5G-NTN GEO-based In-Lab Demonstrator using OpenAirInterface5G

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***Abstract*—The integration of 5G with Non-Terrestrial Network (NTN) components is going through a series of technological advancements and soon satellites will be a part of the 5G ecosystem. Early demonstrators, especially based on open-source implementations, are essential to support further research. In this work, we discuss the ongoing activities and developments related to the project 5G-Enabled Ground Segment Technologies Over-The-Air Demonstrator (5G-GoA) which has been funded under the ESA-ARTES program. The vision of 5G-GoA is developing and implementing suitable modifications in the 5G New Radio (NR) standard for enabling direct radio access to 5G services using a transparent GEO satellite. For this purpose, we have used OpenAirInterface(OAI) which is a Software Defined Radio (SDR) based open-source implementation of the 5G-NR protocol stack. We adapted it to address the challenges caused by the excessive round-trip delay in GEO satellites. Our solutions encompass all the layers of the 5G protocol stack: The physical layer (e.g. synchronization) up to upper layer implementations (e.g. timers and random-access procedure) of the Radio Access Network. Our modifications comply with the specifications mentioned for 5G-NTN in the recently frozen 3GPP Release-17. An end-to-end demonstrator has been developed for in-lab validation over a satellite channel emulator prior to over-the-satellite testing. Our initial experiments show promising results and the feasibility of direct access to 5G services through transparent GEO satellites.**

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

I. Introduction

Besides the features such as data rates far beyond gigabytes, virtually unlimited number of connected devices, and ultra-low latency, 5G also promises seamless connectivity, ultra-reliable connection, and connection to previously under-served and un-served areas of the earth [1], [2]. However, 5G terrestrial network infrastructure alone cannot fulfill such promises. In the parallel regime of satellites, in particular, the communications satellites have evolved enormously in recent years and are capable to cater applications that require large bandwidths. Now, it is possible to have a high volume of traffic through space [3], thanks to digitization, flexible payloads, and the large constellation of high throughput satellites.

The potential role of communication satellites to complement terrestrial services has been identified during 3GPP Release-15 and Release-16 which led to a detailed study of deployment scenarios, channel models, frequency ranges, satellite constellation, access modes, foot-print size, antenna models, etc in [4], [5]. Now, 3GPP has finalized the specifications for the integration of 5G with satellites; also termed as 5G-NTN; in the 3GPP Release-17 which is frozen in March 2022. For the first time, satellites are being considered outside the transport network and research is focused on providing direct access to 5G services at the user terminal. This means the NR-Uu interface does not terminate at the satellite and the user terminal on the ground directly connects to a ground-based gNB via a satellite channel (Figure-1).

In this context, we discuss the ongoing activities and developments of the project 5G-Enabled Ground Segment Technologies Over-The-Air Demonstrator (5G-GoA) [6], which is being funded under the ESA ARTES program. 5G-GoA aims toward the development and implementation of the necessary modifications in the 5G protocol stack for enabling direct radio access to 5G services using a transparent GEO satellite. The modifications encompass all the layers of the 5G protocol stack: The physical layer (e.g. synchronization) up to upper layer implementations (e.g. timers and random-access procedure) of the Radio Access Network. In course of its development, the project has closely followed the 3GPP work items on 5G-NTN and complies with the specifications mentioned in the recently frozen 3GPP Rel-17. During the first phase of 5G-GoA challenges pertaining to integrating GEO NTN components in 5G and respective solutions were identified. In the second and final phase, an SDR-based end-to-end demonstrator has been developed which utilizes the open-source 5G protocol stack OpenAirInterface (OAI) [7]. The demonstrator facilitates testing of the 5G-NTN link using (a) Emulated satellite channel for in-lab experiments and (b) a GEO satellite for over-the-satellite experiments.

In this work, we discuss the demonstrator architecture and present the results obtained by conducting in-lab experiments over the emulated GEO satellite channel. Using the modified OAI 5G protocol stack, a static SDR OAI UE was connected to an SDR OAI gNB in Stand-Alone (SA) access mode. The throughput was measured on uplink and downlink traffic for 5MHz and 10MHz bandwidths. Our initial results show maximum downlink throughput of 3.9Mbps(for 5MHz) and 7.4Mbps(for 10MHz) and maximum uplink throughput of 0.1Mbps(for 5MHz) and 0.2Mbps(for 10MHz).

The rest of this paper is organized as follows: In Section-II Standardization of 5G-NTN in 3GPP is discussed. Section-III presents the current status of development in OAI. Section-IV details the adaptations done in OAI during 5G-GoA. Section-V describes the demonstrator architecture and results of the in-lab experiments conducted over the emulated satellite channel. Finally, Section-VI draws concluding remarks with an outlook on the future work.

II. Standardization of 5G-NTN in 3GPP

Standardization efforts to include satellites within terrestrial networks were started by the 3GPP Radio Access Network (RAN) Working Group(WG) with two fundamental studies [4] and [5] concerning deployment scenarios, channel models, frequency ranges, satellite constellation, access modes, footprint size, antenna models, etc. This was followed by the drafting of extensions and modifications in the terrestrial 5G-NR RAN, Core Network(CN), and interfaces that are required to support NTN in 3GPP Release-17. In March 2022 Release-17 has been frozen. For the first time, satellite-based communication links will be supported by the 3GPP standards which were formerly limited to terrestrial cellular networks [8].

The prime focus of the works has been on the integration of *transparent (non-regenerative) payload satellite* systems providing *direct-access* to the 5G user-terminal for both Low Earth Orbit (LEO) and Geostationary Orbit (GEO) scenarios by evolving the protocols and functions of the 5G-RAN, 5G-CN, and the 5G-NR radio interface. In the case of a transparent payload only radio frequency filtering, frequency conversion, and signal amplification are performed, whereas regenerative payloads allow also for modulation/demodulation, coding/decoding, and routing. Figure-1 depicts 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. Further, earth-fixed tracking areas, Frequency Division Duplexing (FDD), and UE with Global Navigation Satellite System (GNSS) capabilities are assumed. Besides, handheld devices in FR1 and power class-3 while VSAT devices in FR2 are supported in Release-17.

Standardization of the integration of NTN components in the 5G ecosystem is still in progress and current efforts represent only the first phase of the seamless integration of non-terrestrial systems in future 5G-Beyond architectures.

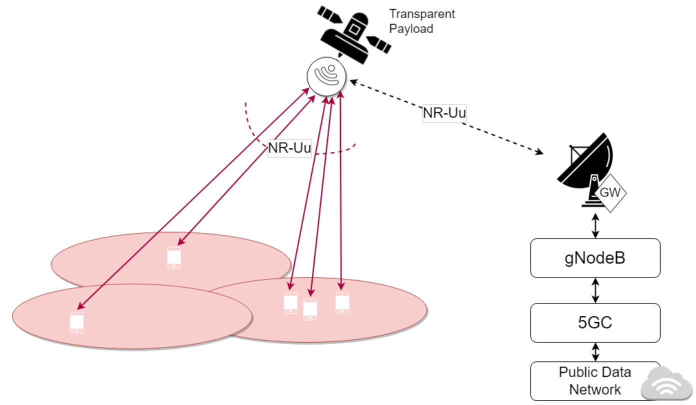

Fig. 1: A Direct Access Transparent Payload NTN architecture. The UE connects to gNB via the Nr-Uu interface while the gNB connects to the 5G Core Network via the NG interfaces.

III. OpenAirInterface

OpenAirInterface (OAI) is an Open-Source Software(OSS) project that implements fully experimental yet 3GPP standard compliant (Release-15 and above) 5G RAN and Core Network on general-purpose Linux optimized x86 computing hardware and Commercial Off-The-Shelf (COTS) SDR. OAI exploits the Single Instruction Multiple Data (SIMD) instruction sets (SSE, SSE2, SSS3, SSE4, and AVX2) for implementing highly optimized DSP routines on Intel chips. OAI follows a Software Defined Radio (SDR) based approach which gives it the advantage of the flexibility and low cost of upgrading to new or changed transmission/reception standards through software upgrades. Among many other OSS such as GNURadio [9], srsRAN [10], currently, OAI provides the most advanced implementation of 5G-NR gNB and 5G-NR UE with the Stand-Alone (SA) mode of access using the OAI 5G-NR Core Network (5G-NR CN). From the NTN point of view, SA mode is more suitable as the UE can directly connect to the gNB (Figure-2). Further, OAI also distinguishes itself from other similar projects through its unique open-source license, the OAI public license v1.1 [12]which was created by the OAI Software Alliance (OSA) in 2017.

On the 5G-RAN side, OAI implements all the physical channels and signals as per 3GPP Release-15. Sub-Carrier Spacing (SCS) of 30KHz in FR1 and 120KHz in FR2 is supported with bandwidth up to 100MHz. For channel estimation DMRS, CSI-RS and SRS are supported. PTRS is planned to be included which could be useful for NTN use-cases. Besides, highly efficient 3GPP compliant implementation of Low-density parity-check code(LDPC) encoder/decoder (BG1 and BG2) and Polar encoder/decoder are available. On the Core Network (CN) side basic Access and Mobility Management Function (AMF), Session Management Function (SMF), and User Plane Function (UPF) are implemented which allow the deployment of a 5G Service Based (SBA) core network using

TABLE I: Modifications done in OpenAirInterface for 5G-GoA

LAYER	NTN Specific Feature Extensions	Adaptations Necessary for NTN Implementation
PHY	• Support for Phase Tracking Reference Symbols in PDSCH,PUSCH • Support for 5MHz bandwidth with 15KHz SCS • Extended support for multiple bandwidth parts (BWP)	• Extend OAI RF-Simulator to support the simulation of long delay • Consider Timing Relation for UL scheduling at gNB • Disabling HARQ at gNB and UE
MAC	• Support for Multi-UE • Implementation of real FDD Scheduling • Implementation of QoS scheduling	• Adapting Uplink timing advance and RA procedure
RLC	• Increased discard timer for SDU buffer • Increased reordering timer for PDU buffer • Increased size of PDU buffer	• Disable HARQ-ARQ interaction since HARQ is disabled • Increased ARQ buffer size to cope with large GEO delay • Increased maximum Sequence Number value
PDCP		• Increased discardTimer for transmit entity • Increased t-Reordering timer for receive entity
RRC	• Increased selected timers (T300, T301, T311)	• Increase selected Timers (T300, T301, T311)
NAS		• No adaptations foreseen
Miscellaneous	• Implementation of new GUI for NTN specific KPIs	

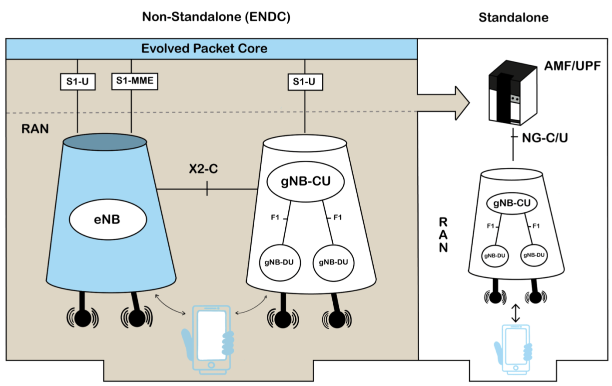

Fig. 2: In the Stand-Alone mode of access, the UE can directly connect to 5G gNB and the 5G Core network without the need of an LTE EPC [11].

docker-compose. OAI gNB can reach a downlink throughput higher than 250 Mbps with a single layer 80MHz configuration with a COTS UE [13]. A complete feature list for OAI 5G-RAN can be found in [14].

IV. 5G-NTN Adaptations in OpenAirInterface

In this section, we discuss the adaptations made in OAI in order to address the challenges associated with the project 5G-GOA. This project aims to develop and implement the necessary modifications in the terrestrial 5G-NR standard to enable the direct-access of terrestrial 5G services via transparent payload GEO satellite systems. For a GEO satellite system, the major concern is excessive Round-Trip-Delay (RTD) which is approximately $\approx$ 520ms. Delay of such extent is way more than the terrestrial 5G-NR can tolerate. Hence, all the closed-loop procedures in 5G-NR, at all the layers of the protocol stack start to fail followed by expiry of timers such as [4], [5]:

- HARQ processes
- PHY procedures such as Adaptive Coding and Modulation, Power Control
- Random Access Procedures
- Timing Advance
- Timers in PDCP, RLC, and RRC layer

To address these issues, modifications have been done at all the layers (PHY, MAC, RLC, PDCP, RRC) of the OAI protocol stack; on both the user plane and control plane. Besides several other features have been included in OAI which are broader than NTN, however, necessary for NTN experimentation. Since the current focus is on transparent payload, all the adaptations have been done assuming that both gNB and UE are located on the ground while the satellite simply relays the signal, i.e., the termination of the radio interface is within the terrestrial gNB. Table-**??** provides a list of such modifications done in OAI.

One of the significant contribution of 5G-GOA is extending the existing OAI-RFSimulator to emulate the delay which is experienced by GEO satellites. This facilitates quick validation of the NTN-specific adaptations done in OAI even before moving to channel emulator or OTS.

V. 5G NTN Demonstrator, Experiment and Result

In this section, we discuss the Proof-of-Concept(POC) demonstrator which has been developed for in-lab validation of the OAI 5G-NTN extensions, initial experiments conducted, and results obtained.

Demonstrator Set-up

The end-to-end 5G-NTN demonstrator uses the modified OAI code as per Table-**??**. To realize gNB and UE, general purpose x64 workstations hosting Linux operating systems are used. For the RF front-end, Ettus USRP X300 is used for both gNB and UE and connected to the workstations via PCI cables. The gNB CPU is also connected to a 5G-NR Core Network and creates a Stand-Alone network. Transparent payload GEO satellite impairments are generated using the IZT C3040 satellite channel emulator which is configured to produce a delay of 260ms and connected to gNB and UE via SMA cables. A separate instance of the channel emulator is used for uplink and downlink traffic which creates an RTD of 520ms. gNB$\rightarrow$USRP X300$\rightarrow$IZTC3040$\rightarrow$USRP X300$\rightarrow$UE connection comprises

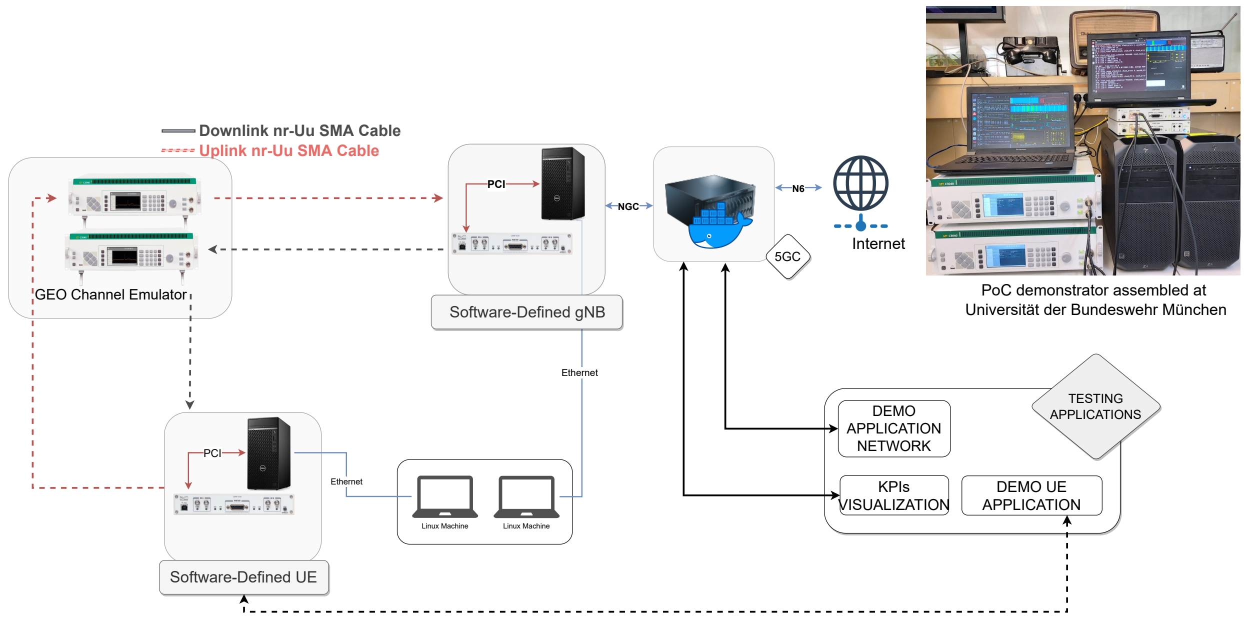

Fig. 3: Schematic diagram of the in-lab demonstrator for 5G-GoA(actual set-up in the top right). An SDR OAI UE is provided direct access to the SDR OAI gNB via separate GEO satellite channel emulators for uplink and downlink. Satellite channel emulators create delay of $\approx$ 260ms, i.e., RTD of $\approx$ 520ms

the forward link (Downlink) and UE$\rightarrow$USRP X300$\rightarrow$IZT-C3040$\rightarrow$USRP X300$\rightarrow$gNB connection comprises the return link (Uplink).

The schematic of the demonstrator is shown in Figure-3 which also shows the actual demonstrator(top-right) which has been assembled at Universität der Bundeswehr München. Note that two separate Linux PCs are connected via Ethernet cables to the gNB and UE workstations for performing the experiments remotely and logging the KPIs.

Experiments and Results

As a part of early experimentation, we performed UDP throughput tests for uplink and downlink using iperf3 [15] by making the client-server connection between the gNB and UE. Separate testing was done for carrier bandwidths of 5MHz and 10MHz. The maximum UDP throughput obtained for each of the carrier bandwidths is listed in Table-**??**.

TABLE II: UDP throughput(Mbps) observed during uplink and downlink traffic on 5MHz and 10MHz carriers with round-trip-delay of 520ms

Carrier Bandwidth	5 MHz	10 MHz
UDP Throughput Uplink [Mbps]	3.9	7.4
UDP Throughput Downlink [Mbps]	0.1	0.2

VI. Conclusions and Ongoing works

Early demonstrations and validations are essential to support the standardization of 5G-NTN at 3GPP. The objective of 5G-GoA is to develop a gNB-based gateway and UE compliant with the 3GPP Release-17 for demonstrating the direct-access via transparent payload GEO satellite. A PoC demonstrator has been developed for this purpose which uses OpenAirInterface 5G-NR RAN protocol. Necessary adaptations and feature extensions have been done in OpenAirInterface; at all the layers of the protocl stack; which are also compliant with the specifications mentioned for 5G-NTN in 3GPP Release-17. GEO satellite channel impairments are introduced using satellite channel emulator. In this work, we report the initial results obtained during the in-lab validations. Results and experience gained from the lab results will be used to improvise the adaptations for 5G-NTN. Live demonstrations over the satellite are planned at ASMS2022 [16] and ICSSC2022 [17]. The modified OAI protocol stack is in the process to be merged with the main development branch of OAI.

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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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