UNICO I+D Project
6G-INTEGRATION-01

6G-INTEGRATION-01-E13

Integration in 5G test bench

ABSTRACT

This document presents the results of the Factory Acceptance Test (FAT) defined and performed on the 6G-INTEGRATION-01 antenna prototype. This deliverable focuses on testing and validating the antenna prototype that allows to connect to a LEO satellite constellation in Ku band.

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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 programme.

Contenido

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LIST OF ACRONYMS

ACU: Antenna Control Unit

AIM: Antenna Interface Module

EIRP: Effective Isotropic Radiated Power

ESA: Electronic Steerable Antenna

FAT: Factory Acceptance Test

GNSS: Global Navigation Satellite System

GPS: Global Positioning System

G/T: Gain over Temperature

LEO: Low Earth Orbit

OW: One Web

RF: Radiofrequency

RX: Reception

SPI: Serial Peripheral Interface

SSM: Satellite Subscriber Module

TX: Transmission

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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. Para ello, se prueba que el terminal desarrollado es capaz de operar con la red de satélites LEO. Además, se identifican las necesidades para la integración en el banco de pruebas.

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 necesidades del terminal satelital para su integración en el banco de pruebas de la red de 5G proporcionada por el laboratorio 5TONIC.

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 conducted during the integration of the prototype developed by INSTER in the testbed provided by Ericsson. To this end, it is tested that the developed terminal is capable of operating with the LEO satellite network. Additionally, the requirements for integration into the testbench are identified.

The document is divided into two parts:

- Definition of the tests that INSTER will perform in the laboratory before integration into the testbed, to ensure the correct functioning of the system in isolation.
- Definition of the satellite terminal requirements for its integration into the 5G network testbed provided by the 5TONIC laboratory.

For the execution of these tests, a series of prerequisites have been identified to ensure their successful completion:

- 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

There is a growing demand in the market for 5G services on static and mobile platforms (boats, trains, land vehicles, airplanes, etc.). Consequently, the use cases of the 6G-INTEGRATION-01 project are proposed for this type of applications and can provide a wide range of benefits for businesses, individuals, and governments. They can help extend high-speed connectivity to remote and underserved areas, facilitate disaster response and recovery, offer service continuity and support a wide variety of emerging technologies and applications.

The 5G User Terminal integrated into the terminal does not need to operate under mobility conditions, thus avoiding many network synchronization issues, and it does not require the integration of an INS. The terminal maintains pointing automatically using information from simple inertial sensors, accelerometers, and a system that provides heading with sufficient accuracy, such as a dual receiver. Additionally, it could include an integrated Wi-Fi access point to facilitate network connection for equipment deployed in the field.

Therefore, the system includes an ESA (Electronic Steerable Antenna), an ACU (Antenna Control Unit) capable of pointing based on information provided by the satellite network and simple inertial sensors, as well as implementing the necessary communication protocol with the constellation. The main features that the terminal must have, are listed below:

- Electronic scanning
- Support for handover between LEO satellites
- High directivity
- Beam hopping and frequency hopping capabilities
- Full-duplex operation
- Included IMU and dual GNSS

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2. TEST PLAN

The following criteria have been carried out to check the that the user terminal specifications meet the satellite constellation requirements and can be integrated into the 5G test bench.

The test procedure conducted to verify the requirements is outlined below. The assigned engineer will record the results and determine whether each test passes or fails as part of the testing process.

The FATs include the tests that must be performed at a system level. These tests ensure that the system performance meets the design specifications and verify the consistency in the integration of all components involved in the assembly, configuration and manufacturing processes.

The tests that are done in this test plan ensure the Prototype operation within the Satellite Constellation Network.

Performance tests within satellite constellation: The user terminal tracking specifications have been tested, including parameters such as latency, signal tracking, handover, and synchronization to ensure operation within the satellite constellation network.

- **Signal acquisition and tracking**: Evaluation of the terminal's capability to acquire and track signals from LEO satellites. The time required to acquire satellite signals, tracking accuracy, and robustness against signal loss or interruptions during handovers between satellites will be measured.
- **Handover evaluation**: Performance tests of the terminal during transitions between LEO satellites. Measurements of latency, packet loss, and service continuity during handovers to ensure uninterrupted connectivity and smooth transitions between satellites.
- **Latency and delays**: Measurement of the latency and delay introduced by the LEO satellite communication link. Evaluation of the terminal's performance in real-time applications, such as video streaming, gaming, and Voice over IP (VoIP).
- **Recovery times after different reception blockage**: the system recovery time is evaluated after the reception aperture is partially or fully covered. Different blockage times are measured: short blockage (2 seconds of blockage), medium blockage (20 seconds) and long blockage (60 seconds).

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2.1. TEST SETUP

The evaluation of the antenna prototype is conducted in an outdoor environment to demonstrate its tracking capabilities with the LEO constellation. The primary goal of this testing scenario is to verify the antenna's functionality and effectiveness in establishing and maintaining connections with a LEO satellite constellation.

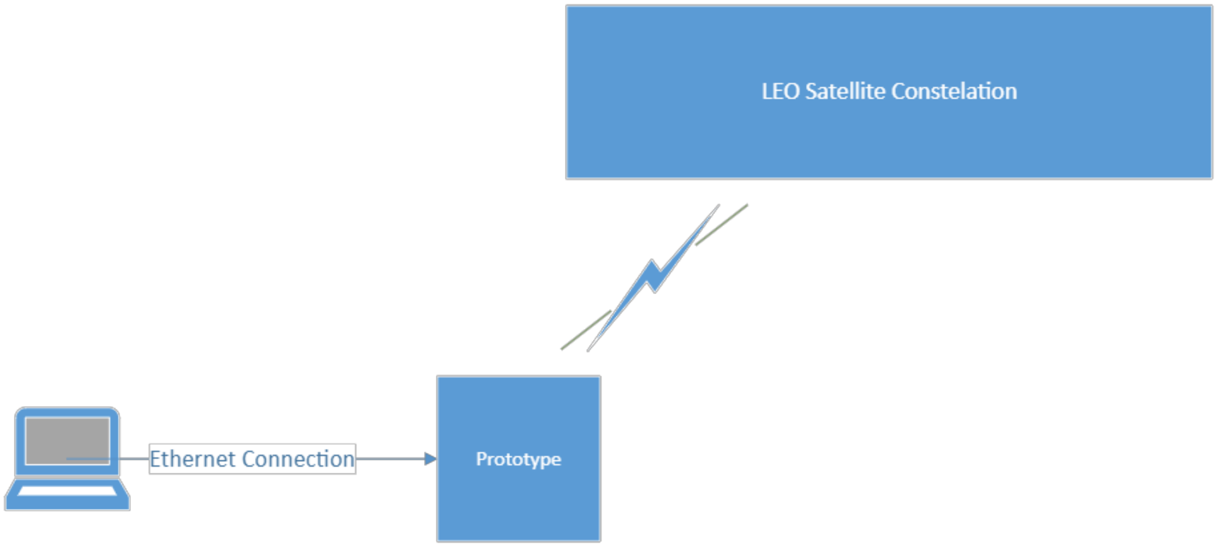

FIGURE 1 HIGH LEVEL TEST SETUP DIAGRAM

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FIGURE 2 INSTER TESTING CAMPAIN

The setup involved the following components and steps:

1. **Antenna prototype:** The fully assembled prototype, including all necessary components required for its operation.
2. **Antenna installation:** The LEO antenna prototype is securely mounted on a stable platform in an open outdoor area to ensure clear signal reception and transmission.
3. **Mounting and connection accessories:** These include all the necessary hardware and cables for securely mounting the antenna in an outdoor environment and connecting it to the user's PC. This setup ensures proper alignment and stable communication between the antenna and the satellite system, while allowing the user to monitor the status and results of the tests in real time.
4. **Signal source:** The LEO satellite constellation is used to test the antenna's reception capabilities. The antenna transmission is also tested as traffic tests are performed to evaluate the prototype performance.

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5. **Measurement equipment:** The user's PC is used to measure the signal strength, quality, and overall performance of the antenna using different software tools. The prototype is accessible though ethernet connection and the LUI (Local User Interface) of the modem is used to operate the prototype.
6. **Environmental conditions:** Tests are conducted in various environmental conditions to evaluate the antenna's robustness and reliability. These conditions include cloudy weather, but rain is excluded from testing scenarios.
7. **Data collection:** Data on signal strength, connection stability, and transmission quality is collected and analysed to determine the antenna's performance metrics.
8. **Satellite Link Availability:** Ensure the satellite link is available and operational for the duration of the test.

2.2. TEST MATRIX

Various parameters have been measured to verify the User Terminal (UT) performance within satellite constellation:

- Acquisition time
- Tracking and handovers performance
- Latency and delays in real-time applications
- Reacquisition time

The tests that are performed are summarized in the following table:

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TEST MATRIX Nº 11				
Project		6G-INTEGRATION-01 UNICO I+D Project		
Test type	Item Under Test		Applicable specification	Contractual Specification
FQT	Synchronism module		N/A	N/A
Nº	Requirement	Test	Description	Method
1	Additional	FAT-1	Acquisition tests	T
2	Additional	FAT-2	Tracking	T
3	Additional	FAT-3	Traffic data performance	T
4	Additional	FAT-4	Reacquisition	T

TABLE 1 FAT TEST MATRIX

3. TEST PROCEDURE

3.1. ACQUISITION TIME

Test Description:

The UT is powered on in an outdoor scenario with dual GNSS signal reception and the time to get locked in the satellite constellation network is measured.

Test result:

Req ID	Test	Test sequence	Specified value	Test result
Additional	FAT-1	Acquisition time	≤ 5	OK x / NOT OK ☐

The user terminal gets into network in **3 minutes** since it has been powered on. The time is measured with a chronometer since the power on button is pushed until the prototype shows the Tracking status on the LUI.

The User Terminal status is provided by the LUI (Local User Interface). Through this interface, the system health in the acquisition process is verified:

- GNSS status is verified: Dual GNSS and number of GPS and GLONASS satellites reception

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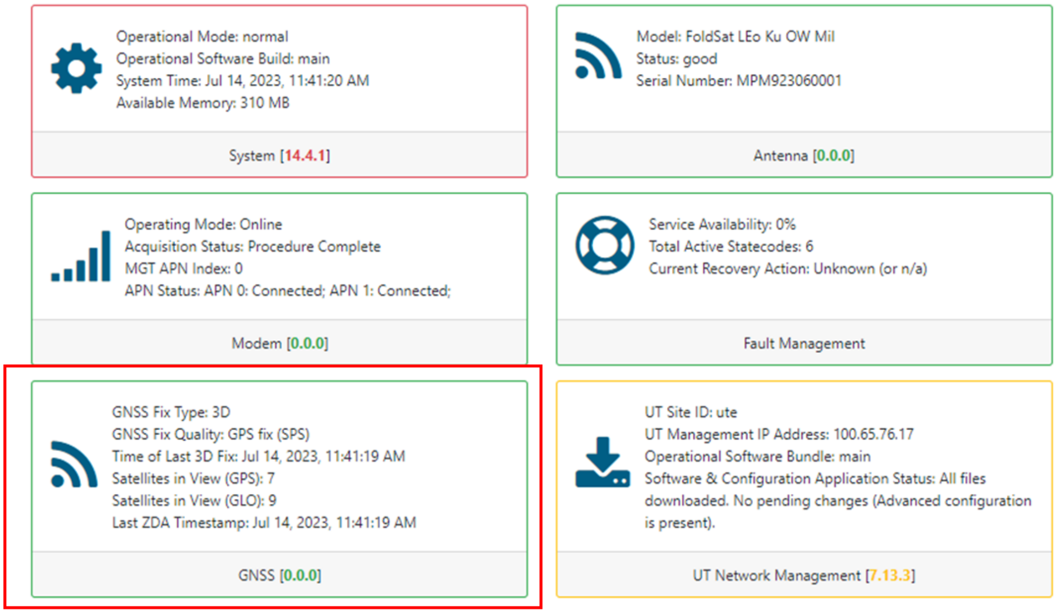

FIGURE 3 GNSS RECEPTION STATUS

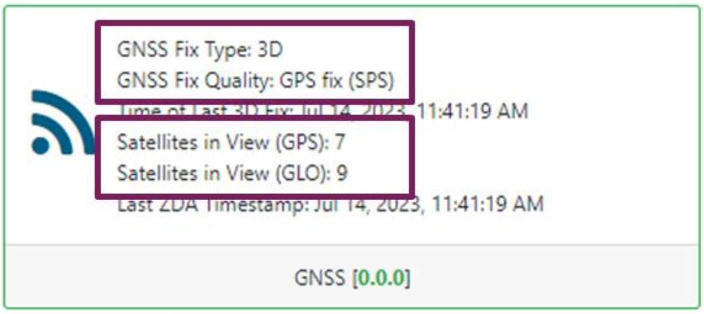

FIGURE 4 GNSS STATUS ZOOM

- Installation information is verified:

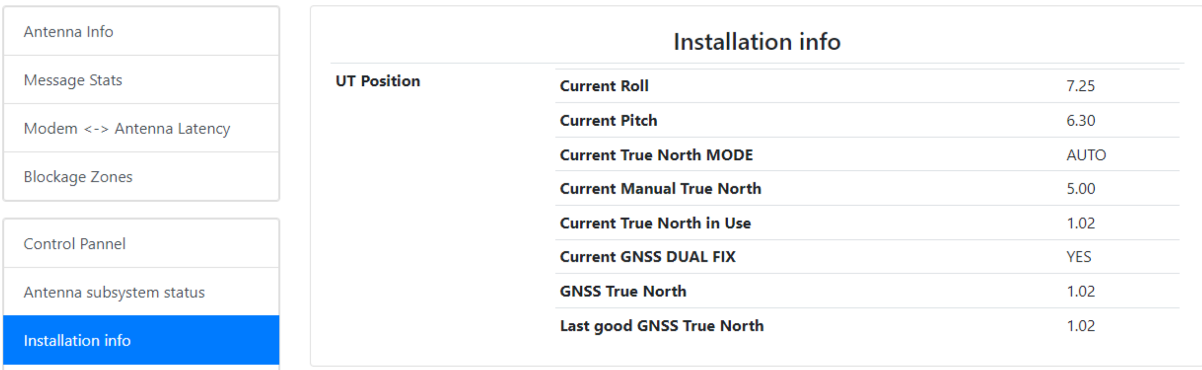

FIGURE 5 INSTALLATION INFORMATION

This section shows the heading of the terminal and if the GNSS reception is good.

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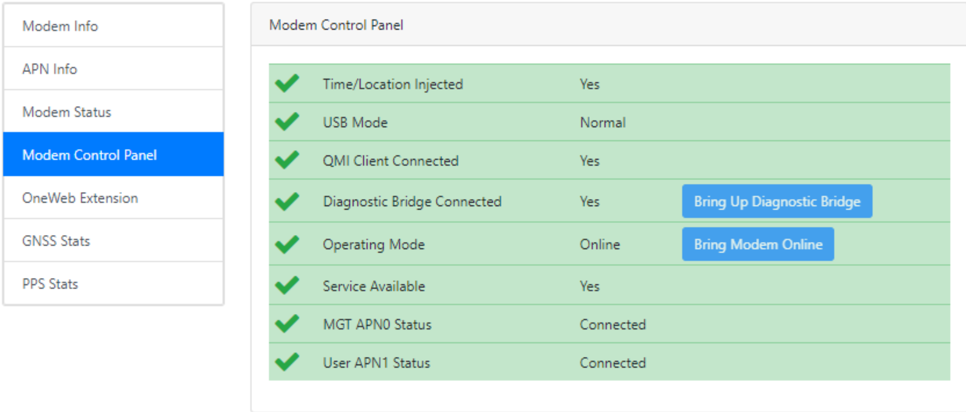
- Modem status is verified



When the user terminal is in tracking, the Antenna section in the LUI, Antenna subsystem status is set to TRACKING as shown:

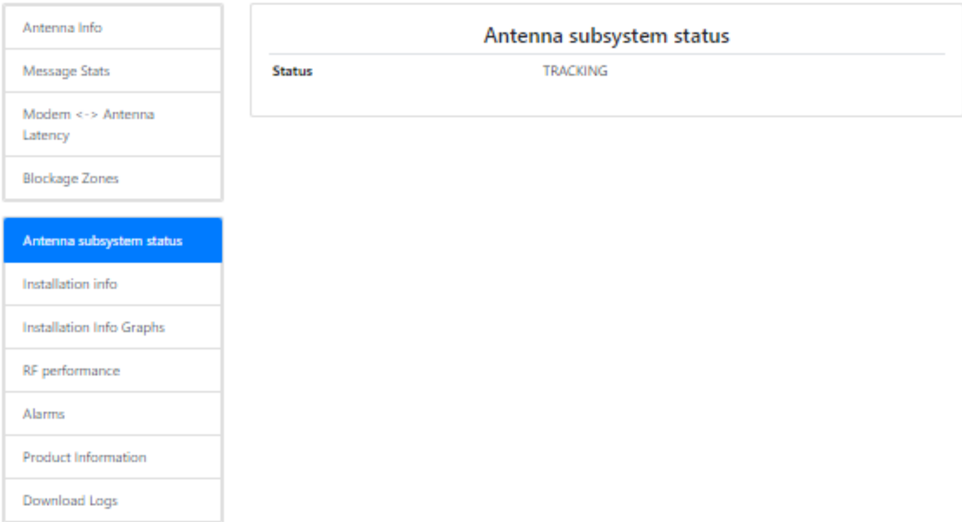


FIGURE 6 ANTENNA SUBSYSTEM STATUS

Finally, the prototype health can be checked on the Alarms section on antenna website in the LUI:

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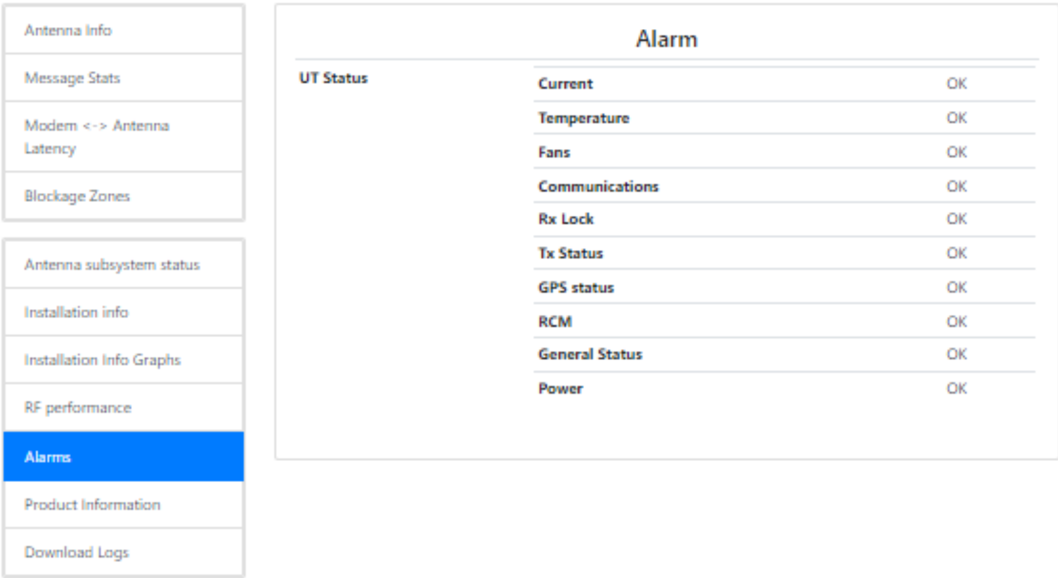

FIGURE 7 USER TERMINAL STATUS

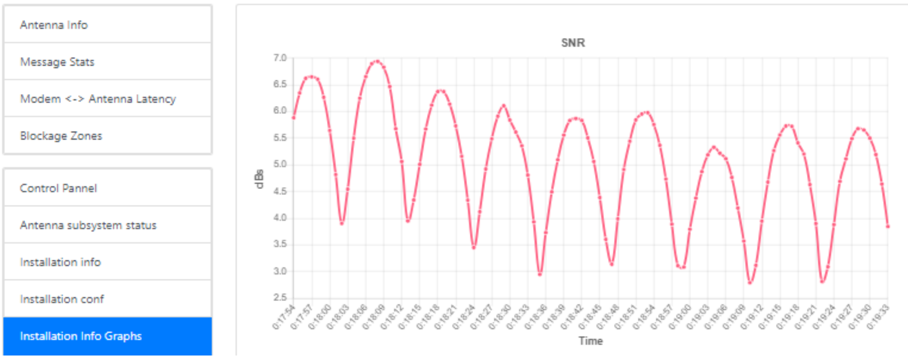

FIGURE 8 SNR AND INSTALLATION GRAPHS

3.2. TRACKING PERFORMANCE

Test Description

Once the UT is into network the tracking performance has been analysed with the system logs.

During this test, a continuous ping is also done to measure the system latency and traffic availability.

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Test Result

Req ID	Test	Test sequence	Specified value	Test result
Additional	FAT-2	Tracking	SNR performance not drops to 0 Continuous ping	**OK x / NOT OK ☐**

The user terminal received SNR is shown in the following graph:

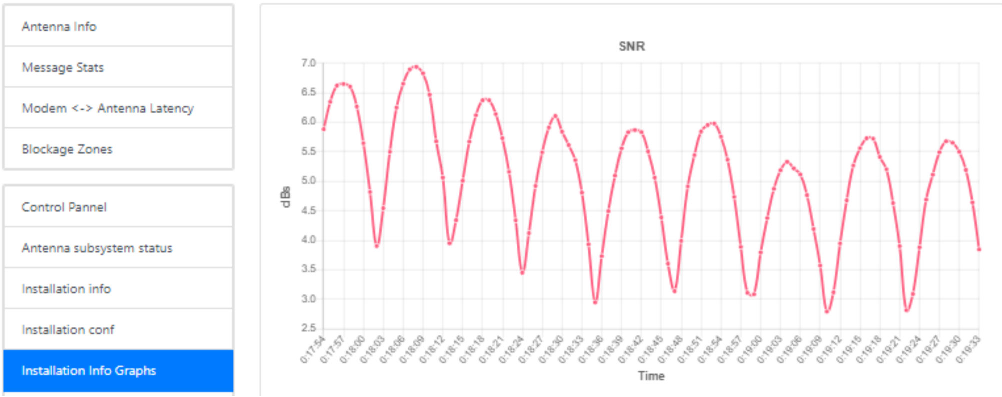

FIGURE 9 AVERAGE SNR (DB)

In the graph, the SNR fluctuation is due to the satellite constellation planes changes. The system uses ephemeris information to carry out the handovers. The Modem indicates to the ACU (Antenna Control Unit) the exact moment in which the beam-forming needs to be executed (frequency, position, etc). To demonstrate that the handover process does not affect the tracking performance, a continuous ping is launched every 200ms.

The ping performance is the expected and no data packets are lost during the tracking. The ping latency is also within the expected values (around 100ms and maximum 150ms).

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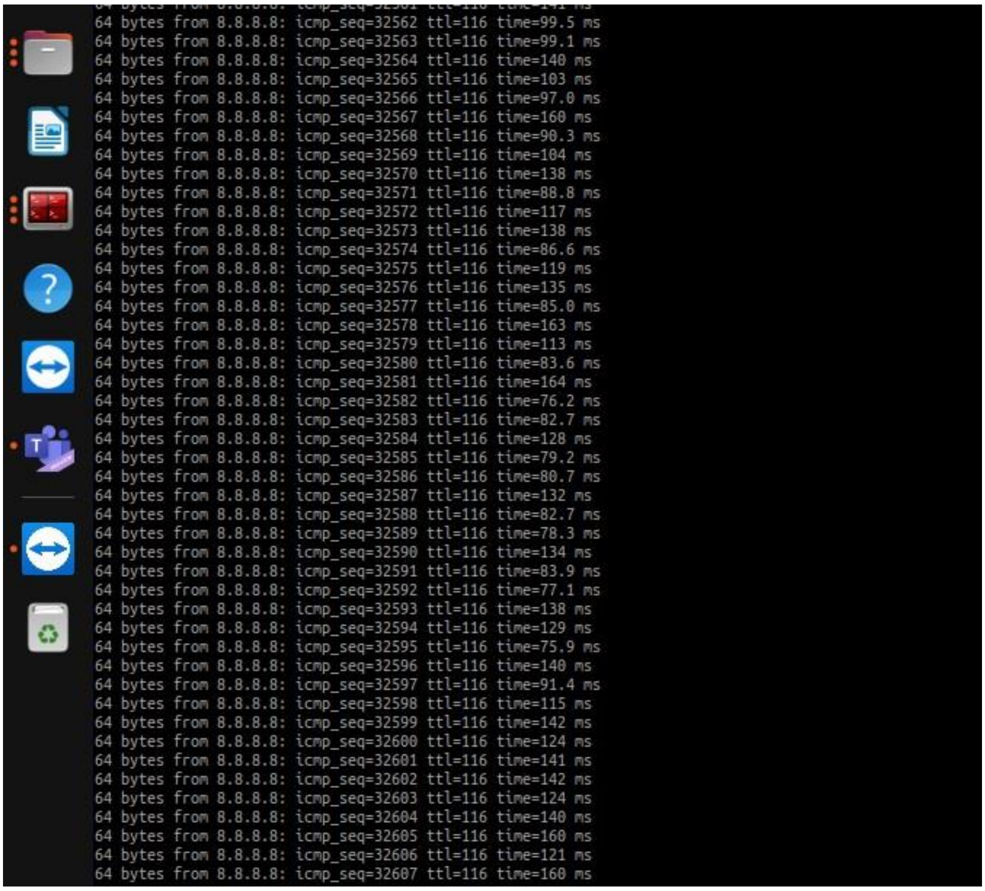

FIGURE 10 PING RESULTS DURING TRACKING TEST

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3.3. TRAFFIC TEST AND LATENCY

Test description:

This test is performed when the system is in tracking, after the acquisition tests.

The User Terminal throughput performance is measured with a speed test, concretely, the one offered by the website www.speedtest.net (others could also be used). The traffic throughput result is limited regarding the satellite constellation provisioning plan (the data service configured by the Hub (Satellite constellation)

Connect the user PC to the prototype ethernet port and run the speedtest several times to check the performance.

Test Result:

Req ID	Test	Test sequence	Specified value	Test result
Additional	FAT-3	Traffic data performance	Continuous ping Throughtput according to provisioning plan Latency less than 150ms	**OK x / NOT OK ☐**

Below, the user terminal speed test result is shown.

- Upload Throuhgput: 5,76 Mbps
- Download Thouhgtput: 75,14 Mbps
- Latency: 142 ms average

FIGURE 11 THROUGHPUT TEST

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Additionally, a speed with a local script (Speedtest by Ookla) has been performed to evaluate the traffic bandwidth of the terminal.

```
   Speedtest by Ookla

      Server: 31173 Services AB - Amsterdam (id: 23094)
         ISP: OneWeb
Idle Latency:    69.65 ms   (jitter: 0.62ms, low: 68.57ms, high: 70.35ms)
    Download:    77.94 Mbps (data used: 101.2 MB)
                601.72 ms   (jitter: 102.77ms, low: 71.54ms, high: 1357.56ms)
      Upload:    12.44 Mbps (data used: 20.6 MB)
               1458.77 ms   (jitter: 101.63ms, low: 115.00ms, high: 2319.39ms)
 Packet Loss:     0.0%
  Result URL: https://www.speedtest.net/result/c/a28a7e96-15e2-4c8c-84b8-767a03537d98
```

FIGURE 12 SPEED TEST

The results are aligned with these configured parameters.

3.4. REACQUISITION TIME

Test Description:

The reacquisition tests involve covering the reception aperture and measuring the time required for the system to reacquire the signal once the field of view is restored.

Some reacquisition measurements have been done by blocking the reception aperture during different time periods (2 seconds of blockage, 20 seconds of blockage and 60 seconds of blockage). During these tests, a continuous ping has also done to measure the system latency and ping recovery time after the blockage of the reception signal.

Test Result:

Req ID	Test	Test sequence	Specified value	Test result
Additional	FAT-4	Reacquisition after short blockage	< 2 seconds	**OK x / NOT OK ☐**
		Reacquisition after medium blockage	< 10 seconds	**OK x / NOT OK ☐**
		Reacquisition after long blockage	< 10 seconds	**OK x / NOT OK ☐**

The SNR has been measured during the reacquisition test.

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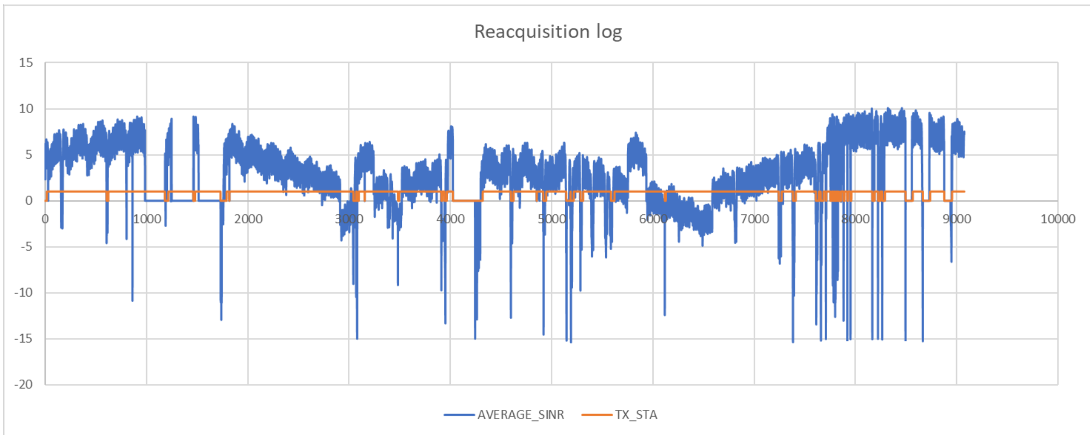

FIGURE 13 SNR AND TX STATUS DURING REACQUISITION TEST

Additionally, the test has been repeated performing a ping to see in real time when the UT has lost the link to the satellites.

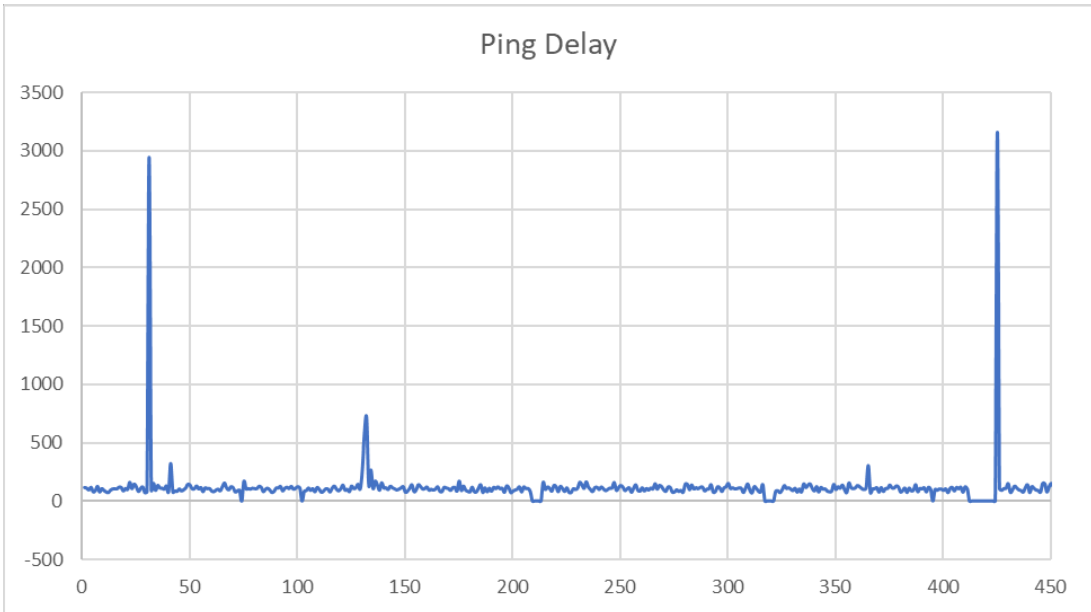

FIGURE 14 PING DELAY DURING REACQUISITON TEST

- **Short Blockage**: reception signal blockage during 2 seconds

Parameter	Time to recover the ping
Recovery 1 from LUI data	<2 seconds
Recovery 1 from LUI data	<2 seconds
Recovery 1 from LUI data	<2 seconds

TABLE 2 RECOVERY AFTER SHORT BLOCKAGE

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- **Medigum Blockage**: reception signal blockage during 20 seconds

Parameter	Time to recover the ping
Recovery 1 from LUI data	1 second
Recovery 1 from LUI data	3 seconds
Recovery 1 from LUI data	2 seconds

TABLE 3 RECOVERY AFTER MEDIUM BLOCKAGE

- **Long Blockage**: reception signal blockage during 60 seconds

Parameter	Time to recover the ping
Recovery 1 from LUI data	3 seconds
Recovery 1 from LUI data	2 seconds
Recovery 1 from LUI data	2 seconds

TABLE 4 RECOVERY AFTER LONG BLOCKAGE

4. DATA INTEGRATION AND USER TERMINAL NETWORK CONFIGURATION REQUIREMENTS.

This section outlines the tests to be conducted within the 5G Test Bench preconditions. It details the minimum required hardware and configuration parameters necessary for preparing the prototype integration on the test bench.

4.1. PURPOSE

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

The tests will be divided in two main parts:

- INSTER will test the network configuration of the prototype in an isolated scenario to check the viability of the solution before the integration in the test bench.
- Integration of INSTER's prototype in the test bench.

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4.2. 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.

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

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- **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.

4.3. STEPS

This section describes the high-level steps required to prepare and configure the prototype antenna for the internal tests in INSTER and the integration tests in the test bench.

4.3.1. Steps to configure the network for INSTER internal tests

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 5 MAIN STEPS FOR INSTER INTERNAL TEST

4.3.2. Steps to configure INSTER terminal in the test bench

INSTER needs to provide the IP Public of the user terminal in the test moment to Ericsson. This step is required to configure the communications tunnels.

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Action	Expected result
Network configuration	Share network configuration

TABLE 6 NETWORK CONFIGURATION

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5. SUMMARY AND CONCLUSIONS

This document outlines the tests and measurements performed to ensure the antenna prototype meets all established requirements to operate in the selected Satellite Network Constellation. The positive outcomes of these tests support the completion and validation of the antenna prototype for further operational use and deployment. The successful performance of the prototype confirms both the design and manufacturing quality of the prototype. Comprehensive testing has ensured that the prototype is ready for its intended application, offering reliable and enhanced beam management for dynamic pointing of LEO satellites.

The requirements for advancing to the next steps in the 6G-INTEGRATION program are outlined. These requirements will enable the commencement of preliminary integration tests of the prototype on the test bench and ensure that the tests are conducted according to the defined final use cases.

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