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Design of Moving Experimentation Facility to Showcase Satellite Integration into 5G

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Abstract — This paper presents the end-to-end design of the Satellite-enabled 5G Moving Experimentation Facility (S5GMEF) currently under development as part of the H2020 5G PPP Phase III project "5G-VINNI" and the ESA ARTES project "SATis5", which aims to showcase the satellite integration into 5G with focus on satellite backhauling solutions. It addresses the split of the 5G system between the Central Node and the Edge Node hosted on-board a satellite connected vehicle, elaborates on the satellite transport network between the 5G Radio Access Network (RAN) and the 5G Core, and describes also the Management and Orchestration (MANO) and Network Functions Virtualisation Infrastructure (NFVI) features of the S5GMEF.

Keywords—5G; 5G testbed; satellite backhauling; satellite connected vehicle; edge-central network split; SDN; NFV; MEC.

I. INTRODUCTION

5G is the first truly multi-technology communication system, which is expected to have a large impact on society and industry. 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). It is widely recognised that, in order to be successful and meet user demands, the 5G infrastructure will be an ecosystem of networked networks, utilizing multiple different and complementary technologies.

The satellite role in the 5G ecosystem is being proven on the basis of its benefits and its integration in the overall network. The consensus and wider agreement on what satellite brings to achieve the 5G Key Performance Indicators (KPIs) are: service ubiquity, service continuity, service scalability, broadcast (simultaneity) and security [1].

To this end, several EU/ESA initiatives have been dealing with the satellite integration into 5G [2], [3]. Figure 1 illustrates the cartography of the three H2020 5G-PPP Phase III projects which develop 5G end-to-end test facilities to serve advanced validation trials across vertical industries. In particular, this paper focuses on the Satellite-enabled 5G Moving Experimentation Facility (S5GMEF) which addresses customised solutions for satellite integration into 5G with focus on satellite backhauling, and is currently under development within the H2020 5G-PPP Phase III project "5G-VINNI" (5G Verticals Innovation Infrastructure) [4] and the ESA ARTES funded project "SATis5" (Demonstrator for Satellite Terrestrial Integration) [5].

The remainder of the paper is organized as follows. Section II discusses the use cases and capabilities of the S5GMEF. In Section III, the architecture of the S5GMEF is presented, while Section IV provides the edge-central network split and requirements for the interconnection of the 5G edge node with the 5G central node. Finally, Section V concludes the paper.

Figure 1 H2020 5G-PPP ICT-17 Platforms Cartography [2]

II. USE CASES AND CAPABILITIES OF THE S5GMEF

The S5GMEF mainly provides satellite backhaul capabilities. It can support 5G use cases for both eMBB and mMTC usage scenarios [6], [7] and for various verticals. It is enabled by the SES' owned Rapid Response Vehicle (RRV) which is satellite connected [8] (see Figure 2). RRV is a multi-purpose communications platform mainly used for governmental and Public Protection and Disaster Relief (PPDR) vertical applications. However, other verticals can be supported as well, such as Media and Transportation.

The RRV provides satellite backhaul capabilities (either as a primary or backup connectivity) enabling local terrestrial communications. Its architecture is modular and supports evolution, it is highly resilient due to its multi-band capability, it is designed to be easily configured, even remotely, quickly deployed and operational in minutes, and built for client showcases and demonstrations. It is already equipped with a variety of capabilities, including Wi-Fi technology, licensed Very High Frequency (VHF) radios for Push-to-Talk (PTT)

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applications as well as with high-definition video surveillance cameras and autonomous power supply. Other local terrestrial communications systems which can be integrated with the RRV infrastructure correspond to Customer Furnished Items (CFIs) and include systems such as e.g., cellular Radio Access Network (RAN), Terrestrial Trunked Radio (TETRA), and Machine-to-Machine / Internet of Things (M2M/IoT).

Figure 2 SES' Rapid Response Vehicle (RRV)

In the context of the 5G-VINNI and SATis5 projects, the RRV capabilities are extended towards 5G in order to enable the S5GMEF to become a rolling lab for 5G mission specific solutions. To this end, the S5GMEF will host a satellite-enabled 5G Edge Node with Software Defined Networking (SDN) / Network Function Virtualization (NFV) / Multi-access Edge Computing (MEC) capabilities, enabling Network Slicing of eMBB and mMTC use cases over the SES' multi-orbit and multi-band satellite fleet.

III. S5GMEF ARCHITECTURE

In the S5GMEF, the SES' RRV hosting the 5G Edge Node is interconnected through the SES's satellite fleet and SES' teleport facility site located in Betzdorf (Luxembourg) with the 5G Core Network located at Fraunhofer FOKUS' premises as depicted in Figure 3. The S5GMEF architecture is illustrated in Figure 4, where its key features are summarised in Table 1 and elaborated hereinafter.

Table 1 S5GMEF Implementation Approach

Domain	Approach	Vendor
5G RAN	CFI	3rd Party
5G Core	Open5GCore	Fraunhofer FOKUS
Transport Network	Satellite Backhauling	VT iDirect, SES
MANO	Open Baton	Fraunhofer FOKUS
NFVI	Open-Source, OpenStack based	Fraunhofer FOKUS, VT iDirect

5G RAN

The 5G RAN (gNB and User Equipment (UE)) is assumed to be provided by a 3rd party as a CFI to be integrated with the 5G Edge Node residing within the SES' RRV infrastructure.

5G Core

The 5G Core Network of the S5GMEF corresponds to Fraunhofer FOKUS' Open5GCore [9], which is compliant with the 3GPP Release 15 and is located at Fraunhofer FOKUS's premises in Berlin, Germany, which is interconnected to the Satellite Hub platform located at SES' teleport in Betzdorf, Luxembourg.

The edge-central network split is expressed as the split of the 5G system between edge and central network. In this context, in order to assure the connectivity to the 5G network though the different backhauls, the 5G Core Network is deployed with a functional split between the edge and the core network (see Figure 4). Further details on the Edge-Central Network Split are provided in Section IV.

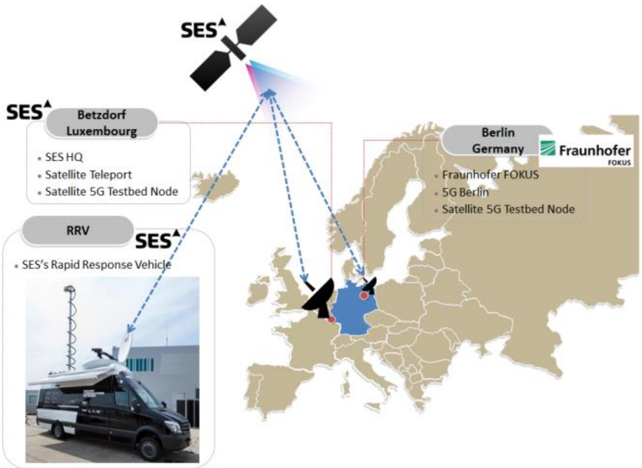

Figure 3 Satellite Interconnection between 5G Edge Node and 5G Core Network

Transport Network

The S5GMEF mainly provides satellite backhaul capabilities. As such, the transport network between the 5G RAN and 5G Core corresponds to a satellite transport network.

The 5G Edge Node on-board the SES' RRV is equipped with an SDN/NFV/MEC-enabled 5G testbed node and satellite communication equipment in order to be interconnected through satellite to the Satellite Hub platform located at SES' teleport in Betzdorf, Luxembourg. For the satellite connectivity between the 5G Edge Node and the 5G Core Network, the SES' multi-orbit and multi-band transparent (bent-pipe) satellite fleet and the VT iDirect's Velocity™ satellite ground segment are employed. With respect to the latter, the Satellite VNFs are particularly highlighted hereinafter.

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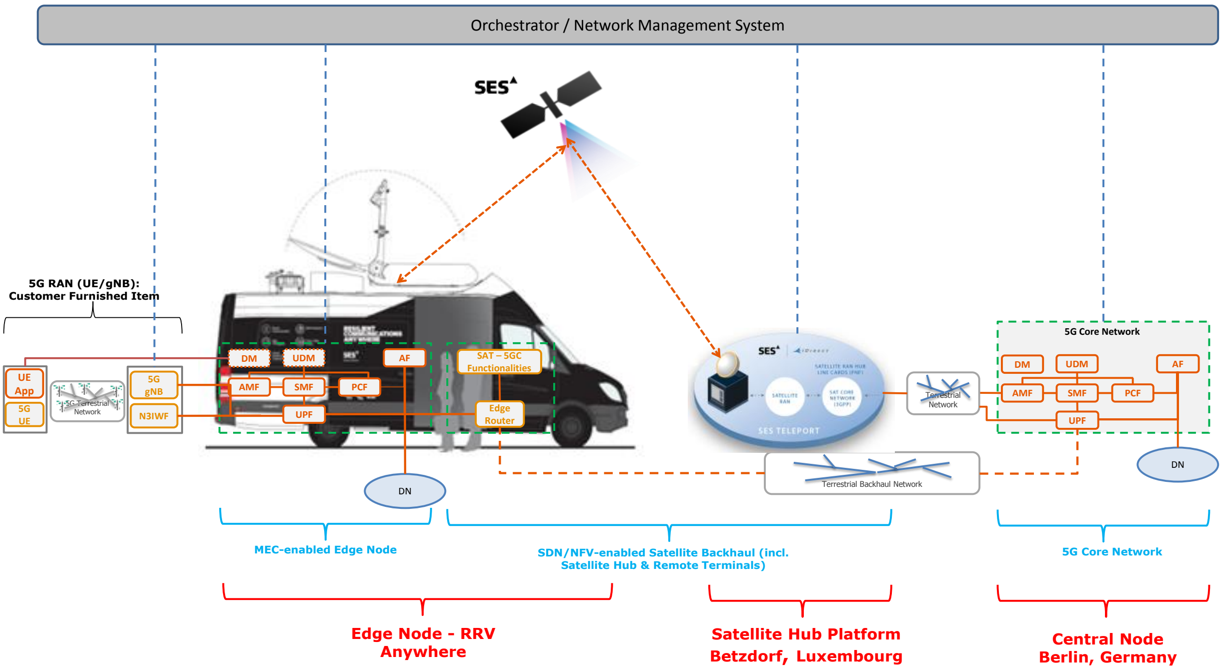

Figure 4 S5GMEF Architecture

- **Satellite VNFs:** The satellite network functions are virtualised by transferring their execution environment from a dedicated server to a Virtual Machine (VM) using the OpenStack Pike VIM. Satellite Virtual Network Functions (VNFs) include the Satellite Radio Access Network (SatRAN) software element, the satellite 3GPP Core Network function, and additional auxiliary VNFs deployed on the same system using the OpenStack Virtualised Infrastructure Manager (VIM). Other possible satellite VNFs include: Transmission Control Protocol (TCP) Performance-Enhancing Proxy (PEP), Quality of Service (QoS) adaptation, mapping satellite QoS flow to satellite resources, gNB mobility management, etc.

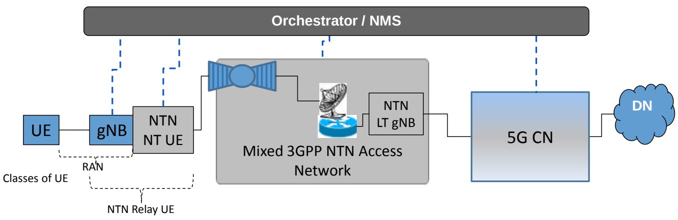

Figure 5 Indirect Mixed 3GPP Non Terrestrial Network (NTN) Access with Bent-Pipe Payload [10]

With reference to [10] and Figure 5, the integration scenario of satellite networks in the 5G system architecture which is of interest here is the so-called "Indirect Mixed 3GPP Non Terrestrial Network Access". In this integration scenario, 5G UEs are served by an access point. This access point is served by a trusted mixed 3GPP NTN access network. UE management applies to the NTN enabled UE. The NTN enabled UE endorses a multiplexer node role. Another wording for this scenario could be "Indirect 3GPP NTN access with non-3GPP L2, non-3GPP L1". In this case, there is indirect connection through a 5G satellite access network (bent-pipe satellite case) but with a mixed 3GPP NTN access network instead of a 5G satellite access network (i.e. instead of a 3GPP defined NTN NR-Radio Access).

Furthermore, with reference to Figure 4, the "Edge Router" network function for the backhaul selection acts as a Software Defined – Wide Area Network (SD-WAN) router able to determine which backhauls are available and to steer the data traffic according to a set of routing policies over the backhauls. As this intermediary node represents the interaction across different types of backhaul, the Edge Router should include the security associations to be able to forward messages across the backhaul as well as other mechanisms necessary for proper data packet packaging and reliability of communication.

Management and Orchestration (MANO)

The management and orchestration of the S5GMEF is based on Fraunhofer FOKUS' Open Baton, which is an open-source implementation of the ETSI NFV MANO specification [11]. It follows a modular approach with the main components being an NFV Orchestrator (NFVO), a generic VNF manager and VIM drivers to support different types of VIMs (e.g. OpenStack and Docker).

The MANO solution of the S5GMEF is split into two sub-categories:

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- **MANO for 5G Edge Node and 5G Central Node**: The 5G Core VNFs at the 5G Edge Node and 5G Central Node are orchestrated by Open Baton.
- **MANO for Satellite Ground Segment**: OpenStack VIM is selected as the SDN/VIM framework of choice for the satellite transport network. Satellite VNFs include the SatRAN software element, the satellite 3GPP Core Network function, and additional auxiliary VNFs deployed on the same system using the OpenStack VIM.

Network Functions Virtualisation Infrastructure (NFVI)

The NFVI solution of the S5GMEF is also split into two sub-categories:

- **NFVI for 5G Edge Node and 5G Central Node**: The 5G Core VNFs at the 5G Edge Node and 5G Central Node will be deployed using a mix of containers and virtual machines using OpenStack, orchestrated by Open Baton.
- **NFVI for Satellite Ground Segment:** The network functions in the satellite network are virtualised by transferring the execution environment of a satellite function from a dedicated server to a VM using the OpenStack Pike VIM.

IV. Edge-Central Network Split in S5GMEF

As mentioned in Section III, the S5GMEF implements an edge-central network split. In order to make the appropriate split between the 5G Edge Node and the 5G Central Node, a set of considerations should be made on the opportunity of such a placement and several considerations on the communication.

- Edge placement will reduce the communication needs with the central location – the main reason to place functions at the edge is to reduce the communication needs to the central location.
- Placement at the edge will require trust into the edge node for the specific functionality – a remote node is very easy to tamper with including man-in-the-middle attacks. Sensitive information for the functioning of the system such as user profiles or user credentials should not be placed at the edge.
- Placement at the edge requires available compute and storage.
- The state within the edge node will have to be handed over to a new edge node in case of a handover – this would require in most of the cases the passing of the state information through the central node.

For the different elements, the following considerations should be made:

- Access and Mobility management Function (AMF) placement at the edge will provide local access and mobility management, giving the possibility for the remote node to control the mobility within the local area. During a handover to a terrestrial network not using the same backhaul or self-backhaul (in proxy mode), an AMF-to-AMF handover should be made. This is similar to terrestrial-only edge nodes.
- Session Management Function (SMF) placement at the edge will provide the local control of the data path, independent of the central locations. The SMF cannot be placed at the edge without an AMF placement (due to the procedures of data path establishment which follow the UE-AMF-SMF signalling path). The SMF can be placed at the edge when:
    - The edge SMF establishes the edge data path (the local node can be independent).
    - The edge SMF can communicate with the central SMF for an end-to-end data path including the edge and the central node.
- Policy Control Function (PCF) placement at the edge – PCF can be placed at the edge only when the AMF and SMF are placed at the edge. Edge PCF is useful in all the situations when an edge SMF is involved for the local communication. Otherwise, a central PCF would be connected to the central location.
- User Plane Function (UPF) placement at the edge – in any situation when an application function is placed at the edge, a UPF is required to enable the local offload. As the UPFs can be dynamically chained, a second one can be placed at the central location for the end-to-end connectivity without incurring any standard modifications.
- Unified Data Management (UDM) placement at the edge – this is not recommended as the UDM includes private information on the subscriber. A temporary UDM partially synchronized can be added to be able to maintain the functioning of the edge node in case the backhaul connectivity completely fails.
- Data Management (DM) placement at the edge – the device management considerations are the same as for UDM.

Based on these considerations, the following slice models are currently supported by the S5GMEF for enabling the various 5G use cases (see Figure 6):

1. **Centralized slice** – all the network functions are placed at the central location. This solution relies on the advantage of the optimized satellite direct connectivity (and on the foreseen integration of the satellite specific protocols with the 5G ones) to establish a large scale gNB at the hub side.
2. **Local offload with centralized control plane** – the edge node is able to offload the data traffic to the edge, however, the control is done from the central

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location. As the control remain centralized, in this situation a larger end-to-end procedure delay for establishing the offloading is required.

3. **Local mobility** – placing the AMF on the edge side will enable the optimized authentication and authorization (less as the UDM remains in the central side) and especially mobility management in the local coverage area. One aspect is the efficient reachability of the devices as the paging procedure is executed only in the coverage area. Furthermore, the control plane signalling is optimized and can be implemented using the Service Based Architecture, as there are no interfaces between edge and central location directly related to the radio technologies. The establishment of the data path is the same as in the previous model, as the SMF remains centralized.

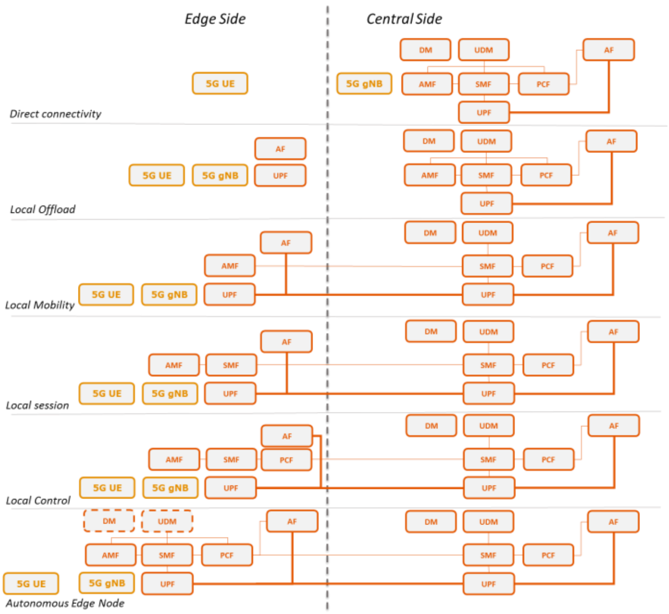

Figure 6 Slice Models Supported in S5GMEF

4. **Local session** – placing an additional SMF on the remote side provides the means to locally control the local data path, with a minimal signalling to the core network towards the PCF. This solution requires the chaining of SMFs as well as the interaction with the PCF only at the last SMF. Because of this interaction with a centralized PCF, this solution is mainly optimized for the end-to-end connection and less for the local offload, where the control plane signalling will have to reach the central PCF for establishing the communication rules.

5. **Local control** – placing the comprehensive control plane elements at the edge will enable the system to act as an autonomous connectivity island which takes decisions on its own functioning. However, for the end-to-end communication the edge side will have to interact with the central SMF as in the local session case and with the local PCF.

6. **Autonomous Edge Node** – the edge node may include an additional front-end for device management and for user data subscription, using information stored in the local cache and default subscription profiles. In this case the edge side can function in a complete manner when the backhaul connectivity is lost. However, with passing the subscription profiles to the edge node, an increase security of these nodes has to be established. This solution should be considered only when the trust in these edge nodes is large.

V. CONCLUSION

This paper provided a high-level design for the network services offered by the Satellite-enabled 5G Moving Experimentation Facility (S5GMEF). S5GMEF is enabled by the SES' Rapid Response Vehicle hosting the 5G Edge Node, which is interconnected through satellite with the 5G Central Node, and implements an edge-central network split. The capabilities and the use cases supported by the S5GMEF were discussed. The S5GMEF end-to-end design was described with focus on the satellite transport network features. Finally, the edge-central network split between the 5G Edge Node and 5G Central Node was elaborated and the interconnection requirements were specified.

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