5G-STARDUST: Multi-Connectivity Exploitation in Future 5G-NTN Systems

Tomaso de Cola, Benjamin Barth, Roshith Sebastian
Institute of Communications and Navigation
German Aerospace Center (DLR)
Oberpfaffenhofen, Germany
email: (tomaso.decola, benjamin.barth, roshith.sebastian)@dlr.de

***Abstract*—5G-STARDUST is the EU SNS funded project from Call 1-2022 dealing with the consolidation and evolution of 5G-Advanced 3GPP phase towards the inclusion of NTN as native element of forthcoming 6G systems. The unification of TN and NTN architectures is a challenging exercise in light of the different physical and functional peculiarities there exposed, which have resulted in non-converging networks in the past decades. In particular, the case of multi-connectivity support is particular compelling from a business and system operation standpoint, but it introduces some key research challenges because of the diverse operating conditions of TN and NTN, whereby a novel and unified framework is needed. In this regard, this paper illustrates the main directions taken from the 5G-STARDUST project and overviews the design of an integrated testbed to demonstrate the potentials for multi-path protocol exploitation in 5G-NTN integrated networks.**

Keywords*—*Non-terrestrial Networks, 5G-Advanced, SNS, Network Integration, Multi-Link connectivity

I. Introduction

The recognition of non-terrestrial networks (NTN) at 3GPP standardisation and overall industry level [1] as one of the technology enablers for meeting the service requirements expected in the IMT2030 vision is paving the way towards the unification of terrestrial and non-terrestrial networks in the forthcoming 6G systems. In this respect, it is worth recalling that 6G will represent an important evolution of 5G systems, by leveraging on the important technology achievements currently recorded in the present 5G-Advanced phase of the 3GPP standardisation, which is being consolidated with Rel. 19 on the basis of the already concluded Rel. 17 and 18. As such, an important element of this evolutionary path is represented by the integration of NTN into 5G [2], which has been object of many national and international initiatives at worldwide level from both academia and industry. Notably, the Smart and Networks Services (SNS) Joint Undertaking (JU) within the EC Horizon Europe (HE) programme and the 5G Strategic Programme Line (5GSPL, later re-denominated as 6GSPL) from ESA have importantly contributed to achieving a more unified vision of how TN and NTN could interwork in the present context of 5G and in the forthcoming landscape of 6G [3].

With respect to the HE SNS-JU programme development, a special note has to be devoted to the 5G-STARDUST ("Satellite and Terrestrial Access for Distributed, Ubiquitous, and Smart Telecommunications") project[1] that has receive co-funding from the first **HE SNS call within Stream A-01-02** *"Ubiquitous Radio Access"* in year 2022. Its main mission is to design, develop and demonstrate a deeper integration of TN and NTN, by delivering a fully integrated 5G-NTN autonomous system with novel self-adapting end-to-end connectivity models for enabling ubiquitous radio access. Such an ambitious vision builds on very tangible objectives that corresponding to the main R&D directions followed by the project:

- To define an integrated terrestrial-satellite network building on 5G-compliant regenerative satellite payloads, enabling cost-effective connectivity in un(der)served areas.
- To ensure a more efficient user connectivity concept by providing geographic coverage according to user-centric approaches (i.e. cell-free strategies).
- To define a self-organised end-to-end network architecture able to adapt to diverse verticals' requirements and to time-varying network operations (e.g., data traffic loads and topology changes).
- To provide end-to-end network flexibility by means of data driven AI-based multi-connectivity and resource allocation strategies.
- To guarantee cost reduction and capability to scale up the integration of satellite with terrestrial infrastructures to efficiently manage the deployment and operation of massive capacity networks.

In more detail, the 5G-STARDUST is aimed at exploring the potential of regenerative payloads, in the overall framework of *5G-Advanced*, so that space nodes have to be intended as smart flying nodes able to provide connectivity according to the well-established communication and networking 5G paradigms. As such, the 5G-STARDUST project assumes the implementation of a full gNB in space, hosted on satellite platforms along with dedicated User Plan Functions (UPF), necessary to perform specific networking functions in space such as QoS management, routing [4], edge computing [5],

[1]More details available at the project website, reachable at https://5g-stardust.eu/

just to cite a few. In particular, the convergence of TN and NTN under the same communication ecosystem opens up the door to multi-link connectivity to allow user establishing data connectivity through different network paths also simultaneously, hence enabling more effective capacity exploitation and eventually load balancing too. Achieving such a complex picture is quite ambitious and is subject to many scientific challenges arising from the fact that TN and NTN exhibit very diverse physical characteristics and providing a common framework for multi-party multi-link communication is a very ambitious exercise, which is further detailed throughout the rest of the paper.

In more detail, the remainder of the paper is structured as follows. Section II introduces the main scenarios under study and the resulting architecture designed for fulfilling the project objectives. Them Section III addresses the multi-connectivity options considered in the study, with a special note dedicated to the testbed under development. Finally, considerations about the next steps to carried out in the project and the preliminary lessons learnt from the study conducted so far are drawn in Section IV.

II. Reference Scenario and Architecture

The overall reference scenario taken as baseline in the 5G-STARDUST project is depicted in Figure 1, where the key elements such as integrated TN-NTN framework, regenerative satellite and usage of AI-based functions are sketched.

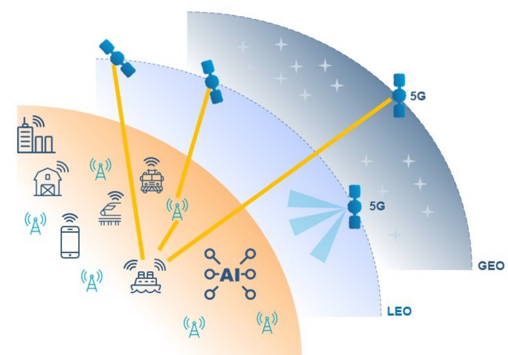

Fig. 1. 5G-STARDUST: Reference Scenario

In order to exploit the potentials of the aforementioned network concept, a number of corresponding use-cases have been correspondingly drawn, in terms of 1) *dual connectivity* and 2) *architecture and service distribution*. As to the former, it is about the actual coexistence of terrestrial and non-terrestrial infrastructure, whereby the opportunity of alternately or simultaneously exploiting them is an added value. On the other hand, the latter builds on the concept of service-based architecture pushed forward since the initial conception of 5G, whereby new use cases targeting the convergence between terrestrial and non-terrestrial network architectures are identified. Achieving an effective data distribution and provide an appropriate connectivity model for the above use-cases is the key function for a reference architecture, whose design has been one of the key exercises done in the first phase of the 5G-STARDUST project. In particular, the foundation of the network architecture has been the allocation of gNB functionalities in space in a distributed fashion, to achieve a more flexible satellite payload concept able to meet possible SWaP constraints. In more detail, it is assumed that all satellites are embarked with a 5G-enabled payload (i.e., implementing 5G functionalities), but their activation depends on the specific satellite operation in terms of data traffic being services and geographical coverage. In addition to that, user-plane functionalities are also implemented onboard satellite, in order to enable routing procedures in space, QoS management (by logically core to RAN slicing), and multi-link connectivity. Last but not the least, the availability of gNB in space along with UPF can enable the development of edge caching and computing concepts, which are becoming particularly attractive for a few scenarios.

III. Multi-Connectivity Exploitation

As mentioned in the previous section, the opportunity of deploying gNB and UPF functions in space enables new use-cases but also broaden the applicability of some functions typically delegated to the terrestrial core network, such as multi-connectivity concept. In this respect, the starting point is represented by the ATSSS functionalities suitably adapted to support the coexistence of multiple 3GPP-native solutions. In particular, the exploitation of multi-path protocol solutions is considered promising because of the intrinsic functionalities of traffic fetching and dispatching to different links, by even simultaneously exploiting the resources available from more than one link and hence naturally achieve load-balancing. In this framework, natural solutions are then represented by MPTCP and MPQUIC, the former being long standardized in IETF whereas the latter is still in the approval process that may complete not earlier than late 2024. In particular, MPQUIC offers interesting capabilities mostly inherited from the characteristics of QUIC, especially for what concerns the establishment of secure end-to-end data transactions, whereas MPTPC (similarly to TCP alone) must rely on additional protocols or related extensions to provide security features.

On the other hand, the adaptive allocation to traffic flows to the different available network segments necessitates advanced scheduling and fetching mechanisms, suitably coordinated by an end-to-end controller. This opens the door to exploiting AI/ML-based algorithms for optimally selecting the best paths through a dedicated path manager and make use of the recorded network status (i.e., registered KPI, traffic fluctuations, etc.) through the NWDAF module as input to the actual optimization modules. The general architecture is then presently being implemented in a dedicated testbed (sketched in Figure 2), where all the aforementioned nodes and related protocol functionalities are identified. It is also worth noticing that AI functionalities are also being considered for implementing effective traffic prediction algorithms, necessary to forecast possible variations in demands of network resources and hence accordingly trigger the decision making process at the path manager for what concerns the adaptation or reinforcement of given traffic splitting and switching policies.

Last but not the least, the testbed will also be integrated with the more general-purpose project demonstrator, whose general aim is to show the interworking of TN and NTN in a general 5G-based framework, where real and emulated assets are integrated in a test bench hosted by Thales Alenia Space

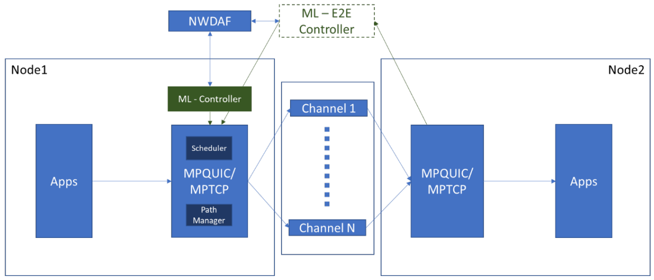

Fig. 2. 5G-STARDUST: Reference Scenario

France in Toulouse, whose finalisation is planned for early Summer 2025 with system demonstrations happening then in second half of the year.

IV. Conclusions

This paper focused on the main technology enablers taken as reference by the 5G-STARDUST project, namely with respect to radio interface unification, self-organised network architecture, and regenerative payload exploitation towards an effective unification of terrestrial 5G/6G ecosystems and NTN counterparts. In this respect, a special attention has been devoted to the potentials offered by multi-connectivity networking paradigms offered by the 3GPP-based ATSSS framework and its related implementation through multi-path protocol such as MPTCP and MPQUIC. In particular, the future direction of the project is to finalise the development of a dedicated testbed integrating multi-path capabilities along with AI-based functionalities to optimally allocate data path and schedule traffic flows accordingly. Last but not the least, the ultimate goal of this activity will be integrate the aforementioned testbed with the broader scope proof-of-concept (PoC) under development in the 5G-STARDUST project, whose final goal is to prove the performance benefits stemming from a full convergence of TN and NTN systems within a common 5G/6G framework.

Acknowledgment

5G-STARDUST project has received funding from the Smart Networks and Services Joint Undertaking (SNS JU) under the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101096573. This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

References

[1] M. Giordani, M. Polese, M. Mezzavilla, S. Rangan, and M. Zorzi, "Toward 6g networks: Use cases and technologies," *IEEE Communications Magazine*, vol. 58, no. 3, pp. 55–61, 2020.

[2] A. Guidotti, A. Vanelli-Coralli, V. Schena, N. Chuberre, M. El Jaafari, J. Puttonen, and S. Cioni, "The path to 5g-advanced and 6g non-terrestrial network systems," in *2022 11th Advanced Satellite Multimedia Systems Conference and the 17th Signal Processing for Space Communications Workshop (ASMS/SPSC)*, 2022, pp. 1–8.

[3] X. Lin, S. Cioni, G. Charbit, N. Chuberre, S. Hellsten, and J.-F. Boutillon, "On the path to 6g: Embracing the next wave of low earth orbit satellite access," *IEEE Communications Magazine*, vol. 59, no. 12, pp. 36–42, 2021.

[4] M. Roth, H. Brandt, and H. Bischl, "Implementation of a geographical routing scheme for low earth orbiting satellite constellations using intersatellite links," *International Journal of Satellite Communications and Networking*, vol. 39, no. 1, pp. 92–107, 2021.

[5] D. Bhattacherjee, S. Kassing, M. Licciardello, and A. Singla, "In-orbit computing: An outlandish thought experiment?" in *Proceedings of the 19th ACM Workshop on Hot Topics in Networks*, ser. HotNets '20. New York, NY, USA: Association for Computing Machinery, 2020, p. 197–204.