UNICO I+D Project 6G-INTEGRATION-01

6G-INTEGRATION-01-E14

Test results of the integration of the prototype in the B5G/NTN

ABSTRACT

This document presents the results of the integration of the Inster-Oesia Group Developed prototype within the B5G7NTN defined on the 6G-INTEGRATION-01 program. This document consists of presenting the tests that have been carried out prior to the final integration in the test bench, as well as the tests carried out together with the test bench according to the different use cases presented.

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DOCUMENT PROPERTIES

Document number	6G-INTEGRATION-01-E14
Document title	Antenna Prototype
Document responsible	Daniel Segovia (UC3M)
Document editor	Manuel Rebollo Gordillo, Marta Sánchez Sánchez (INSTER)
Editorial team	Manuel Rebollo Gordillo, Marta Sánchez Sánchez (INSTER)
Target dissemination level	Confidential
Status of the document	Final
Version	1.0
Delivery date	09/12/2024
Actual delivery date	09/12/2024

PRODUCTION PROPERTIES

Reviewers

DISCLAMER

This document has been produced in the context of the 6G-INTEGRATION-01 Project. The research leading to these results has received funding from the Spanish Ministry of Economic Affairs and Digital Transformation and the European Union-NextGenerationEU through the UNICO 5G I+D program.

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LIST OF ACRONYMS

NTN	Non-Terrestrial Networks
LEO	Low Earth Orbit
ATSSS	Access Traffic Steering-Switching-Splitting
KPI	Key Performance Indicators
IP	Internet Protocol
UCT	User Connectivity Test
IT	Integration Test
SATCOM	Satellite Communications
QoS	Quality of Service
UDP	User Datagram Protocol
TCP	Transmission Control Protocol
IPsec	Internet Protocol Security
IKE	Internet Key Exchange
ESP	Encapsulating Security Payload
PFS	Perfect Forward Secrecy
PSK	Pre-Shared Keys
NAT	Network Address Translation
VPN	Virtual Private Network
DPD	Dead Peer Detection
SAs	Security Associations
ACLs	Access Control Lists
DHCP	Dynamic Host Configuration Protocol
AES	Advanced Encryption Standard
SHA	Secure Hash Algorithm
RTT	Round Trip Time
RAN	Radio Access Network
TN	Terrestrial Network
CSP	Content Security Policy

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CPE	Customer Premises Equipment
B5G	Beyond 5G
3GPP	3rd Generation Partnership Project
DL	Downlink
EAB	Network Address Translation
ms	milliseconds
UL	Uplink
HQ	High Quality

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RESUMEN EJECUTIVO

Este documento se centra en la documentación de las pruebas realizadas durante la integración del prototipo desarrollado por INSTER en el banco de pruebas proporcionado por Ericsson. El objetivo es presentar tanto las pruebas preliminares a la integración en el banco de pruebas como las pruebas a realizar con el banco de pruebas según los casos de uso definidos.

El documento se divide en dos partes:

- Definición de las pruebas que INSTER realizará en el laboratorio antes de la integración en el banco de pruebas, para garantizar el correcto funcionamiento del sistema de forma aislada.
- Definición de las pruebas a realizar en el banco de pruebas según los casos de uso definidos por Ericsson.

Para la realización de estas pruebas, se han identificado una serie de pre-requisitos necesarios para su ejecución exitosa:

- Solicitud del servicio satelital para garantizar la operatividad del terminal proporcionado por INSTER.
- Disponibilidad del prototipo para las pruebas.

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EXECUTIVE SUMMARY

This document focuses on the documentation of the tests carried out during the integration of the prototype developed by INSTER in the test bench provided by Ericsson. The objective is to present both the preliminary tests before integration into the test bench and the tests to be carried out with the test bench according to the defined use cases.

The document is divided into two parts:

- Definition of the tests that INSTER will carry out in the laboratory before integration into the test bench, to ensure the correct functioning of the system in isolation.
- Definition of the tests to be carried out in the test bench according to the use cases defined by Ericsson.

For the execution of these tests, a series of prerequisites necessary for their successful execution have been identified:

- Request for satellite service to ensure the operability of the terminal provided by INSTER.
- Availability of the prototype for testing.

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1. INTRODUCTION

In the rapidly evolving landscape of telecommunications, the integration of satellite terminals within a 5G network has become increasingly essential. This necessity arises from the need to extend connectivity to remote and underserved areas where traditional wired infrastructure is impractical or impossible to deploy. By incorporating satellite technology, 5G networks can achieve broader coverage, ensuring seamless communication and data transfer even in the most challenging environments. This integration not only enhances the overall network resilience but also supports critical applications such as disaster recovery, remote monitoring, and IoT deployments in isolated regions. As we strive for ubiquitous connectivity, the synergy between satellite and 5G technologies represents a pivotal step towards a truly global and inclusive digital ecosystem.

Non-terrestrial networks (NTN), including satellites and high-altitude platforms, play a crucial role in complementing and enhancing terrestrial 5G networks as mentioned before. Here are some key reasons:

1. **Global Coverage**: NTN can provide connectivity in remote and hard-to-reach areas where terrestrial networks are unavailable, ensuring that even the most isolated communities have access to high-speed internet.
2. **Resilience and Redundancy**: In the event of natural disasters or failures in terrestrial infrastructure, NTN can serve as a backup, maintaining connectivity and facilitating emergency communications.
3. **Low Latency**: Low Earth Orbit (LEO) satellites offer lower latency and higher data transfer speeds, which are essential for applications requiring high responsiveness, such as augmented reality and autonomous systems.
4. **Capacity Expansion**: As the demand for 5G bandwidth increases, NTN can help prevent terrestrial network congestion by providing additional capacity and improving service quality.
5. **Innovation and New Use Cases**: Integrating NTN with 5G networks opens new applications and services, from offshore connectivity to coverage at temporary events and rural areas.

In summary, non-terrestrial networks are essential for ensuring robust, widespread, and high-quality connectivity, complementing the limitations of terrestrial networks and enabling true global coverage.

Throughout the following sections, we demonstrate the feasibility of integrating this satellite terminal into the 5G network. Initially, isolated validations are performed on the prototype terminal to identify and confirm its capability to integrate into the 5G network. Subsequently, tests are conducted under typical use cases defined for the 5G network.

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2. Use Cases for Integrating NTN in 5G Test Bench

The integration of non-terrestrial networks (NTN) with 5G technology presents a range of innovative use cases that enhance connectivity, resilience, and scalability. This integration is crucial for extending the reach and capabilities of 5G networks, particularly in remote and underserved areas.

The proposed use cases will be tested within the 6G-INTEGRATION program. 5TONIC plays a pivotal role in this project by providing a collaborative innovation laboratory where the integration and testing of the terrestrial terminal with OneWeb's LEO satellite network can take place.

These use cases highlight the potential benefits and applications of NTN in 5G:

Service Continuity (NTN as Backhaul): NTNs can be used to provide backhaul connectivity for terrestrial networks, especially in remote or underserved areas. This ensures that even locations without direct access to fibre or other high-capacity terrestrial links can still benefit from high-speed internet and mobile services [1]. This is particularly useful for maintaining connectivity in remote or underserved areas [4].

NTNs can also serve as backhaul links for isolated 5G cells, connecting them to the network core. This is useful for providing connectivity to remote villages, industrial sites, or moving platforms like ships and aircraft [4].

Service Ubiquity (NTN as Backup Backhaul): In scenarios where terrestrial backhaul links fail due to natural disasters, technical issues, or other disruptions, NTNs can serve as a reliable backup. This redundancy helps maintain continuous service and supports disaster recovery efforts [2].

Multi-Connectivity (Multiaccess with NTN Networks (ATSSS)): Access Traffic Steering, Switching, and Splitting (ATSSS) allows for seamless integration of NTNs with terrestrial networks. This multiaccess approach ensures optimal use of available network resources, improving overall connectivity and user experience. It enables devices to switch between terrestrial and non-terrestrial networks based on factors like signal strength, latency, and bandwidth availability [3].

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2.1. 5TONIC Laboratory

5TONIC laboratories have the required equipment and knowledge to create real 5G scenarios as described below:

- 5TONIC provides a state-of-the-art testbed, which includes the necessary infrastructure and tools to conduct comprehensive tests on the integration of LEO satellite communications with 5G networks. This environment is crucial for validating the performance and reliability of the terrestrial terminal in real-world scenarios.
- As a leading open research and innovation laboratory, 5TONIC brings together experts from various fields, including telecommunications, satellite communications, and network integration. This collaborative environment fosters innovation and ensures that the project benefits from a wide range of expertise and insights.
- 5TONIC's facilities and resources enable the exploration of multi-connectivity scenarios, where the terrestrial terminal can seamlessly switch between terrestrial and non-terrestrial networks. This capability is essential for ensuring continuous and reliable connectivity, especially in remote or underserved areas.
- The project benefits from the resources and support provided by 5TONIC, including access to advanced technologies and research facilities. This support is vital for the successful development and testing of the terrestrial terminal.

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3. Test Plan

The purpose of this test plan is to outline the strategy and approach for validating the functionality, performance, and reliability of the system under test. This document provides a comprehensive framework for conducting tests, ensuring that all aspects of the system are thoroughly evaluated against the specified requirements and use cases.

The test plan will be divided into two parts:

1. **Prototype Internal Configuration and Data Transmission Tests**: These tests will be conducted in isolation to configure and validate the network settings of the equipment. The goal is to ensure that the system functions correctly on its own before integration in the 5G network as efficient backhauling solution to support data transmission process.

   The following KPI's will be considered to validate the solution before the integration:

   - Data Transmission Capability
   - Interoperability with EAB - IP connectivity
   - System latency

2. **Integration Tests in the 5G Test Bench**: These tests will involve integrating the equipment into the 5G test bench to evaluate its performance and compatibility under typical 5G network use cases.

   The following use cases will be taken into consideration:

   - Non-terrestrial network (NTN) as backhaul
   - NTN as backup backhaul
   - Multiaccess with NTN networks (ATSSS)

3.1. Prototype Connectivity Tests Matrix

The following tests will be carried out in this phase to ensure that the prototype network configuration is compatible with the 5G Test Bench required network configuration.

Test Reference	Test Description	Validation Method
User Connectivity Test 1 (UCT1)	Data transmission	Test
User Connectivity Test 2 (UCT2)	Interoperability with EAB - IP connectivity	Test
User Connectivity Test 3 (UCT3)	Latency	Test

TABLE 1 USER CONNECTIVITY TEST MATRIX

3.2. Integration tests in the 5G Test Bench Test Matrix

The following tests will be carried out during the integration within the 5G Test Bench:

Test Reference	Test Description	Validation Method
Integration Test 1 (IT1)	Non-terrestrial network (NTN) as backhaul	Test
Integration Test 2 (IT2)	NTN as backup backhaul	Test
Integration Test 3 (IT3)	Multiaccess with NTN networks (ATSSS)	Test

TABLE 2 INTEGRATION TEST MATRIX

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4. Test Procedure

4.1. Prototype connectivity Tests Procedure

4.1.1. User Connectivity Test 1 (UCT1) - Data transmission

4.1.1.1. UCT1-Purpose:

The 6G-INTEGRATION program should use 5G Satellite technologies (SATCOM links) as efficient backhauling solution to support data transmission process.

4.1.1.2. UCT1-Precondition:

Network Setup can be found in the following

- **Satellite Link Availability**: Ensure the satellite link is available and operational for the duration of the test.
- **Correct IP Configuration**: Verify that all devices in the network (e.g., client, server, satellite modem) have correct IP configurations, including subnet masks, gateways, and DNS settings.
- **Network Topology**: Clearly define the network topology, including the position of the client, server, satellite modem, and any intermediate devices like routers or switches.

Iperf3 Configuration

- **Iperf3 Installation**: Ensure iperf3 is installed on both the client and server machines.
- **Version Consistency**: Both client and server should run the same version of iperf3 to avoid compatibility issues.

Hardware and Software Preconditions

- **Hardware Capabilities**: Confirm that all hardware (computers, network interfaces, satellite modems) can handle the expected throughput without causing bottlenecks.
- **Operating System**: Ensure the operating systems on the client and server are stable and have the necessary updates installed.

Test Environment

- **Environmental Factors**: Account for any environmental factors that might affect the satellite link, such as weather conditions.

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Quality of Service (QoS) and Traffic Shaping

- **Disable QoS**: If possible, disable any QoS or traffic shaping rules that could affect the test traffic.
- **Consistency**: Ensure the QoS settings are consistent across the network if they cannot be disabled.

Latency and Jitter Considerations

- **Latency Measurement**: Measure the baseline latency of the satellite link as satellite communications typically introduce higher latency.
- **Jitter Control**: Understand the typical jitter range on the satellite link.

Security and Access Control

- **Firewall Rules**: Adjust firewall rules to allow iperf3 traffic (default TCP/UDP ports 5201).
- **Access Permissions**: Ensure both client and server have the necessary permissions to run iperf3 and access the network.

Satellite Link Characteristics

- **Bandwidth**: Know the maximum bandwidth of the satellite link.
- **Data Cap**: Be aware of any data caps or fair usage policies that might affect the test.

Test Parameters and Scenarios

- **Protocol**: Choose between TCP and UDP based on what aspect of the performance you want to test.
- **Direction of Test**: Determine whether the test will be conducted in one direction (client to server or server to client) or both directions.

4.1.1.3. UCT1-Steps:

The following steps needs to be performed to perform the network configuration tests in the laboratory.

Action	Expected result
The terminal logs into the network	Terminal provides internet access
The IPsec tunnel is established	The tunnel allows to reach end to end
Server and clients are set and perform iperf test	Maximum bandwidth

TABLE 3 UCT1 STEPS

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4.1.1.4. UCT1-Test Setup:

The test case has been successfully proven in Madrid, for the next phase the objective is to test everything with the rest of demonstrator's setups. Iperf test attached in the test case.

For the setup we are going to configure 2 firewalls, one would be in the bubble site (Netgate 2100) and the other one is going to be placed in the HQ/lab (Paloalto Pa220).

The Netgate is going to connect with INSTER's terminal, that will provide the IP connection via OneWeb's LEO constellation.

As pointed in the figure the Prototype will give a DHCP address to the Netgate and then internally it will NAT to a private IP range.

The test case has been successfully proven in Madrid in a real scenario, the terminal was set up outside standalone, just connected to satellite provider network and deployed along a PC and a firewall. The other end of the network is formed by an edge router providing a public IP and connected to another firewall with the tunnel configured. This way we can establish a tunnel between a fixed station and a deployed station. It can be seen in the following figure:

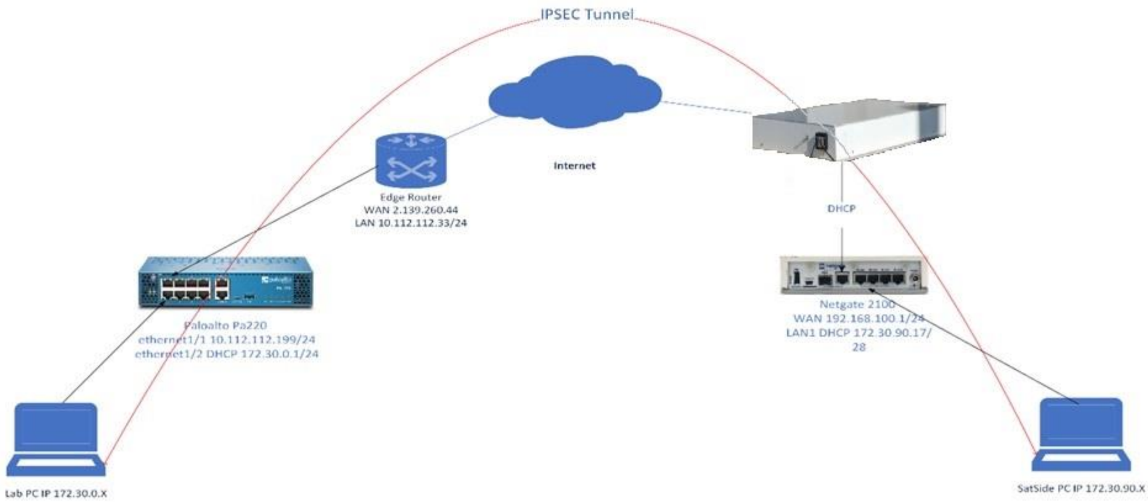

FIGURE 1 TEST SETUP DIAGRAM - USER CONNECTIVITY TEST 1

For this test, we will use two PCs with iperf3 installed on both. The Lab PC (172.30.0.17) will act as the server, and the Bubble PC (172.30.90.23) will act as the client.

We will focus on the uplink (from Bubble to Lab) since it has a lower bandwidth of 25 Mbps. During the test, traffic will be sent from the Bubble PC to the Lab PC through an IPsec tunnel that we used in our other tests. The protocols used for the tests are TCP and UDP. Our primary goal is to transmit data using the maximum bandwidth possible with minimal errors, as all the traffic is going to pass through the satellite network and then arrive at the other end of the tunnel in Madrid.

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IPsec configuration:

1. **IKE (Internet Key Exchange) Configuration**:

    - **IKE (Internet Key Exchange) Configuration**:
    - **IKE Version**: IKEv2.
    - **Authentication Method**: Pre-shared keys (PSK).
    - **Encryption Algorithm**: AES-256-cbc
    - **Hash Algorithm**: SHA-256
    - **Diffie-Hellman Group**: Group 14
    - **Lifetime**: 8 hours

2. **IPsec Configuration**:

    - **IPsec Protocol**: ESP (Encapsulating Security Payload)
    - **Encryption Algorithm**: AES-256-cbc
    - **Integrity Algorithm**: SHA-256
    - **Perfect Forward Secrecy (PFS)**: Enabled, Group 2
    - **Lifetime**: 1 hours

3. **Tunnel Mode**:

    - **Tunnel Mode**: Encrypts the entire IP packet, commonly used for site-to-site VPNs.

4. **Endpoints Configuration**:

    - **Local and Remote IP Addresses**: 172.30.0.X and 172.30.90.X
    - **Peer address**: dynamic

5. **NAT Traversal (NAT-T)**:

    - **Enable NAT-T**: Allows IPsec to work across devices that perform Network Address Translation (NAT).
    - **UDP Encapsulation Ports**: UDP port 4500.

6. **Keep-Alive and Dead Peer Detection**:

    - **Keep-Alive**: Regular checks to ensure the tunnel is still active.
    - **Dead Peer Detection (DPD)**: enabled.

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4.1.1.5. UCT1-Test Results and Remarks

The iperf3 test was a success, confirming that our network infrastructure is operating as intended. We achieved the expected bandwidth with minimal error, indicating a stable and reliable connection. While iperf3 provides valuable insights, it's worth considering incorporating other traffic sources, in the next phase we aim to test with sources from other partner companies.

TCP test from client to server at maximum bandwidth is illustrated bellow:

```
carolina@carolina-HP-ProBook-440-14-inch-G9-Notebook-PC:~$ iperf3 -c 172.30.0.17
Connecting to host 172.30.0.17, port 5201
[  5] local 172.30.90.23 port 45242 connected to 172.30.0.17 port 5201
[ ID] Interval           Transfer     Bitrate         Retr  Cwnd
[  5]   0.00-1.00   sec   872 KBytes  7.14 Mbits/sec    0    166 KBytes
[  5]   1.00-2.00   sec  1.28 MBytes  10.7 Mbits/sec    0    223 KBytes
[  5]   2.00-3.00   sec  1.21 MBytes  10.2 Mbits/sec    0    291 KBytes
[  5]   3.00-4.00   sec  2.43 MBytes  20.4 Mbits/sec    0    397 KBytes
[  5]   4.00-5.00   sec  2.79 MBytes  23.4 Mbits/sec    0    511 KBytes
[  5]   5.00-6.00   sec  2.00 MBytes  16.8 Mbits/sec    0    630 KBytes
[  5]   6.00-7.00   sec  3.28 MBytes  27.5 Mbits/sec    0    749 KBytes
[  5]   7.00-8.00   sec  1.82 MBytes  15.3 Mbits/sec    0    866 KBytes
[  5]   8.00-9.00   sec  3.10 MBytes  26.0 Mbits/sec    0    985 KBytes
[  5]   9.00-10.00  sec  2.31 MBytes  19.3 Mbits/sec    0   1.08 MBytes
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Retr
[  5]   0.00-10.00  sec  21.1 MBytes  17.7 Mbits/sec    0             sender
[  5]   0.00-10.49  sec  19.8 MBytes  15.8 Mbits/sec                  receiver

iperf Done.
carolina@carolina-HP-ProBook-440-14-inch-G9-Notebook-PC:~$ iperf3 -c 172.30.0.17 -b 0
Connecting to host 172.30.0.17, port 5201
[  5] local 172.30.90.23 port 57278 connected to 172.30.0.17 port 5201
[ ID] Interval           Transfer     Bitrate         Retr  Cwnd
[  5]   0.00-1.00   sec   704 KBytes  5.77 Mbits/sec    0    143 KBytes
[  5]   1.00-2.00   sec  1.03 MBytes  8.66 Mbits/sec    0    193 KBytes
[  5]   2.00-3.00   sec  1.64 MBytes  13.8 Mbits/sec    0    265 KBytes
[  5]   3.00-4.00   sec  2.31 MBytes  19.4 Mbits/sec    0    370 KBytes
[  5]   4.00-5.00   sec  2.55 MBytes  21.4 Mbits/sec    0    489 KBytes
[  5]   5.00-6.00   sec  2.43 MBytes  20.4 Mbits/sec    0    607 KBytes
[  5]   6.00-7.00   sec  3.10 MBytes  26.0 Mbits/sec    0    726 KBytes
[  5]   7.00-8.00   sec  1.76 MBytes  14.8 Mbits/sec    0    841 KBytes
[  5]   8.00-9.00   sec  3.10 MBytes  26.0 Mbits/sec    0    957 KBytes
[  5]   9.00-10.00  sec  1.09 MBytes  9.16 Mbits/sec    0   1.01 MBytes
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Retr
[  5]   0.00-10.00  sec  19.7 MBytes  16.5 Mbits/sec    0             sender
[  5]   0.00-10.65  sec  18.8 MBytes  14.8 Mbits/sec                  receiver

iperf Done.
```

FIGURE 2 IPERF TEST 1 MAXIMUM BANDWIDTH FROM CLIENT

TCP test from Server and client views are depicted in the previous and following figures respectively. TCP and UDP tests were conducted from the client with the bandwidth set to 20 Mbps. TCP and UDP tests were conducted from the client with the bandwidth set to 20 Mbps (Server view):

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```
C:\Windows\system32>iperf3 -s
-----------------------------------------------------------
Server listening on 5201 (test #1)
-----------------------------------------------------------
Accepted connection from 172.30.90.23, port 45226
[  5] local 172.30.0.17 port 5201 connected to 172.30.90.23 port 45242
[ ID] Interval           Transfer     Bitrate
[  5]   0.00-1.01   sec   384 KBytes  3.12 Mbits/sec
[  5]   1.01-2.01   sec  1.12 MBytes  9.44 Mbits/sec
[  5]   2.01-3.01   sec  1.25 MBytes  10.5 Mbits/sec
[  5]   3.01-4.01   sec  2.12 MBytes  17.8 Mbits/sec
[  5]   4.01-5.00   sec  2.25 MBytes  19.1 Mbits/sec
[  5]   5.00-6.01   sec  2.25 MBytes  18.8 Mbits/sec
[  5]   6.01-7.01   sec  2.38 MBytes  19.8 Mbits/sec
[  5]   7.01-8.01   sec  2.25 MBytes  18.9 Mbits/sec
[  5]   8.01-9.01   sec  2.38 MBytes  19.9 Mbits/sec
[  5]   9.01-10.00  sec  2.25 MBytes  19.1 Mbits/sec
[  5]  10.00-10.49  sec  1.12 MBytes  19.4 Mbits/sec
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate
[  5]   0.00-10.49  sec  19.8 MBytes  15.8 Mbits/sec                  receiver
-----------------------------------------------------------
Server listening on 5201 (test #2)
-----------------------------------------------------------
Accepted connection from 172.30.90.23, port 57272
[  5] local 172.30.0.17 port 5201 connected to 172.30.90.23 port 57278
[ ID] Interval           Transfer     Bitrate
[  5]   0.00-1.00   sec   256 KBytes  2.09 Mbits/sec
[  5]   1.00-2.01   sec  1.00 MBytes  8.35 Mbits/sec
[  5]   2.01-3.00   sec  1.38 MBytes  11.6 Mbits/sec
[  5]   3.00-4.00   sec  2.12 MBytes  17.8 Mbits/sec
[  5]   4.00-5.00   sec  2.25 MBytes  18.9 Mbits/sec
[  5]   5.00-6.00   sec  2.38 MBytes  20.0 Mbits/sec
[  5]   6.00-7.01   sec  2.25 MBytes  18.8 Mbits/sec
[  5]   7.01-8.00   sec  2.25 MBytes  19.0 Mbits/sec
[  5]   8.00-9.02   sec  2.38 MBytes  19.6 Mbits/sec
[  5]   9.02-10.01  sec  1.50 MBytes  12.6 Mbits/sec
[  5]  10.01-10.65  sec  1.00 MBytes  13.1 Mbits/sec
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate
[  5]   0.00-10.65  sec  18.8 MBytes  14.8 Mbits/sec                  receiver
-----------------------------------------------------------
```

FIGURE 3 IPREF TEST 1 MAXIMUM BANDWIDTH FROM SERVER

```
carolina@carolina-HP-ProBook-440-14-inch-G9-Notebook-PC:~$ iperf3 -c 172.30.0.17 -b 20M
Connecting to host 172.30.0.17, port 5201
[  5] local 172.30.90.23 port 33938 connected to 172.30.0.17 port 5201
[ ID] Interval           Transfer     Bitrate         Retr  Cwnd
[  5]   0.00-1.00   sec  1.06 MBytes  8.92 Mbits/sec    0    245 KBytes
[  5]   1.00-2.00   sec  1.75 MBytes  14.7 Mbits/sec    0    324 KBytes
[  5]   2.00-3.00   sec  2.25 MBytes  18.9 Mbits/sec    0    434 KBytes
[  5]   3.00-4.00   sec  2.62 MBytes  22.0 Mbits/sec    0    553 KBytes
[  5]   4.00-5.00   sec  2.50 MBytes  21.0 Mbits/sec    0    670 KBytes
[  5]   5.00-6.00   sec  2.12 MBytes  17.8 Mbits/sec    0    773 KBytes
[  5]   6.00-7.00   sec  1.50 MBytes  12.6 Mbits/sec    0    846 KBytes
[  5]   7.00-8.00   sec  2.50 MBytes  21.0 Mbits/sec    0    962 KBytes
[  5]   8.00-9.00   sec  2.50 MBytes  21.0 Mbits/sec    0   1.05 MBytes
[  5]   9.00-10.00  sec  2.62 MBytes  22.0 Mbits/sec    0   1.17 MBytes
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Retr
[  5]   0.00-10.00  sec  21.4 MBytes  18.0 Mbits/sec    0             sender
[  5]   0.00-10.51  sec  20.4 MBytes  16.3 Mbits/sec                  receiver

iperf Done.
carolina@carolina-HP-ProBook-440-14-inch-G9-Notebook-PC:~$ iperf3 -c 172.30.0.17 -u -b 20M
Connecting to host 172.30.0.17, port 5201
[  5] local 172.30.90.23 port 41396 connected to 172.30.0.17 port 5201
[ ID] Interval           Transfer     Bitrate         Total Datagrams
[  5]   0.00-1.00   sec  2.38 MBytes  20.0 Mbits/sec  1805
[  5]   1.00-2.00   sec  2.39 MBytes  20.0 Mbits/sec  1807
[  5]   2.00-3.00   sec  2.38 MBytes  20.0 Mbits/sec  1806
[  5]   3.00-4.00   sec  2.38 MBytes  20.0 Mbits/sec  1806
[  5]   4.00-5.00   sec  2.39 MBytes  20.0 Mbits/sec  1807
[  5]   5.00-6.00   sec  2.38 MBytes  20.0 Mbits/sec  1806
[  5]   6.00-7.00   sec  2.39 MBytes  20.0 Mbits/sec  1807
[  5]   7.00-8.00   sec  2.38 MBytes  20.0 Mbits/sec  1806
[  5]   8.00-9.00   sec  2.38 MBytes  20.0 Mbits/sec  1806
[  5]   9.00-10.00  sec  2.39 MBytes  20.0 Mbits/sec  1807
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-10.00  sec  23.8 MBytes  20.0 Mbits/sec  0.000 ms  0/18063 (0%)  sender
[  5]   0.00-10.79  sec  22.5 MBytes  17.5 Mbits/sec  0.535 ms  1044/18063 (5.8%)  receiver
```

FIGURE 4 IPERF TEST 1 20MBPS BANDWIDTH FROM CLIENT

```
-----------------------------------------------------------
Server listening on 5201 (test #5)
-----------------------------------------------------------
Accepted connection from 172.30.90.23, port 33922
[  5] local 172.30.0.17 port 5201 connected to 172.30.90.23 port 33938
[ ID] Interval           Transfer     Bitrate
[  5]   0.00-1.01   sec   640 KBytes  5.17 Mbits/sec
[  5]   1.01-2.00   sec  1.50 MBytes  12.8 Mbits/sec
[  5]   2.00-3.01   sec  2.12 MBytes  17.8 Mbits/sec
[  5]   3.01-4.00   sec  2.38 MBytes  20.0 Mbits/sec
[  5]   4.00-5.00   sec  2.25 MBytes  18.9 Mbits/sec
[  5]   5.00-6.01   sec  2.00 MBytes  16.7 Mbits/sec
[  5]   6.01-7.00   sec  1.50 MBytes  12.6 Mbits/sec
[  5]   7.00-8.01   sec  2.25 MBytes  18.8 Mbits/sec
[  5]   8.01-9.00   sec  2.25 MBytes  18.9 Mbits/sec
[  5]   9.00-10.01  sec  2.38 MBytes  19.7 Mbits/sec
[  5]  10.01-10.51  sec  1.12 MBytes  19.0 Mbits/sec
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate
[  5]   0.00-10.51  sec  20.4 MBytes  16.3 Mbits/sec                  receiver
-----------------------------------------------------------
Server listening on 5201 (test #6)
-----------------------------------------------------------
Accepted connection from 172.30.90.23, port 56768
[  5] local 172.30.0.17 port 5201 connected to 172.30.90.23 port 41396
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-1.00   sec  1.84 MBytes  15.4 Mbits/sec  0.603 ms  71/1466 (4.8%)
[  5]   1.00-2.00   sec  2.18 MBytes  18.3 Mbits/sec  1.769 ms  111/1762 (6.3%)
[  5]   2.00-3.00   sec  2.17 MBytes  18.2 Mbits/sec  0.538 ms  121/1765 (6.9%)
[  5]   3.00-4.01   sec  2.18 MBytes  18.1 Mbits/sec  0.535 ms  116/1765 (6.6%)
[  5]   4.01-5.01   sec  2.21 MBytes  18.4 Mbits/sec  0.572 ms  91/1766 (5.2%)
[  5]   5.01-6.00   sec  2.18 MBytes  18.5 Mbits/sec  1.281 ms  121/1771 (6.8%)
[  5]   6.00-7.00   sec  2.16 MBytes  18.1 Mbits/sec  0.965 ms  134/1767 (7.6%)
[  5]   7.00-8.00   sec  1.57 MBytes  13.2 Mbits/sec  0.534 ms  86/1274 (6.8%)
[  5]   8.00-9.00   sec  1.90 MBytes  15.9 Mbits/sec  0.462 ms  37/1477 (2.5%)
[  5]   9.00-10.01  sec  2.22 MBytes  18.4 Mbits/sec  0.684 ms  109/1793 (6.1%)
[  5]  10.01-10.79  sec  1.86 MBytes  20.1 Mbits/sec  0.535 ms  47/1457 (3.2%)
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-10.79  sec  22.5 MBytes  17.5 Mbits/sec  0.535 ms  1044/18063 (5.8%)  receiver
-----------------------------------------------------------
```

FIGURE 5 IPERF TEST 1 20MBPS BANDWIDTH FROM SERVER

4.1.1.6. UCT1-Expected Results:

The terminal should grant at least 20Mbps in uplink. As seen in the previous images, the terminal is operating close to 20 Mbps, which meets expectations. The bandwidth may be slightly lower due to environmental factors.

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4.1.2. User Connectivity Test 2 (UCT2)- Interoperability with EAB - IP connectivity

4.1.2.1. UCT2-Purpose

The purpose is to establish global IP connectivity between a fixed command post and the main HQ via satellite connection.

4.1.2.2. UCT2-Precondition

Network Setup can be found in the following:

- **IPsec Tunnel Configuration**: Ensure that the IPsec tunnel is properly configured on both endpoints, including all necessary parameters such as IP addresses, authentication methods, encryption algorithms, and security policies.
- **Network Reachability**: Verify that the underlying network is operational and that both endpoints can reach each other over the network. This includes making sure there are no routing issues or network ACLs blocking the traffic.
- **Security Associations:** Check that the Security Associations (SAs) for the IPsec tunnel are correctly established and active. This involves ensuring that Phase 1 (IKE) and Phase 2 (IPsec) negotiations have been successfully completed.
- **Correct Time Synchronization:** Ensure that both endpoints have synchronized clocks, as IPsec relies on accurate timing for the establishment and maintenance of SAs. Time synchronization protocols like NTP should be configured and functioning properly.
- **Firewall and ACL Configuration**: Verify that firewalls and access control lists (ACLs) on both endpoints and intermediate devices permit the IPsec traffic.
- **Interface Status:** Ensure that the network interfaces involved in the IPsec tunnel on both endpoints are up and running, without errors or misconfigurations.
- **Credential Validity:** Confirm that any certificates or pre-shared keys used for authentication are valid and not expired.
- **IPsec Policy and Profile Application:** Make sure the correct IPsec policies and profiles are applied to the interfaces or routes that will use the IPsec tunnel.

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4.1.2.3. UCT2-Steps

Action	Expected result
The terminal logs into the network	Terminal provides internet access
The IPsec tunnel is established	The tunnel allows to reach end to end
Perform speed test, traceroute from end to end, public servers	Expected times around 100-120ms

TABLE 4 UCT2 STEPS

4.1.2.4. UCT2- Test Setup

For thus setup, the 2 firewalls are being configured. One would be in the bubble site (Netgate 2100) and the other one is going to be placed in the HQ/lab (Paloalto Pa220).

The Netgate is going to connect with INSTER's Prototype, that will provide the IP connection via OneWeb's LEO constellation.

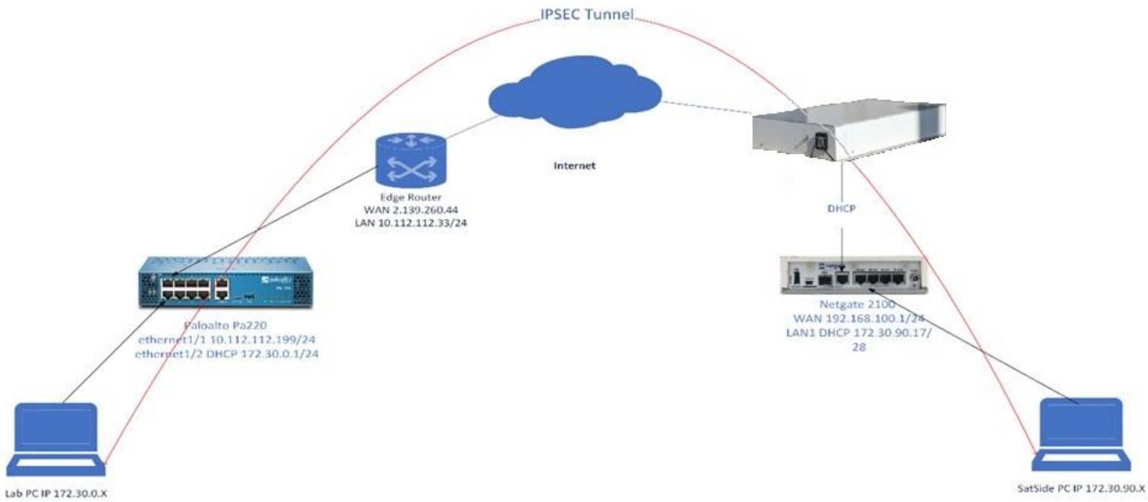

FIGURE 6 TEST SETUP DIAGRAM FOR UCT2

As pointed in the figure the Prototype will give a DHCP address to the netgate and then internally it will nat to a private IP range.

The test case has been successfully proven in Madrid in a real scenario, the terminal was set up outside standalone, just connected to satellite provider network and deployed along a PC and a firewall. The other end of the network is formed by an edge router providing a public IP and connected to another firewall with the tunnel configured. This way we can establish a tunnel between a fixed station and a deployed station. It can be seen in the previous figure.

The following configuration parameters are used during this test:

1. **IKE (Internet Key Exchange) Configuration**:

   - **IKE Version**: IKEv2.
   - **Authentication Method**: Pre-shared keys (PSK).
   - **Encryption Algorithm**: AES-256-cbc
   - **Hash Algorithm**: SHA-256
   - **Diffie-Hellman Group**: Group 14
   - **Lifetime**: 8 hours

2. **IPsec Configuration**:

   - **IPsec Protocol**: ESP (Encapsulating Security Payload)
   - **Encryption Algorithm**: AES-256-cbc
   - **Integrity Algorithm**: SHA-256
   - **Perfect Forward Secrecy (PFS)**: Enabled, Group 2
   - **Lifetime**: 1 hours

3. **Tunnel Mode**:

   - **Tunnel Mode**: Encrypts the entire IP packet, commonly used for site-to-site VPNs.

4. **Endpoints Configuration**:

   - **Local and Remote IP Addresses**: 172.30.0.X and 172.30.90.X
   - **Peer address**: dynamic

5. **NAT Traversal (NAT-T)**:

   - **Enable NAT-T**: Allows IPsec to work across devices that perform Network Address Translation (NAT).
   - **UDP Encapsulation Ports** : UDP port 4500.

6. **Keep-Alive and Dead Peer Detection**:

   - **Keep-Alive**: Regular checks to ensure the tunnel is still active.
   - **Dead Peer Detection (DPD)**: enabled.

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4.1.2.5. UCT2-Test Results and Remarks

The test case has been successfully proven in Madrid, for the next phase the objective is to test everything with the test bench including the 5G network. At the beginning stage of this tests, the OneWeb satellite constellation was suffering some degradation in the network that affected the system latency. This issue was solved during the execution of these tests and the system latency reach the expected values (around 100 ms).

Interoperability Testing: Current testing is limited to one 5G bubble, and there is a need to test with multiple bubbles to ensure interoperability and smooth performance in more complex network environments.

4.1.2.6. UCT2-Expected Results

Ping Test:

- Pings from lab site (fixed post) to deployed site should result in successful responses.
- Round-trip times (RTT) should be low and consistent, indicating a stable tunnel with minimal packet loss.

Traceroute Test:

- Traceroute from Endpoint A to Endpoint B should show a valid path through the IPsec tunnel.
- The path should typically display fewer hops, primarily showing the entry and exit points of the tunnel, confirming encapsulation.

4.1.3. User Connectivity Test 3 (UCT3)- Latency

4.1.3.1. UCT3-Purpose

The satellite user terminal shall support a latency around 100-120ms.

4.1.3.2. UCT3-Precondition

Network Setup can be found in the following:

- **Access to LEO Satellite Network**: Ensure access to the LEO satellite network being tested. This may involve coordination with the satellite provider or access to a simulated network environment.
- **Stable Network Infrastructure**: Have a stable ground network infrastructure in place to communicate with the LEO satellites. This includes reliable internet connectivity and appropriate hardware.

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- **Satellite Tracking and Communication Equipment**: Utilize satellite tracking and communication equipment capable of interfacing with the LEO satellites being tested. This may involve specialized antennas, receivers, and transmitters.
- **Clear Line of Sight**: Ensure there is a clear line of sight between the ground station and the LEO satellites. Any obstructions or interference could affect the test results.
- **Collaboration with Satellite Provider**: Collaborate closely with the LEO satellite provider to coordinate testing schedules, access necessary resources, and troubleshoot any issues that may arise during the testing process.

4.1.3.3. UCT3-Steps

Action	Expected result
The terminal logs into the network	Terminal provides internet access
The IPsec tunnel is established	The tunnel allows to reach end to end
Perform speed test, traceroute from end to end, public servers	Expected times around 100-120 ms

TABLE 5 UCT3 STEPS

4.1.3.4. UCT3-Test Setup

For the setup we are going to configure 2 firewalls, one would be in the bubble site (Netgate 2100) and the other one is going to be placed in the HQ/lab (Paloalto Pa220).

The Netgate is going to connect with INSTER's terminal, that will provide the IP connection via OneWeb's LEO constellation.

As pointed in the figure the Prototype will give a DHCP address to the netgate and then internally it will NAT to a private IP range.

The test case has been successfully proven in Madrid in a real scenario, the terminal was set up outside standalone, just connected to satellite provider network and deployed along a PC and a firewall. The other end of the network is formed by an edge router providing a public IP and connected to another firewall with the tunnel configured. This way we can establish a tunnel between a fixed station and a deployed station. It can be seen in the following diagram:

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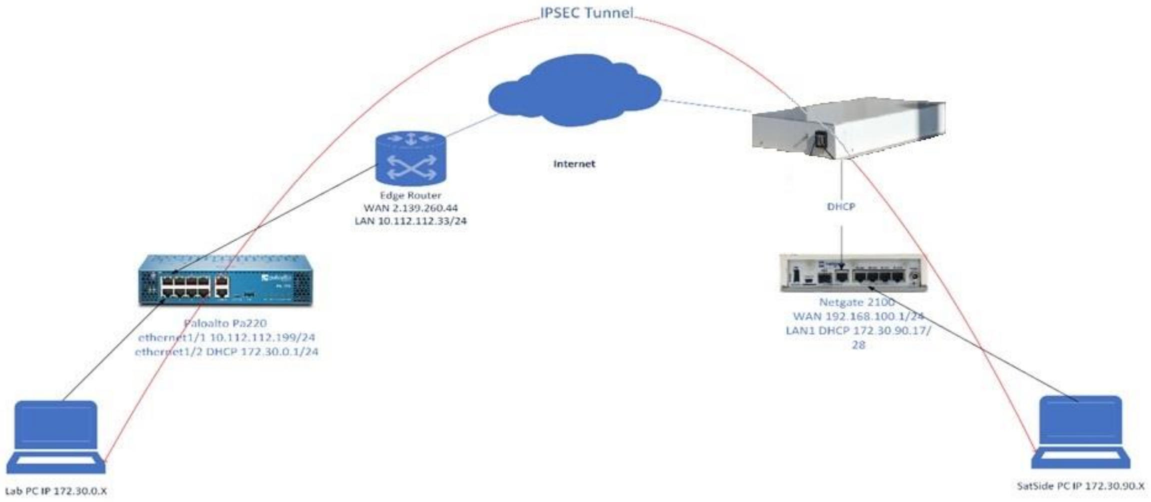

FIGURE 7 UCT3 – SETUP DIAGRAM

This delay test is going to be done from the PC connected to INSTER's terminal, that is a deployed command post simulating what could be a 5G bubble.

1. **IKE (Internet Key Exchange) Configuration**:

   - **IKE Version**: IKEv2.
   - **Authentication Method**: Pre-shared keys (PSK).
   - **Encryption Algorithm**: AES-256-cbc
   - **Hash Algorithm**: SHA-256
   - **Diffie-Hellman Group**: Group 14
   - **Lifetime**: 8 hours

2. **IPsec Configuration**:

   - **IPsec Protocol**: ESP (Encapsulating Security Payload)
   - **Encryption Algorithm**: AES-256-cbc
   - **Integrity Algorithm**: SHA-256
   - **Perfect Forward Secrecy (PFS)**: Enabled, Group 2
   - **Lifetime**: 1 hours

3. **Tunnel Mode**:

   - **Tunnel Mode**: Encrypts the entire IP packet, commonly used for site-to-site VPNs.

4. **Endpoints Configuration**:

    - **Local and Remote IP Addresses**: 172.30.0.X and 172.30.90.X
    - **Peer address**: dynamic

5. **NAT Traversal (NAT-T)**:

    - **Enable NAT-T**: Allows IPsec to work across devices that perform Network Address Translation (NAT).
    - **UDP Encapsulation Ports**: UDP port 4500.

6. **Keep-Alive and Dead Peer Detection**:

    - **Keep-Alive**: Regular checks to ensure the tunnel is still active.
    - **Dead Peer Detection (DPD)**: enabled.

For the next phase the objective is to test everything within the 5G Test Bench.

4.1.3.5. UCT3-Test Results and Remarks

This is the output of a ping test we could see:

- Minimum delay: 72.280 ms
- Average delay: 120.374 ms
- Maximum delay: 181.260 ms

4.1.3.6. UCT3-Expected Result

Given these latency results, the system is expected to perform perfectly when integrated into the 5G Test Bench.

4.2. Integration tests in the 5G Test Bench

4.2.1. Integration Test 1 – NTN as Backhaul

4.2.1.1. IT1-Purpose

The objective of this test is to show that satellited-based NTN backhaul can be employed as an alternative to terrestrial connections (fiber optic in the test bench use case).

4.2.1.2. IT1-Precondition

Network Setup can be found in the following:

- **Access to LEO Satellite Network**: Ensure access to the LEO satellite network being tested. This may involve coordination with the satellite provider or access to a simulated network environment.
- **Stable Network Infrastructure**: Have a stable ground network infrastructure in place to communicate with the LEO satellites. This includes reliable internet connectivity and appropriate hardware.
- **Satellite Tracking and Communication Equipment**: Utilize satellite tracking and communication equipment capable of interfacing with the LEO satellites being tested. This may involve specialized antennas, receivers, and transmitters.
- **Clear Line of Sight**: Ensure there is a clear line of sight between the ground station and the LEO satellites. Any obstructions or interference could affect the test results.
- **Collaboration with Satellite Provider**: Collaborate closely with the LEO satellite provider to coordinate testing schedules, access necessary resources, and troubleshoot any issues that may arise during the testing process.
- **Network configuration to stablish the IPSec:** OneWeb Hub Public IP

4.2.1.3. IT1-Steps

Action	Expected result
The terminal logs into the network	Terminal provides internet access
The IP to configure the IPsec tunnel is shared	This IP is used in the IPSec tunnel configuration in the Test Bench side
Traffic KPI evaluation	The results are in the expected range for each parameter.

TABLE 6 IT1 - STEPS

4.2.1.4. IT1-Test Setup

In this scenario, a user device connects to a 5G network that integrates both terrestrial and satellite infrastructure. The network utilizes a non-terrestrial network (NTN) backhaul to enable secure communication between the Radio Access Network (RAN) and the 5G core network via satellite links. To enhance security, data integrity, and authentication, an IPSec tunnel will be established between the RAN and the core through the NTN backhaul.

The following diagram is provided by Ericsson and the Test setup (IT1) on the Test Bench is shown:

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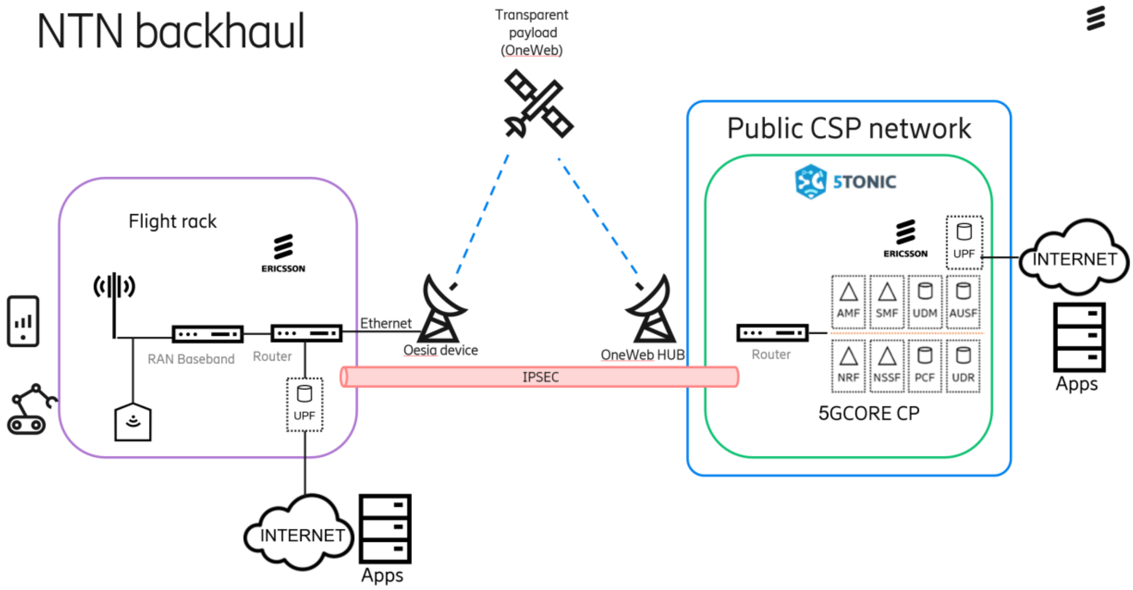

FIGURE 8 NTN BACKHAUL SCENARIO DIAGRAM (ERICSSON)

4.2.1.5. IT1-Test Results and Remarks

The following table presents the throughput measurements taken after establishing the backhaul via the satellite link. For reference, the fixed backhaul throughput values are also included.

The following KPIs are analysed:

TCP Traffic Upload and Download throughput: The throughput is measured in upload and download links when TCP traffic is sent. This parameter is limited to 75 Mbps during these tests due to satellite operator restrictions.

UDP Traffic Upload and Download throughput: The throughput is measured in upload and download links when UDP traffic is sent. This parameter is limited to 15 Mbps during these tests due to satellite operator restrictions.

Jitter: This parameter shows the short-term variations in the timing of signal pulses. It is a key parameter to ensure the 5G Quality of Service (QoS), specially, on real-time data transmissions.

Latency: Latency refers to the time it takes for data to travel from the source to the destination and back. In the context of 5G, it measures the delay between sending a request and receiving a response [5].

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	TCP		UDP		Jitter		Latency
	DL	UL	DL	UL	DL	UL	
Fixed backhaul	900Mbps	35Mbps	900Mbps	35Mbps	0.017	0.7	13 ms
Satellite backhauls	72Mbps	14Mbps	75Mbps	14Mbps	0.111	2.8	150ms

TABLE 7 IT1 TEST RESULTS

The comparison between the NTN and the TN has been conducted. While the satellite backhaul has some limitations compared to the TN, it is performing well given the nature of the signal.

The jitter is always higher in NTN networks as it depends on different real time parameters, such as Satellite movement, variable path lengths or atmospheric conditions. The system latency is also closed to jitter parameter. The values measured in the test allowed to integrate the 5G data using the NTN, so they are in the expected range.

4.2.1.6. IT1-Expected Result

The results obtained from using the satellite-based NTN network to integrate 5G traffic were positive, and the measured KPIs were within the expected ranges.

4.2.2. Integration Test 2 – NTN as backup backhaul

4.2.2.1. IT2-Purpose

The purpose of this test is to demonstrate that the satellite-based NTN can be used as a reliable backup to maintain the continuity on the service under extreme conditions when the TN is unavailable.

4.2.2.2. IT2-Precondition

Network Setup can be found in the following:

- **Access to LEO Satellite Network**: Ensure access to the LEO satellite network being tested. This may involve coordination with the satellite provider or access to a simulated network environment.
- **Stable Network Infrastructure**: Have a stable ground network infrastructure in place to communicate with the LEO satellites. This includes reliable internet connectivity and appropriate hardware.
- **Satellite Tracking and Communication Equipment**: Utilize satellite tracking and communication equipment capable of interfacing with the LEO satellites being tested. This may involve specialized antennas, receivers, and transmitters.

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- **Clear Line of Sight**: Ensure there is a clear line of sight between the ground station and the LEO satellites. Any obstructions or interference could affect the test results.
- **Collaboration with Satellite Provider**: Collaborate closely with the LEO satellite provider to coordinate testing schedules, access necessary resources, and troubleshoot any issues that may arise during the testing process.
- **Network configuration to stablish the IPSec:** OneWeb Hub Public IP

4.2.2.3. IT2-Steps

Action	Expected result
The terminal logs into the network	Terminal provides internet access
The IP to configure the IPsec tunnel is shared	This IP is used in the IPSec tunnel configuration in the Test Bench side
Handover from fix TN to NTN	The traffic is correctly switched from the TN to NTN
Handover from fix NTN to TN	The traffic is correctly switched from the NTN to TN

TABLE 8 IT2 – STEPS

4.2.2.4. IT2-Test Setup

A 5G network is designed to maintain its performance and services by leveraging a combination of fiber optic and satellite-based non-terrestrial network (NTN) backhaul solutions. The primary connection utilizes fiber optic backhaul, but in the event of disruptions such as natural disasters or other issues, the network seamlessly transitions to satellite backhaul.

The following diagram is provided by Ericsson and the Test setup (IT2) on the Test Bench is shown:

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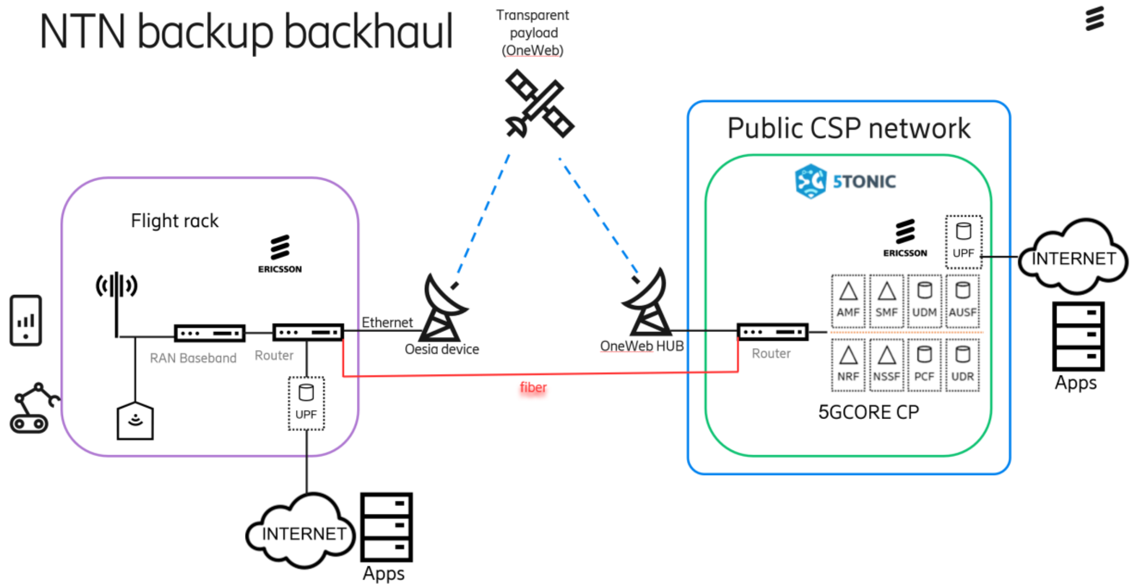

FIGURE 9 NTN BACKUP BACKHAUL (ERICSSON)

During this test, a simulated disconnection of the fiber link between the 'Flight rack' and the 'Public CSP network' was performed, compelling the traffic to reroute over the non-terrestrial network (NTN) backhaul.

4.2.2.5. IT2-Test Results and Remarks

Line switching between TN and NTN was verified by running a continuous ping between the CPE and a core server. This confirmed backhaul activation. The satellite link showed a latency of around 100 ms, while the fixed line had a latency of about 10 ms.

```
64 bytes from 10.11.12.25: icmp_seq=35 ttl=57 time=175 ms
64 bytes from 10.11.12.25: icmp_seq=36 ttl=57 time=119 ms
64 bytes from 10.11.12.25: icmp_seq=37 ttl=57 time=115 ms
64 bytes from 10.11.12.25: icmp_seq=38 ttl=57 time=114 ms
64 bytes from 10.11.12.25: icmp_seq=39 ttl=57 time=157 ms
64 bytes from 10.11.12.25: icmp_seq=40 ttl=57 time=164 ms
64 bytes from 10.11.12.25: icmp_seq=41 ttl=57 time=138 ms
64 bytes from 10.11.12.25: icmp_seq=42 ttl=57 time=113 ms
64 bytes from 10.11.12.25: icmp_seq=43 ttl=57 time=113 ms
64 bytes from 10.11.12.25: icmp_seq=44 ttl=57 time=149 ms
64 bytes from 10.11.12.25: icmp_seq=45 ttl=57 time=126 ms
64 bytes from 10.11.12.25: icmp_seq=46 ttl=57 time=150 ms
64 bytes from 10.11.12.25: icmp_seq=47 ttl=57 time=176 ms
64 bytes from 10.11.12.25: icmp_seq=48 ttl=57 time=122 ms
64 bytes from 10.11.12.25: icmp_seq=49 ttl=57 time=115 ms
64 bytes from 10.11.12.25: icmp_seq=50 ttl=57 time=139 ms
64 bytes from 10.11.12.25: icmp_seq=51 ttl=57 time=126 ms
64 bytes from 10.11.12.25: icmp_seq=52 ttl=57 time=64.0 ms
64 bytes from 10.11.12.25: icmp_seq=53 ttl=57 time=63.5 ms
64 bytes from 10.11.12.25: icmp_seq=54 ttl=57 time=63.9 ms
64 bytes from 10.11.12.25: icmp_seq=55 ttl=57 time=61.0 ms
64 bytes from 10.11.12.25: icmp_seq=57 ttl=58 time=10.5 ms
64 bytes from 10.11.12.25: icmp_seq=58 ttl=58 time=9.91 ms
64 bytes from 10.11.12.25: icmp_seq=59 ttl=58 time=11.4 ms
64 bytes from 10.11.12.25: icmp_seq=60 ttl=58 time=9.20 ms
64 bytes from 10.11.12.25: icmp_seq=61 ttl=58 time=9.00 ms
64 bytes from 10.11.12.25: icmp_seq=62 ttl=58 time=6.94 ms
64 bytes from 10.11.12.25: icmp_seq=63 ttl=58 time=11.7 ms
64 bytes from 10.11.12.25: icmp_seq=64 ttl=58 time=8.61 ms
64 bytes from 10.11.12.25: icmp_seq=65 ttl=58 time=10.8 ms
64 bytes from 10.11.12.25: icmp_seq=66 ttl=58 time=8.47 ms
64 bytes from 10.11.12.25: icmp_seq=67 ttl=58 time=10.8 ms
64 bytes from 10.11.12.25: icmp_seq=68 ttl=58 time=9.66 ms
64 bytes from 10.11.12.25: icmp_seq=69 ttl=58 time=9.98 ms
64 bytes from 10.11.12.25: icmp_seq=70 ttl=58 time=9.76 ms
64 bytes from 10.11.12.25: icmp_seq=71 ttl=58 time=11.5 ms
64 bytes from 10.11.12.25: icmp_seq=72 ttl=58 time=9.17 ms
64 bytes from 10.11.12.25: icmp_seq=73 ttl=58 time=8.29 ms
```

Satellite to fixed

FIGURE 10 NTN TO TN

```
64 bytes from 10.11.12.25: icmp_seq=7 ttl=58 time=11.0 ms
64 bytes from 10.11.12.25: icmp_seq=8 ttl=58 time=10.9 ms
64 bytes from 10.11.12.25: icmp_seq=9 ttl=58 time=11.3 ms
64 bytes from 10.11.12.25: icmp_seq=10 ttl=58 time=11.6 ms
64 bytes from 10.11.12.25: icmp_seq=11 ttl=58 time=9.88 ms
64 bytes from 10.11.12.25: icmp_seq=12 ttl=58 time=11.4 ms
64 bytes from 10.11.12.25: icmp_seq=13 ttl=58 time=10.3 ms
64 bytes from 10.11.12.25: icmp_seq=14 ttl=58 time=10.6 ms
64 bytes from 10.11.12.25: icmp_seq=15 ttl=58 time=12.0 ms
64 bytes from 10.11.12.25: icmp_seq=16 ttl=58 time=11.9 ms
64 bytes from 10.11.12.25: icmp_seq=17 ttl=58 time=12.3 ms
64 bytes from 10.11.12.25: icmp_seq=18 ttl=58 time=9.76 ms
64 bytes from 10.11.12.25: icmp_seq=19 ttl=58 time=16.6 ms
64 bytes from 10.11.12.25: icmp_seq=20 ttl=57 time=117 ms
64 bytes from 10.11.12.25: icmp_seq=21 ttl=57 time=115 ms
64 bytes from 10.11.12.25: icmp_seq=22 ttl=57 time=117 ms
64 bytes from 10.11.12.25: icmp_seq=23 ttl=57 time=117 ms
64 bytes from 10.11.12.25: icmp_seq=24 ttl=57 time=115 ms
64 bytes from 10.11.12.25: icmp_seq=25 ttl=57 time=122 ms
64 bytes from 10.11.12.25: icmp_seq=26 ttl=57 time=115 ms
64 bytes from 10.11.12.25: icmp_seq=27 ttl=57 time=157 ms
64 bytes from 10.11.12.25: icmp_seq=28 ttl=57 time=127 ms
64 bytes from 10.11.12.25: icmp_seq=29 ttl=57 time=116 ms
64 bytes from 10.11.12.25: icmp_seq=30 ttl=57 time=116 ms
64 bytes from 10.11.12.25: icmp_seq=31 ttl=57 time=117 ms
64 bytes from 10.11.12.25: icmp_seq=32 ttl=57 time=155 ms
64 bytes from 10.11.12.25: icmp_seq=33 ttl=57 time=156 ms
```

Fixed to satellite

FIGURE 11 TN TO NTN

4.2.2.6. IT2-Expected Result

The test result was positive, and in both cases, it was observed that there were no traffic discontinuities when switching from the TN network to the NTN network or vice-versa.

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4.2.3. Integration Test 3 – Use Case 3

4.2.3.1. IT3-Purpose

This use case explores the incorporation of Non-Terrestrial Networks (NTN) into a 3GPP and non-3GPP multi-access framework (ATSSS) to improve the dependability of Beyond 5G (B5G) networks.

4.2.3.2. IT3-Precondition

Network Setup can be found in the following:

- **Access to LEO Satellite Network**: Ensure access to the LEO satellite network being tested. This may involve coordination with the satellite provider or access to a simulated network environment.
- **Stable Network Infrastructure**: Have a stable ground network infrastructure in place to communicate with the LEO satellites. This includes reliable internet connectivity and appropriate hardware.
- **Satellite Tracking and Communication Equipment**: Utilize satellite tracking and communication equipment capable of interfacing with the LEO satellites being tested. This may involve specialized antennas, receivers, and transmitters.
- **Clear Line of Sight**: Ensure there is a clear line of sight between the ground station and the LEO satellites. Any obstructions or interference could affect the test results.
- **Collaboration with Satellite Provider**: Collaborate closely with the LEO satellite provider to coordinate testing schedules, access necessary resources, and troubleshoot any issues that may arise during the testing process.
- **Network configuration to stablish the IPSec:** OneWeb Hub Public IP

4.2.3.3. IT3-Steps

Action	Expected result
The terminal logs into the network	Terminal provides internet access
The IPsec tunnel is established	The tunnel allows to reach end to end
Switching from 3GPP to non-3GPP	No discontinuity is shown
Switching from non-3GPP to 3GPP	No discontinuity is shown

TABLE 9 IT3 STEPS

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4.2.3.4. IT3-Test Setup

This use case assesses the capability of an NTN network to augment and support terrestrial 5G infrastructure by providing enhanced connectivity and resilience. It focuses on the implementation of Access Traffic Steering, Switching, and Splitting (ATSSS) to facilitate seamless traffic management between terrestrial 5G access and satellite-based non-3GPP access. This includes dynamic traffic steering, switching, and splitting to optimize network performance and ensure uninterrupted service continuity.

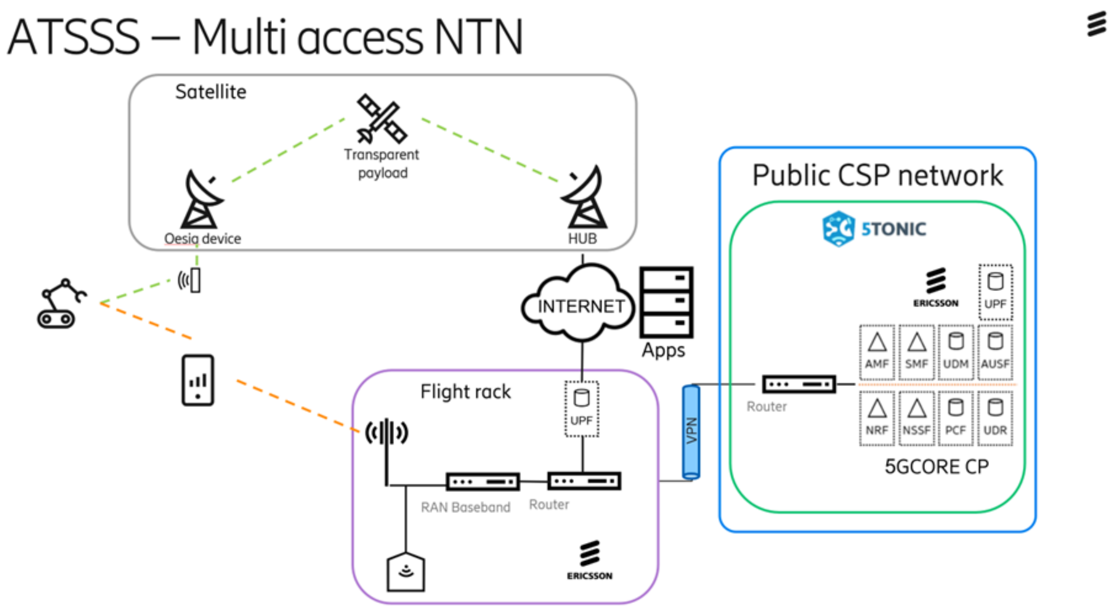

FIGURE 12 ATSSS - MULTIACCESS NTN (IT3) SETUP (ERICSSON)

4.2.3.5. IT3-Test Results and Remarks

In this scenario, the miniPC is used from the Flight rack to test the switching functionality of ATSSS technology. On this device, two routes are configured to reach Google with different priorities, ensuring one acts as a backup for the other. One route will direct traffic through the 5G infrastructure (3GPP), while the other will provide direct internet access via the satellite link (non-3GPP). The latency values will confirm which access method is being used to route the traffic. The non-3GPP link exhibits a latency of around 70 ms, while the 3GPP access shows a latency of approximately 10 ms.

```
ericsson@mini-pc01:~$ ping 8.8.4.4
PING 8.8.4.4 (8.8.4.4) 56(84) bytes of data.
64 bytes from 8.8.4.4: icmp_seq=1 ttl=111 time=10.7 ms
64 bytes from 8.8.4.4: icmp_seq=2 ttl=111 time=9.69 ms
64 bytes from 8.8.4.4: icmp_seq=3 ttl=111 time=9.98 ms
64 bytes from 8.8.4.4: icmp_seq=4 ttl=111 time=9.33 ms
64 bytes from 8.8.4.4: icmp_seq=5 ttl=111 time=11.0 ms
64 bytes from 8.8.4.4: icmp_seq=6 ttl=111 time=9.89 ms
64 bytes from 8.8.4.4: icmp_seq=7 ttl=111 time=10.5 ms
64 bytes from 8.8.4.4: icmp_seq=8 ttl=111 time=9.52 ms
64 bytes from 8.8.4.4: icmp_seq=10 ttl=115 time=68.8 ms
64 bytes from 8.8.4.4: icmp_seq=11 ttl=115 time=69.6 ms
64 bytes from 8.8.4.4: icmp_seq=12 ttl=115 time=68.5 ms
64 bytes from 8.8.4.4: icmp_seq=13 ttl=115 time=69.3 ms
64 bytes from 8.8.4.4: icmp_seq=14 ttl=115 time=69.3 ms
64 bytes from 8.8.4.4: icmp_seq=15 ttl=115 time=70.0 ms
64 bytes from 8.8.4.4: icmp_seq=16 ttl=115 time=69.4 ms
64 bytes from 8.8.4.4: icmp_seq=17 ttl=115 time=69.1 ms
64 bytes from 8.8.4.4: icmp_seq=18 ttl=115 time=70.0 ms
64 bytes from 8.8.4.4: icmp_seq=19 ttl=115 time=70.2 ms
64 bytes from 8.8.4.4: icmp_seq=20 ttl=115 time=69.8 ms
64 bytes from 8.8.4.4: icmp_seq=21 ttl=115 time=69.2 ms
64 bytes from 8.8.4.4: icmp_seq=22 ttl=115 time=69.3 ms
64 bytes from 8.8.4.4: icmp_seq=23 ttl=115 time=68.7 ms
64 bytes from 8.8.4.4: icmp_seq=24 ttl=115 time=69.3 ms
64 bytes from 8.8.4.4: icmp_seq=25 ttl=115 time=68.5 ms
64 bytes from 8.8.4.4: icmp_seq=26 ttl=111 time=2040 ms
64 bytes from 8.8.4.4: icmp_seq=27 ttl=111 time=1039 ms
64 bytes from 8.8.4.4: icmp_seq=28 ttl=111 time=17.8 ms
64 bytes from 8.8.4.4: icmp_seq=29 ttl=111 time=11.3 ms
64 bytes from 8.8.4.4: icmp_seq=30 ttl=111 time=9.90 ms
64 bytes from 8.8.4.4: icmp_seq=31 ttl=111 time=8.20 ms
64 bytes from 8.8.4.4: icmp_seq=32 ttl=111 time=17.0 ms
64 bytes from 8.8.4.4: icmp_seq=33 ttl=111 time=16.0 ms
64 bytes from 8.8.4.4: icmp_seq=34 ttl=111 time=9.17 ms
64 bytes from 8.8.4.4: icmp_seq=35 ttl=111 time=9.85 ms
64 bytes from 8.8.4.4: icmp_seq=36 ttl=111 time=9.92 ms
64 bytes from 8.8.4.4: icmp_seq=37 ttl=111 time=10.5 ms
64 bytes from 8.8.4.4: icmp_seq=38 ttl=111 time=8.42 ms
```

TN to NTN

NTN to TN

FIGURE 13 IT3 TEST RESULT

4.2.3.6. IT3-Expected Result

The multi-connectivity tests were successfully completed, demonstrating the integration of satellite terminals in 5G use cases.

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5. SUMMARY AND CONCLUSIONS

It has been demonstrated throughout the document that the integration of a Non-Terrestrial Network (NTN) based on Low Earth Orbit (LEO) satellite communications within the 5G network is feasible. This integration can be utilized in various capacities, including as a backhaul, a backup backhauls, and in multi-connectivity scenarios.

This project aims to develop a terrestrial terminal capable of operating within OneWeb's LEO satellite network and integrate it into Ericsson's 5G test-bench for testing purposes (5TONIC). Thanks to the project, the necessary resources have been allocated to carry out these tasks, and collaboration with 5TONIC has been secured for this purpose.

The completion of this project brings us one step closer to realizing the integration of Non-Terrestrial Networks (NTN) as a backhaul for 5G, making it possible to harness the numerous advantages this integration can offer as mentioned in this document. In summary, NTNs complement terrestrial 5G networks by providing broader coverage, enhancing resilience, reducing latency, and supporting a wide range of applications and services. This integration is essential for achieving the full potential of 5G technology on a global scale.

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[2] Insert Title in Document properties

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[5] https://www.ericsson.com/en/blog/2022/8/who-cares-about-latency-in-5g

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