CO-EXISTENCE ANALYSIS OF NON-TERRESTRIAL (NTN) AND TERRESTRIAL (TN) 5G NETWORKS IN THE MILLIMETRE BANDS (FR2)

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Abstract

This paper outlines the current Terrestrial Network (TN) and Non-Terrestrial Network (NTN) co-existence status in general. The focus is on Frequency Range 2 (FR2) band and the ongoing 3GPP RAN4 FR2 TN-NTN adjacent channel co-existence study. The study scenarios and methodologies are presented along with a system level simulator C-DReAM which is used in the simulation work of the European Space Agency (ESA) project called “Satellite Performance Evaluation for Coexistence with Terrestrial Radio Applications” (5G-SPECTRA). The first results are positive for the TN-NTN co-existence. However, several challenges are identified which are further researched during the project along with TN-NTN coexistence with FR1 mobile broadband and IoT-NTN use cases.

1. Introduction

During the past decade, terrestrial communications have evolved considerably, enabling high data rates and low latency, supporting connectivity in dense and high mobility environments, and facilitating new communication standards/technologies, such as autonomous vehicles, Internet-of-Things (IoT), real-time video, network slicing and connectivity for edge computing. Despite their unprecedented advantages, terrestrial communications have certain limitations, such as poor coverage in remote areas, vulnerability to natural disaster events, and long-distance transmission delays. Meanwhile, a series of advancements in aerospace technology, such as Low Earth Orbit (LEO) satellites and High-Altitude Platform Stations (HAPS), have broadened the use cases of satellite communications, in terms of suitability, and enabled further research and ultimately deployment of satellite systems into terrestrial applications.

NTN is now accepted as necessary to allow 5G and 6G networks to be extended towards 100% coverage. NTN can add value to the existing 5G infrastructure by providing solutions to problems such as allowing or enhancing coverage to remote areas and/or over-crowded events.

One of the main problems in the coexistence of NTN and TN in the same or adjacent frequency bands is the interference between the two systems. In the background of the ever-increasing role of NTN in the 3GPP 5G standard and their integration, it is significant to analyse the interference scenarios and define the Radio Frequency (RF) requirements of NTN and TN systems to finalise the decision on enabling the use of satellites in 5G scenarios.

The significance and challenges regarding studies related to the co-existence of terrestrial cellular and non-terrestrial systems have been emphasized by the standardization bodies and the research community [1] to [4].

The interference analysis for the co-existence between mmWave cellular networks and the Fixed-Satellite Services (FSS) in the portion of the spectrum from 17 GHz to 30 GHz, based on different Base Station (BS) deployment scenarios, mmWave channel models and corresponding system parameters is investigated in [5]. The analysis proved that the co-existence of FSS and mmWave base stations in the same area is feasible considering the utilization of the features of mmWave scenarios like RF beamforming.

Co-existence analysis of TN and NTN on adjacent frequency bands in FR1 is carried out and the system-level simulation results are presented in [6],[7]. The analysis carried out is based on the 3GPP technical reports. According to the co-existence analysis carried out in [7], NTN User Equipment (UE) can reuse the current requirements of the TN UE which allows the same terminal to connect to both terrestrial networks and non-terrestrial satellite constellations.

Various studies recommend cognitive radio and spectrum sharing techniques to solve the interference issues with flexible spectrum usage. In this respect, [4] focused on dynamic spectrum sharing and cognitive radio approach for system co-existence. Several works discussed power allocation schemes for cognitive uplink in satellite-terrestrial co-existence scenarios [8],[9]. The use of 3D beamforming satellite antennas to further mitigate the interference to terrestrial networks is explored in [10]. A centralized scheme for Dynamic Spectrum Sharing (DSS) to efficiently utilize scarce spectrum resources for co-channel deployments and enable coexistence between NTN and TN systems has been studied within the DYNASAT project is proposed in [11]. A general framework for the coexistence of these networks and analytical expressions for the outage probability are provided in [12], while [13] evaluated a more advanced scenario where the satellite simultaneously serves multiple users and is equipped with a uniform planar antenna array. Furthermore, an analytical expression for the beamforming weights was provided in [13]. An integrated satellite network utilizing massive multiple-input multiple-output (MIMO) was considered and intra-system interference between the satellite and terrestrial systems was evaluated in [14], and a hybrid precoding algorithm to mitigate intra-system interference was also proposed.

In a current ESA project 5G-SPECTRA, we are contributing to 3GPP RAN4 FR2 coexistence studies for NR-NTN and IoT-NTN and this paper contains early results on the NR-NTN coexistence due to adjacent channel interference. The simulator developed within the project is also proposed to produce wider interference results in both FR1 and FR2.

The main purpose of the work presented in this paper is to provide early-stage results on the NR-NTN coexistence, due to adjacent channel interference, at FR2, based on the ongoing standardisation and discussions in 3GPP RAN4 working group. To produce these results, a C-DReAM system level simulator was implemented mainly targeting at successful standardisation of NTN at 3GPP. Moreover, based on the ongoing 3GPP activity the NR-NTN bands in FR2 are provided along with the eight, 3GPP agreed, interference scenarios for TN-NTN coexistence in FR2. With the aid of the developed system level simulator, all interference scenarios for TN-NTN coexistence in the FR2 frequency band were investigated and simulated. The preliminary results obtained are presented and discussed, noting here that some parameters and thus outcomes are subject to change, due to the still ongoing work for the 3GPP RAN4 group.

2. NTN and TN bands in FR2

The frequency spectrum is allocated worldwide in three different Regions by the International Telecommunication Union (ITU) with priorities and protection given for certain services e.g., FSS, Fixed Services (FS), BS, UE in various bands that may differ slightly between regions. Some bands are exclusive to a service e.g., part of the Ka band for satellite. However, above Ka band there are no exclusive satellite bands. 3GPP designates certain bands for the operation of mobile (TN) and satellite and NTN radio services, e.g., FR1 for spectrum below 6GHz and FR2 for spectrum above 10GHz. Some of these bands overlap or fall close to ITU-designated bands and thus pose issues of in-band or adjacent band interference. In general, in-band interference is a regulatory issue dealt with by the ITU, and adjacent band interference is studied in 3GPP.

Frequencies in the Ku and some Ka band fall into the spectrum gap that is currently between FR1 and FR2 and 3GPP are still considering how to handle the spectrum between 7.125 and 24GHz. However, discussions on NR-NTN are focused on above 10GHz as this is the range offering broadband services. The initial focus in 3GPP is on Ka band. ITU frequency spectrum for Ka band is given in Table 1.

Table 1 - ITU Frequency Spectrum for Ka Band

	Ka band	
Allocation	**Down (GHz)**	**Up (GHz)**
Exclusive	19.7 – 20.2	29.5 – 30.0
Shared	17.7 – 19.7	27.5 – 29.5
Government	20.2 – 21.2	30.0 – 31.0
BSS (coord)	17.3 – 17.7	
Available to use	**2.5 /2.9 GHz**	**2.5 GHz**

Currently, the 29.5 to 30 GHz uplink band is heavily used for the return channel from Very Small Aperture Terminals (VSAT) operating in Broadband (BB) internet networks. The in-band interference with FS has been previously investigated in the literature [15] but this was not related specifically to NTN bands, which at that stage were not designated. The shared band is due to be used more in Very High Throughput Satellites (VHTS) that are beginning to appear and so are relevant to NTN overlapping.

In 3GPP RAN4 (RAN 4 meeting 106, March 2023) the NTN bands and frequency ranges, listed in Table 2, were agreed upon.

Table 2 - UL/DL Spectrum for n512, n511 and n510

NTN operating band	**UL** **Earth-to-Space**	**DL** **Space-to-Earth**
n512[1]	27.5 - 30.0 GHz	17.3 - 20.2 GHz
n511[2]	28.35 - 30.0 GHz	17.3 - 20.2 GHz
n510[3]	27.5 - 28.35 GHz	17.3 - 20.2 GHz

1. This band is applicable in the countries subject to CEPT ECC Decision (05)01 and ECC Decision (13)01.
2. This band is applicable in the USA subject to FCC 47 CFR part 25.
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 operations in this band (47 CFR 25.202).

Figure 1 shows the NTN and TN bands within the Ka band. It is noted that there are no TN bands in the Ka downlink spectrum and so the interference work has been prioritised to the uplink. The 27.5 to 30GHz band is split up between the full band (n512) designated in most countries and a split band (n510 and n511) designated in the US and other countries deploying these assignments.

The 3GPP designated TN bands all have operation in TDD whereas the NTN bands are FDD due to the long delay. This raises the question of interference between TDD and FDD which needs further study.

As seen from Figure 1, TN bands n261 (27.5 to 28.5 GHZ) and n257 (26.5 to 29.5 GHz) will provide in-band interference whereas n258 (24.5-27.5 GHz) will provide adjacent channel interference only.

5G FR2 cellular systems are proposed mainly for urban areas and will operate via much smaller cells, circa 100m radius, and thus the cell density is increased over that in the FR1 band. In addition, there will be use of array antennas for the BS and the UE and beamforming within the cells rather than the fixed sectorised cells in FR1.

It was noted that no NTN bands have so far been defined in Ku satellite downlink bands although there is current interest in 3GPP NTN to address this topic.

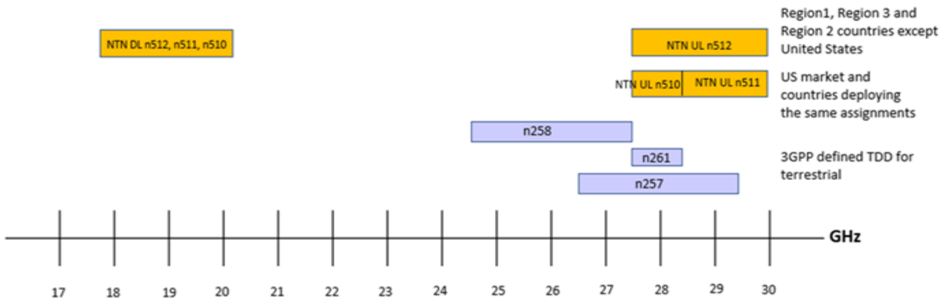

Figure 1 - FR2 NTN bands and interfering TN bands.

3. Interference scenarios and interference modelling

The TN-NTN coexistence scenarios for frequency bands above 10GHz were agreed at the 3GPP RAN4 meeting in Athens [16]. For TN-NTN coexistence, a reference frequency of 17 GHz for NTN DL cases and 27 GHz for NTN UL cases are assumed [16],[17]. There was also consideration of the use ~30GHz as UL and ~20GHz as DL. For coexistence between Ka-Band DL and adjacent TN bands, there are no 3GPP-defined/specified TN bands. Based on the discussions, eight scenarios were defined and are summarized in Table 3.

Table 3 - Coexistence Scenarios in above 10GHz

Id	Description	Aggressor	Victim	Interference Type	Frequency Band Satellite Orbit, Environment
i1	UL NTN – UL TN	NTN UL	TN UL	NTN VSAT UE to TN gNB	• FR2, 27GHz for Uplink, 17 GHz for downlink simulations • GEO, LEO-600, LEO-1200 • Urban
i2	UL TN – UL NTN	TN UL	NTN UL	TN UE to Satellite	
i3	UL NTN – DL TN	NTN UL	TN DL	NTN VSAT UE to TN UE	
i4	DL TN – UL NTN	TN DL	NTN UL	TN gNB to Satellite	
i5	DL TN – DL NTN	TN DL	NTN DL	TN gNB to NTN VSAT UE	
i6	DL NTN – DL TN	NTN DL	TN DL	Satellite to TN UE	
i7	UL TN – DL NTN	NTN DL	TN UL	Satellite to TN gNB	
i8	UL TN – DL NTN	TN UL	NTN DL	TN UE to NTN VSAT UE	

TN-NTN co-existence evaluations will be performed for these scenarios, each for GEO, LEO-600 (km), LEO-1200 (km) satellite cases (a total of 24 scenarios), and satellite elevation angles of 25 and 90 degrees. The interference scenarios corresponding to i1- i8 in Table 3 are illustrated in Figure 2.

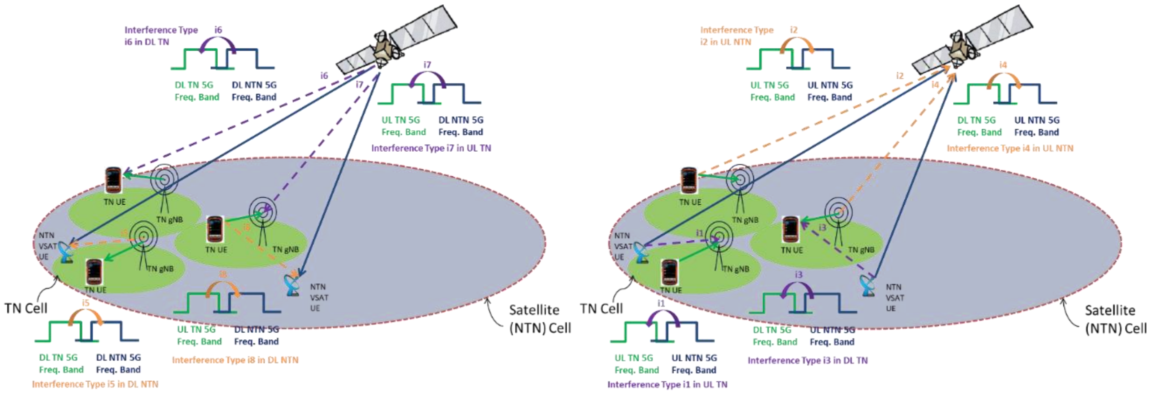

Figure 2 - FR2 coexistence scenarios for use cases i1-i4 (left) and i5-i8 (right) [18]

In the 3GPP RAN4 co-existence evaluation methodology throughput of Adjacent Channel Interference (ACI) enabled cases is compared to no-ACI reference case, and less than 5% loss is required. Throughput is calculated by using a modified Shannon formula. In SINR calculations sender Adjacent Channel Leakage Ratio (ACLR) and receiver Adjacent Channel Sensitivity (ACS) are applied separately. A flat equal bandwidth ACI model is used where aggressor and victim bandwidths are equal and ACI on victim bandwidth is spread evenly.

4. System level simulator

C-DReAM [19],[20],[21] is a capacity-level system simulator implemented in Python with the capability to simulate small to mega-size Non-Geostationary Satellite Orbit (NGSO) constellations of satellites with flexible payloads at the capacity level. The simulator was originally developed within C-DReAM project [22] and further enhanced within DASCE [23] and EAGER projects [24]. The simulator is implemented as a chain of modules where each functionality is contained within its container. All the modules are fully parameterized to maximize the user control level and they have a well-defined interface for intermodular communication.

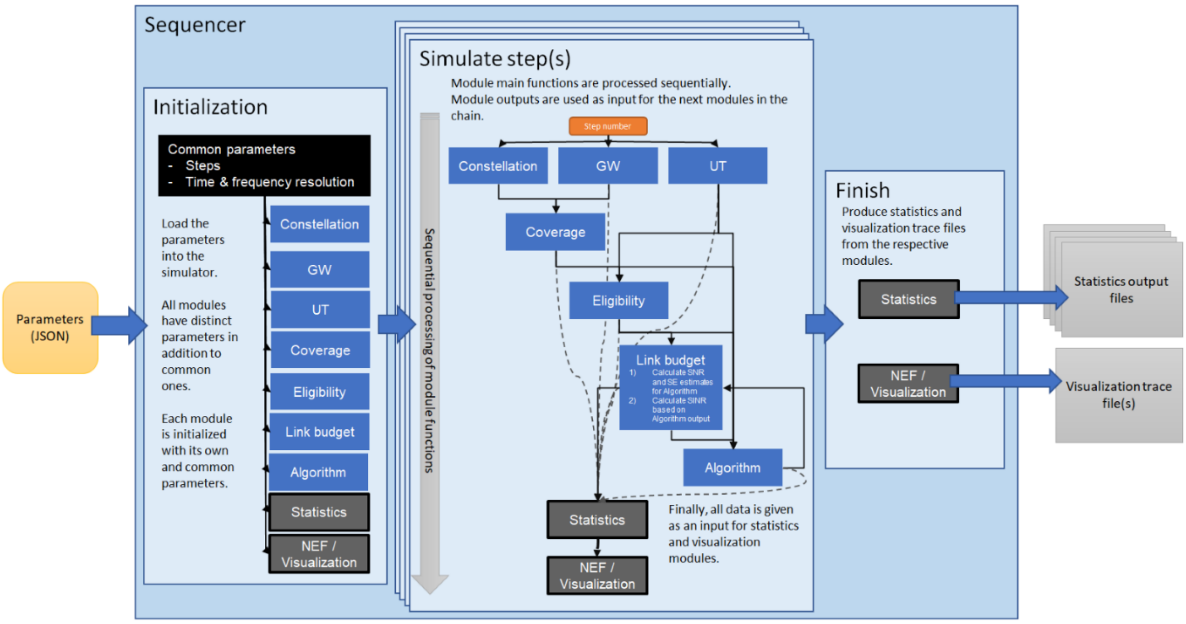

Figure 3 - C-DReAM architecture

Figure 3 shows the high-level overview of the simulation workflow. The Sequencer Module works as the main component in the simulator. First is the initialization phase where the Sequencer reads the parameter files and initializes configured modules. Each module is a lightweight Python class that implements the necessary interface, namely initialization and the function(s) required to operate in a predefined sequence with other modules. After the initialization phase, the simulation starts and the Sequencer works as the main loop calling the other modules, reading information, and passing the information on to other modules. This loop continues until the simulation has gone through all the steps at which point the simulation ends, and output is collected from the statistics and visualization modules.

One of the main use cases of the C-DReAM simulator is the capacity level evaluation of large NGSO constellation systems with different design assumptions such as constellation parameters, payload configuration, link budget parameters, terminal distributions, frequency bands, resource allocation algorithm, etc. Thus, the main use case is highly dynamic.

C-DReAM simulator has been extended towards TN deployments as well as hybrid TN and NTN deployments, either at the same or adjacent frequency bands. The simulator models, features, and parameters have been aligned with 3GPP NTN assumptions, e.g., TR 38.811 [25] and TR 38.821 [26], to be able to simulate both the NTN system-level calibration scenarios, but especially the RAN4 TN-NTN adjacent channel coexistence deployment scenarios.

The output from the C-DReAM visualization module can be used e.g., by Magister SimLab Visualization Player which is illustrated in Figure 4. The figure shows a LEO 600 FR2 TN-NTN co-existence scenario with one central statistic beam and six interfering beams. The urban TN cluster is situated in the middle of the central beam. Visualization Player is a standalone software that can show the scenario layout, different metrics, and timeline playback from a simulation run. In addition, the player is also part of the Magister SimLab simulation service [27], which is a web service supporting the complete simulation workflow: scenario definition, simulation execution, visualization, and statistics plotting. C-DReAM is one of the simulators supported by SimLab Service.

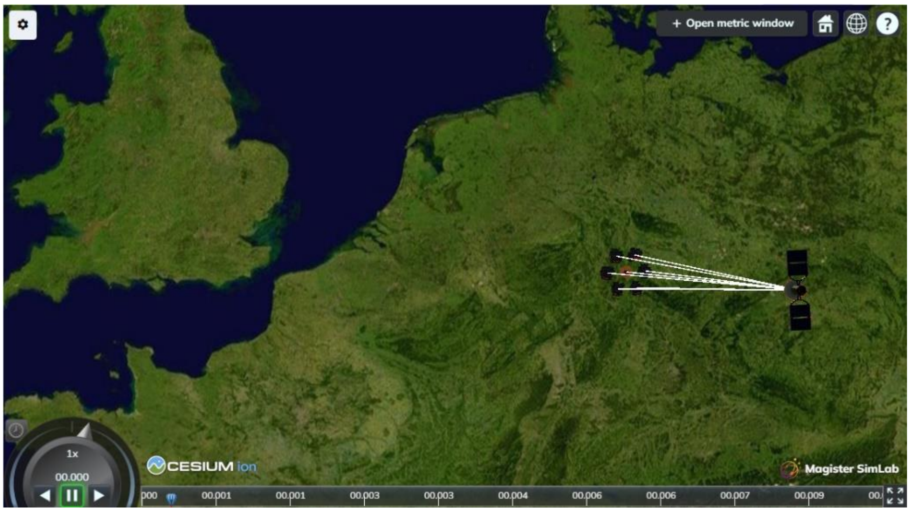

Figure 4 - Leo 600 FR2 co-existence scenario in Magister SimLab Visualization Player

5. NR Adjacent channel interference results

In this section, we present simulation results for TN-NTN FR2 co-existence simulations. The simulation assumptions, scenarios, and parameters are presented in RAN4 #107 co-existence assumption document [28]. The essential differences and other parameters are listed in

Table 4. An overview of the results is shown in Table 5 and the complete set of results is shown in [29].

Table 4 - Main simulation parameters

Parameter	**Value**
Number of random drops	10
NTN UE	VSAT at 1.5 m altitude
Central beam elevation	90°
TN scaling	Disabled

Table 5 - FR2 Co-existence Results

Scenario	**TN ACS config**	**Varied NTN ACI parameter**	**ACI requirement for < 5% TP loss**		
			LEO 600	**LEO 1200**	**GEO**
1	gNB ACS 24 dB	UE ACLR	< 0 dB	< 0 dB	< 0 dB
2	UE ACLR 17 dB	SAN ACS	< 0 dB	< 0 dB	< 0 dB
3	UE ACS 23 dB	UE ACLR	< 0 dB	< 0 dB	< 0 dB
4	gNB ACLR 28 dB	SAN ACS	< 0 dB	< 0 dB	< 0 dB
5	gNB ACLR 30 dB	**UE ACS**	**16 dB**	**16 dB**	**16 dB**
6	UE ACS 25 dB	SAN ACLR	< 0 dB	< 0 dB	< 0 dB
7	gNB ACS 26 dB	SAN ACLR	< 0 dB	< 0 dB	< 0 dB
8	UE ACLR 19 dB	UE ACS	< 0 dB	< 0 dB	< 0 dB

The results in Table 5 show the NTN side ACS and ACLR values required for achieving < 5 % average throughput loss compared to no-ACI reference case. Almost all cases show < 0 dB ACS/ACLR requirement as smaller values were not simulated. The only exception is scenario 5 where TN gNB downlink transmission interferes with NTN UE downlink reception where at least 16 dB NTN UE ACS is required. The initial results are therefore very positive and do not show a need for special ACS/ACLR requirements for NTN. Unlike in earlier FR1 scenarios [7], the NTN users are within the TN cluster, but because of the usage of beamforming in TN and NTN UE directional antennas, the interference between the systems is reduced.

However, the results here clearly do not show the whole story. The assumed 90° satellite elevation angle provides a good antenna gain separation as NTN users are never pointing toward the gNBs. With lower elevation angles the situation changes and the likelihood of NTN UE pointing toward the gNBs increases. That is why 3GPP has updated the simulation assumptions with another simulation set assuming a 25° central beam satellite elevation angle.

In scenarios 2 and 4, where the satellite is the victim, only one TN cluster with 57 sectors was simulated. However, the satellite will receive adjacent channel interference from the whole beam area and the macro-TN cluster is small compared to the beam area. But for example, a GEO beam can cover over 5000 macro-TN clusters which is practically impossible to simulate. Therefore, in FR1 co-existence simulations ACI scaling factor concept was used. It is simply a scenario-constant factor used in ACI calculations. A similar approach can also be applied in FR2 co-existence studies, and it will inevitably increase the NTN SAN ACS requirements.

The current results assume a VSAT NTN terminal i.e., the usage of a parabolic antenna pattern with at least 60 dB 90° off-axis attenuation [30]. In addition, there has been a discussion in RAN4 on specifying the usage of a phased-array antenna with approximately 40 dB 90° off-axis attenuation. Reducing the NTN UE off-axis attenuation inevitably increases the adjacent channel interference and should be studied. It should be noted that the sidelobe attenuation of the used antenna patterns in general fluctuates significantly and the attenuation can vary tens of decibels with a few degrees change which causes variance to the simulation results.

On the other hand, we have assumed a 1.5 m altitude for the NTN UEs and no separation distance between the NTN and TN UEs or gNBs. Especially, higher NTN UE altitude will help separate the two systems. However, the work in 3GPP RAN4 is still ongoing, thus the assumptions are still being updated which will inevitably change results.

6. Conclusions

In this paper, we have discussed how the usage of satellites in 5G is inevitable to achieve complete coverage and how spectrum utilization aspects are an important issue that must be solved before Non-Terrestrial Networks can be used as part of the 5G ecosystem. The focus is on the adjacent channel co-existence in the FR2 band. We presented the 3GPP RAN4 FR2 TN-NTN co-existence scenario and methodologies, and the C-DReAM tool used in the simulation campaigns. The presented first results are promising and no unreasonable requirements for the NTN equipment are needed. However, the co-existence study in 3GPP is still a work in progress and we have identified several aspects which can require more demanding requirements. The objective of the 5G-SPECTRA project is to continue this FR2 research with new simulations and contributions on the topic. Furthermore, we will also study the IoT-NTN and NR-NTN in FR1 co-existence scenarios using the C-DReAM simulator. Also, there has been interest in Ku band usage in NTN but the co-existence with TN has not yet been studied and is therefore also a very interesting and potential topic.

7. Acknowledgments

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