6G LINO - A 5G/6G satellite in Orbit realizing a NTN-Developer laboratory

Jens Haala
Digital Systems Development
Tesat-Spacecom
Backnang, Germany
Jens.Haala@tesat.de

Ralf Kurz
Digital Circuit Design
Tesat-Spacecom
Backnang, Germany
Ralf.Kurz@tesat.de

Laura Manoliu
Systems Development
Tesat-Spacecom
Backnang, Germany
Laura.Manoliu@tesat.de

***Abstract*—6G LINO is an in-orbit laboratory envisaged to execute various demonstrations. A consortium consisting of six members located in UK and Germany drives its development and operation. The goal is to have a flexible payload in orbit and demonstrate various use-cases for future 5G/6G applications. Therefore, the project is not limited to space assets but is also including ground equipment to enable feeder and user equipment links. The project has started recently and is currently in the design phase of the platform and the payload. This paper presents the preliminary design of the 6G LINO system and the challenges that are faced.**

***Keywords*—5G, 6G, laboratory, demonstration, gNodeB, transparent, regenerative, feeder link, user link.**

I. Introduction

Discussions on utilizing satellites in future mobile communication networks have been ongoing for years. The latest release of 3GPP standards also includes aspects of non-terrestrial networks [1]. However, to identify the best technical solutions for some of the remaining challenges and provide relevant recommendations to the community, it is essential to gain practical experience. Conducting such experiments, however, is complex and costly.

TESAT is proud being selected by ESA to lead a mission that brings a 5G/6G laboratory into orbit. A consortium has been established, comprising all the necessary assets and expertise to conduct experiments, including both space and ground segments. 6G LINO project is a pioneering initiative placing a full gNodeB in orbit. This platform combines satellite and terrestrial networks, featuring dual-band (S-band and K/Ka-band) duplex links and AI-driven spectrum monitoring for real-time channel optimization. Experimenters can access this platform to trial their algorithms, fostering open innovation. With reconfigurability, adaptability and performance, 6G LINO redefines global communication and positions Europe at the forefront of next-generation network technology.

This presentation provides an overview of the mission and the challenges that need to be addressed. The satellite features a digital processing payload that enables the configuration of various algorithms to simulate different scenarios. A high-performance programmable logic unit, paired with a multi-core processor, forms the foundation of the payload, along with RF equipment for feeder and user links. Additionally, the project includes corresponding ground equipment to support these efforts.

Finally, the presentation offers an outlook on the in-orbit experimentation phase of the mission. Four use cases are planned and will be executed by the consortium. Moreover, external parties are invited to develop and implement new experiments, either on real space hardware, ground infrastructure, or both.

II. Consortium Setup

The consortium consists of six members from two states. This chapter describe the responsibility of each member.

A. *TESAT*

TESAT is the prime of the project and mission. In addition, TESAT will develop and produce the digital payload for the satellite and coordinates the payload system development. This setup is special, as typically the platform manufacturer takes this role. However, TESAT has performed many projects as payload prime in large satellite projects and has experience in coordinating an international team. Taking over the primeship is a next step and strengthens TESATs system knowledge.

B. *Fraunhofer Institute for Integrated Circuits IIS*

Fraunhofer IIS has in-depth experience in 5G networks and own important assets to realize the demonstration phase of the mission. That is not only necessary RF infrastructure for establishing the feeder and user link to the satellite, but also the necessary gNodeB and Core Network infrastructure. Another lab containing User Equipment and terrestrial gNodeB completes the infrastructure needed for all sort of experiments.

C. *Open Cosmos*

Open Cosmos is a satellite manufacturer based in UK and has already successfully launched various sizes of CubeSats. For this project, they are developing a 16U CubeSat being able to operate the payload needed for the experiments.

D. *University of Surrey*

The work on this project will be undertaken by the 5G & 6G Innovation Centre and includes working on the use-cases and preparing the UK 6G facility for the tests.

E. *Airbus Defence and Space*

Airbus brings their experience in managing large-scale satellite missions. Their work is concentrating on end-to-end aspects.

F. VTT

VTT has been selected as provider of the RF payload components. That includes filters, amplifiers, and antennas for S- and Ka-band transmission links.

III. Communication Payload

The 6G LINO activity aims to design, develop, launch, and operate an entire satellite mission where the satellite itself ensures the maximum flexibility to be used as an open laboratory for 5G-Advanced, and 6G applications. This includes all segments: space, ground, and user segment. The primary objectives of the 6G LINO project include:

- Developing an experimental 6G system with a full gNodeB in orbit, integrating terrestrial (TN) and non-terrestrial (NTN) networks, performing hand-over and demonstrating the capabilities of each network across different scenarios;
- Supporting two duplex links in S-band and Ka-band to test connectivity across frequencies and across applications;
- Utilizing artificial Intelligence (AI)-driven spectrum monitoring to adaptively manage transmission channels.

The core component is a digital processor that contains a state-of-the-art chip offering not only a high-performance programmable logic but also a processing system capable of running an operating system (OS).

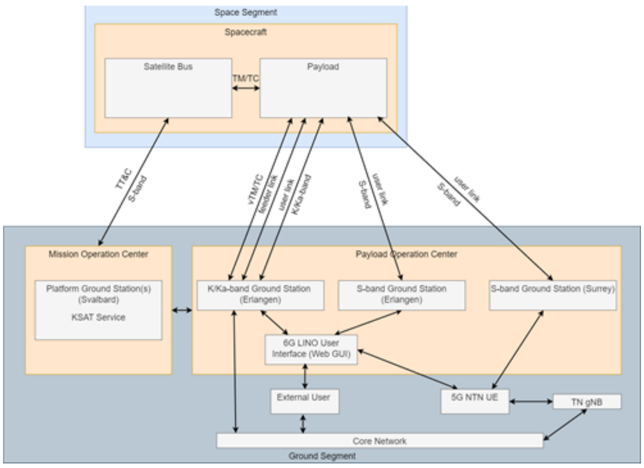

Fig. 1. 6G LINO system components and overview

The system consists of the space segment, which includes a satellite and the ground segment, which includes the mission operation center, the payload operations center, user terminals and a core network. The satellite payload contains a powerful digital processing unit with AI-cores, the capabilities and resources of implementing a full gNodeB in space, as well as two RF frontend circuitry: in S-band and Ka-band. The system allows user plane integration with the on board 5G radio access and it supports voice calls over NTN new radio, utilizing both transparent and regenerative payload architectures.

The 6G LINO system in Fig. 1 is the sum of all the segments: The space segment and the ground segment. The 6G LINO space segment refers to one spacecraft, a 16U CubeSat, which contains a satellite bus and a payload. The ground segment contains the TT&C link, performed through a dedicated platform ground station to/from satellite bus, via an S-band link and operated from the mission operation center (MOC). The payload operation center (POC) operates the payload. The payload is able to communicate with multiple ground stations located in Germany and UK.

Three ground terminals are in contact with the payload. The Ka-band link in Erlangen is initially used for Telemetrie/Telecommand (TMTC) to control and monitor the payload and to set-up the experiments. The Ka-band link can additionally be used as feeder link and as user link in desired use Cases. The S-band links are only used as user links for the experiments. While the platform switches on or off a specific link, the payload can enable the data transmission on a specific link by powering on the corresponding RF transceiver.

IV. Demonstration Phase

A demonstration phase of 12 months is planned to execute a number of tests and experiments. The consortium prepares 4 use cases for demonstration. However, the 6G LINO platform is open for other experiments, too. Experimenters outside the consortium are welcome to approach the consortium and ask for additional demonstrations. The consortium will support with knowledge, on-ground testbed and even development activities if in favour of the experimenter.

A. Use Cases

The consortium realizes four use cases and will demonstrate them during the demonstration phase. The resulting software and hardware can be used as basis for other demonstrations and test cases.

1) Use Case 0 – Initial Configuration

The first use case is a basic configuration that is also used as a fallback and can be considered as “golden image”. The functions includes the ability to upload and update the on-board processor incl. the digital processing hardware for the other use cases and additional new experiments.

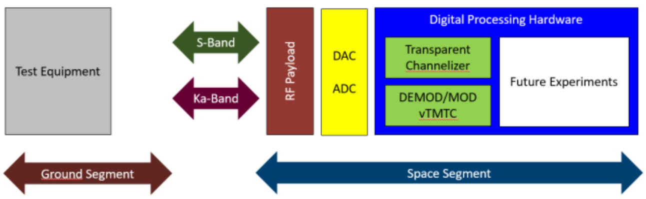

Fig. 2. 6G LINO - Use Case 0

As one can see the setup is quite simple and there will be no functionality dedicated to 5G or 6G. That saves memory space inside the digital payload for software and gateware images needed for experiments. The vTMTC channel is an additional TMTC channel. The data transmitted over this channel (using possibly the Ka-Band frequency band) is not adding up to the TMTC data used for the satellite maintenance. In addition the Ka-Band channel offers more bandwidth than the satellite TMTC. Therefore the upload of new software is much faster using that function.

2) Use Case 1 – End to End

Fig. 3 shows use case 1. It realizes an end-to-end configuration where a user equipment (UE) connects via a gNodeB to a core network. Use Case 1 consist actually of two scenarios. A transparent scenario, where the gNodeB is on the ground segment (upper figure in Fig. 3) or in a regenerative scenario with the gNodeB in the space segment (lower figure in Fig. 3).

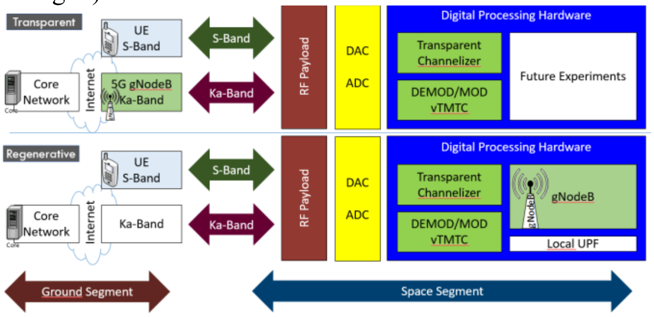

Fig. 3. 6G LINO - Use Case 1

3) Use Case 2 – Handover between NTN and TN

Use Case 2 is an extension of Use Case 1. To demonstrate the handover between terrestrial and non-terrestrial gNodeB a terrestrial gNodeB has to be added to the scenarios in Use Case 1.

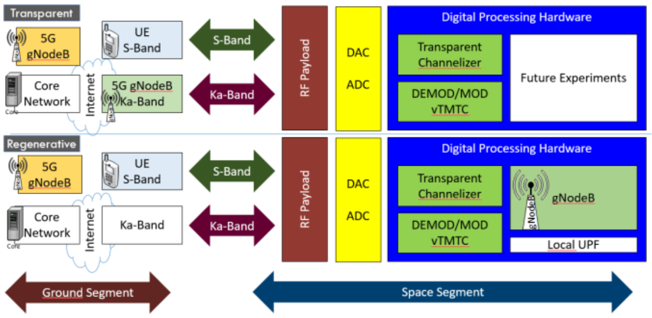

Fig. 4. 6G LINO - Use Case 2

It has to be noted that also for Use Case 2 there are again two scenarios foreseen. The scenarios cover the transparent and regenerative case.

4) Use Case 3 – Spectrum Monitoring

Spectrum monitoring in these bands can be beneficial in understanding the user activity level to enable dynamic spectrum sharing. Use Case 3 will enable spectrum monitoring on the space segment and evaluate to which extent artificial intelligence (AI) is able to support dynamic spectrum sharing. Furthermore, the spectrum monitoring can also be used to identify interference levels to enable higher data rates for broadband subscribers and support operation of larger number of IoT devices.

5) Use Case 4 – 6G Waveforms

3GPP defines for 5G NR a multi carrier OFDM waveform with cyclic prefix (CP) and supports single carrier discrete Fourier transform spreading OFDM (DFT-s-OFDM) only in case of limited uplink coverage. One of the main disadvantages of OFDM waveform is the high peak-to-average power ratio (PAPR). Waveforms with low PAPR allows to operate the PA with less non-linear distortion at the same OBO. To reduce the PAPR is among others one of the main goals of the new 6G waveform. Goal of the Use Case 4 is to implement other waveforms and demonstrate their performance in a real space environment.

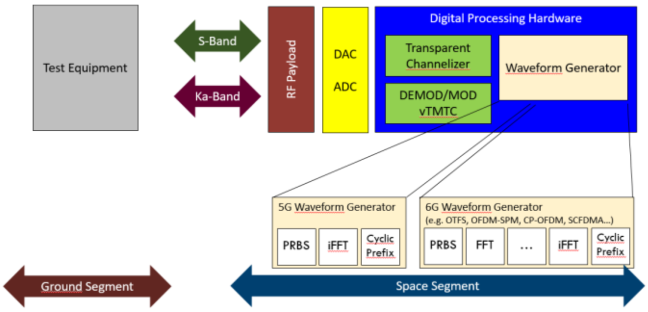

Fig. 5. 6G LINO - Use Case 4

Fig. 5 shows the setup of the digital payload for use case 4. It is clear, that for this use case also the terrestrial infrastructure has to be updated to support the waveforms as well.

6) Conclusion

The main challenge of such a project is to bring the 6G laboratory in space and operate it reliable in the LEO, considering its reconfigurable nature. Each experiment includes different software stacks and different on-board resource allocation. The Doppler shift and Doppler rates are playing a crucial role in the transparent mode requiring precise positioning and synchronization knowledge as well as real-time data processing. Connecting Surrey and Erlangen core networks through the 6G LINO orbiting in the LEO imposes strict accommodation requirements and careful consideration of satellite pointing as well as orbit trajectory. Another important aspect is the New Space philosophy, which this project is adhering to, combining high-TRL components with COTS devices in order to comply with the budget and the development timeline. Last but not the least, frequency coordination is an immense administrative challenge, particularly when using the S-band and Ka-band.

On the other hand, it is important to highlight that this project provides a unique opportunity to test and demonstrate 5G and 6G functionality in orbit. However, its scope is not limited to the space segment; it also includes terrestrial infrastructure for feeder links, user links and core network. Moreover, the assets are not exclusively available to the consortium. Other parties interested in utilizing the 6G LINO are warmly invited to contact the consortium to explore how their experiments can be supported.

V. Summary

This paper introduced the newly started 6G LINO satellite mission, which aims to build and operate an open laboratory for advanced 5G and 6G applications. The platform integrates satellite and terrestrial assets, featuring dual-band duplex links and AI-driven spectrum monitoring for real-time channel optimization as well as handover between NTN and TN by operating a fully functional gNodeB in the LEO.

Acknowledgment

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