The 5GENESIS testing facility as an enabler for integrated satellite/terrestrial 5G experimentation

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***Abstract*—Satellite/terrestrial integration in the context of 5G is a very promising aspect, as it combines the unrivaled performance of 5G with the unprecedented benefits of satellite communications, such as ubiquitous broadband coverage and inherent multicast capabilities. This paper presents the design and implementation of an end-to-end experimental testbed for integrated satellite/terrestrial 5G services, developed in the frame of the EU 5GENESIS project. The testbed encompasses all the components of the 5G network and it is suitable for wide-area field trials over several use cases corresponding to the needs of vertical industries.**

Keywords—Satcom, 5G, satellite-terrestrial integration, experimentation

I. INTRODUCTION

Ubiquitous broadband connectivity, extended to rural and low-density areas as well as supporting long-haul transportation media, is recognized as a key requirement for 5G [1]. To that end, the role of satellite networks in tomorrow's communication landscape is indeed irreplaceable to reach those areas where the terrestrial service is limited or simply not available, as well as for the delivery of services that can be more efficiently supported through satellite communications (e.g. broadcasting services). The new generation of satellites, using diverse technologies and configurations (e.g., use of Ka, Q/V-band High Throughput Satellites or HTS, Low Earth Orbit/Medium Earth Orbit or LEO/MEO constellations) are offering high capacity and ubiquitous connectivity under all circumstances and all locations. By 2020-2025 it is expected that there will be over 100 HTS systems in orbit, delivering Terabits of connectivity across the world using Ku- and Ka- bands [2]. Interworking of HTS systems and terrestrial technologies is envisaged to ensure a high-speed, robust, inclusive 5G ecosystem. The supported services are not limited to personal communications and Internet access but also embrace many others such as multimedia distribution, critical communications services and Machine Type Communications (MTC) [3]. For all these reasons, satellites are considered an essential element of future 5G infrastructures [3][4]. Remarkably, a requirement for 3GPP systems to be able to provide services using satellite access has been included within the normative Stage 1 requirements for next generation mobile telecommunications being elaborated by 3GPP [5]

Several R&D projects, such as H2020 SaT5G [6] and ESA SatIs5 [7] are already developing lab-based integrated demonstrators to showcase and assess specific features of Satcom and 5G integration. The next crucial step in this direction is the establishment of an end-to-end integrated satellite/terrestrial 5G network testbed, which encompasses all the domains of the 5G infrastructure and is suitable for field experimentation by potential end users representing vertical use cases/industries. This is among the objectives of the 5GENESIS project.

II. THE 5GENESIS EXPERIMENTAL FACILITY

5GENESIS (5th Generation End-to-end Network, Experimentation, System Integration, and Showcasing) [8] is a European project funded under the EU Horizon 2020 framework programme. The aim of 5GENESIS is to build a European end-to-end 5G experimentation facility for validating 5G KPIs and allowing testing of various vertical use cases. To that end, a key challenge undertaken by the project is to integrate highly diverse results and technologies from EU, global as well as internal (corporate) R&D projects, to "glue together" the 5G picture and unveil the potential of a truly full-stack, end-to-end 5G platform, able to meet the defined KPI targets. 5GENESIS started in July 2018 and is currently in its first phase, finalizing the overall technical design and commencing implementation.

The 5GENESIS facility (Fig.1) is distributed across five experimental platforms in five EU cities (Athens, Malaga, Berlin, Surrey and Limassol). The platforms have diverse yet complementary capabilities, while all of them implement the full 5G stack and integrate all essential components, as defined by 3GPP.

Fig. 1. The five platforms of the 5GENESIS facility

The Limassol platform, described in this paper, is one of the five platforms of the 5GENESIS Facility. The unique feature of the Limassol platform is that it incorporates a satellite communications component in the 5G infrastructure, and its aim is to show the unique benefits of Satcom-5G integration by validating the associated vertical use cases.

III. Overview of the Limassol platform

The Limassol 5G platform will integrate several infrastructures in the city of Limassol, Cyprus, in order to form an interoperable multi-radio facility, combining terrestrial and satellite communications with the ultimate aim of efficiently extending 5G coverage to underserved areas. To this end, the Limassol 5G platform will employ NFV and SDN enabled satellite communications as well as tight integration of different access and backhaul technologies, in order to achieve the following innovative features: i) ubiquitous coverage with reduced latency, ii) support for multi-radio slicing, iii) 5G throughput enhancement via air interface aggregation, where necessary and iv) dynamic spectrum allocation between satellite and terrestrial. Fig.2 depicts a high-level topology of the Limassol platform, highlighting the main assets involved.

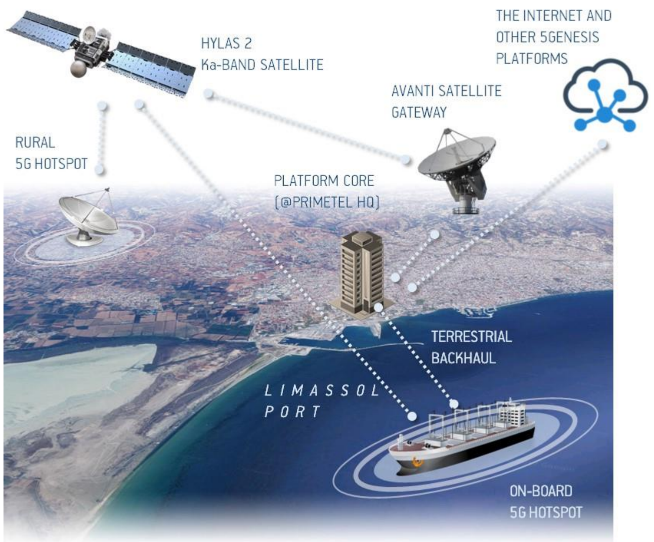

Fig. 2. Key infrastructures and assets of the Limassol Satcom/5G platform

The key infrastructures on which the platform will be built are:

- The Avanti Satellite Gateway at Makarios Earth Station. The Avanti Ground Earth Station facility in Cyprus will be used to provide managed Satcom services over its HYLAS 2 and HYLAS 4 satellites using a professional grade network platform supporting efficient transport of cellular traffic, as well as management interfaces and APIs via its cloud operational support system (OSS) and network platform (NMS);
- The Primetel R&D experimental testbed in Limassol. It is located in the company's central building close to the Limassol port. The Primetel testbed will act as the core node of the platform by: i) hosting, in its private Data Centre, all the management components and services for the platform, ii) providing the interconnection to the Satellite Gateway and the Internet, as well as to the other 5GENESIS platforms.
- A remote site, which will host the edge 5G equipment necessary for deploying ad-hoc remote 5G hotspots. This includes the backhaul (satellite and terrestrial) link terminals, edge computing equipment, software-defined networking switches as well as a 5G gNB.
- A cargo vessel (crude oil tanker), operated by Maran Gas Maritime, will be used to showcase 5G maritime communications (see use cases description in Sec. V) while a second scenario will be deployed in rural and underserved areas.

IV. Architecture, Topology and Components

A. *Functional architecture overview*

The overall functional architecture of the Limassol testbed is shown in Fig.3. The architecture is aligned with the common reference architecture of 5GENESIS [9] which applies to all its five platforms. The 5GENESIS reference architecture ensures that each platform is administratively independent, yet interoperable with the other platforms. It also consolidates all elements which have been identified as essential in 5G networks, including: 5G New Radio (NR) RAN; 5G NG Core; service and resource slicing with service automation; satellite and terrestrial backhauling; Network Functions Virtualization (NFV); Software-Defined Networking (SDN); Multi-access Edge Computing (MEC); User Plane/Control Plane (UP/CP) separation; spectrum management. The proposed platform reference architecture inherits several concepts from relevant 3GPP documents (e.g. TS 23.501, TS 23.502 and TS 23.503) as well as from the ETSI NFV ISG and ETSI GS MEC. It is also compliant with the 5G generic architecture, as defined by the 5G PPP [10].

As seen, the architecture of the Limassol platform is split into three main layers: Coordination, Management & Orchestration and Infrastructure. The principal functional components of the layers are described below.

B. *Functional components and selected technologies*

1) *Coordination Layer*

At the Coordination layer, the key component is the *Platform Coordinator* module. Its role is to provide the interfaces to the Experimenters (graphical and programmatic/API) for the configuration and the automated execution of the experiments. It is also in charge of the management of the experiment lifecycle and the processing and visualization/export of measurements. The Platform Coordinator will be designed and developed in the

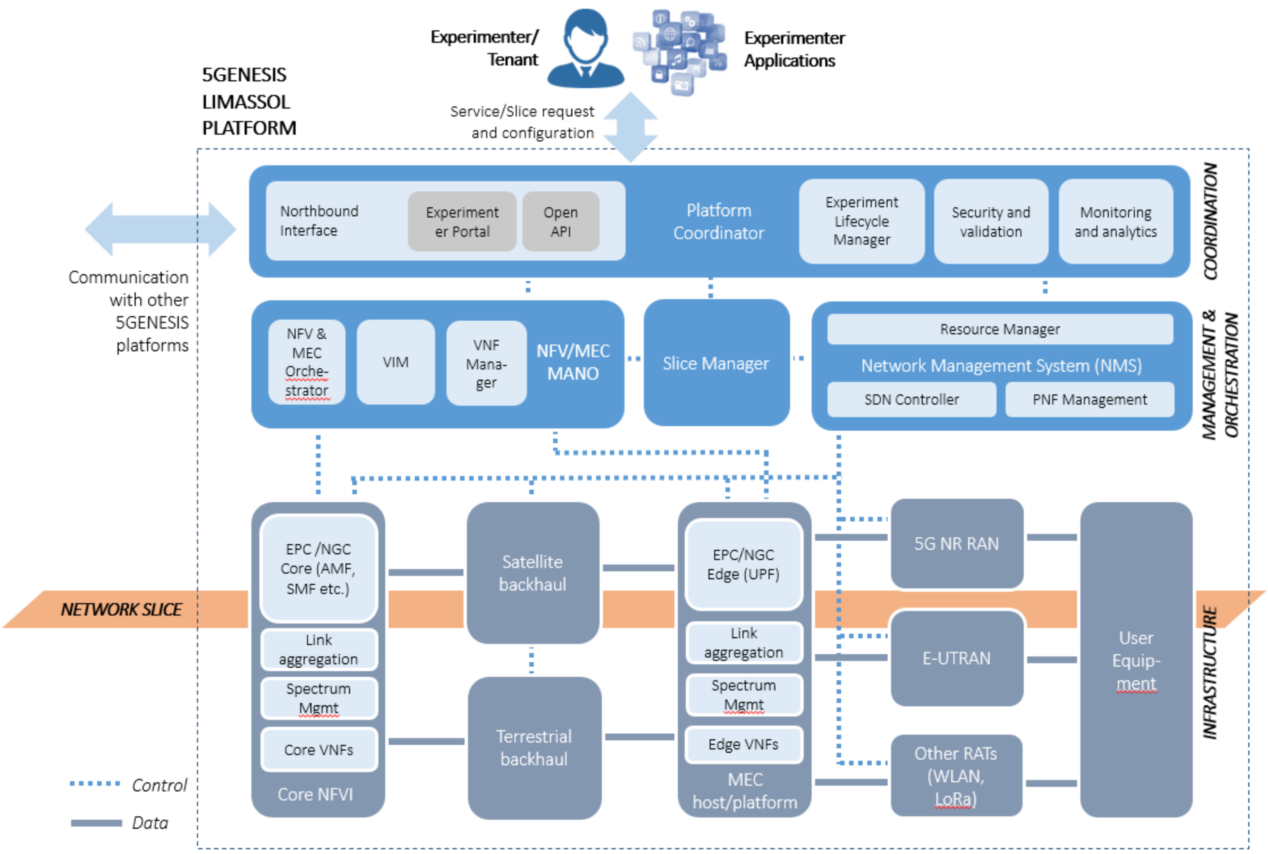

Fig. 3. Functional architecture of the 5GENESIS Limassol platform

5GENESIS project and will be common for all the five project platforms. Established technologies for testing and automation will be leveraged.

2) Management and Orchestration layer

At the Management and Orchestration layer, a key component is the *Slice Manager*, whose role is to configure and activate the end-to-end Network Slice Instances (NSIs), on which the experiments will be run. Fully aligned with the 5G slicing vision, the NSIs will consist of heterogeneous network and compute resources both at the core and the edge, along with virtual network functions (including EPC/NGC functions) as well as radio resources. Similarly to the Coordinator mentioned above, the Slice Manager will be developed within 5GENESIS and will be common for all the five project platforms. Established technologies for network slicing, especially those developed in EU 5G-PPP Phase 1 and Phase 2 projects, will be leveraged.

The *NFV/MEC MANO* is in charge of deploying and managing Virtual Network Functions at the core and the edge. It will be built on Open-Source MANO (OSM) [11] and OpenStack, with the appropriate adaptations. A particular challenge in the context of satellite/terrestrial integration will be the performance and possible implications of remotely managing the edge applications over the satellite link.

The *Network Management System (NMS)* will encompass the management of the physical network functions (PNFs). In the Limassol platform, this will also incorporate the management of the satellite Gateway, exploiting the appropriate APIs for configuring traffic handling. The aim will be the integrated management of the network slice across the terrestrial and satellite segments.

3) Infrastructure layer

The Infrastructure layer involves all the physical and virtual network elements involved in the handling of the user traffic (data plane). In specific:

The *NFVI* hosts the virtualized network functions at the core of the network. It will be implemented on a cluster of OpenStack compute nodes.

The *EPC and 5G NG Core (NGC)* functions are provided by Athonet SRL [12] (commercial modules) and feature the deployment of the User Plane Functions (UPF) at the edge, a capability which is of particular value for the Satcom edge. The aim is to realise the aspect of “Satellite Edge Computing”, which is expected to reduce latency for several applications and reduce the utilization of the satellite link.

The *satellite backhaul* will be over the Avanti HYLAS-2/HYLAS-4 GEO satellites, using high-throughput Ka-band beams. Particular effort will be devoted in the tight integration of the platform management of the satellite GW APIs. The terminals and antennas to be employed will support both stationary/portable use as well as mobile use, allowing the ad-hoc deployment of 5G “hot-spots” anywhere and anytime and supporting all use cases, as mentioned in Sec. V.

The *terrestrial backhaul* will be implemented using point-to-point microwave links or (as alternative) commercial 4G links. The aim will be to showcase the abilities to combine and jointly manage a terrestrial and satellite backhaul.

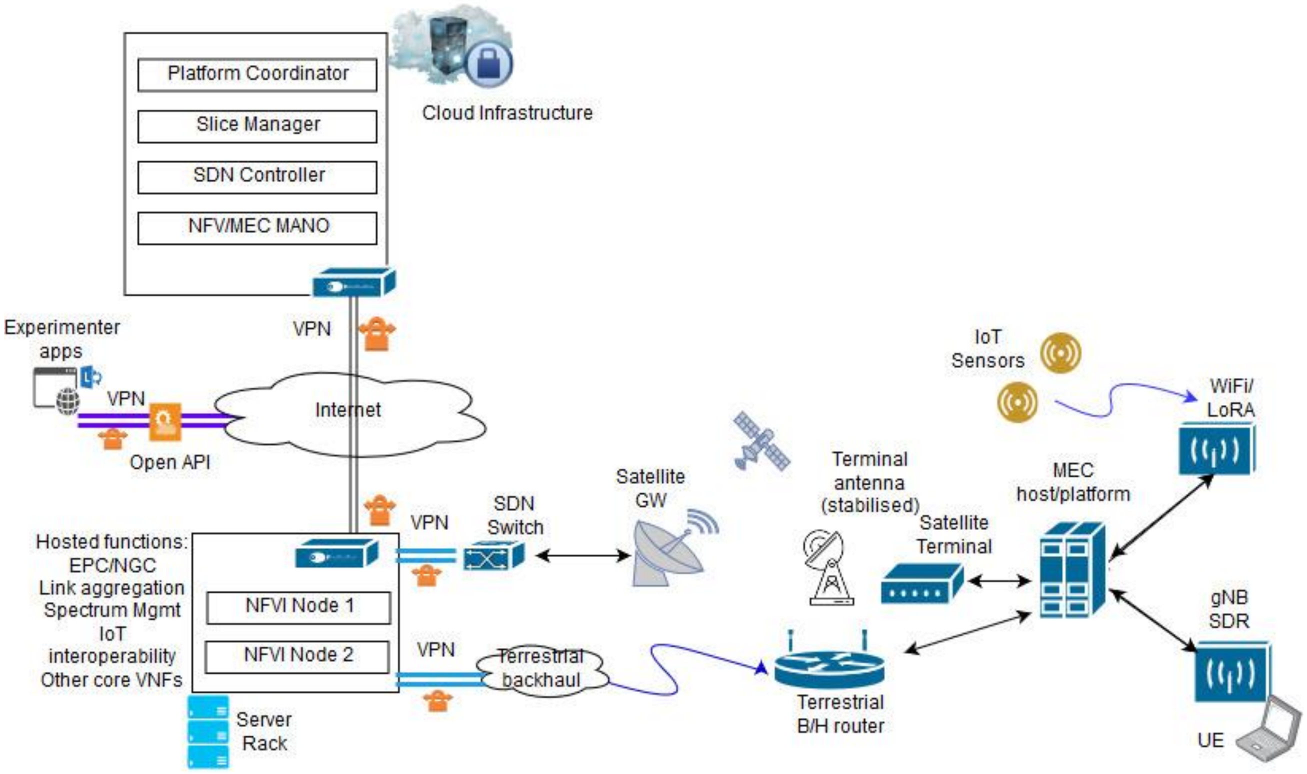

Fig. 4. Physical topology of the 5GENESIS Limassol platform

At the remote 5G node, the *4G and 5G radio access networks (RANs)* are implemented in a Software-Defined Radio (SDR) platform using the open-source OpenAirInterface software suite [13], which is also evolving in the frame of 5GENESIS to integrate 5G New Radio (NR) features. The aim is to go for a Non-Standalone (NSA) implementation, meaning that the gNB will be driven directly by a NGC instance.

The *Link Aggregation / WAN optimization virtual functions*, provided by Ekinops [14], will achieve i) WAN throughput acceleration using TCP acceleration and Data Redundancy Elimination and ii) satellite & terrestrial link bonding, using MPTCP core combined with innovative modem agnostic Link Estimation, interactive vs transfer Traffic Classification and user experience oriented Traffic Distribution. The pair of link aggregation functions will be placed on the N3 interface between the RAN and the core network, thus aggregating all the backhaul links (satellite and terrestrial) in 2 separate points. These functions will steer, switch and split incoming data flows over available backhaul links using algorithms that take into account the actual link characteristics as well as the size of transmitted objects.

Spectrum management is also a very relevant topic in satellite/terrestrial integration. The Limassol platform will engage dedicated *Spectrum management functions* at the core and at the edge in order to i) distribute and dynamically allocate spectrum between the terrestrial and satellite components and ii) allocate the appropriate band and radio technology for each network slice.

Finally, with respect to other application-focused Core and Edge VNFs, the Limassol platform, towards supporting IoT-oriented use cases, will deploy an *IoT interoperability service,* which facilitates collection, processing and homogenisation of sensor data. This service comprises physical data link layer gateways (based in open access network implementations as LoRa, Panstamp or SigFox), virtual access points and virtual gateways deployed in the field, using MEC technology, implementing functions such as protocol conversion, bottom-up communication transfer and data compression. Additionally, an interoperability middleware is provided, in order to provide uniform access to data from heterogeneous IoT platforms. In this way, the sensor data coming from the different sources (e.g., rural sensor networks, on-board ship sensors and network management systems) can be stored, handled and accessed through a unified point. The IoT interoperability service will be based on the results of the H2020 INTER-IoT project [15]

C. Physical topology

Fig.4 shows the physical topology of the deployed Limassol platform.

The core functions of the platform are deployed in a server rack in the Primetel data centre in the city of Limassol, bridged over a dedicated VPN connection with the Avanti satellite gateway in Makarios earth station, Cyprus. The management and orchestration modules, at least for the first phases of the project, will be deployed in a secure public cloud, allowing easy resource scaling up/down, according to the needs of the services in terms of compute and storage resources.

The remote 5G node is served by a satellite terminal with a stabilized antenna (also suitable for mobile use) and includes the compute platform for the edge (MEC) services, as well as the RANs (4G/5G, as well as WiFi/LoRA for the IoT scenarios).

V. Use Cases and KPIs

The Use Cases to be experimented upon correspond to specific business cases, are highly relevant to Satcom/5G integration and are selected to demonstrate the benefits which it brings.

A. *Use Case 1: 5G Maritime Communications*

Satellite networks provide the only means of ubiquitous connectivity for long-range transportation media. Cargo vessels, with international routes far beyond the coverage of terrestrial cellular networks, typically use Satcom for connectivity, mostly for voice, vessel-to-office communication, as well as typical Internet access for the entertainment of the crew.

While these type of services are commonly offered by dedicated devices on-board or via short-range WiFi networks, this use case will show how the integration of Satcom and 5G can help to deploy full-scale 5G communications and services on board. In particular, this use case will involve the deployment of a "5G hotspot" in the sea, either on a ship or an offshore facility, using satellite as backhaul and 5G RAN and edge services to allow i) access by the personal 5G terminals of the crew (BYOD case) and ii) localised session handling between two or more on-board terminals. In particular, the platform will be able to demonstrate direct communication between the 5G terminals on the ship, as well as, local access to vessel services (Local Break-out function). The focus will be on eMBB services on-board, demonstrating slices with different characteristics for crew entertainment and vessel-to-office communications.

Moreover, virtual network functions related to multi-link optimisation and aggregation will be deployed, to boost throughput and reduce latency when the vessel is close to the shore, which allows employing a secondary backhaul channel (e.g. the port's WiFi or microwave point-to-point or LTE provided by a terrestrial operator). The link aggregation VNFs will share the traffic between the satellite and terrestrial backhaul in an optimal manner.

The will be carried out on the tanker, as described in the previous section, and the network to be installed shall offer local 5G connectivity and interconnection with the core or backbone network via wireless links (when close to the shore) or satellite connections (when in the open sea).

B. *Use Case 2: 5G Capacity-on-demand and IoT in Rural Areas*

Satcom is commonly engaged to extend data connectivity to areas not well covered by terrestrial cellular or fixed broadband infrastructure (rural or underdeveloped areas, etc.). The support of cellular backhauling as well as remote sensor networks are common application scenarios. However, most services are currently restricted to plain Internet connectivity and are independent from 3G or 4G services. A tight integration with 5G will enable seamless session management, dynamic provision of virtualised services (VNFs, edge applications etc.) at the core and at the edge, as well as software-defined networking over Satcom.

This use case foresees the ad-hoc deployment of a "5G hotspot" in areas not (adequately) covered by the existing cellular network or fixed broadband infrastructure. Possible application scenarios include (1) cellular backhauling e.g. capacity boost for a flash crowd event, or the dynamic provision of network slices for multimedia services for large-scale events, as well as, (2) enhanced support for remote sensor networks (IoT services). The focus will be both on eMBB and mMTC communications, employing slices of different characteristics.

This use case will also involve features such as:

- the dynamic spectrum sharing between satellite and terrestrial, based on a mixture of centralised and distributed resource management functions;
- the deployment of core and edge virtual services for the efficient handling of IoT traffic, implementing functions such as protocol conversion, bottom-up communication transfer and data semantic contextualisation and translation. Additionally, an interoperability middleware will be provided, in order to provide uniform access to data from heterogeneous IoT platforms. In this way, the sensor data coming from the different sources (e.g., rural sensor networks, on-board ship sensors and network management systems) can be managed and accessed through a unified point.

C. *Target Performance Requirements and KPIs*

The 5G performance requirements, which the Limassol platform plans to focus on are:

- *Ubiquity*; almost ubiquitous coverage is expected thanks to the use of the Satcom component;
- *Latency*; the virtualised data plane components, locally deployed in the remote network, are meant to significantly alleviate the high satellite latency;
- *Reliability*; the multi-radio bandwidth aggregation in the backhaul segment, powered by SDN and NFV, will help to eliminate the effect of network outages by rapidly switching to failover links;
- *Capacity*; in respect to:
    - Data rate; the multi-radio bandwidth aggregation in the backhaul segment, powered by SDN and NFV for multipath delivery, will combine the high data rate of 5G backhauls with Ka-band Satcom in order to deliver data rates much higher than the ones currently experienced in maritime and rural access scenarios;
    - Multicast Capacity; the impact of the use of efficient multicast services over the satellite link to offload high data rate traffic from cellular unicast services to devices.
- *Service creation time*; service virtualisation and end-to-end automation is expected to radically reduce service creation time, especially for satellite services.

These performance indicators/KPIs will be validated according to the 5G KPI propositions by 5GPPP [16] and NGNM Alliance [17].

VI. Conclusions

Demonstrating the actual value of satellite/terrestrial integration in the context of 5G through realistic field trials is among the ambitions of the 5GENESIS project. The aim is to prove how the engagement of satellite communications can contribute towards fulfilling the 5G KPIs. This paper presented how this can be made possible via an end-to-end experimental testbed, built on specific cutting-edge technologies. Following the completion of the implementation phase, the next steps will include the end-to-end component integration, testing and verification of the platform, the validation of the 5G performance requirements and KPIs as well as a more general functional, operational and performance assessment in the field via the discussed use cases.

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