5G Experimentation Facility Supporting Satellite-Terrestrial Integration: The 5GENESIS approach

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***Abstract*— This paper describes the pathway towards the realisation of a 5G Facility that will allow Satellite/terrestrial integration with scope the validation of the unprecedented benefits, such as ubiquitous broadband coverage and inherent multicast capabilities. The paper reflects the approach that the 5GENESIS project adopts in this direction for the Facility realization, including the design of a common implementation blueprint that will be instantiated across the five 5GENESIS Platforms distributed across Europe. Special emphasis is put on the design and implementation of the Limassol platform, which builds on integrated satellite/terrestrial 5G services. The platform encompasses all the necessary components of the 5G network and it is suitable for field trials over satellite-terrestrial use cases.**

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

I. INTRODUCTION

The "Genesis of 5G" has entered the crucial phase of experimentation, and currently faces the challenge of validating the 5G network KPIs and verifying the 5G technologies with an E2E approach. Towards this objective, a key challenge is to integrate all the highly diverse results and technologies from R&D projects, to "glue together" the 5G picture and unveil the potential of a truly full-stack and E2E 5G Facility, to meet the targeted KPIs. Several R&D projects, such as H2020 SaT5G [1] and ESA SatIs5 [2] 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.

While the establishment of European experimentation facilities oriented to networking and Future Internet technologies has been significantly promoted by the EU FIRE (Future Internet Research and Experimentation) initiative [3], there is to date no open facility for experimentation and testing in an integrated satcom/5G context. This is among the gaps which the 5GENESIS project intends to address.

In this context, the paper describes the key design principles and the innovative 5G Facility that the recently EU-funded 5GENESIS [4], [5], research project will build. The novel Facility will be composed of several so-called Platforms, i.e. enhanced existing 5G testbeds and related applications, which aim to address some societal challenges and still not fully solved technical aspects of 5G networks. Each Platform forms a validation setup and the combination of all Platforms build an open, flexible and distributed experimentation facility.

The Limassol Platform of 5GENESIS offers radio interfaces of different characteristics and capabilities, combining terrestrial and satellite communications, integrated to showcase service continuity and ubiquitous access in underserved areas together with interoperability of IoT components deployed within these areas. 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 [6]. 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 [7]. 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) [8].

For all these reasons, satellites are considered an essential element of future 5G infrastructures [8][9]. 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 [10].

II. OVERVIEW OF THE LIMASSOL PLATFORM

A. *Key Infrastructure and Assets overview*

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.

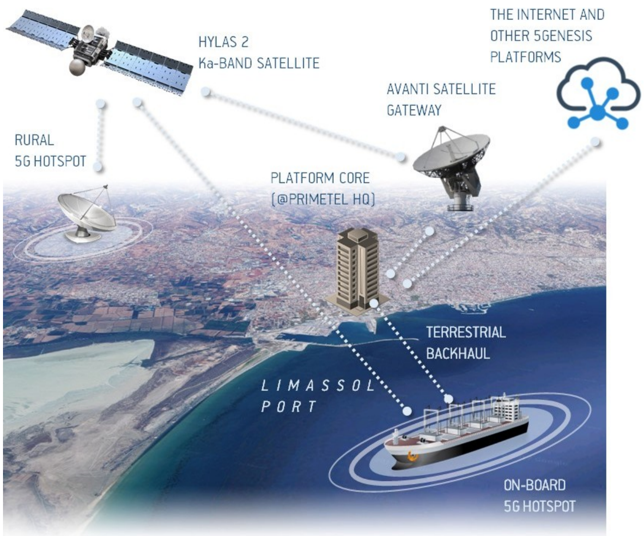

Fig. 1. Key infrastructures and assets of the Limassol Satcom/5G platform

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.1 depicts a high-level topology of the Limassol platform, highlighting the main assets involved.

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) will be used to showcase 5G maritime communications, while a second scenario will be deployed in rural and underserved areas.

B. *Functional architecture overview*

The overall functional architecture of the Limassol testbed is shown in Fig.2.

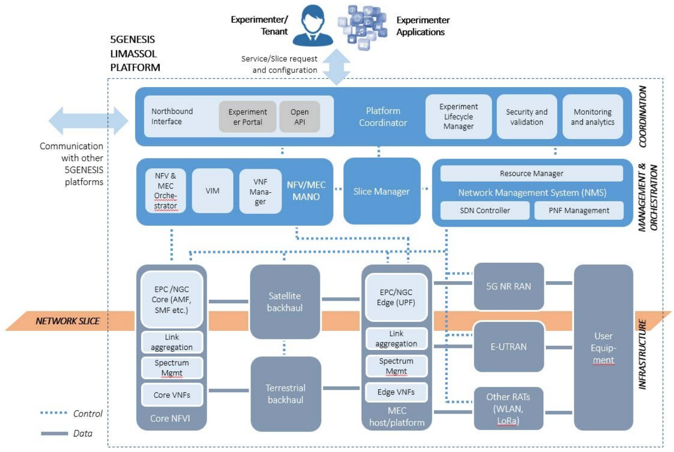

Fig. 2. Functional architecture of the 5GENESIS Limassol platform

The architecture is aligned with the common reference architecture of 5GENESIS, which applies to all its five platforms [5]. 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 [11].

C. Physical topology

Fig.3 shows the physical topology of the deployed Limassol platform.

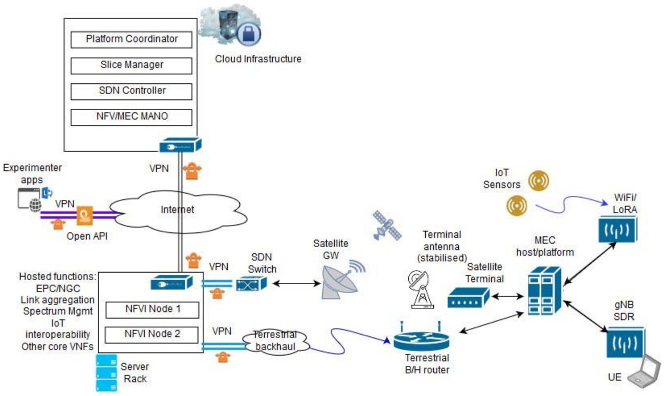

Fig. 3. Physical topology of the 5GENESIS Limassol platform

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).

III. Satellite-Related KPIs And Use-Cases

A. Target KPIs

In alignment with the 5G-PPP targets for the experimentation phase of 5G, the 5GENESIS Facility in Limassol will mainly be used to validate the following performance indicators:

- *Ubiquity*; almost ubiquitous coverage is expected thanks to the use of the Satcom component. The platform will combine satellite communications links with terrestrial backhaul and access technologies, employing advanced link aggregation and optimisation technologies, integrating them all in the overall 5G network.;
- *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:

  (1) 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; (2) 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 5GENESIS validation and experimentation framework, which considers also 5G KPI propositions by 5GPPP and NGNM Alliance.

B. Use-Cases

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.

1) 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 types 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).

2) 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

IV. ENGAGEMENT PROCESS WITH 5GENESIS FACILITY

The facility is planned to be provided as an experimental asset to the vertical industries that are interested to test the performance of their services in 5G. Satellite industry is a potential interested player and for this reason Limassol platform is built with focus on satellite and terrestrial integration. Figure 1 provides a sequence diagram of the steps that should be followed by a vertical industry in order to use 5GENESIS facility for experimentation purposes.

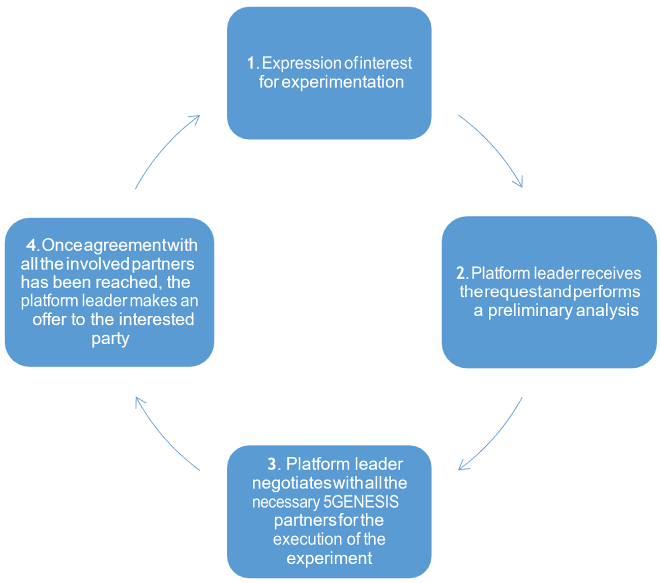

Fig. 4. Process diagram of 5GENESIS facility exploitation by a vertical industry

For each of the five platforms that realises the 5GENESIS facility, the responsible platform leaders from the 5GENESIS consortium will act a point of contact, where the interested parties/verticals will get in touch in order to express their interest and submit their request for experimentation. The platform leader upon performing a requirements analysis of the requested experiment will contact all the involved partners which are needed for the execution of the experiment and will eventually submit to the interested party a business offer and pricing for the execution of the experiment.

V. 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. This paper presented how the engagement of satellite communications can contribute towards fulfilling the 5G KPIs 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.

ACKNOWLEDGMENT

The work described in this paper has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815178.

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