5G NTN LEO Based Demonstrator Using OpenAirInterface5G

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***Abstract*—3GPP Release-17 formally recognizes Non-Terrestrial Network (NTN) components as an integral part of future telecom networks. The integration of 5G with NTN has gained significant traction due to the joint effort from academia, industry, and government space agencies. The first phase of 5G-NTN prototype development has been successful using GEO satellites. Moving ahead, LEO satellites can provide higher data rates and lower latency compared to GEO. In this paper, we discuss the ongoing activities, and planned experiments related to the project 5G-LEO (OpenAirInterface5G Extension for 5G Satellite Links). 5G-LEO aims to provide direct access of 5G services to a ground UE via a transparent payload LEO satellite. To the best of our knowledge, 5G-LEO is the first work involving the adaptation of 5G protocol addressing the challenges presented by the LEO satellite channel for example high and time-varying Doppler and frequent handover. Open-source 5G-NR protocol stack OpenAirInterface5G has been taken as the baseline and 3GPP Release 17 compliant adaptations have been done in all the layers for this purpose. An end-to-end hardware demonstrator has been developed for in-lab validation. The results of the experiments using the LEO satellite channel emulator will be summarised in the full paper.**

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

I. Introduction

The inclusion of satellite components in the 3GPP Release 17 has expedited the long-awaited integration of Terrestrial Networks (TN) and Non-Terrestrial Networks (NTN) [1]. 5G-NR protocol stack, although developed for TN, however, through its peculiar physical layer characteristics it has been chosen as the RAN technology to be adapted for 5G-NTN [2]. However, such integration of 5G-TN and NTN components is not straightforward as the 5G-NR TN protocol stack development has never considered satellite channels in any of its deployment scenarios! Thus significant adaptations are required in the existing 5G-NR TN protocol stack before the deployment of 5G-NTN-based services.

Notably, the last few years have seen the development of several Proof-of-Concept (PoC) demonstrators for 5G-NTN in academia accelerated by the support from industry and government space agencies. Some examples include (a) 5G-GOA: The 5G-Enabled Ground Segment Technologies Over-The-Air Demonstrator [3] (b) 5G-ALL STAR: 5G AgiLe and flexible integration of SaTellite And cellulaR (5G-ALLSTAR) [4] (c) 5G-EMUSAT: 5G New Radio EMUlation over SATellite(5G-EmuSat) [5]. 5G-ALLSTAR and 5G-EMUSAT focused mainly on the PHY and MAC layer, and represent a precursor to lay the foundation for 5G-NTN prototype development using open-source SDR implementation. These two projects already implemented a number of 5G features necessary for integration with NTN. Later, 5G-GOA helped to further develop the stack and included adaptations on the higher layers (RLC, PDCP, RRC) as well as facilitating a Stand-Alone (SA) deployment of 5G-NTN.

The aforementioned projects have laid the foundation for 5G-NTN research, however, more development is yet to be done for the 5G-NTN technology to be as mature as its TN counterpart. The next step is to move from GEO satellites to LEO satellites. LEO satellites are advantageous compared to GEO satellites in terms of supporting higher data rates and lower latency, however, this comes at a price - very high and time-varying Doppler-shift and frequent handovers, among others.

In this work, we discuss 5G-LEO [6] which continues the developments from 5G-GOA [3] and further adapts the 5G-NTN protocol stack of OpenAirInterface5G [7] to work under high and time-varying Doppler plus frequent handover. To the best of our knowledge, this is the first work that adapts the 5G-NR TN protocol for LEO satellites. The adaptations comply with the solutions discussed in 3GPP Release 17. The work is a way forward to achieving a higher Technological Readiness Level (TRL) toward realizing 5G-NTN. Similarly to the 5G-GOA project, an SDR-based PoC demonstrator has been developed for in-lab validations. The source code of NTN adaptations devised in 5G-LEO will be merged in the development branch of OpenAirInterface5G and will be free to use. Currently, the project is in the phase of testing the individual modules (developed by different partners), which we expect to be completed by the end of June 2023. This

Layer	Modifications
PHY	Extension of OAI rf-simulator to support simulation of time-variant propagation delays and frequency offset Continuous frequency offset estimation and compensation Continuous timing drift estimation and compensation Uplink Power Control (Open-loop and Closed loop)
MAC	Support for up to 32 HARQ Processes (following 3GPP Release 17) Channel State Information (CSI) Reporting DL/UL Adaptive Modulation and Coding (AMC) Timer-based Handover between multiple beams
RLC	Disabling HARQ-ARQ interaction in Acknowledged Mode transmissions Increase ARQ buffer size Increase t-Reassembly Timer
RRC	Increase selected UE timers (T300, T301, T311)
GUI	Extension of OAI GUI (Scope) to enable monitoring of real-time KPIs

TABLE I: OAI modifications for 5G-NTN in the 5G-LEO

will be followed by extensive testing over commercial satellite channel emulators. Results obtained from the experiments will be summarized in the full paper.

II. Key Challenges and Our Solutions

The basic architecture of 5G-NTN in 5G-LEO is partially inherited from 5G-GOA (transparent payload and direct access) due to implementation simplicity and demo feasibility. The main challenge originates from the inclusion of the LEO satellite. In LEO-based systems, channel impairments such as time-varying RTT and time-varying Doppler due to excessive satellite velocity (7.5 km/s) are critical. For instance, a variable frequency offset of up to 25 ppm of the carrier frequency can be observed in such systems, which can be multiple times the SCS [8]. These challenges add on top of the challenges faced in 5G-GOA [3]. This means that further enhancements are required in all the layers of the 5G NR protocol stack. For example (a) robust and reliable mechanisms to continuously track the time-varying frequency and timing offsets (b) a seamless handover process between multiple beams etc. Table I lists the modifications performed in 5G-LEO at the different layers of the 5G-RAN.

III. Demonstrator Architecture and Experiments

In 5G-LEO we aim to demonstrate relevant 3GPP Release 17 5G-NTN features during July 2023. An end-to-end PoC demonstrator has been developed using COTS SDR and OpenAirInterface5G. LEO satellite channel will be emulated using commercial channel emulator [9]. The schematic of the in-lab demonstrator is shown in Figure-1. The demonstrator consists of two gNB Distributed Units(DU), gNB-DU-0 and gNB-DU-1, and a Central Unit gNB-CU. CU and DU are connected over F1 interface. The 5G Core Network (5G-CN) is connected to the gNB-CU. The gNB is connected to Keysight Satellite Channel Emulator which is responsible for emulating (a) Continuous time varying Doppler (b) Continuous timing drift (c) Power level variations etc. A SDR UE is connected that switches between gNB-DU-0 and gNB-DU-1 following a configurable timer, i.e., a timer based handover is implemented. Performance will be evaluated in terms of (a) Doppler compensation and tracking (b) Initial synchronization success (c) Timing drift compensation (d) Performance in terms of packet loss and jitters (e) Adaptive video streaming etc.

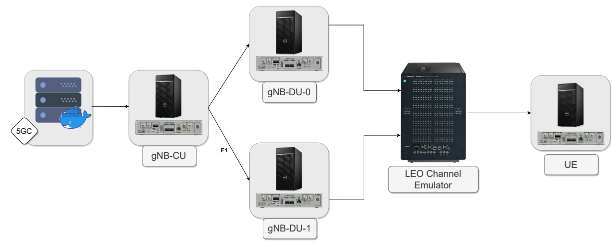

Fig. 1: Schematic diagram of the in-lab demonstrator for 5G-LEO. SDR gNB has been implemented with CU-DU split. Satellite channel emulator creates time varying frequency offset, timing drift and movement of the satellite

IV. Summary

Early demonstrations and development of PoC demonstrators, especially based on open-source tools and SDR are essential to support the standardization of 5G-NTN at 3GPP. The objective of 5G-LEO is to develop a gNB-based gateway and UE compliant with 3GPP Release 17 for transparent payload LEO satellite-based 5G-NTN. Necessary modifications are made to the OpenAirInterface5G protocol stack for this purpose. In-lab validations will be conducted in July 2023 and the results of the experiments will be summarized in the full paper. In addition, the project will merge the developed source code extensions into the main development branch of OpenAirInterface5G and release it as a part of the open-source OAI protocol stack. Although that 5G-LEO does not involve testing of live satellites, nonetheless, the development and iterative testing over satellite channel emulator will reduce the number of variables when the project will be further used for live tests in the future.

Acknowledgment

5G-LEO is funded under the ESA ARTES program with ESA Contract No. 4000135152/21/NL/FGL. [1]

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