Building a 5G Non-Terrestrial Network using OpenAirInterface Open-source Software

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***Abstract*—Satellite-enabled 5G services have the potential to provide worldwide connectivity. In this paper, we give an introduction on the roadmap in 3GPP standardization of 5G as well as on the enhancements to support non-terrestrial networks (NTN) in Release 17. We further provide first over-the-air test results of a successfully demonstrated extension of 5G New Radio (NR) to support non-terrestrial networks (NTN). As an proof of concept, we tested some of the planned extensions for 5G NR for NTN via a geostationary satellite. The 5G base station as well as the 5G user equipment utilized in our experiments were fully software-defined solutions. Both components were based on OpenAirInterface (OAI), an open-source implementation of the 5G New Radio protocol stack, which runs on general purpose platforms.**

I. Introduction

The latest generation of mobile communications, 5G, is set to revolutionize the world of mobile communications. Data rates far beyond the gigabit limit, a virtually unlimited number of networked devices, and ultra low latency are expected. But many of the performance parameters that mobile network operators are promising with 5G cannot be achieved with terrestrial networks alone. Communications satellites have evolved enormously in recent years. From weather-sensitive TV broadcasters and expensive relay stations for satellite phones in the last millennium to high-capacity, stable, broadband IP access networks. Technical developments, such as flexible and digital payloads and constellations of low-flying, high-throughput satellites expected to begin service in the next few years, are enabling performance in space that was barely imaginable a few years ago. A major evolution of 5G constitutes the upcoming integration of non-terrestrial networks (NTN) including both geostationary and low earth orbit satellite constellations.

The 3rd generation partnership program (3GPP) has completed the standardization of 5G in Release 15 and 16 and is currently completing standardization of NTN as part of Release 17, which is expected to be completed by the end of 2021. Early prototypes of this technology are important for the community and the standardization progress. This paper reports a first such prototype based on the OpenAirInterface (OAI) open-source software and off-the-shelf radio hardware and presents results from an over-the-air trial over a transparent GEO satellite.

II. 5G Standardization for non-terrestrial networks

After finalizing two study items in Release 15 [1] and Release 16 [2], the 3GPP Radio Access Network (RAN) working group currently specifies the extension of 5G New Radio to support Non-Terrestrial Networks as part of the Release 17. So, for the first time, satellite communication will be supported by the 3GPP standards which were formerly limited to terrestrial cellular networks. The RAN work item covers a frequency range from 2 to 30 GHz and GEO, MEO, and LEO satellite constellations. It is planned to support transparent payload based spaceborne as well as airborne 5G systems. Different terminal types are considered, either smartphone type with +23 dBm transmit power and omnidirectional antenna, or Very Small Aperture Terminals (VSAT) with directional antennas. A detailed link budget analysis for various system constellations is included in [2]. To complement the upcoming 5G New Radio broadband standard for satellites, another study item is carried out in 3GPP Release 17 on the adaptation of the LTE based technologies NB-IoT and eMTC to support low data rate use cases with satellites [3].

III. Status of OpenAirInterface 5G

OpenAirInterface™ (OAI) is an open-source project that implements 4G and 5G Radio Access Network (RAN) and core network as specified by the 3rd Generation Partnership Project (3GPP) on general purpose x86 computing hardware and Commercial Off-The-Shelf (COTS) Software Defined Radio (SDR) cards like the Universal Software Radio Peripheral (USRP). It makes it possible to deploy and operate a 4G Long-Term Evolution (LTE) as well as 5G New Radio (NR) networks at a very low cost [4].

Most terrestrial 5G NR deployments today use the non-standalone access (NSA) mode, which requires an existing 4G LTE network. For non-terrestrial deployment the standalone (SA) access is much more attractive, which does not depend on legacy LTE but requires a new 5G core network. Today OAI supports NSA and and soon also SA, as well as an intermediate mode called the noS1 mode which was used in the demonstration of the 5G NR NTN. It is a mixture of the NSA and SA modes where it is possible to connect an OAI UE to an OAI gNB without the support of an eNB or a connection to the core network. Only user-plane traffic is supported (except for the random access procedure, which is also happening in noS1 mode) which can be injected and received through a Linux network interface. At the UE all the configuration of the parameters is known beforehand and is fed to the UE through a configuration file.

A. Extensions for NTN Rel-17

The 5G NR stack as implemented by Fraunhofer IIS is based on the open source OAI NR stack and it implements a subset of the adaptations to support non-terrestrial networks as proposed in [1]. In 5G NR context, the reference architecture is depicted in Figure 1 and consists in a 5G NR link between UE and gNB, both on the ground, with the air Uu interface relayed by a transparent satellite.

The main impairment introduced on the 5G signal over the satellite channel is due to the large propagation delay which can amount to hundreds times the average terrestrial delay. The bent-pipe payload translates into a one-way propagation delay, from gNB to UE, which is the build up of the feeder link and user link propagation delay and a Round Trip Time (RTT) which is the delay over the path gNB-Satellite-UE-Satellite-gNB. Therefore, in a GEO satellite scenario (at 35786 km altitude), the one-way delay is in the order of 250 ms, with a rough RTT of 0,5 seconds.

In order to account for the longer satellite propagation delay, the main changes that have been implemented in OAI are: (i) The time domain allocation, determined by the parameter k_2, is extended by means of a slot offset k_{offset} corresponding to at least twice the one-way delay; (ii) The Random Access Response (RAR) window, is extended by means of a slot offset; (iii) Disabling of HARQ.

IV. 5G-NTN Trials over GEO satellite

We demonstrated the selected extensions of 5G NR to support future NTN successfully with a bidirectional transmission over a geostationary satellite. The satellite is located at 13.2 East and provided a single beam for our service zone in Germany. We carried out the bidirectional over-the-air tests based on the extended OAI 5G NR protocol stack for satellite. The ground segment equipment was located at the Munich Center for Space Communications a research facility for true over-the-air testing of satellite and space communications equipment and technologies located at the Bundeswehr University Munich in Neubiberg, Germany. The transmissions utilized a bandwidth of 10 MHz for the gNB uplink and gNB downlink. We selected a 4.9 m parabolic antenna that is able to operate between 7 GHz 11 GHz for both transmitting and receiving. The antenna receive gain is 50 dbi. Compared to terrestrial base station antennas satellite antennas usually have a very narrow directional antenna pattern which requires exact pointing towards to satellite. The GEO satellite itself operated as a relay which frequency-converted, amplified and forwarded the received NR signal in space.

Both gNB and UE were running on consumer computers with ETTUS X310 USRPs operating below 2 GHz. A block upconverter (BUC) was used in the transmission (uplink) of the satellite signals. It converted a band of frequencies from the lower USRP frequency to the higher satellite transmission frequency. We utilized a low-noise block downconverter (LNB) to convert the received satellite signals to the the lower USRP frequencies. All the traffic terminated at the gNB (no-S1 mode), so that no transport and core network was required for end-to-end IP traffic.

During the over-the-air tests, the UE performed the initial connection setup to the gNB by using a specifically adapted random access procedure for 5G over satellite. After the successful setup of the connection, the 5G uplink and downlink

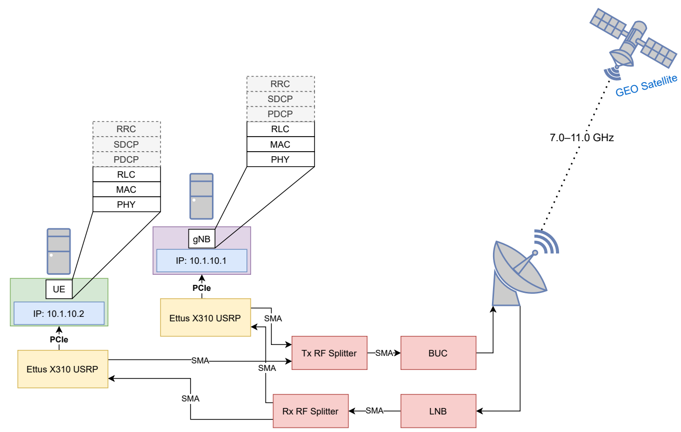

Fig. 1. 5G-NTN End-to-End Architecture (no-S1 mode). Prototype includes adapted PHY, MAC and RLC layer.

transmission signals were decoded with two different modulation schemes, namely QPSK and 16-QAM. Furthermore, a 5G timing advance (TA) procedure, which worked smoothly, was tested to keep the UE synchronized to the gNB.The implementation of this TA procedure revealed the drift of the used GEO satellite around its orbital station-keeping box. Both the UE and the gNB were located on ground, so that the round-trip time of the system from gNB. (IP: 10.1.10.1) to UE (IP: 10.1.10.2) and back was measured between 530 and 570 milliseconds utilizing the Linux ping command.

V. Conclusions

This first pre-test establishes the baseline for the further development of a standard compliant 5G NTN network. The work will be continued in the ESA funded 5G-GOA project. The project produces a hardware and software prototype, consisting of at least two user terminals and a base station to verify bi-directional end-to-end communication. We plan to demonstrate the end-to-end solution including a 5G core network, using the developed terminals and the modified 5G base station connected via a direct satellite link. The gNB based gateway and the UE compliant with the 5G New Radio standard release 17 will demonstrate the direct radio access connectivity in NTN using the full protocol stack over GEO satellite. HTTP based live video streaming will be presented to demonstrate the capabilities of the NTN network.

References

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