AI for Satellite 5G Communications (AIComS)

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I. Introduction

The overall goal of the project "AI for Satellite 5G Communications (AIComS)" is to develop AI/ML-based software and hardware platforms for future products of an integrated satellite and 5G&beyond communication network that allows for NG-RAN logical architectures with different functional splits across the networking nodes. In particular, AIComS focuses on the development of components of the physical layer of the 5G NR based on Machine Learning (ML) from the low Earth orbit (LEO) satellites and gNB to provide communication between the terrestrial UE and IoT terminals (service link) and the gNB (feeder link) via LEO satellites. In addition, AIComS will develop 5G&beyond compliant ML-based routing, network slicing, and security components for LEO satellites that are connected via ISLs to form a satellite backhaul network. AIComS will further develop AI-based flight control algorithms to ensure accurate positioning of satellites in formation as well as orbit control concepts to guarantee satellite lifetime and communication service provisioning as required.

II. Technical Approaches

Non-terrestrial networks (NTNs) are key elements in the 5G network architecture to achieve ubiquitous coverage [1]–[3]. Satellites of NTNs refer to spaceborne vehicles in LEO, very low Earth orbit (vLEO), medium Earth orbit (MEO), geostationary orbit (GEO) or in highly elliptical orbit (HEO) possibly supplemented by high-altitude platforms (HAPs) as visualized in Fig. 1.

In AIComS, the main focus will be on (v)LEO-based NTNs, as they have advantages over other satellite orbits in terms of latency and propagation losses. Furthermore, regenerative satellite based 3GPP Next Generation RAN (NG-RAN) architectures [3] will be considered facilitating different payload options like Next Generation eNodeB (gNB) processed payload with or without inter-satellite-links (ISLs) or options that allow NG-RAN logical architectures with different functional splits by means of remote units (RUs), centralized units (CUs) and distributed units (DUs) [4].

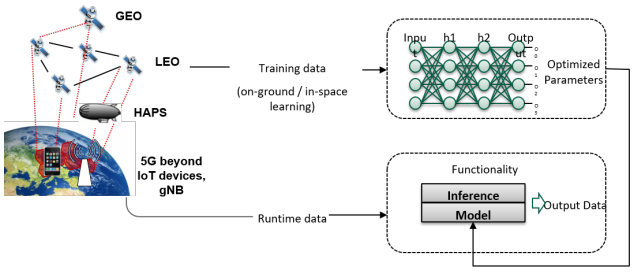

Fig. 1. Schematic mapping of AI/ML onto integrated satellite and 5G&beyond communication network

AIComS will develop main products for implementing key functionalities of a space based 5G&beyond network such as baseband processing, routing, security for communications and flight control for (v)LEO satellites. To this end, selected functionalities will be replaced by AI/ML-based counterparts, as illustrated exemplarily in Fig. 1.

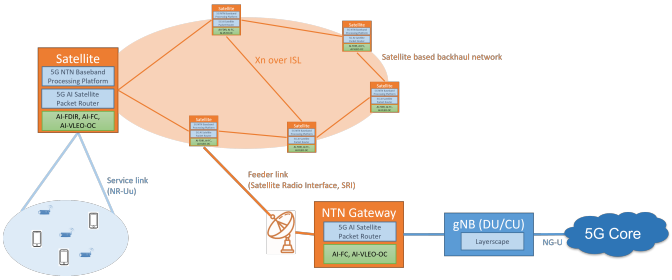

Fig. 2. Regenerative satellite based NG-RAN architecture

Fig. 2 illustrates the regenerative satellite based NG-RAN architecture as well as the assignment of the main target products to the network elements to be developed in AIComS. This figure shows a single option of 5G functional placement of RU/DU/CU currently under discussion by 3GPP and O-RAN. Other split options will be considered in the project as well. Subsequently, the main target products are described in more detail.

A. 5G NTN Baseband Processing Platform

In the 5G Open Radio Access Network (ORAN) architecture, the gNB functionality can be split into RU/DU/CU with the possibility to also collocate functionality. The actual placement of key functionalities to these elements is determined by the chosen functional split. Within AIComS a High Performance Data Processing Unit (HPDPU) will implement the corresponding gNB functionality on satellites and the remaining gNB functionality is realized by the NXP Layerscape® platform on ground as indicated in Fig. 2. The HPDPU is a powerful and innovative hardware platform that targets flexible but low-cost computations for satellite-based baseband signal processing for 5G NTN systems. It will enable ultra-fast and parallel processing of modern fault-tolerant deep learning algorithms with inherent stochastic robustness, e.g. Bayesian networks. The NXP Layerscape® provides a software-defined unit for higher layer processing. Promising functional split options for the 5G NTN system will be investigated in AIComS. Furthermore, ML-based approaches for PHY layer processing that complement satellite processing are subject to research. To this end, we will investigate on-ground learned ML-based receiver approaches. In addition, transfer learning and few-sample learning concepts will be exploited for in-space learning.

B. 5G AI Satellite Packet Router

AIComS will develop the 5G AI Satellite Packet Router (5G-AI-SPR) to support the increasing traffic demands and the demanded flexibility to handle the ever changing network topologies in satellite systems. Update capabilities will be mandatory to answer the changing nature of the networks. New security features will be developed and studied to improve the overall security of potentially large systems and path the way for secure updates in such systems. The Artificial Intelligence (AI) supported control plane could increase the routing and network slicing capacity and deal with not deterministic describable network traffic. On-ground and in-space learning can be combined to get the best possible system performance with the given computing power of the different entities. The determinism in the motion profile of the satellites can be exploited to reduce the complexity of the ML procedures and to improve the quality of the training data. The end product could be capable to serve routing and network slicing capabilities in the 100 Gbps range.

C. Satellite Flight Control

For (v)LEO satellites the communication payload design has to be closely coordinated with the attitude and orbit control system (AOCS). Thus, during the pass of a ground station, the antenna tracking by the AOCS at the high relative velocity of the satellite with respect to the Earth's surface has to ensure the link quality. 5G-service provision requires implementing the communication payload sub-components in strong link with AOCS and power provision needs. The operational integrity is maintained for each individual satellite by related fault detection, identification and recovery (FDIR) methods, the overall integration of all individual satellites to a self-organizing system is realized by the formation control (FC) in order to meet the 5G NTN data provision (service) requirements. Basis for this are ISLs, where all satellites exchange data for coordination activities (e.g., providing coverage and routing capabilities, collision avoidance). ISLs might require appropriate antenna pointing and tracking, such that the target is in field of view and a link can be established. In this very dynamical system, suitable simulation environments are to be established to allow the necessary tracking. For the operation of satellites AIComS will develop data driven approaches by means of AI-based-FC (AI-FC), AI-based-FDIR (AI-FDIR), and AI-based (v)LEO Orbit Control (AI-vLEO-OC).

III. Consortium and Company benefits

The project AIComS is part of the ARTES strategic program line "Space for 5G & 6G" within the ESA ARTES 4.0 Technologies and Products frame and started November 2022. The Department of Communications Engineering at the University of Bremen is the prime contractor. Subcontractors are Deutsches Zentrum für Luft- und Raumfahrt e.V., DSI Aerospace Technologie GmbH, NXP Semiconductors Germany GmbH, Tesat-Spacecom GmbH & Co. KG, Smart Small Satellite Systems GmbH (S4), and Zentrum für Telematik GmbH. In addition, Nokia Solutions and Networks GmbH & Co. KG and OHB System AG support the project as associated partners.

The tight cooperation with the research institutions enables the companies involved in AIComS to align the development of the innovative technological approaches and concepts with their product specifications and market strategies at an early stage. This early coordination and harmonization of technologies enables companies to actively the standardization processes for 5G-NTN or 3D networks of 6G - a prerequisite for being in a leading market position in the future and benefiting from the economies of scale of the mobile communications market.

Acknowledgment

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References

[1] B. Di, L. Song, Y. Li, and H. V. Poor, "Ultra-dense LEO: Integration of satellite access networks into 5G and beyond," *IEEE Wireless Communications*, vol. 26, no. 2, pp. 62–69, 2019.

[2] I. Leyva-Mayorga, B. Soret, M. Röper, D. Wübben, B. Matthiesen, A. Dekorsy, and P. Popovski, "LEO small-satellite constellations for 5G and beyond-5G communications," *IEEE Access*, vol. 8, pp. 184 955–184 964, 2020.

[3] 3GPP, "Solutions for NR to support non-terrestrial networks (NTN)," *TR 38.821 V16.1.0*, May 2021.

[4] ——, "NG-RAN; Architecture description," *TR 38.401 V17.3.0*, Dec. 2022.