (FRFs) applied to a cluster of beams. Fractionary Frequency Reuse (FFR) systems use different FRFs to divide available bandwidth into sub-bands.

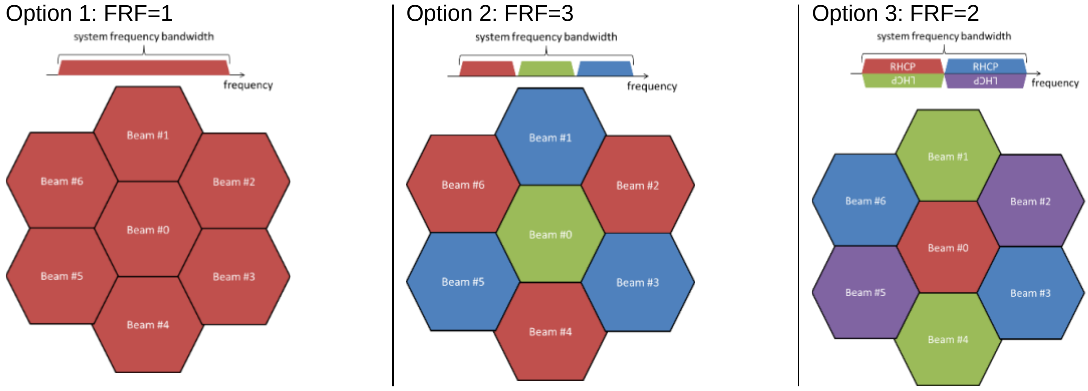

FIGURE 18: DIFFERENT FREQUENCY REUSE FACTORS APPLIED TO A CLUSTER OF BEAMS

9 CONCLUSION

The main parameters needed to have a common base for subsequent simulations and interference analysis were defined throughout this deliverable. Considered frequency bands and coexistence scenarios, relevant parameters for terrestrial and non-terrestrial components of the 6G-NTN architecture, as well as state-of-the-art on interference mitigation have been addressed in this deliverable.

The considered frequency bands for the next steps are the Q/V band (UL 37 GHz, DL 47 GHz) and C band (with Lower C in-band FDD UL 4 GHz/DL 3.5 GHz and C band FDD UL 6.5 GHz/DL 3.7 GHz being the preferred options).

Coexistence scenarios in adjacent bands with aggressor and victim pairings have been defined for these frequency bands. Previous coexistence studies done in 3GPP allowed us to remove redundant ones and keep 6 scenarios: for lower C in-band FDD, NTN DL with TN UL and vice versa; for C band FDD, NTN UL with TN UL or TN DL and vice versa.

Antenna parameters are subject to changes, depending on interference and link budget analysis in subsequent deliverables. Considering the fact that no commercial implementation and regulation exists yet for the studied bands, the parameters for TN base stations are tentative and based on extrapolated known values from existing bands (n260-n262).

Simulation phases for the next deliverables will be done as follows:

- Phase 1: Initial result from simulations (in **D4.7**)
    - NTN service link evaluation (CDF (Cumulative Distribution Function), SINR)
- Phase 2: Calibration of the simulators (path loss, no interference evaluation)
- Phase 3: Coexistence simulation (in **D4.8**)
    - NTN-TN in adjacent bands (NTN Uu service link – TN Uu) - 3GPP related
    - TN-NTN (TN Uu – NTN feeder link) - non-3GPP related (could be implementation-based and some isolation distance could be considered)

The next deliverable will focus more heavily on simulations, now that the common parameters for simulations have been defined. As part of this work package, link budget will also be evaluated with respect to different UE and specific service types (antenna aperture, SINR target). Subsequent simulation activity in Phase 1 and Phase 2 will allow to determine:

- The link budget (will be done in line with D3.1 and subsequent versions of this deliverable)
- The required antenna characteristics
- SNR, etc.

Moreover, NTN-TN adjacent band coexistence analysis is essential for:

- Definition of RF core requirements (ACLR, ACS, etc.);
- Introduction of new NTN bands in standardisation activities such as 3GPP.

The requirements to be identified through simulation activity in future deliverables D4.7 and D4.8 will be part of Phase 3. The interference analysis is crucial in order to define and evaluate relevant spectrum management and interference mitigation techniques. Efficiency of different interference mitigation techniques in different coexistence scenarios will also be considered.

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