Over-the-air Tests of a Satellite-backhauled 5G SA Network with Edge Computing and Local Breakout

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***Abstract*— The use of satellite as backhaul in 5G networks is currently the most mature approach for satellite/5G integration, extending the coverage of 5G to underserved areas, beyond the reach of terrestrial backhaul infrastructures. This paper presents an actual implementation and over-the-air tests of a 5G Stand-Alone network, where a satellite link is used to interconnect the 5G Core with the RAN. Furthermore, local breakout is adopted to enable edge computing at the satellite edge; this is achieved by virtualizing and off-loading the 5GC User Plane Function to the edge. The performance of each configuration is evaluated with generic traffic, using the Open5GENESIS experiment automation suite, as well as in the context of an actual use case (5G smart agriculture).**

***Keywords*— satellite/5g integration; edge computing; local break-out; smart agriculture**

I. Introduction

The vision for 5G -and beyond- networks is to realize a truly ubiquitous communication infrastructure, extending beyond the reach of terrestrial fixed backhaul networks. For this purpose, close integration with satellite communication infrastructures is envisaged, to be able to reach out to remote/underserved areas[1]. While, lately, the focus of 3GPP study items has been on satellite used for the RAN segment (i.e. NR over satellite[2]), it is true that one of the most mature scenarios for satellite/5G integration is the use of the satellite link as backhaul, connecting the 5G radio front-end (gNB) with the core (5GC)[3].

The integration of the satellite link in the 5G service chain comes with increased latency (especially for geostationary orbit satellites) as well as bandwidth limitations. To mitigate this effect, a satellite edge computing infrastructure can be adopted, where 5G applications are deployed at the satellite edge close to the gNB, rather than in the core of the network. With the use of local breakout (LBO) configurations, the data plane functions of the 5G core can also be deployed at the satellite edge, allowing edge application traffic to be locally routed, rather than traverse the satellite backhaul. This configuration is demonstrated in the present work.

Several works have previously studied the role of satellite as a backhaul in 5G networks and the value of edge computing. In [4], the authors discuss the value of edge caching for content distribution in 5G-backhauled satellite and present the architecture also adopted by the present paper; yet, the implementation is restricted to WiFi access after the satellite segment (i.e., not 5G RAN). [5] presents over-the-air tests of a backhauled cellular network with distributed core functions, yet the implementation is based for 4G, not 5G. [6] presents an over-the-air demo of satellite integration with 5G core network, however the RAN part is implemented with a 4G eNB and local EPC component. In [7] and [8], the authors implement edge caching to optimize resources in a satcom/5G network, still the results are derived from simulations, not actual implementation.

Thus, according to our literature survey and to the best of our knowledge, this paper presents the first real implementation of a satellite-backhauled 5G Stand Alone (SA) network, with 5G radio and core, enabling edge computing with local breakout - i.e., the 5GC User Plane Function (UPF) deployed at the satellite edge, co-located with the RAN. This is the key innovation of the presented work. Performance measurements are derived using generic traffic generation tools, while a vertical use case in the 5G smart agriculture domain is also demonstrated and assessed via field trials.

The paper proceeds as follows: Section II presents the configuration of our testbed, its topology and the technologies used. Section III compares two alternative configurations; full

5G satellite backhauling vs. local breakout with edge computing. Section IV presents the implementation and performance of the vertical use case using the two above mentioned configurations and, finally, Section V draws the conclusions of the paper.

II. Experimental Network Configuration and Setup

Our experimental network is based on the integrated satellite/5G infrastructure of one of the 5G experimental platforms of the H2020 5GENESIS project [9], namely the Limassol platform [10]. The demo setup implements a 5G stand-alone (SA) network, backhauled by a geostationary satellite link.

The network setup (shown in Fig. 1) comprises three main segments:

- the core, running an OpenStack-based NFVI, which hosts the 5G core functions, the Management and Orchestration components, as well as the Open5GENESIS suite and portal for test automation (explained further below). The open-source Open5GS suite (v.2.2.6) was used as 5G core, deployed as a VNF on OpenStack.
- the satellite backhaul link, over the Avanti HYLAS 2 geostationary satellite, served by the Makarios Earth Station in Cyprus. An IPSec VPN is established to interconnect the platform core with the earth station.
- the 5G satellite edge segment, comprising the satellite antenna and terminal, the edge computing infrastructure (compact edge server also running OpenStack) and the 5G gNB, all integrated in a portable rack (Fig.2).

Two scenarios are considered; a first scenario in which all 5GC functions are deployed at the platform core, and a second one in which LBO configuration is considered. More information about these scenarios and their performance in terms of latency and throughput is given in the next section.

Table I lists the main technical specifications of the experimental network. A more detailed presentation of the full configuration and the features of the 5GENESIS Limassol platform can be found in [11]

Fig. 2. Satellite edge segment integrated in a portable rack

TABLE I. Technical specs of the experimental network

Component	Specifications
5G Core	Open5GS v.2.2.6 (Rel.16) - virtualised
5G configuration	Stand-Alone (3GPP Option 2)
Experiment automation framework	Open5GENESIS suite
NFVI (Core & Edge)	OpenStack Rocky
Satellite backhaul	Ka-band over Hylas 2 satellite, 5Mbps DL/UL
Edge server	Dell Edge Gateway 5100
gNB	Amari Callbox Classic
5G NR configuration	20 MHz, 2x2 MIMO, band 78
UE	Raspberry Pi 4 w/ Waveshare 5G Hat (Snapdragon X55)

The measurements presented in this paper are automated using the experiment automation suite (“Open5GENESIS”)

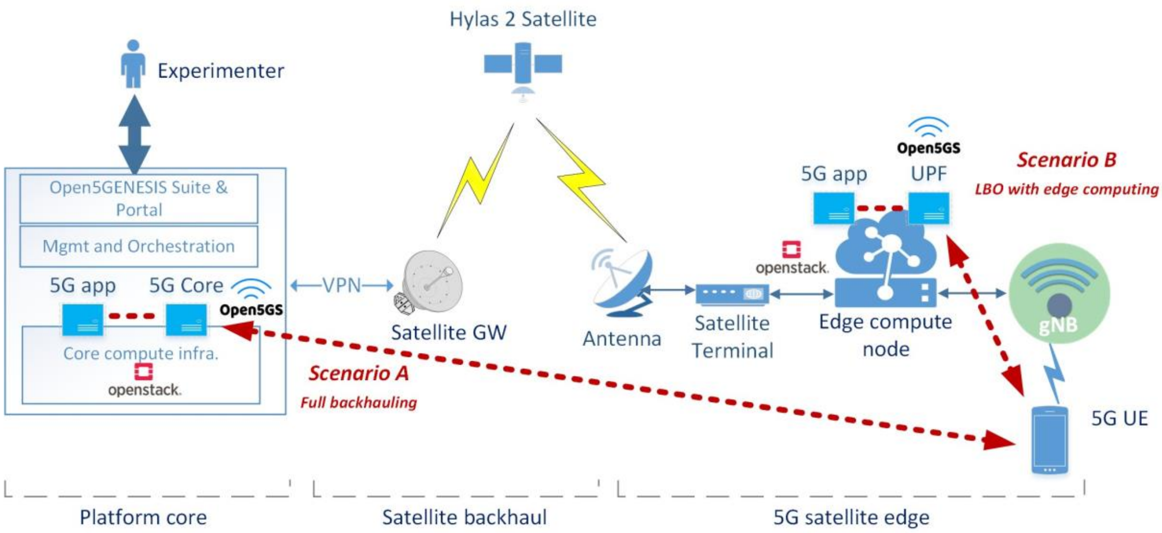

Fig. 1. Experimental network setup

[12], also developed in the 5GENESIS project. Open5GENESIS is an open-source framework for experimentation, especially tailored for automating tests in 5G infrastructures. As a front-end of the automation engine, a web portal is used. For the throughput and RTT measurements presented, iperf3 and ping agents respectively are used, deployed at the endpoints, which feed the results back to Open5GENESIS for analysis. A more detailed presentation of the Open5GENESIS suite is beyond the scope of this paper and can be found in [13]

III. Scenarios Evaluation

A. *Scenario A: 5G fully backhauled over satellite*

The first scenario tested involves the 5GC fully backhauled over the satellite link, i.e., with all 5GC functions deployed at the platform core, while the RAN resides at the satellite edge. This implies that the satellite link carries N1, N2 and N3 traffic. All user data also traverse the satellite link. This configuration is depicted in Fig.3., which shows the distribution of the 5G Core functions in the different network segments. More details about the 5G Core and its deployment in a satellite network can be found in [14].

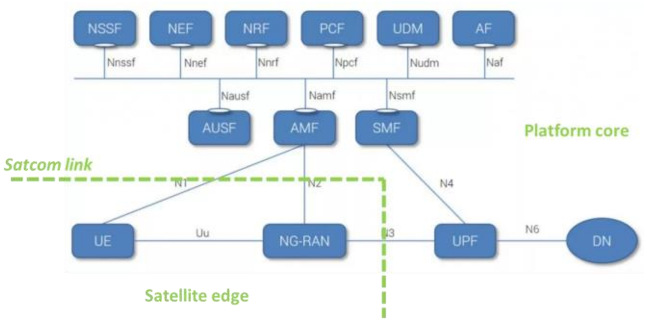

Fig.3. Distribution of 5GC functions in the full backhauling configuration

Throughput is measured using the Open5GENESIS iperf3 agents, deployed at the core node and the UE. Following the pre-defined test case template, 25 iterations are performed, each one lasting 100 seconds. The visualisation of the results from the Open5GENESIS portal is shown in Fig. 4. As seen, the download throughput measurement was on average 2.22 Mbps, and its standard deviation (SD) was 1.11 Mbps. This is due to the satellite backhaul being limited to 5 Mbps as well as the overhead due to the double tunnelling over satellite (i.e. GTP over GRE, necessary for establishing reachability between network segments).

The RTT is measured using ping agents at the core node and the UE. 25 iterations were performed, each one involving 100 ICMP requests. The visualisation of the results in the Open5GENESIS portal is shown in Fig. 4. The RTT mean value was on average 838.34 msec, with a SD of 38.48 msec, values are fairly high mainly as a result of the latency introduced by the satellite link.

B. *Scenario B: Satellite-backhauled 5G with edge computing and local breakout (LBO)*

The next step has been to implement the local breakout configuration. The UPF function was off-loaded to the satellite edge, deployed as separate VM in the edge NFVI, while the rest of the 5GC functions (AMF, SMF etc.) remained behind the satellite link at the core of the platform. This implies that the satellite link carries N1, N3 and N4 control traffic, whereas use plane traffic (N2) is handled locally at the satellite edge and is routed (N6) either to the local server or via the satellite link for external services. This configuration is depicted in Fig.5 (which is a modification of Fig. 3), showing the revised distribution of the 5G components in the different network segments.

The throughput is measured using iperf3 agents at the edge node and the UE. As expected, the traffic destined for the local node is routed locally, yielding a considerable increase in throughput, whose mean increases from 2.2 to 30.3 Mbps (SD: 3.44 Mbps). The RTT is measured using ping agents at the edge node and the UE. In the local breakout scenario, it drops

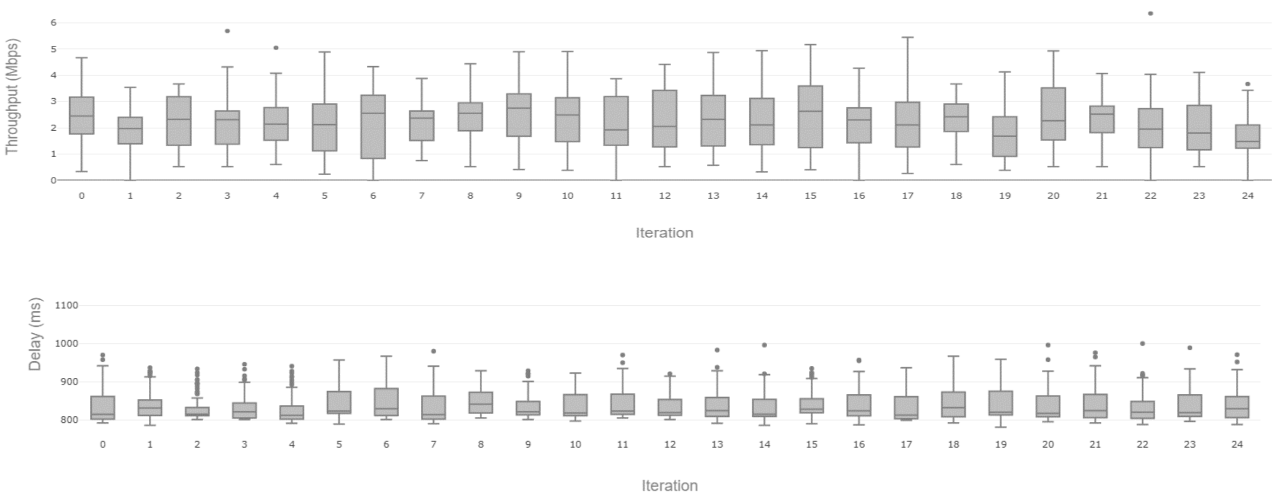

Fig. 4. Full backhauling configuration – Download throughput and RTT

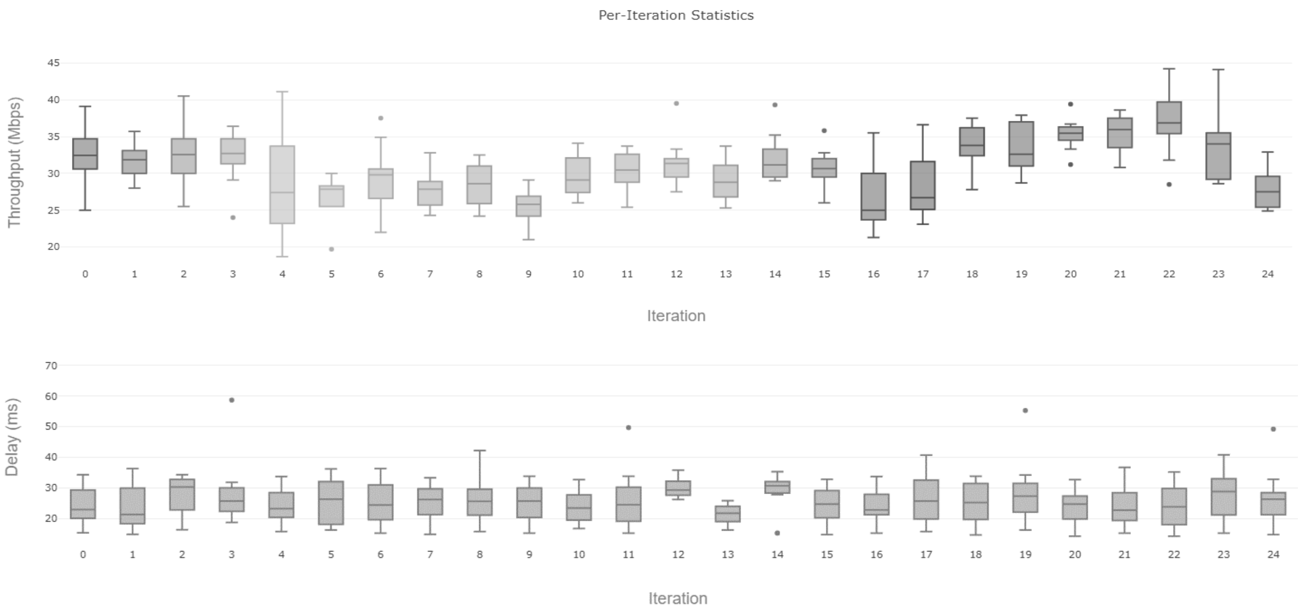

Fig. 6. LBO at the satellite edge – Download throughput and RTT

from 848 msec in the full backhauling setup to 25.7 msec (SD: 6.7 msec). The results are visualized in Fig.6.

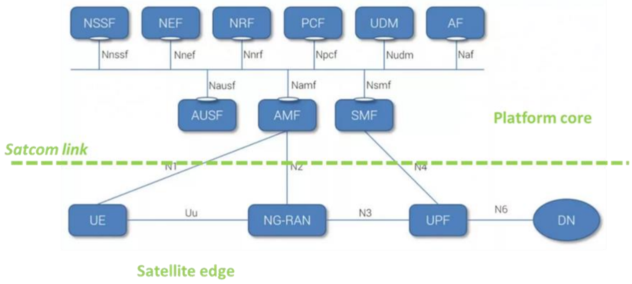

Fig. 5. Distribution of 5GC functions in the satellite LBO configuration

IV. USE CASE DEMONSTRATION: 5G SMART AGRICULTURE

In addition to the RTT/throughput tests, the two alternative configuration scenarios were evaluated in a field trial demo of a relevant vertical use case. The use case demonstrated is based on a 5G smart agriculture bespoke application. The application uses computer vision and Deep Learning-based analysis of drone-captured crop images for detection of specific plants in rural fields. More details about the app and the use case demo setup can be found in [15] and [16].

The AI model of the plant detection application runs on Tensorflow. The images are captured by a 5G UE (Huawei P40) mounted on a drone scanning the crop and are sent for analysis to the back-end application (Fig.7). To demonstrate the value brought by satellite edge computing, two alternative scenarios directly relevant to the scenarios described in the previous section were considered:

Fig.7. Drone with mounted 5G UE during the field trials

- In Scenario A (full backhauling, without edge computing), all 5G Core functions are deployed at the core data center, behind the satellite link. The smart agriculture application is also deployed at the core. Traffic handled by the application has to traverse the satellite link.
- In Scenario B (with LBO and edge computing enabled), the UPF function is deployed at the edge (in the field) to enable local breakout functionality. The smart agriculture application is also deployed at the edge.

A second UE (based on the open-source Gotify server) was used to visualize the detection results in a web interface, in real time (Fig.8)

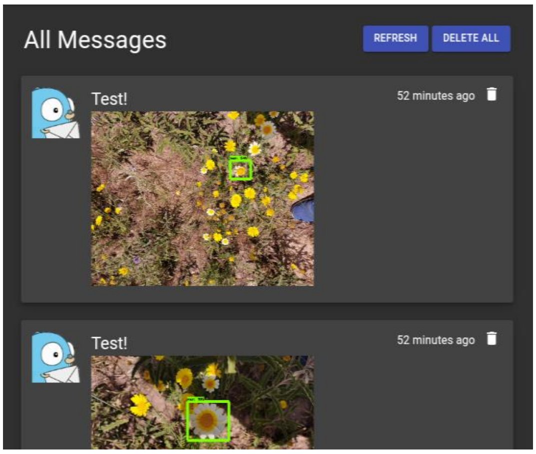

Fig.8. Visualisation of real-time plant detection

The metric measured is the application response time measured at the UE, i.e., the time interval from the submission of the captured image by the UE until the reception of the outcome of the image analysis. Apart from the application response time, the image processing time (inference time needed for the AI process) is also captured.

For the planning and automation of experiments, as well as results analysis using the Open5GENESIS suite, a bespoke measurement agent at the UE was implemented. The agent, in turn, interfaces with the smart agriculture application using a REST API to collect application-level metrics.

Fig. 9 depicts the reduction of the delay when the application is deployed at the edge node. While processing delay remains the same around 0.1 sec, end-to-end delay drops from ~4 sec in Scenario A to ~0.5 sec in scenario B. This corresponds to the almost tenfold RTT reduction described in Section 3, taking into account that a full application transaction requires several RTTs to complete.

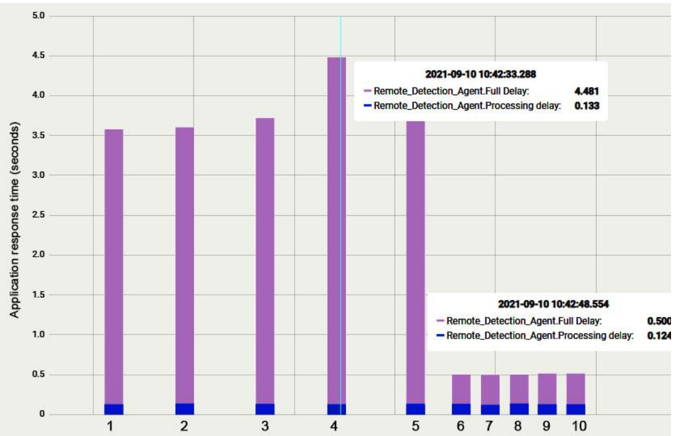

Fig. 9. Application response time reduced using LBO and edge computing (Measurements 1-5: Scenario A, measurements 6-10: Scenario B)

V. Conclusions

In this paper, the implementation of an experimental setup was presented, with satellite backhauling fully integrated in a 5G Stand-Alone network configuration. The operation of the 5G Core with the N1, N2 and N3 interfaces operating over satellite, was verified. Also, the 5G SA LBO configuration was evaluated, with the UPF off-loaded to the satellite edge; this is also one of the key innovations of this paper. 5G SA LBO configuration exhibited approximately a tenfold improvement in throughput and latency for the considered edge applications. A more in-depth investigation of the 5GC behaviour under such a configuration and its fine-tuning for further optimisation of its performance will be the next steps in our research.

The application demonstrated, in the domain of smart agriculture, was well suited to showcase the capabilities of an integrated satcom/5G setup. Once again, the feasibility and value of edge computing to reduce latency and improve throughput -particularly for bandwidth-demanding applications such as real time video analytics- was demonstrated.

Finally, it must be mentioned that the trials were performed using exclusively open-source software for all components except the gNB: 5GC (Open5GS), NFVI (OpenStack), experiment automation (Open5GENESIS), which significantly facilitates the reproducibility of the setup.

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 (5GENESIS). It is being continued in the frame of the DEGREES project (Development and Evolution of the Greek Governmental Satcom), co-funded by the European Space Agency.

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