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Architecture Options for Satellite Integration into 5G Networks

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Abstract— **Integration of satellite networks into 5G is considered a crucial endeavour to fully satisfy the challenging 5G connectivity requirements. In the frame of the SaT5G (Satellite and Terrestrial Network for 5G) project, advanced and innovative architecture concepts are discussed in this paper aiming at fostering satellite seamless integration within 5G networks and therefore, enabling high-value attractive solutions for satellite and terrestrial stakeholders. These options need to be further analysed and confronted to technical and economical requirements in order to propose a framework for integrated network design.**

Keywords—satellite;5G;plug-and-play;virtualisation;network management;3GPP;network slicing

I. INTRODUCTION

Future 5G networks represent a great opportunity for both the Satellite Communication (SatCom) industry and terrestrial operators to foster the ultimate seamless integrated satellite/terrestrial network able to cope with the challenging telecommunications ecosystem foreseen by the future 5G network generation.

It is widely recognised for 5G that no single technology will satisfy all requirements and that the only way to fulfil 5G challenging key performance indicators (KPIs) is considering a 'network of networks' approach. In this context, the SatCom industry certainly has a unique and timely window of opportunity to define in 3GPP Release 16, the solutions that will natively integrate SatCom in the 5G ecosystem. The role of satellites in 5G has been extensively studied in the EU technology platform NetWorld2020 SatCom WG [1] as well as recently in two ESA projects SPECSI [2] and MENDHOSA [3]. In all of them, there has been consensus and wider agreement on the contribution satellites can have towards the achievement of the challenging 5G KPIs: i.e. ubiquity, mobility, simultaneity (broadcast) and security.

Historically, in previous mobile network generations, the integration of SatCom was based on proprietary tailored solutions at both SatCom and mobile network level. Most of the time, telecommunication satellites were considered independently 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 hardly accessible individual cells as a simple, non-flexible and potentially rather expensive transport network.

With the wide-scale growth of 5G networks, the vision of the SaT5G project [4] is to foster the development of an attractive "plug and play" SatCom solution for 5G, for terrestrial operators and network vendors to accelerate 5G deployment while at the same time creating new and growing market opportunities for SatCom industry. This requires major challenges to be addressed: i) exploit SatCom capabilities (e.g. broadcast, ubiquity, reliability) while mitigating its inherent constraints (e.g. propagation latency) in stand-alone or multi-link network topology; ii) design SatCom solutions targeting integrated satellite/terrestrial 5G architectures by means of adoption and integration of key 5G features (such as SatCom ground segment virtualisation and 5G protocol adoption); iii) ensure seamless integration of SatCom in 5G at network management and security levels and, last but not least; iv) have an active role in 3GPP and ETSI standardisation efforts to foster satellite inclusion in the 5G ecosystem as a key access network technology to fulfil 5G implementation in our society.

The rest of the paper is organised as follows: Section II presents the SaT5G use cases considered for the architecture design. Section III presents the generic satellite link positioning options in the 3GPP system architecture. Section IV reviews some improved features provided by the different integration options. Section V discusses the required integrated network management features and section VI presents SaT5G implementation approach of the proposed architectures.

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II. CONSIDERATED SATELLITE USE CASES FOR ARCHITECTURE DEFINITION

The Architecture options presented in this paper have been defined in the frame on the SaT5G project and based on the defined SaT5G use cases. The four defined SaT5G use cases are presented in the **Table 1** and Fig. 1 below.

Table 1: SaT5G Use Cases: Selected Satellite Use Cases for eMBB

Use Case	**Description**
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, , group communications, Multi Access Computing, VNF update distribution
Use Case 2: “5G fixed backhaul”	Broadband connectivity where it is difficult or not (yet) possible to deploy terrestrial connections to towers (remote/isolated areas)
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, trains, or vessels

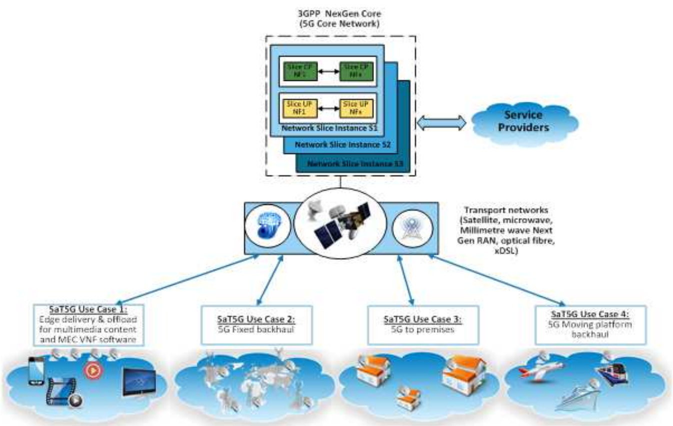

Fig. 1. SaT5G Use Cases in 5G Integrated Satellite-Terrestrial Networks

Further details on the SaT5G Use Cases can be found in [15] and [16].The architecture options presented in this paper are designed to fulfil the requirements of each SaT5G use case, without significant adaptation.

III. GENERIC POSITIONING OF SATELLITE IN THE 5G SYSTEM ARCHITECTURE

The satellite link can be integrated into 5G with two principal approaches: direct access or backhauling. These two types of integration are represented in Fig. 2.

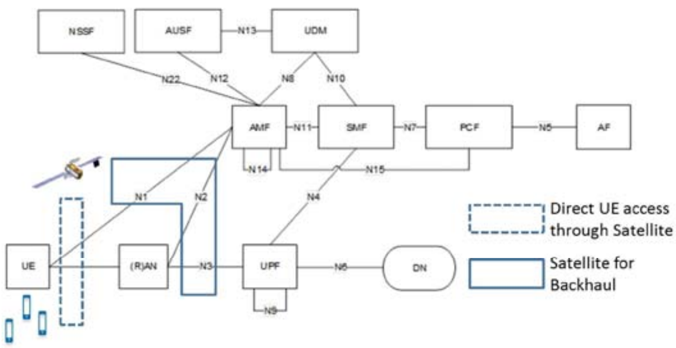

Fig. 2. Generic Positionning options of satellite link

A. Backhauling

For decades, satellite has always been an option to perform backhauling for terrestrial network, especially for serving remote areas. This role has not changed.

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 [8].

In such context, the hybridisation 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. 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 that sense, it is necessary to study these impacts and if necessary and possible, adapt the protocol configuration when using a satellite link.

In addition other optimisations are required:

Existing satellite network capabilities of link optimisation 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’ quality of experience (QoE);

Some network functions (NF) can also be delocalised to the edge, leading to the transport of different 5G interfaces as defined in [7] through the satellite. In the backhaul example depicted in Fig. 2, no NF is delocalised; therefore, the satellite would carry N1, N2, 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 standardisation bodies working groups, especially 3GPP. Two recent satellite centred contributions submitted in 3GPP, [13] and [14], reinforce the position of the backhauling with as a key topic of standardisation as incorporated in 3GPP TR

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22.822 [12] and the requirement to analyse the impacts of satellite link in core network protocols as addressed in [13].

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 etc. However, these terminals are not directly connected to the terrestrial network core and can only access to 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). This case is represented in Fig. 2 with a dashed box representing a satellite link. Typically, this positioning is suitable to serve an isolated single user.

The 3GPP technical report 22.822 [12] depicts this integration option. In addition, on-going initiative is to reuse the 5G New Radio over satellite that will allow seamless integration of satellite in the terrestrial network [11].

A regenerative satellite with sufficient on-board processing capabilities can also been used with the Radio Access Network (RAN) embedded in the satellite.

IV. Satellite to improve 5G network architecture

A. Edge Delivery

Edge delivery is the concept of pushing content to the network edge (local data network -DN- collocated with the next generation nodeB -gNB-) in order to offload network traffic and improve the QoE of the end users.

Satellites are well suited to provide broadcast/multicast resources over wide areas so as to aggregate the largest possible audience and hence to reduce the global delivery cost. Combining satellite broadcast/multicast resources with the terrestrial unicast resources is a powerful way to optimise the content delivery costs and improve scalability. The 5G network infrastructure will select the most appropriate resources depending on the audience to be reached. It can convey “video on demand” services (pull model), “TV channels” and “Live events” (push model) and optimise the cost. As the audience for a TV channel varies over time, the delivery method can be adapted to optimise the network bandwidth and cost.

The content providers can use the virtualised storage and computing resources at the mobile edge to deploy their content and intelligence, e.g. local caching, broadcasting or multicasting of content to selected mobile edges where there are potentially large crowds of consumers on the content.

Using standardised multi-access edge computing (MEC) platform [6] as a basis, intelligent caching prediction algorithm and traffic steering can be implemented using services offered by the platform (e.g. location, bandwidth usage). The content pushing from the content delivery network (CDN) server to the local data network (DN) can then be performed using multicast capabilities (IP Multicast or 3GPP enhanced Multimedia broadcast multicast services -eMBMS-) over the satellite link.

B. Multilink aggregation

The use of satellite to complement the existing terrestrial broadband access link can lead to a hybrid satellite/terrestrial multiplay scenario which can effectively exploit the low-latency of terrestrial networks and high-bandwidth of satellite networks to better support 5G services. Indeed, satellite and terrestrial fixed/mobile access links properly combined together can achieve better QoS / QoE delivered to end-users as well as improve the plurality and the diversity of the offered services.

Envisaged improvements include close integration of proxy enhanced protocol (PEP) and multi-link aggregation proxies into the RAN to accelerate backhaul links and transport 5G traffic. The transport protocol is updated across the multi backhaul links and links aggregation techniques are improved with simplified signalisation, enhancing link estimation and path selection. Techniques for traffic steering, switching and splitting between 3GPP and non 3GPP access studied in TR 23.793 [17] are envisaged for backhaul multilink management.

C. Edge Functions Update

A key topic in 5G is the use of softwarisation and virtualisation paradigms to increase network features and flexibility.

Integrating satellite can lead to delocalisation of 5G network functions to the edge, depending on the use case. Moreover, any function implemented at the edge may need to be updated for different reasons: security, improved functionalities, additional interfaces etc.

Satellite with broadcast/multicast capabilities, is well suited to dispatch such virtualised network functions (VNF) updates to different nodes at the same time for efficient network edge VNF delivery and updating.

V. Integrated network management

Terrestrial networks are rapidly evolving towards software defined networking/ network function virtualisation (SDN/NFV) paradigm to create a more agile and flexible communications infrastructure. Introducing SDN/NFV in the SatCom domain will certainly provide satellite operators with appropriate tools and interfaces to establish end-to-end fully operable virtualised satellite networks.

Based on this ambition and building upon some studies projects such as VITAL [5], three main research areas have been identified in order to enable seamless satellite integration in 5G networks: network slicing support, SatCom ground segment virtualisation and integrated orchestration.

A. Integrated Core Management

Leveraging on softwarisation technologies (SDN/NFV), virtualisation of NF leads to higher flexibility, programmability, automation and significant cost/energy reduction than on non-virtualised platforms. NFV and SDN use embedded general purpose network resources to create new business opportunities for service providers, as well as direct and indirect benefits for end-users. European

Telecommunications Standards Institute (ETSI) plays a leading position in Europe to define a management and orchestration framework for the cloud-enabled SDN/NFV future 5G networks [10]. However, merging 3GPP next generation architecture with network functions virtualisation management and orchestration (NFV MANO) is a very challenging task. Fig. 22 presents the ETSI MANO framework perspective. With the help of virtualisation technologies at Network Functions Virtualisation Infrastructure (NFVI) level part of 3GPP, NFs will be introduced as VNFs.

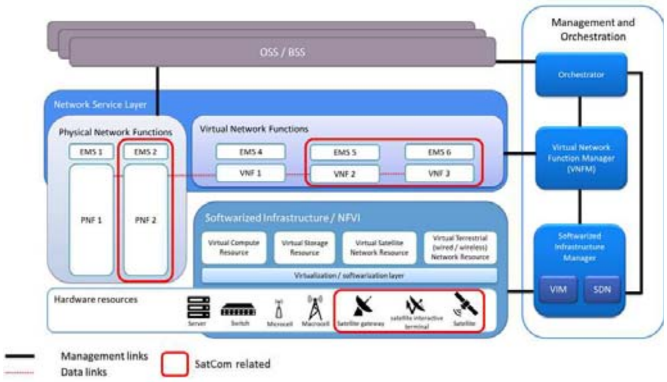

Fig. 3. Integrated satellite/terrestrial network management and orchestration

Three main challenges shall be addressed for this: first, realisation of the VNFs themselves out of the protocol stack; second composing appropriate VNF descriptors (VNFD) for each VNF or VNF type; and third embrace the SatCom NF. It is worth to note that not all satellite or 3GPP functionalities are required to be virtualised. Hopefully, mixing VNF and non VNF (e.g. physical NF) is fully supported in ETSI MANO framework, making it a promising orchestration solution.

B. Network Slicing Support

The network slicing enables the virtualised and non-virtualised network elements and functions to be easily configured and reused, isolated from one another in order to meet various demands. Each slice has its own specific network architecture, mechanism and network provisioning. The main component of network slicing is the orchestrator that enables full lifecycle management of slices and associated resources, including SatCom specific NFV management as well as 5G Core management functions. In this architecture, network slicing follows 3GPP model, which focus on creation, management and orchestration of slices.

The SaT5G network slicing approach covers end-to-end service provisioning, management, and operation workflows on a per-slice basis. It enables services control and orchestration for different verticals, which are provided over multiple terrestrial and satellite platforms. Deployed architecture will be capable of:

- Creating customisable and dynamic SLA-based multi-domain end-to-end 5G slices with flexible and dynamically deployable satellite resources.
- Dynamic provisioning and instantiation of network slices.
- Flexible multi-domain management and operation of virtualised satellite and terrestrial functions.
- Seamless service provisioning at the network level through automated processes. Through the integrated network and management component, the service provisioning time will be reduced from weeks to less than 60 seconds.

C. Satellite Ground Segment Virtualisation

Much like the telecommunication networks, the satellite network functions are primed and well suited for virtualisation. As the satellite industry moves towards integration with the telecoms networks (e.g. core network integration) the satellite ground segment will evolve to look more like a standard telecoms network with a similar core and access domain. The same NFV principles can be leveraged within the satellite domain to provide end-to-end seamless integration from an operator perspective.

VI. Architecture Implementation

A. Transport network with advanced features

This is the natural evolution of current satellite backhauling. Satellite network offers transport features to 5G terrestrial networks, from a 5G core to a gNB. The satellite network is neither managed nor even visible by the 5G core; the 5G core only sees a trusted transparent transport media.

However, an interface evolution between the core and transport networks is needed. Advanced adaptation functionalities are developed between the two networks in order to, e.g. map the requirements from the terrestrial 5G core to the satellite classes of services (SAT CoS).

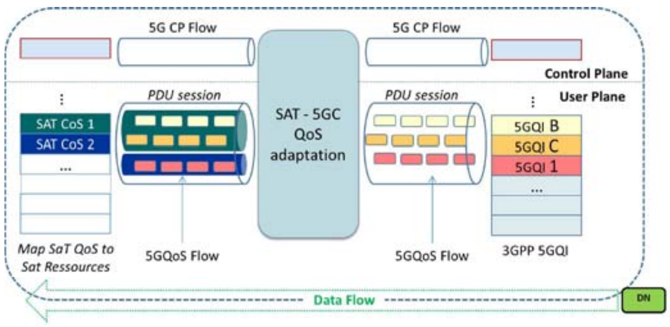

Fig. 4. QoS adaptation function between terrestrial 5G and satellite network

In Fig. 4, this function is represented as SAT-5GC QoS adaptation. The function analyses the 5G QoS flow and detects the 5QI values as defined in [7] and then maps this 5QI to its associated SAT CoS. Within the satellite network core another function is responsible of mapping the satellite class of service to satellite resources. In the SaT5G project, it is considered that all the control plane flows will map to the same satellite class of service.

B. Satellite terminal direct acces and relay node approach

In this model, Satellite Terminal is managed as a UE by the terrestrial 5G core. Further, it implements additional capabilities of relaying features. The satellite terminal is therefore a **relay UE** that aggregates traffic for the different local UEs and relays connections to the terrestrial 5G core through the satellite link.

The satellite Terminal aggregates the traffic from/to multiple local UEs and connects them to the terrestrial 5G core through the satellite link. Such traffic multiplex ensures smoother variations load (i.e. higher predictable load) than a single UE traffic, making the radio resource allocation process more efficient. This translates into higher radio resource usage (statistical multiplexing gain), or into lower access delays for user services. The Relay node approach is illustrated in Fig. 5.

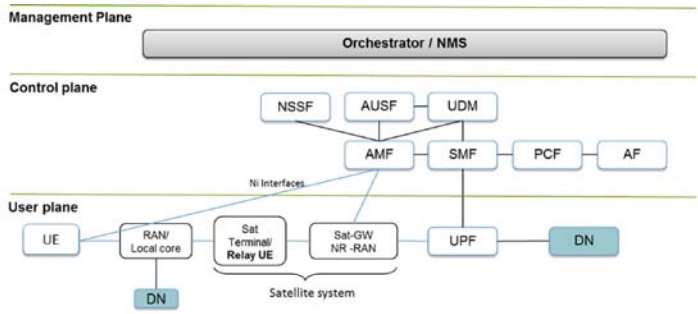

Fig. 5. Satellite terminal as a 5G relay node

C. On-board processing (OBP) satellite-based architecture

A regenerative satellite with advanced features can also be foreseen, offering the possibility to host on board a 3GPP access point The air interface can either be specific to satellite network (e.g. based on DVB standards) or can natively adopt the 5G NR (in the latter case the 3GPP access point is a gNB).

Indeed, unlike the transparent case, when the OBP embeds a 3GPP access point, there is an opportunity to shorten the response time (e.g. for UE access control when it enters in the system, for the radio resource control loop, for the mobility events/handover handling etc.). Satellite with OBP capabilities embedding a gNB is illustrated in Fig. 6.

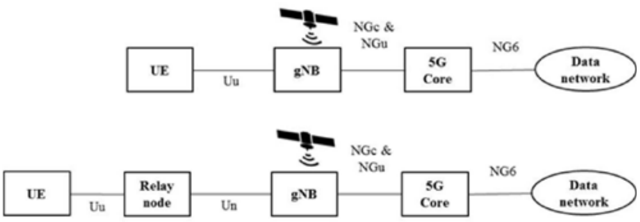

Fig. 6. Illustration of satellite network architectures with on-board processing

For constellation systems satellite with OBP and, ISL (Inter-Satellites Links), embedding a gNB could lead to a better continuity of services over a given tracking area. 3GPP mobility procedures could be used, possibly with minor adaptations, on the satellite terminal / Satellite interface to manage satellite handover. This shall be studied in further steps of the SAT5G project.

CONCLUSION

An overview of architecture options integrating satellite to 5G networks has been discussed in this paper. The positioning of satellite within 3GPP 5G functional architecture has been addressed followed by the identification of key improvements provided by satellite integration into the 5G ecosystem. The importance of integrated network management has also been discussed. Targeting a common management plane as well as virtualising the SatCom ground segment has been pointed out as the necessary means to ease transparent 5G network slicing implementation. Finally, different architecture implementation options have been discussed depending on the role of satellite network, topology and its visibility with respect to the 5G core.

ACKNOWLEDGMENT

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

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