OpenAirInterface as a platform for 5G-NTN Research and Experimentation

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***Abstract*—Technical advancements and experimental works for the integration of 5G and Non-Terrestrial Networks (NTN) have gained significant traction over the past few years. NTN components have been officially included in the 5G ecosystem by 3GPP in the latest Release-17. 5G-NTN research is ongoing and it is desirable to have a platform that facilitates quick prototyping of the proof-of-concept methods. OpenAirInterface(OAI) is an open-source experimental yet 3GPP standard-compliant Software Defined Radio (SDR) based protocol stack that has been widely known for implementing 4G/5G technologies. Due to its proven capabilities and flexibility, OAI is currently in the developmental process of integrating adaptations for the 5G-NTN. In this work, we discuss the peculiar features of OAI which are shaping it towards becoming a preferred tool for research and experimentation related to 5G-NTN. We provide details of completed/ongoing 5G-NTN projects leveraging OAI to achieve their objectives. In particular, we discuss 5G-GOA and 5G-LEO where critical adaptations in OAI are being done to support 5G-NTN use-cases. Such adaptations enable direct-access between UE and gNB via transparent payload Geostationary (5G-GOA) and Non-geostationary satellites (5G-LEO). Both projects have closely followed 3GPP discussions over 5G-NTN and the adaptations are compliant with the currently frozen 3GPP Release-17. OAI adaptations from both projects will be merged into the main development branch of OAI. We also provide a future roadmap of OAI towards 5G-NTN development. We believe that the pioneering steps taken in the course of the aforementioned projects will establish OAI as a preferred tool for 5G-NTN research and experimentations.**

***Index Terms*—5G, Software Defined Radio, Non-Terrestrial Networks, OpenAirInterface**

I. Introduction

Wireless communication is witnessing unprecedented changes leading to high connectivity demands. A huge variety of diverse applications have emerged in 5G demanding connectivity between not only humans but also objects - *Everyone and Everything* needs to be connected. This presents a challenge to the existing 5G terrestrial communication infrastructure. Satellites, with their large footprints and ubiquity, have the potential to complement and improve the value proposition of 5G networks by improving coverage, network resilience, network reliability, and complex use-cases (for example natural and man-made disasters). Taking cognizance of the necessities, the 3rd Generation Partnership Project (3GPP) did two studies [1], [2] during Release-15 and Release-16. This resulted in the drafting of specifications for 5G-NTN in the Release-17 which is frozen in March 2022. Figure-1 illustrates the high level architecture of integrated terrestrial and satellite communication networks with both direct and indirect access. The vision is to deploy NTN as a part of 5G by 2025, however, before any commercial deployment of 5G-NTN-based services, rigorous evaluations and experimentations are required. For that purpose, it is desired to have flexible tools and platforms that offer a wide range of experimentation modes: from real-world testing to controlled

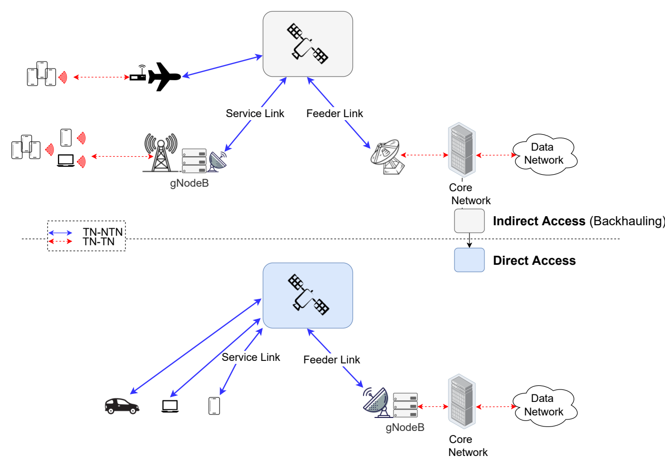

Fig. 1: An integrated terrestrial satellite communication network with direct and indirect access between users and the base-station. Links between Terrestrial Networks(TN) and Non-Terrestrial Networks(NTN) are shown.

and scalable evaluations. Up to 3GPP Release-16, 5G does not support the operation of NR over satellites. It also means that neither commercial 5G equipment nor simulators are available for experimentation with 5G-NTN features. While network simulation software such as NS3 [3], MATLAB [4] etc. have significantly evolved, capturing the effects of real-world satellite impairments and field testing is still essential, especially at the stage of product development and commercial deployment.

In this context, we discuss OpenAirInterface™ (OAI) [5] which is an open-source SDR based implementation of 3GPP compliant 5G base-station (gNB), user equipment (UE), and the core network (5G-CN). Using OAI it is possible to build a 4G/5G network quickly at low cost with COTS SDR and general-purpose x86 processors. OAI is well known in the terrestrial communication research regime, especially to applied researchers. Eventually, the capabilities and flexibility offered by OAI have also paved the way toward exploring new application/technology areas such as 5G-NTN. In the past few years, OAI has gained notable interest from the scientific community, industry, and funding agencies (national and international) to develop it as a tool for 5G-NTN research and experimentations.

We discuss several ongoing/completed research projects which have leveraged OAI in the development of 5G-NTN testbeds, in-lab validations, and over-the-satellite (OTS) experimentations. In particular, we discuss in detail 5G-GOA and 5G-LEO; both European Space Agency (ESA) sponsored projects where significant developments are being made pertaining to 5G-NTN. In these projects, OAI is used as the primary tool to develop simulators, in-lab demonstrators, and up to over-the-satellite testbed by performing adaptations/suggestions as per 3GPP Release-17. Using the OAI software framework for 5G-NTN is also motivated by the belief that extending an open-source solution with an existing user community will help maximize the reuse of the results and achieve a broader impact. After the conclusion of the projects, the source code will be merged with the main development branch of OAI.

The rest of the paper is organized as follows: Section-II discusses the standardization of 5G-NTN in 3GPP. Section-III provides the detail of the current status of OAI. Section-IV provides details of the project leveraging OAI for research and development related to 5G-NTN. The future roadmap of OAI toward the extension of new features is mentioned in Section-V. Finally, conclusions are drawn in Section-VI.

II. Standardization of 5G-NTN in 3GPP

The 3GPP Release-17 is a crucial working point to develop and approve the necessary technical specifications enabling direct access to 5G via satellite. Standardization efforts to include satellites within terrestrial networks started in 2017 with two fundamental studies [1] and [2]. Deployment scenarios, channel models, frequency ranges, satellite constellation, access modes, footprint size, antenna models, etc were studied. The main objective was the identification of a feature set

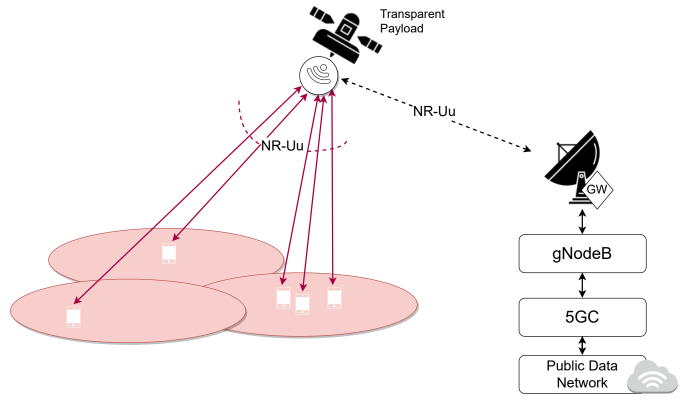

Fig. 2: A transparent payload-based 5G-NTN direct-access architecture. The UE connects to gNB via the Nr-Uu interface while the gNB connects to 5G Core Network via the NG interface

that enables NTN within the 5G system in such a way that impacts on the existing 5G system are minimized. Based on the studies, the 3GPP RAN Working Group drafted the extensions and modifications in the current terrestrial 5G-NR RAN, Core Network (CN), and interfaces that are required to support NTN. Currently, 3GPP Release-17 has been frozen in March 2022 [6].

The focus in Release-17 has been on the integration of *transparent (non-regenerative) payload satellite* [2] systems providing *direct-access* to the 5G UE for both Low Earth Orbit (LEO) and Geostationary Orbit (GEO). Transparent payload satellites do radio frequency filtering, frequency conversion, and signal amplification whereas regenerative payload satellites also allow modulation/demodulation, coding/decoding, and routing, though the latter require more processing power than the former. Figure-2 shows the 5G-NTN architecture with a transparent payload. The choice of the transparent payload is motivated by the low complexity of the satellites and the fact that this is a more mature technology compared to regenerative ones. Not only this but most of the challenges imposed by the satellites are more emphasized when a transparent payload is considered, thus addressing them for a transparent payload would mean that such challenges will not appear again in the case of a regenerative payload.

Besides, Frequency Division Duplexing (FDD), Earth Fixed Tracking Area, UE with Global Navigation Satellite Systems (GNSS) capabilities, and hand-held devices in FR1 (410MHz - 7125MHz) are assumed in Release-17. Finally, not only 5G, LTE-based technologies for integration with NTN such as Narrow-Band Internet of Things (NB-IoT) and enhanced Machine Type Communication (eMTC) for supporting low data rate use cases with satellites [7] are also specified.

Current efforts in Release-17 represent only the first phase; the work is still in progress and Release-18 plans to further enhance the specifications for diverse use-cases of NTN in 5G and beyond. Such enhancements include: (a) Mobility enhancements for satellite and terrestrial networks (b) Coverage enhancements for voice and low-data rate services (c) Network verified device location based on satellite network to name a few.

III. OpenAirInterface: Current Status

OpenAirInterface (OAI) is an open-source initiative that provides a reference implementation of 5G gNB, User Equipment (UE), and 5G Core Network (5G-CN) which is standard-compliant with 3GPP Release-15 (and above). OAI has software-based network functionalities which reduce the implementation cost and increases the flexibility of the deployment. OAI software stack runs on general-purpose Intel x86 architecture-based processors on top of a Linux-optimized environment. This allows OAI to exploit the Single Instruction Multiple Data (SIMD) instruction sets (SSE, SSE2, SSS3, SSE4, and AVX2) [5] for implementing highly optimized DSP routines. OAI distinguishes itself from other similar projects through its unique open-source license, the OAI public license v1.1 which was created by the OAI Software Alliance (OSA) in 2017 [9]. In this section, we discuss the current status of OAI 5G-NR RAN and CN followed by a brief comparison of the comparable SDR platforms.

A. *OpenAirInterface 5G-NR RAN*

Currently, the OAI 5G-NR RAN supports all physical channels and signals as per the 3GPP Release-15 while limited to subcarrier spacing of 30kHz in FR1 and 120kHz in FR2. Supported bandwidths are $10, 20, 40, 80$, and 100MHz. For channel estimation, the Demodulation Reference Signal (DMRS) configuration supports Type-1 and Type-2 with single and double symbols. Shared data channels also provide support for phase tracking using Phase Tracking Reference Signal (PTRS). Physical Random Access Channel (PRACH) supports formats $0, 1, 2, 3$, A1-A3, and B1-B3 for random access. Physical Broadcast Channel (PBCH) generation supports multiple Synchronization Signal Blocks (SSBs) with flexible periodicity. Physical Downlink Shared Channel (PDSCH) and Physical Uplink Shared Channel (PUSCH) generation support Type-A and Type-B mapping. Physical Downlink Control Channel (PDCCH) supports Downlink Control Information (DCI) format limited to $00, 01, 10$, and 11 and includes common and user-specific search space in the downlink, whereas, in the uplink, Physical Uplink Control Channel (PUCCH) provides support for format 0 (2 bits, for ACK/NACK and SR) and 2 (up to 11 bits, mainly for Channel State Information (CSI) feedback).

One of the significant components of 5G for high throughputs is multi-antenna operations. So far, Multiple-Input-Multiple-Output (MIMO) functionality is limited to 2 layers, and a maximum of 4 transmit antennas in the downlink, whereas there is a single layer and antenna in the uplink. There is Channel State Information Reference Signal (CSI-RS) sequence generation in the downlink and Sounding Reference Signal (SRS) in the uplink for channel sounding, which supports the estimation of channel and noise power. Further, there is a highly efficient 3GPP compliant implementation of Low-density parity-check code (LDPC) encoder/decoder (BG1 and BG2), Polar encoder/decoder, and encoder and decoder for a short block. Furthermore, Bandwidth-Parts (BWP) a feature that is useful for power-constrained UEs is also being implemented.

B. *OpenAirInterface 5G-NR CORE NETWORK*

Apart from 5G RAN, the OAI platform provides a 3GPP compliant complete software implementation of the 5G Core Network (5G-CN) and thereby offers support for 5G NSA gNB, 5G SA gNB, 5G NSA UE and 5G SA UE. Further,

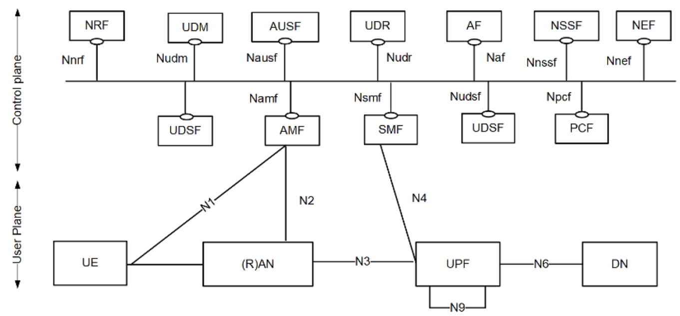

Fig. 3: An overview of the network functions implemented in OAI 5G-CN to support 5G SA mode of operation(source [5]

OAI 5G CN follows Service-Based-Architecture (SBA) which includes basic Access and Mobility Management Function (AMF), Session Management Function (SMF), and User Plane Function (UPF), and allows the deployment of a 5G Service Based (SBA) core network using docker-compose. Figure-3 shows the network functions implemented in OAI 5G-CN. The OAI 5G CN is fully compliant with 3GPP Release 17 as stated in the 5G CN OAI roadmap released by the OSA. Besides, OAI can also be operated with 3rd party core networks such as Open5GS and Open5GCore.

OAI also comes with a softscope tool that can plot physical layer parameters, such as received signal power, channel impulse response, channel frequency response, log-likelihood ratios (LLRs), throughput, and I/Q components (e.g., 4-QAM constellation), etc. It is shown in Figure-5.

The status of OAI for terrestrial cellular 5G-NR SA has been recently demonstrated by Allbesmart [11] in an end-to-

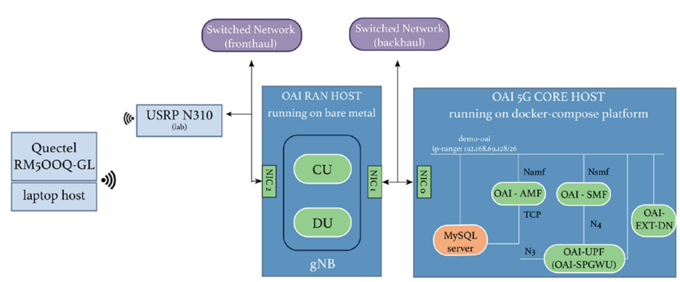

Fig. 4: 5G SA OAI experimental setup with SDR gNB, COTS UE. Using TDD, 100 MHz bandwidth, 256 QAM, and 30 KHz of Sub-Carrier spacing, a downlink bitrate up to 330 Mbit/s with RTT of 10 ms was achieved.

end setup consisting of SDR gNB (USRP N310) and COTS UE (Quectel module RM500Q-GL). Using Time Division Duplexing (TDD), 100 MHz bandwidth, 256 QAM and 30 KHz of Sub-Carrier spacing, a downlink bitrate up to 330 Mbit/s with RTT up to 10 ms was achieved. An illustration of the set-up is shown in Figure-4.

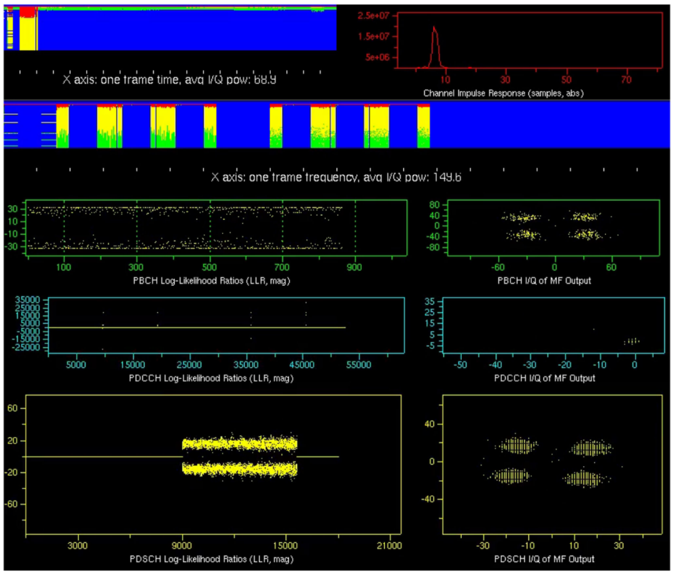

Fig. 5: In built softscope of OAI capable of showing I/Q power, Channel Impulse Response, LLR, and I/Q constellation for PBCH, PDSCH/PDCCH, PDCCH/PUCCH

C. *Comparable Open Source Software Platforms*

- **GNU Radio**: GNU Radio provides an OSS implementation of LTE UE, eNB and EPC implementation [12]. However, there are currently no activities concerning 5G-NR, and even the development of the LTE components has not been continued.
- **srsRAN**: Software Radio Systems (SRS) provides an OSS implementation of several LTE features for UE, eNB and EPC [13]. In April 2021 5G-NSA support was released for the UE. In May 2022, srsRAN brought 5G SA support to both gNB and UE. From a feature set point of view, SRS is very close to OAI, however, it uses a GNU-Affero-General-Public-License (AGPL) V3 as well as commercial licenses which enables SRS for commercial exploitation of the products.
- **OpenLTE**: OpenLTE [14] provides a set of tools to detect and decode LTE signals and also works together with GNU radio, but cannot be run in real-time or establish an end-to-end link with commercial equipment. OpenLTE also uses an AGPL v3 license.

IV. Research Projects Leveraging OpenAirInterface for 5G-NTN

The integration of 5G and NTN is not straightforward due to several technical challenges. New approaches and technologies are being developed which require thorough research and performance assessment. OAI has been a pioneer among the tools used for such projects due to which there has been an accumulation of contributions/feature-extension related to 5G-NTN, thanks to various H2020/National/ESA projects. In this section, we present such completed and ongoing projects.

A. *Completed Research Projects*

1) 5G-ALLSTAR: 5G AgiLe and flexible integration of SaTellite And cellulaR(5G-ALLSTAR) [15] aimed to design, develop, and evaluate via testbeds trials, multiple access-based multi-connectivity (combination of satellite and cellular access) for the support of seamless reliable, and ubiquitous broadband services. Using OAI as the tool for implementation, the project developed a 5G-NTN testbed at Fraunhofer IIS premises. Several features in the PHY and MAC layer of OAI were adapted to cope with satellite impairments (realized in-lab using Keysight PROPSIM-F64 channel emulator) such as timing advance, scheduling, and random access to name a few. In the conclusion, the project demonstrated 5G-NR access through satellite as well as terrestrial networks. The project also contributed to global 5G standardization including 3GPP and ETSI focusing on multi-RAT interoperability and NR based satellite access.

2) 5G-EMUSAT: 5G New Radio EMUlation over SATellite(5G-EmuSat) [16] project developed a demonstrator platform implementing the PHY and MAC layer 5G-NR for direct access via a satellite channel using and extending OAI. Since the project was in-course 2020, several 5G-NR features in OAI were still in progress. Thus, many of the essential features of 5G-NR were implemented such as all relevant 5G-NR channels: PDSCH, PDCCH, PUSCH, PUCCH, PRACH; SS Block; necessary MAC functionalities in OAI such as initial timing advance (TA) signaling, TA updates, frequency offset compensation based on multiple DMRS in PDSCH, data connection for a single static user. The project closely followed the 3GPP standardization process, especially regarding 5G-NTN and extensions for direct-access to UE. In-lab validations were done using a satellite channel emulator and the development done in OAI pertaining to both terrestrial 5G-NR and NTN were merged to the OAI repository.

Besides the aforementioned projects, it is noteworthy to mention two preliminary tests [17] and [18] where direct access through a transparent payload and GEO satellite was achieved. However, the prototypes included modifications only in the PHY and MAC layers. Traffic was injected directly into the PDCP layer and Core-Network was not involved.

B. *Ongoing Research Projects*

1) 5G Space Communications Lab: The 5G Space Communications Lab, from the University of Luxemburg [19], is an interdisciplinary experimental hub combining the expertise and infrastructure of multiple labs dedicated to small satellites, lunar rovers, and satellite communications research. The main goal is to enable testing, validation, and demonstration of the next generation of space applications, with a special focus

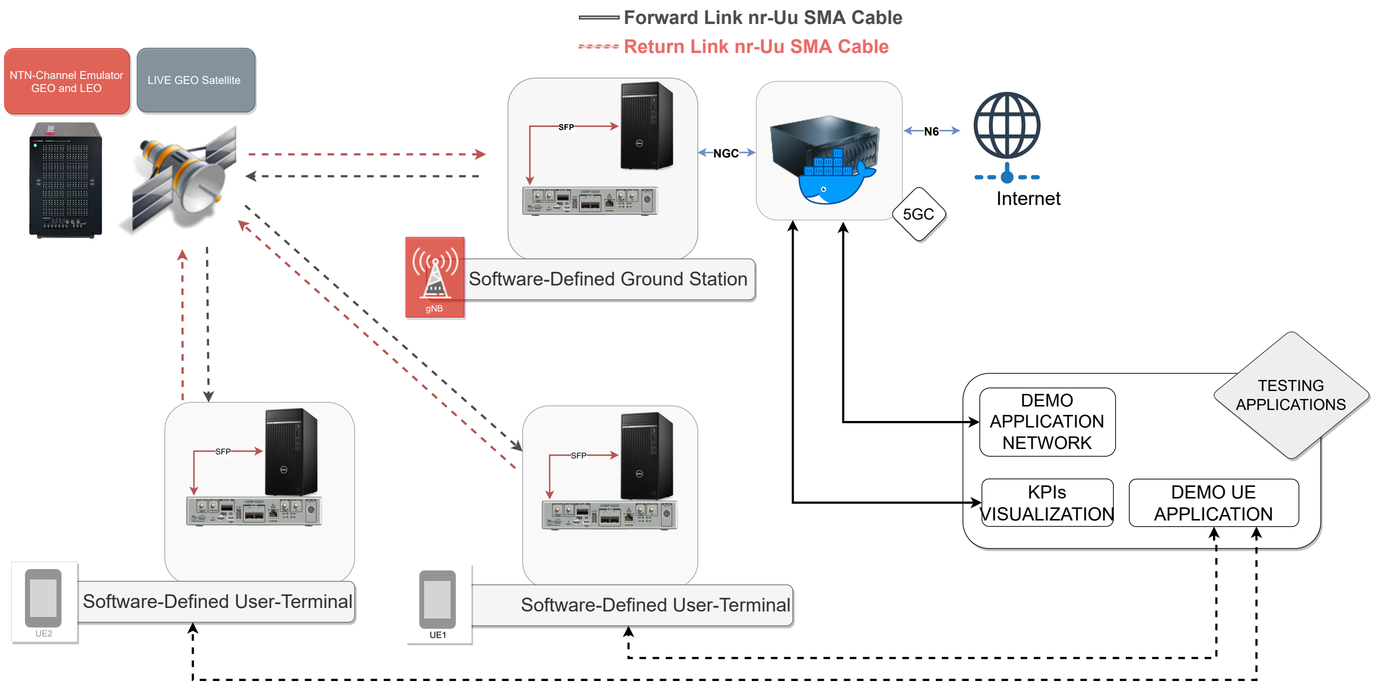

Fig. 6: Architecture of 5G-NTN demonstrator for 5G-GOA(Section-IV-B2) and 5G-LEO(Section-IV-B3). Both the projects share the same infrastructure for their testbed. The demonstrator is capable of in-lab validations and over-the-satellite testing. 5G-GOA uses a transparent payload GEO satellite for direct-access, while 5G-LEO uses a transparent payload LEO satellite for direct access.

on 5G communications from space. To this aim, a proof of concept (POC) testbed is designed with a major focus on two scenarios: Earth-orbiting satellite communications and Earth-Moon communications. Currently, the testbed uses an open-source 4G LTE protocol stack from OAI for RAN and adapts it to function under impairments caused by *MEO* and *GEO* satellites [20]. Satellite impairments are realized using an in-house developed satellite channel emulator. The testbed also emulates Inter Satellite Links (ISL) using GomSpace SDR [21].

2) 5G-GOA: 5G-Enabled Ground Segment Technologies Over-The-Air Demonstrator (5G-GOA) [22] is an ongoing ESA project, developing and implementing the necessary modifications in the 5G-NR standard to enable the direct access of terrestrial 5G services via transparent GEO satellite systems. The hardware and software development relies on and uses existing technologies already available from the OAI. The solutions being developed during the project are directly based on 3GPP discussions and results (compliant with 3GPP Release-17 or later). Scenario A1 [2] is considered where the main impairment due to satellite is the excessive Round-Trip-Delay($\approx$ 520ms). Suitable adaptations to cover physical layer procedures (e.g. synchronization) up to specific protocols and upper layer implementations (e.g., timers and random access procedure) of the radio access network, was done. A prototype is developed consisting of at least two user terminals and a gNodeB base station to verify bi-directional end-to-end communications in the Stand-Alone (SA) mode of access. A pictorial illustration of the prototype is shown in Figure-6. Unlike the previous 5G-NTN projects, 5G-GOA involves the inclusion of 5G-CN for direct-access.

After the project conclusion, a live demo via direct satellite link is planned for October 2022. Besides, a testbed is also developed which facilitates in-lab validation over the emulated satellite channel. The source code used in 5G-GEO has been submitted to the OAI repository under OAI Public License v1.1 and is in the process to be merged with the main development branch.

3) 5G-LEO: OpenAirInterface Extension for 5G Satellite Links (5G-LEO) [23] in an ESA project with the objective to extend the OAI 5G-NR software stack to support transparent payload direct access satellite systems in non-geostationary orbits. The project burrows many developments from 5G-GOA (Section-IV-B2. Scenarios C1(Steerable Beam) and C2(Beam move with satellite) [2] are considered. Besides, to enable 5G direct access through LEO satellite networks, mobility mechanisms play a key role in ensuring service continuity. Hence, one of the challenges of LEO-based NTN is to handle frequent handovers (HOs) without resulting in an increased number of HO failures and ping-pong events. For this purpose, the required HO procedure adaptation in the RRC protocol of the OAI software stack is planned. These extensions will implement a full 5G protocol stack (Release $\geq$ 16) for both the UE and the gNB. The main outcome of this activity will be a publicly available updated version of the OAI with new features to simulate and test 5G-NR LEO satellite

TABLE I: NTN specific feature extensions for 5G GoA and 5G LEO

LAYER	5G GoA	5G LEO
PHY/MAC	• Extend OAI RF-simulator to support simulation of long delay • Consider timing relation for UL scheduling at gNB • Disabling HARQ at gNB and UE • Adapting Uplink timing advance and RA procedure	• Adapted continuous timing drift compensation • Support for up to 32 HARQ Processes (following 3GPP Release 17)
RLC	• Disabling HARQ-ARQ interaction • Increased ARQ buffer size • Increased maximum Sequence Number Value	• Increased t-ReassemblyTimer when HARQ is enabled
PDCP	• Increased discard timer for Tx SDU buffer • Increased t-Reordering timer for Rx PDU buffer • Increased PDU (at Rx) and SDU (at Tx) buffers	• Increased discard timer for Tx SDU buffer • Increased t-Reordering timer for Rx PDU buffer • Increased PDU (at Rx) and SDU (at Tx) buffers
RRC	• Increased selected timers (T300, T301, T311)	• Increasing UE-timers and constant when in RRC CONNECTED, INACTIVE, and IDLE state • Extending sr-Prohibit Timer • Adaptation of the basic 5G NR handover procedure and paging protocols for frequent handovers

communication links.

Table-I lists the adaptations done/planned in OAI during 5G-GOA and 5G-LEO.

V. Future Roadmap

Through 5G-GOA and 5G-LEO, the European Space Agency (ESA) has ensured that comprehensive implementation of the 5G-NTN protocol stack that is compliant with 3GPP Release-17 is available for experimental purposes to the wider community in the shape of OpenAirInterface; shortly after Release 17 has been frozen in March 2022. 5G-NTN implemented in OAI currently supports both GEO and LEO in transparent payload configuration. The implementations will be validated and demonstrated over the air in a geostationary scenario shortly, still within October 2022.

OAI 5G-NTN implementation will support ongoing standardization work towards 5G-NTN and relevant aspects in 3GPP Release-18. However, further enhancements and feature extensions in OAI 5G-NTN implementations are required to capture the complex challenges presented by different satellite constellations and payloads and address them. The consortium involved in 5G-GOA and 5G-LEO foresees some of the challenges (non-exhaustive) which are critical and such challenges have been considered for inclusion in the OAI roadmap for 5G-NTN. They are listed below:

1) **Support for Regenerative Payload Satellite**: Regenerative payload satellite-based NTN, though more complex than transparent payload in terms of complexity of the satellite hardware and computing power, provide a significant upper-hand in terms of latency and offered bandwidth. Besides, Inter-Satellite-Links (ISL) can also be realized. Currently, OAI 5G-NTN supports only the transparent payload. For regenerative payload, the entire gNB 5G-NTN protocol stack has to run over the onboard CPU (i.e., Intel i7/i9 CPU) which could be difficult to achieve in practice. Many gNB architectures are being considered including the different possible gNB functional splits across the *Space Segment* and *Ground Segment*: Radio Head unit (RRU - RF Frontend and Antenna), Distributed Unit (DU - PHY, MAC, RLC), Central Unit (CU - RRC, SDAP) and even User Plane Functions (UPF). For example, Figure-7 shows one such split configuration (F1-split [24]) where gNB RRU and DU are mounted on a satellite while gNB CU and UPF are located on the ground. *Implementing such a split between DU and CU will require handling the delay over the F1 interface.* Furthermore, other flavors of splits will require similar attention to handle the respective delays caused by the interfaces.
2) **Offloading gNB functionalities to FPGA**: This problem follows from the CU-DU split of gNB which has been discussed before. DU components: PHY, MAC, and RLC still require a full-fledged i9/i7 CPU, however, with the availability of Radio Frequency System-on-Chip (RFSoC), it is possible to distribute the tasks within a DU, for example, O-RAN split option 7.2x [24] where low-PHY can be implemented on the FPGA of RFSoC while the high-PHY can be realized on the Co-Processor of the RFSoC. *Offloading of low-PHY functionalities to FPGA will be required* for example [25].

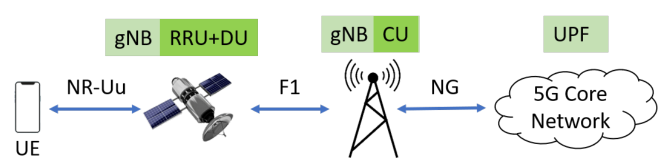

Fig. 7: A regenerative payload satellite with gNB RRU and DU are mounted on the satellite while gNB CU and UPF are located on the ground.

The roadmap is in line with the current invitation to tender by ESA: ”Demonstrating an experimental 5G g-NodeB in Space” [26]. The tender specifically advocates the use of the OpenAirInterface protocol stack implementation that will be ready to support 5G NTN low Earth orbit scenarios after March 2023. Besides, the work statement of the tender also cites 5G-GOA and 5G-LEO. This shows that the activities and results reported in 5G-GOA and 5G-LEO are clearly forming part of an ambitious path set by the European Space Agency aiming to secure a strong position for 5G-NTN in 3GPP.

VI. Summary

5G-NTN technology has still to undergo much long-term evolution. NTN has the potential to be the main service provider in beyond-5G technologies. However, many issues are still unresolved and raise a variety of technical and scientific problems. Early prototypes for 5G-NTN are valuable for further technical maturity and standardization (Release-18). OpenAirInterface projects itself as a powerful, flexible, and open-source tool for research and experimentation on 5G-NTN. Several completed/ongoing research projects, especially, 5G-GOA and 5G-LEO are making significant advancements in 5G-NTN research and developing OpenAirInterface as a tool for simulation, in-lab validation, and over-the-satellite testing through suitable adaptations and feature extensions. In both projects, follow-up activities are planned for Release-18 as well. This paper details the up-to-date adaptations and extensions in OpenAirInterface for 5G-NTN technology and gives an outlook of the future roadmap.

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Disclaimer

The views expressed herein can in no way be taken to reflect the official opinion of the European Space Agency.

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