Paving the Way Towards an NTN-Native 6G Ecosystem: the NexaSphere Approach

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Abstract—**The unification of terrestrial and non-terrestrial networks (TN/NTN) into a common 6G umbrella is one of the main objectives of IMT-2030 and then further reflected into the standardisation activity plan within 3GPP for releases 20 and following. Achieving such a goal is very ambitious, as it entails many technical challenges, ranging from unification of the radio access to networking aspects, all bridged together by means of an effective management and control infrastructure suitable distributed across ground and space assets. The NexaSphere project is aimed at providing the main building blocks to achieve such a unification, by addressing the main aspects from antennas to network integration, through AI-based network control and orchestration optimisation. This short paper overviews the main direction of the projects and introduces the main development streams from industry and research exploitation standpoint.**

Index Terms—**NTN, 6G, AI, Architecture, Unification, 3GPP**

I. INTRODUCTION

The integration and convergence of non-terrestrial networks (NTN) into the final phase of 5G (i.e. 5G-Advanced) [1] has culminated with the contribution to the relevant 3GPP Rel. 17-18 specifications and paved the way towards the inclusion of NTN into the 6G roadmap [2], starting from the ongoing Rel. 19. While the first releases addressed the case of transparent satellite, the recent one and those planned for the future are considering the case of on-board processing satellites, which open the door to the deployment of more advanced processing, computing, and network functions in space. This path has been supported by industry and research organisations by means of internal programmes and a number of projects funded by European Space Agency (ESA) and European Commission (EC). Notably, EC has supported the integration of NTN into the overall transitional map from 5G to 6G through the 6GSNS JU[1] and the relevant projects funded from the first Call, i.e. 5G-STARDUST [3], 6G-NTN [4], and ETHER [5]. More recently, the third EC HE SNS Call has featured a NTN-dedicated project, NexaSphere, standing for "Nexgen 3D Networks Spin Harmonies Across 6G, AI, and Unified TN/NTN", that started on January 1st 2025 and will last for three years.

NexaSphere aligns to the ongoing efforts of the overall community towards the unification of TN and NTN under the same umbrella, by designing the boundaries of such 3D 6G network system and developing the main constituting elements, by addressing both enabling physical layer technologies and networking elements, all conveniently bridged together by an AI-based control infrastructure. The NexaSphere project represents the logical continuation and extension of the research struggles committed by the projects from Call 1 and more importantly develops on strategic priorities from EC, such as a sustainable system offering radio ubiquitous connectivity to industry and society in a broad sense and hence also aligning to the objectives of the ongoing IRIS[22] system development.

The remainder of this paper is structured as follows. Section II presents the main objectives of the paper and related reference scenario, while Section III presents the considered architectural concept and the main building blocks serving as foundation for the NexaSphere system. Finally, Section IV draws the main conclusions and reports the next steps envisioned in the work-plan of the project.

II. REFERENCE SCENARIO

The NexaSphere project features an ambitious work programme, ultimately aimed at demonstrating the potentials of a 3D NTN-based 6G system to serve automotive, aeronautics, and railways vertical sectors. To reach this main goal, a number of key technical objectives have been defined to draw the roadmap to accomplish the NexaSphere mission, which are summarised hereafter:

- To target a set of use cases of mobile transportation, smart industry, society and PPDR for 2030 and beyond by assessing the societal impact of a 3D TN-NTN integrated network.
- To define the technical specification for a sustainable 3D TN-NTN integrated communication system architecture featuring connectivity continuum of radio frequency

links, long-range and short-range wireless-optical links for all network components across ground and space.

- To study, design, and analyse a 6G-based satellite network, implementing onboard processing and storage capabilities towards effective networking and mobile computing in the sky.
- To achieve sustainable data communication through energy-efficient air-interface operations achieved by means of Ku/Ka user terminal antennas and LiFi-enabled devices.
- To achieve effective coexistence of TN and NTN by means of advanced data-driven multipath connectivity solutions.
- To achieve edge-cloud continuum through space and ground network nodes by means of flexible cross-domain orchestration concepts.
- To achieve optimal resource allocation across the whole 6G 3D integrated network, by means of a self-adapting network paradigm.
- To design, implement, and demonstrate (up to TRL 5) E2E services over a fully integrated TN-NTN advanced network architecture with regenerative space nodes for aeronautics, railway, and automotive verticals.

The overall reference scenario taken as baseline in the NexaSphere project is depicted in Figure 1, where the key elements such as integrated TN-NTN framework, regenerative satellite, optical links, and the main verticals are sketched. In particular, it can be noted that the main characteristic of the NexaSphere system is the fusion of ground and space assets in a polymorphic network architecture, which can adapt to traffic conditions and the corresponding final users thanks to the exploitation of diverse technologies and the transversal optimisation of the main involved functions through AI–based decision engines. In this respect, a special attention must be devoted to the deployment of FSO feeder-links, which may be subject to outage because of harsh atmospheric events, hence calling for proper countermeasure at physical and networking layer, in terms of space-diversity solutions and store-forward capabilities. Another key challenge is to achieve an effective network disaggregation concept, so that the proper NG-RAN functional split options are considered for use in such a complex and distributed environment. Last but not the least, the harmonisation of all data connectivity functions must be provided by a suitable orchestration infrastructure, acting in a distributed manner and able to exert control and network configuration in a multi-domain fashion, given the targeted coexistence of TN and NTN segments.

III. ARCHITECTURE CONCEPT

According to the project objectives summarised in the previous section, the overall foundation of the project consists of the following main components:

- Stakeholders: external users, representing the verticals requesting connectivity and data services through the NexaSphere system.
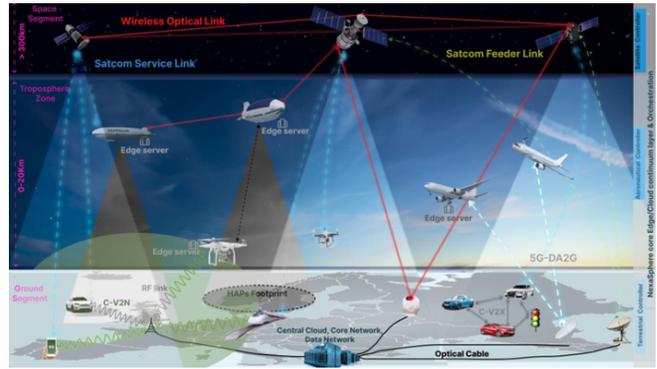

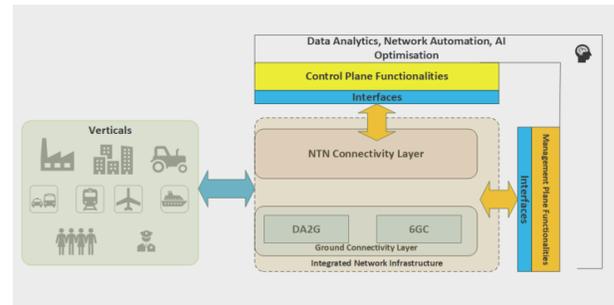Fig. 1. NexaSphere: Reference Scenario

Fig. 2. NexaSphere: Architecture Concept

- Integrated Network infrastructure, consisting of a unified TN/NTN infrastructure involving both NG-RAN and 6G core elements, as well as non-3GPP native segments.
- Control and Management plane functionalities, whose aim is to steer and regulate all data operations in an harmonised and effective way.
- Data analytics, network automation, AI optimisation, which serve as overarching layer on top of control and management planes and providing the necessary decision engines to guarantee optimal network operations.

The overall concept is sketched in 2, where the aforementioned components are visualised and the related interfaces also indicated. It is also worth remarking that the verticals are considered as externals to the systems, but their requirements are exposed through the relevant interfaces (i.e. northbound interfaces) to control and management plane functionalities, for the corresponding lifecycle optimisations conducted through the overarching layer. The specific implementation of data analytics and the usage of specific AI techniques is only partly aligned with the recommendations worked out in 3GPP and ETSI ENI (Experiential Network Intelligence), since some of them are specific of the technologies being considered in the project (i.e. optical links, LiFi, DVB-based satellite technologies).

IV. CONCLUSIONS

This paper introduced the approach currently taken from the HE 6GSNS-funded NexaSphere project, aimed at unifying terrestrial and non-terrestrial networks into a unique 6G

ecosystem, by bridging together sky and ground segments through a flexible 3D network architecture. Some emphasis has been given to the main components of the system aimed at providing a fully-softwarised network architecture, whose control and data plane elements will contribute to achieve optimal system operations through suitable AI-based solutions. The final objective is to come up with a system definition meeting the main requirements exposed by key verticals such automotive, aeronautics, and railway vertical sectors, for which dedicated demonstrations will be carried out in the second phase of the project.

The next steps of the project will be the first draft of the system architecture and the conception of the main building blocks to be further developed in view of the final integration.

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