Benefits and Challenges of Software Defined Satellite-5G Communication

Hamzeh Khalili, Pouria Sayyad Khodashenas, Carolina Fernandez, Daniel Guija
i2CAT, Barcelona, Spain
hamzeh.khalili@i2cat.net

Konstantinos Liolis, Christos Politis, Gint Atkinson
SES Networks
Betzdorf, Luxembourg
Konstantinos.Liolis@ses.com

Joe Cahill, Robert King, Mark Kavanagh
VT iDirect Solutions Ltd.
Killarney, Ireland
jcahill@idirect.net

Boris Tiomela Jou, Oriol Vidal
Airbus
Toulouse, France
boris.tiomela-jou@airbus.com

***Abstract*—The convergence of innovation in satellite communications, 5G terrestrial systems and cloud technology promises a ubiquitous networking solution, which offers a wide range of features, including but not limited to: universal multi-access coverage at extraordinarily high speeds & capacity, multi-tenancy, fixed and wireless access network convergence, software controlled, agile service provisioning, on-demand service-oriented resource allocation, and highly orchestrated. To meet the needs of future communication, a paradigm shift both in the terrestrial and satellite segments is needed, transforming them from data-only transport media to intelligent services, equipped with computational, storage and decision-making capacities. In this article, we present H2020 SaT5G project vision to integrate the next generation satellite systems into 5G terrestrial networks at different levels. To this end, after highlighting the benefits of the integrated satellite-5G systems via some potential use cases, we detail the architectural options proposed by the project. In addition, we will present a management solution for the effective management and orchestration of the end-to-end heterogeneous technologies (terrestrial and satellite services).**

Keywords—5G, Satellite, Orchestration, 3GPP, ETSI

I. Introduction

Mobile communication has become an essential part of our daily lives; from social networking to online shopping, smart home appliances or in-car infotainment systems, the pervasiveness and ubiquity of connected services and mobile devices has never been higher. By 2021 the number of connected mobile devices to fifth-generation (5G) networks is expected to exceed 11 billion [1]. As socio-economic conditions continue to evolve towards an increased demand for ubiquitous connectivity, it drives the telecom industry to pursue new generations of communication systems. The next several years will represent a significant transformation as networks continue to evolve to meet the global connectivity demand for pervasive connectivity, significant increase in efficiency, instantaneous user expectations and services, and scalable with a wider array of devices.

To meet next generation communication goals, convergence and interoperability of disparate telecommunication technologies is a crucial prerequisite [2]. Such a technological convergence is happening in all networking levels and using various technologies. For example, 5G mobile operators should deliver highly dynamic services that leverage satellite technologies such as High Throughput Satellites (HTS).

In previous generations, the integration of satellite communication (SatCom) was based on proprietary tailored solutions at both SatCom and mobile network level. In many cases, telecommunication satellites were considered completely independent of terrestrial networks. In the rare cases where hybrid solutions were proposed, the satellite network was mainly used to provide backhaul to some remote and nigh-inaccessible individual cells as a simple, non-flexible, and potentially expensive transport network. This situation created challenges to service programmability, and agility; precluding the mobile operators from effectively leveraging satellite in mobile networks.

With the wide-scale growth of 5G networks, the vision of the SaT5G project [3] is to foster the development of an attractive plug-and-play SatCom solution for 5G, which will enable terrestrial operators and network vendors to accelerate 5G deployment, while at the same time creating new and growing market opportunities for the SatCom industry. This requires significant efforts to:

1. Design SatCom solutions, targeting integrated satellite/terrestrial 5G architectures by means of adoption and integration of key 5G features (such as SatCom ground segment virtualization and 5G protocol adaptation);
2. Exploit SatCom capabilities (e.g. broadcast, ubiquity and reliability) while mitigating its inherent constraints (e.g. propagation latency) in standalone or multi-link network topology;
3. Ensure seamless integration of SatCom in 5G at orchestration and security levels;
4. Foster satellite inclusion in the 5G ecosystem as a key access network technology, to fulfil 5G implementation in our society (by playing an active role in 3GPP and ETSI standardization efforts).

At the same time, it is important to define a set of specifications and solutions that will ensure that satellite solutions for 5G support multi-vendor interoperability, interoperate seamlessly with the 5G system, and leverage 5G technologies and protocols as much as possible to benefit from the economy of scale of the 5G global market. This will open up new market opportunities for satellite communication solutions, and introduce the benefits of integrated satellite/5G network communications to users across the globe.

Among all technologies that are changing the face of future communication systems, network softwarization seems like a proper candidate to answer the systems interoperability and multi tenancy challenges. It represents an overall transformation trend for designing, implementing, deploying, managing and maintaining network equipment/components via software programming. Leveraging network softwarization technologies, i.e. Network Function Virtualization (NFV) [4] and Software Defined Networking (SDN) [5]; higher flexibility, programmability, automation and significant cost/energy reduction are achievable. With the help of NFV and SDN, the embedded resources of the network are employed to offer added-value services, aiming to improve the end user's Quality of Experience (QoE) and creating new and dynamic business opportunities.

Nevertheless, despite all flexibilities offered by the network softwarization, coordination and collaboration on the end-to-end services to optimize the use of satellite to assist service delivery to 5G will be a key innovation. Convergence around open source virtualization, orchestration, and network programmability will be a significant step towards helping customers for sensing the benefits of pervasive connectivity, instantaneous and scalable networking technologies as economically suitable to meet the needs of future innovative services.

This work aims to present possible solutions to integrate satellite systems into 5G networks, with special focus on the network management and orchestration level. To this end, after highlighting the potential benefits of converged satellite-5G networks for the future of connectivity via reviewing selected use cases, the paper details the architectural options proposed by SaT5G to integrate satellite systems into 5G networks. Next, the convergence at the network management and orchestration will be studied.

The paper is organized as follows: Section II discusses potential use cases. Section III presents integrated satellite system into 3GPP architecture. Section IV reviews a solution for the management and orchestration of satellite systems. Section V concludes the paper.

II. SATELLITE USE CASES FOR EMBB

The advanced communications of 5G are expected to bring Enhanced Mobile Broadband (eMBB), Ultra Reliable and Low Latency Communications (URLLC), and Massive Machine-Type Communications (mMTC), which correspond to the 5G usage scenarios defined by ITU‐R for International Mobile Telecommunications for 2020 and beyond [6].

With the identified satellite strengths and based on the anticipated market needs, SaT5G focused on the eMBB Usage Scenario for 5G. Based on the analysis results obtained from relevant ESA ARTES projects, such as SPECSI [7] and MENDHOSA [8], the broadband and broadcast services will have the highest revenue in 2025 and thus form the primary SaT5G target markets. Furthermore, from the mobile operator's viewpoint for the inclusion of satellite support in the early 5G roll out, congested backhaul and offloading high bandwidth video download have been found to be the major drivers. These operator drivers also fall under the 5G usage scenario of eMBB. Therefore, SaT5G addresses specifically the eMBB Usage Scenario towards "broadband access everywhere". There are many other benefits to integrating satellite communications with 5G, but they are beyond the scope of our work.

SaT5G concentrates its efforts on four selected Satellite Use Cases for eMBB:

- Use Case 1: Edge delivery & offload for multimedia content and MEC VNF software – Providing efficient multicast/broadcast delivery to network edges for content such as live broadcasts, ad-hoc broadcast/multicast streams, group communications, MEC VNF update distribution
- Use Case 2: 5G Fixed backhaul – Broadband connectivity across a wide geographic region where it is difficult or not (yet) possible to deploy terrestrial connections to towers; e.g., maritime services, coverage on lakes, islands, mountains, rural areas, isolated areas or other areas that are best or only covered by satellites
- Use Case 3: 5G to premises – Connectivity complementing terrestrial networks, such as broadband connectivity to home/office small cell in underserved areas, in combination with terrestrial wireless or wireline
- Use Case 4: 5G Moving platform backhaul – Broadband connectivity to platforms on the move, such as airplanes, vessels, and land vehicles.

Each of the SaT5G Use Cases corresponds to one of the four Satellite Use Case Categories in 5G identified by ESOA [9]. Further details on the SaT5G Use Cases can be found in [10], [11] and [12].

III. INTEGRATING SATELLITE SYSTEM INTO 3GPP ARCHITECTURE

Integrating of satellite access network into 5G is considered a crucial endeavor to fully satisfy the challenging 5G connectivity requirements. Advanced and innovative architecture concepts are thus targeted in the frame of this work, aiming at fostering satellite seamless integration within terrestrial 5G networks and therefore, enabling high-value attractive solution for SatCom and main terrestrial actors. Solutions are explored in order to best exploit satellite potential to meet 5G requirements and provide a technical efficient solution to the use cases described above. The first step in this direction is to clearly identify the positioning of the satellite link in 5G system architecture as defined in 3GPP. The satellite link can be integrated into 5G with two principal approaches: backhauling and direct access [2].

A. Backhauling

For decades, satellite has always been an option to perform backhauling for terrestrial network, especially for serving remote areas. In parallel, the required bandwidth and data consumption in telecommunication network have significantly increased and are still increasing. This has led to advanced network efficiency, protocol and air interface design both in terrestrial and satellite networks, but mostly independently [13].

In such context, the hybridization of satellite and 5G terrestrial networks need to be much more efficient than what it has been so far in order to fulfil the 5G requirements. Thanks to satellite, which remains the best potential solution to provide connectivity to aircrafts and maritime, a group of users in such platform will still benefit from 5G terrestrial services. Another aspect is the requirement for flexibility, limited on existing backhaul solutions. For instance, instead of static backhaul link set up between the terrestrial core and a remote node, there is a need to be more flexible and therefore adaptable to the traffic dynamic. Further, the specified 5G protocols might be impacted by the transport of such interfaces over a satellite link. In this case, it is necessary to investigate these impacts and if necessary and possible, adapt the protocol configuration when using a satellite link.

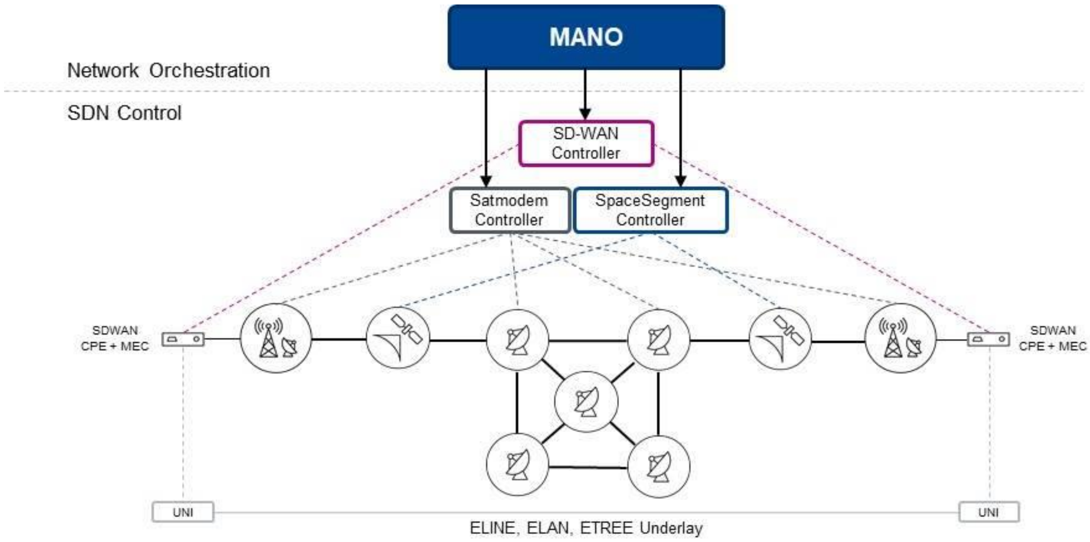

Figure 1: Distributed SDN Controller Architecture

In addition, existing satellite network capabilities of link optimization should be maintained in these cases to avoid capacity or satellite bandwidth waste and maximize efficiency. In some cases, content might be pushed to the edge in order to offload the network and improve the end users' QoE. Some Network Function (NF) can also be migrated to the edge, leading to the transport of different 5G interfaces as defined in [14] through the satellite. In the backhaul example, no NF is migrated, thus the satellite would carry 5G N1, N2 and N3 interfaces.

Future satellite backhaul for terrestrial 5G system shall provide to 5G compliant connectivity to isolated group of users including those in mobile platform where the satellite remains the only viable solution to provide broadband connectivity. This work is done in line with the specification from the standardization bodies, especially 3GPP as part of the development [15], [16].

B. *Direct Access*

Current end user satellite terminals are usually connected to a specific satellite core network, which provides certain features such as TV broadcast, voice service, internet access, to name a few possibilities. However, these terminals are not directly connected to the terrestrial network core and can only access to the other terrestrial terminals through the bridge setup between the satellite core and the terrestrial core.

With 5G, a direct access of satellite terminal to terrestrial 5G core is foreseen with the satellite terminal being considered as a 5G User Equipment (UE). Typically, this case is suitable to serve an isolated single user. This integration option is demonstrated in the 3GPP technical report 22.822 [15]. In addition, on-going initiatives is to reuse the 5G new radio over satellite that will allow full integration of satellite in the terrestrial network [16], [17]. A regenerative satellite with sufficient on-board processing capabilities can also be used with Radio Access Network (RAN) functions embedded in the satellite.

IV. Integrated Management and Orchestration of Converged 5G-Satellite Systems

Currently, terrestrial and satellite networks are managed by independent systems; where each segment holds its own OSS/BSS and systems [18]. SDN technologies enable resource abstractions in operation and management components in access network [19]. In parallel, the virtualization of specific network function provides a cloud-like view for the management system, adding both the traditional Network Management System (NMS) and the lifecycle service and orchestration functionalities associated to the original cloud-based system [20]. Meanwhile, orchestrators like ETSI Open Source MANO (OSM) or Open Networking Automation Platform (ONAP) provide a solution for management and orchestration of the network resources and services.

In this work, we propose an architecture based on ETSI MANO and 3GPP standard that opens up the network platform by virtualizing and automating the end-to-end network service platform across access, aggregation, and space segment network domains. Standardized open-source and commercial cloud technologies can be combined to address the following challenges:

- Open interfaces to deliver automation, self-service operations and partner integration for high speed and agility. With adaptive automation, service usage drives on-demand resource requirements; triggering operational closed-loop feedback to adjust resources and services to real-time changes
- Intent and event-driven orchestration that guides service and system-wide performance and management.
- Personalized services that are easily configured by the end-user at the service or network resource level to fit individual or organization's requirements
- Dynamic SLA-based resource allocation and provisioning over multiple domains with flexible and dynamic deployable satellite resources.
- Lifecycle management as devised in the ETSI MANO framework. Abstraction of the requirements for the provisioning of network services is achieved through resource modelling, in the form of the descriptors (TOSCA, ETSI).

- Flexible multi-domain management and operation of virtualized satellite and terrestrial functions.
- Seamless service provisioning through the automated process and the integrated network management component.

Together these capabilities deliver automated lifecycle management of end-to-end network services from the 5G access network, across the space segment, and through cloud connectivity to on-net global wide cloud services. Nevertheless, reaching across a network to provision an end-to-end service is certainly challenging in any network with diverse control across a multi-layer and heterogeneous service network.

As shown in Figure 1, an end to end satellite 5G service transvers across several distinct domains, i.e. terrestrial ground segment (represented by SD-WAN domain in Figure 1); satellite ground segment (including satellite terminals, modems, gateways, etc.); and satellite space segment (e.g. GEO, MEO and LEO satellites). Each of the mentioned domains has its own requirements and characteristics. For example, in aerospace satellite segment there is the constant challenge of variable performance and reliability that can add hundreds of milliseconds of latency. This creates exceptional challenges for the management and control planes to constantly monitor and detect mal performances and improve the network status either by changing transmission parameters at the satellite ground segment, e.g. modulation format or signal power, or assigning alternative routes, e.g. switching from a GEO link into MEO link based on availability and latency requirements. In the latter case, a tight coordination between the aerospace satellite segment and the ground segment is crucial.

Centralized Orchestration or SDN Controller architectures are vulnerable to a high frequency of command exchanges across the space segment. Furthermore, synchronized message exchanges suffer on high latency and variable availability links. These demanding operating conditions need a resilient and recoverable control architecture that provides durability in the face of variable performance that a physically centralized architecture does not sustain. A distributed and possibly federated SDN Controller architecture puts greater intelligence and autonomy at the edge beyond the space segment, minimizing the dependency and use of space segment resources using distributed intelligence to maintain a rich control interface with local devices where terrestrial networks are typically available. Figure 1 illustrates specialized controllers for various layers and segments of the network where each controller can support either the centralization or distribution of network control functions. These functions can typically be implemented as virtualized network functions that are placed at the network edge in devices that support a virtualization infrastructure.

V. Conclusion

Integration of satellite systems into 5G networks plays a crucial role in the future communication, especially for eMBB use cases. This paper, based on the work performed in the H2020 SaT5G project, presents some challenges and solutions to integrated satellite systems into 5G terrestrial networks. Different levels of integration were reviewed, including 3GPP architectural options and the management and orchestration systems. The outlined work lays down a framework to continue the presented research lines on an active research project that will contribute to realization of the future communication vision. It enables integration and unification of heterogeneous technologies such as satellite systems and 5g terrestrial networks, with the end-to-end management and network orchestration.

Acknowledgment

This work was conducted within the framework of the SaT5G (Satellite and Terrestrial Network for 5G) project, funded by European Union’s Horizon 2020 research and innovation program under grant agreement No 761413.

References

[1] Cisco Systems, “Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016–2021 White Paper,”, Updated: March 28, 2017.

[2] Tiomela Jou, et al., “Architecture Options for Satellite Integration into 5G Networks,” EuCNC 2018.

[3] SaT5G, Satellite and Terrestrial Network for 5G, http://sat5g-project.eu.

[4] ETSI NFV white paper, “Network Function Virtualisation: An Introduction, Benefits, Enablers, Challenges and Call for Action,” 2012.

[5] R. Jain and S. Paul, “Network Virtualization and Software Defined Networking for Cloud Computing – A Survey,” IEEE Comm. Mag., vol. 51, no. 11, pp 24-31, 2013.

[6] ITU-R, “IMT Vision – Framework and overall objectives of the future deployment of IMT for 2020 and beyond,” [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf.

[7] SPECSI, Stategic Positioning of the European and Canadian SatCom Indusry, https://artes.esa.int/projects/specsi.

[8] MENDHOSA, Media and Entertainment Delivery over HetNet with Optimized Satellite Architecture, https://artes.esa.int/projects/mendhosa.

[9] ESOA 5G White Paper, “Satellite Communications Services: An integral part of the 5G Ecosystem,” ESOA, 2018. [Online].

[10] SaT5G Consortium, Deliverable D2.1 “Satellite Reference Use Cases and Scenarios for eMBB”, August 2017.

[11] K. Liolis, et al., “Use cases and scenarios of 5G integrated satellite‐terrestrial networks for enhanced mobile broadband: The SaT5G approach”, *International Journal of Satellite Commununications and Networking*, 2018;1–22, https://doi.org/10.1002/sat.1245

[12] K. Liolis, et al., “Satellite Use Cases and Scenarios for 5G eMBB”, Book: “Satellite Communications in the 5G Era”, Editors: S. Krishna Sharma, S. Chatzinotas, P.-D.M. Arapoglou, IET, 2018, ISBN: 978-1-78561-427-9.

[13] ETSI TR 103 272 , “Hybrid SS satellite/terrestrial network architecture for high speed broadband access,” 26 March 2015.

[14] 3GPP TS 23.501 V.15.0, System Architecture for 5G system, Rel 15.

[15] 3GPP TR. 22.822, Study on using Satellite Access in 5G, Rel 15.

[16] 3GPP TDOC C4-181327, Satellite specific technical issues to be considered in 5G Core specification.

[17] 3GPP TR.38.811, Study on NR to support non-terrestrial networks, Rel. 15.

[18] “Satellite role in 5G Eco-System & Spectrum identification for 5G some perspectives,” 5G Radio Technology Seminar. Exploring Technical Challenges in the Emerging 5G Ecosystem, pp. 1-16, 2015.

[19] X. Liu and . Effenberger, “Trends in PON - fiber/wireless convergence and software-defined transmission and networking,” in Opto-Electronics and Communications Conference (OECC), 2015.

[20] J. Ferrer Riera et al., “Software-defined wired-wireless access network convergence: The SODALES approach,” IEEE Globecom Workshops, 2014.