IOD MISSION FOR DIRECT 5G BROADBAND ACCESS FROM LEO

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ABSTRACT

Under the European Space Agency's ARTES framework, the project "Demonstration of Direct 5G Broadband Access from LEO to Small Aperture Terminals" aims to integrate 5G New Radio (NR) technology with Low Earth Orbit (LEO) satellite constellations, facilitated by the recent completion of the NR standard by 3GPP Release 17.

Technical solutions developed by Tyvak International and partners PICOSATS, RAME, and TIM, leverage recent NR 3GPP standards for Non-terrestrial Networks to establish data links between ground devices and space-based assets.

The project encompasses two mission concepts: "Direct Access 5G Satcom Reference Mission" (REMI) and "Direct Access Live Demonstration" (LIDE). REMI evaluates the feasibility of providing 5G broadband access to land terminals using small satellite constellations, while LIDE involves designing and testing a 12U spacecraft and small aperture terminals to demonstrate a bidirectional K/Ka band link. Key performance indicators including C/N, latency, and throughput data rates of at least 1 Mbps in uplink and 10 Mbps in downlink are assessed during in-orbit operations.

The project is significant for advancing European telecommunication capabilities, with implications for future 3GPP protocols and 6G technology. Scheduled for launch in between Q4 2024 and Q1 2025, the 12U CubeSat will undergo Flight Readiness Review in July 2024.

1 INTRODUCTION

In recent years, the completion of the 5G New Radio (NR) standard by the 3rd Generation Partnership Project (3GPP) and the increasing interest in establishing connectivity from space through extensive constellations of Low Earth-orbiting satellites (LEO) have reshaped the landscape of telecommunications. This convergence has not only opened avenues for integrating 5G with traditional satellite communications but has also introduced a new paradigm of ubiquitous connectivity, characterized by the notion of "anything, anytime, anywhere."

Of interest in this evolving framework is the integration scenario involving direct access to 5G broadband by terminals with small apertures, including portable, vehicular, and handheld devices terminals. Within this context, the project "DEMONSTRATION OF DIRECT 5G BROADBAND ACCESS FROM LEO TO SMALL APERTURE TERMINALS" within the European Space Agency's ARTES (Advanced Research in Telecommunications Systems) framework, stands as a beacon of innovation.

Technical solutions are being spearheaded by leading companies Tyvak International, European leader in innovation and development of Small Satellites, PICOSATS, engaged in the research and development of telecommunications systems through the use of nano-satellites, Radio Analog Micro Electronics (RAME), a company specialized in the field of microelectronics and in the experimental implementation of 5G NR technologies, and TIM, leader in the fixed and mobile telecommunications services, data, internet and broadband. Leveraging novel guidelines incorporated in recent NR 3GPP standards, the project aims to establish Non-terrestrial Networks (NTN), enabling seamless data links between ground devices and space-based assets.

The program uses novel guidelines incorporated in recent NR 3GPP standards, for the definition of Non-terrestrial Networks (NTN), to allow data links between ground devices and space-based assets.

2 MISSION OBJECTIVES

The project consists of two missions, the first called "Direct Access 5G Satcom Reference Mission" (REMI), which consists of a feasibility study on the provision of 5G NTN broadband access to land terminals, in rural and suburban areas, using a constellation of satellites, and the second called "Direct Access Live Demonstration" (LIDE), a simplified and resized version of the REMI scenario, which will serve as a test-bed for 5G broadband services from LEO orbit, through the use of an in-orbit demonstrator satellite based on Tyvak 12U standard Platform.

During LIDE mission, a transparent bent-pipe transponder operating in K/Ka band will be used to carry out direct access data tests to two ground terminals: a Gateway (GW), and a User Terminal (UE). The two terminals will run a commercial SW Radio Stack solution compliant with Release 17 of the 3GPP standard, introducing Non-Terrestrial Network (NTN) scenarios. When the spacecraft hosting the K/Ka Transponder is in line of sight with the two ground terminals, a bidirectional link, achieving 1 Mbps in uplink and 10 Mbps in downlink, will be established between the GW and the UE.

Two different ground terminals locations have been selected for the LIDE: an Italian site in Leonessa (Rome), and the ESA 5G laboratory, currently under development in ESTEC headquarter. These two sites will allow to execute link experiments and characterization during the entire mission lifetime of one year.

Phase 1 of the program successfully ended in March 2023; It focused on establishing technical specifications and a baseline for the mission, along with the definition of the space platform, its engineering budgets as well as its associated RF payload, signal, and ground segment components. The Consortium is now actively working on reaching the next key milestones of Phase 2: the System Integration Readiness Review and the Flight Readiness Review of the program.

Satellite Assembly, Integration and Test phase will be performed in Turin, exploiting Tyvak International ISO-7 cleanroom and the TIM anechoic chamber environment for the Payload validation activities. The target launch of the mission is planned between Q4 2024 and Q1 2025.

During the in orbit operative phase, managed from Tyvak International Mission Control Center in Turin, a series of communication experiments will be executed establishing bidirectional K/Ka band links through the Payload transponder with the aim of measuring and evaluating the link though key performance indicators (KPIs) such as C/N, latency, and throughput. By demonstrating this capability, the project aims to bridge the gap between traditional satellite communications and innovative 5G technology, thus introducing a new paradigm of connectivity. This objective aligns closely with broader industry initiatives that aspire to realize the vision of "anything, anytime, anywhere" connectivity, ensuring seamless access to broadband services regardless of geographical location or terminal size.

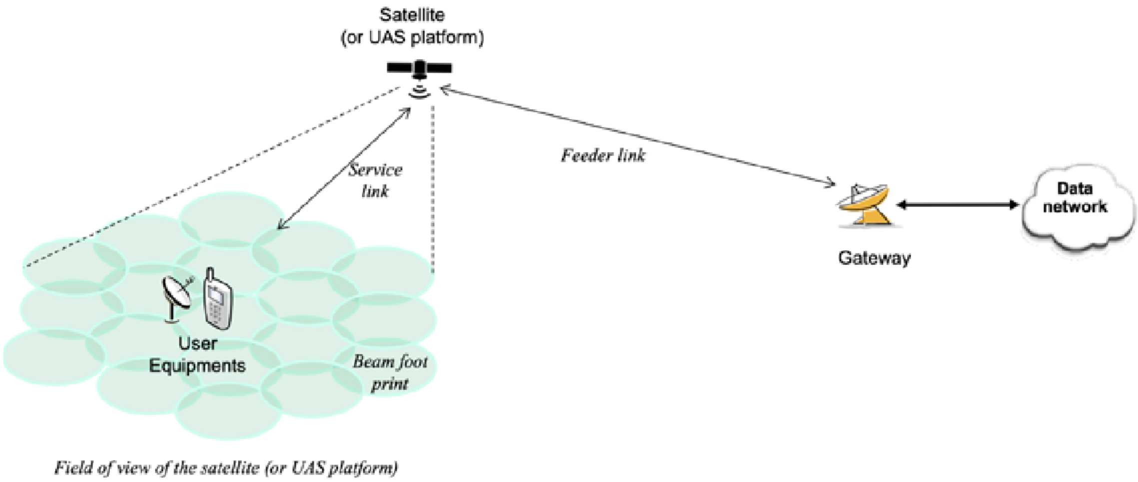

Figure 1. LIDE experiment scenario

The successful execution of this mission promises to significantly advance European 5G/6G telecommunication capabilities, serving as a pivotal milestone in the pursuit of unprecedented throughput values and laying the groundwork for future operating platforms.

3 SYSTEM OVERVIEW

The "Demonstration of Direct 5G Broadband Access from LEO to Small Aperture Terminals" project integrates innovative technologies and subsystems to realize its mission objectives of establishing direct 5G broadband access from Low Earth Orbit (LEO) satellites to small aperture terminals. This section provides a detailed overview of the system architecture, highlighting the key components, interfaces, and operational functionalities.

3.1 Space Segment

The space segment comprises the spacecraft and associated payload subsystems responsible for transmitting and receiving 5G signals to and from ground terminals. Key elements of the space segment include:

- Spacecraft: The spacecraft serves as the primary platform for housing and operating the payload subsystems. It is designed to operate in LEO and maintain precise orbital parameters to ensure optimal communication coverage with ground terminals.
- Payload Subsystems: The payload subsystems consist of advanced transponders, antennas, and processing units responsible for modulating, demodulating, and routing 5G signals. These subsystems are designed to operate in the K/Ka band frequency range and support bidirectional communication links with ground terminals.

3.1.1 Spacecraft

The Tyvak 12U Platform has been selected for this mission. This Platform allows the two Payload units to accommodate and ensure the external surface required by the Payload antennae set.

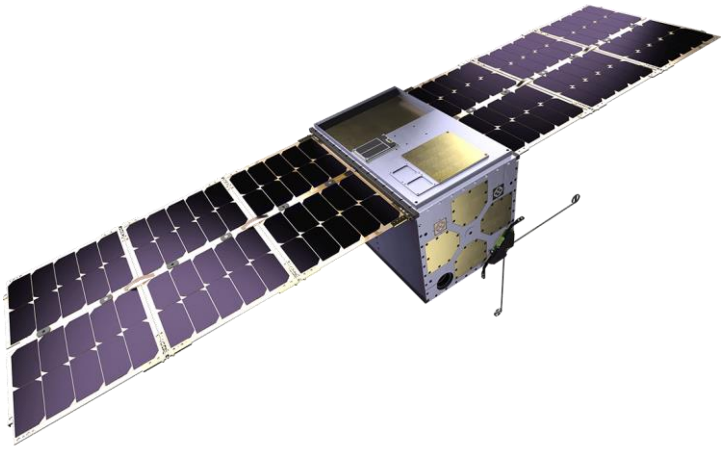

Figure 2. Renegade 12U Platform concept

The Renegade 12U platform offers a high heritage solution allowing to maximize Payload available volume, mass and power.

The platform presents a powerful processing system designed with a radiation-hardened watchdog microcontroller, for hot-swap redundant functionality. The processing modules contain on-board storage for housekeeping telemetry collection.

The ADCS software can interface with multiple star trackers for guaranteed stellar coverage and an Inertial Measurement Unit (IMU). As a backup, sets of redundant coarse sensors and magnetometers allow performing attitude determination functionality independent of the IMU and star trackers. For actuation, the system uses a family of reaction wheels depending on vehicle size and agility, along with torque rods for momentum management (in LEO missions). A combination of UHF and S-band radio options are available for telemetry and command of the satellite.

The Renegade platform power generation subsystem is highly modular to satisfy the power requirements of a vast range of missions. A standard deployable solar array configuration adopting 120 solar cells is proposed to maximize power generation. A single, high-efficiency MPPT transfers the energy sourced from solar arrays to the two parallelly-installed battery modules. Each battery pack is composed of six lithium-ion cells, for a total battery capacity of 150Wh.

From the battery pack, power is regulated and monitored by the Load Controller Module (LCM) and finally distributed via a dedicated power channel to each subsystem, including the Payload unit.

Table 1. Renegade platform specification

Specification	Capabilities
Spacecraft Platform	12U
Payload Mass	13kg
Payload Volume	~9U
Payload Peak Power	Up to 180W
Standard Payload Interfaces (x3)	
Data Buses	RS-422, Ethernet
Power Rails	9-12.6V Unregulated, 5V
General Purpose I/O	4
Thermistors	1
Survival Heaters	1
Umbilical Passthroughs	9
Pulse Per Second Signal	1
Guidance Navigation and Control Performance	
System Pointing Accuracy	120 arc-sec
System Pointing Knowledge	35 arc-sec
System Position Knowledge	+/- 4m
Standard Radio Configurations	
Half-Duplex UHF, Full-Duplex S-Band	UHF Uplink/Downlink: (9.6kbps) S-Band Uplink: (Up to 125kbps) S-Band Downlink: (Up to 2Mbps)
Solar Array Peak Power	Up to 133W

The following picture illustrates the general mechanical configuration, with the aid of the conceptual CAD.

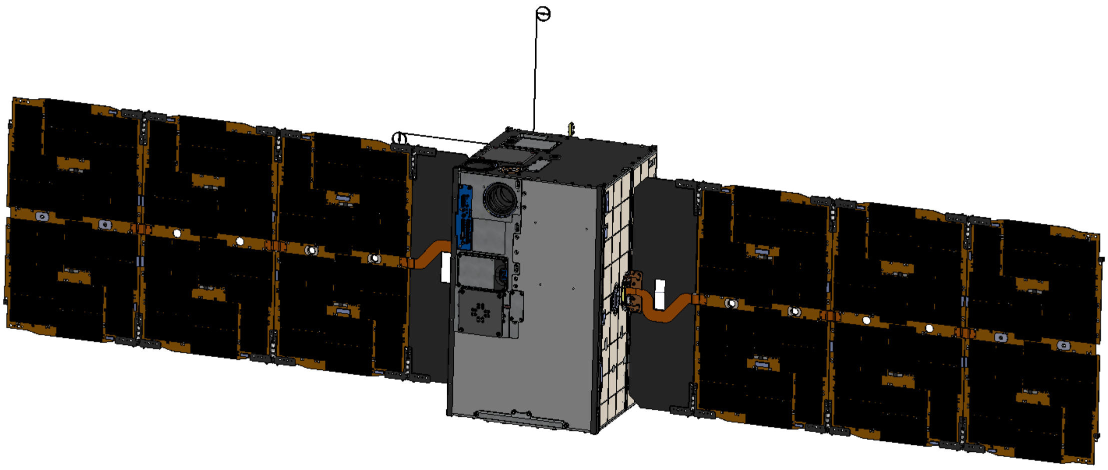

Figure 3. Spacecraft CAD drawing

Panel-Z of the spacecraft houses a configuration adopting four antennae: 2x K band TX antennae at 18.8 GHz and 19.2 GHz, and 2x Ka band RX antenna at 29.1 GHz and 29.5 GHz.

3.2 Payload

The payload includes:

- Primary Payloads
  - 2x Transponders
  - 2x TX K band antennae
  - 2x RX Ka-band antenna
- Secondary Payloads (not part of the ARTES mission)
  - 1x Spectrum monitoring module
  - 1x S-band RX antenna

The Payloads will be mechanically interfaced to the main structure aluminum panels.

The primary payload architecture comprises transparent bent-pipe transponders, antennas, and signal processing units designed to facilitate direct 5G broadband access. The transponders modulate incoming signals from ground terminals into the K/Ka band frequency range for transmission to the space segment. Similarly, they demodulate signals received from the space segment for onward transmission to ground terminals.

3.2.1 Transponders

The transponder is an analog transceiver in a bent-pipe configuration. It features coaxial connectors as input from the receiving antenna and as output to the transmitting antenna. There is also a connector for the interface with the payload interface board.

The transponder consists of three main boards: one that operates as a receiver and converts the signal to an intermediate frequency, one that amplifies and filters in IF, and finally one that operates as a transmitter by reconverting to high frequency and amplifying the signal. These boards are connected internally by coaxial cables for the RF signal and by a data connector with an RS485 bus where the transmitter, operating as the main board, coordinates the others.

The connector used for the interface with the platform allows to carry power to the transponder and includes an RS422 bus, as the transponder control interface, and an RS485, used as an auxiliary connection to perform debugging (i.e., sniffing internal commands) or firmware update functions for the transponder.

Each board consists of an RF signal chain driven by the local oscillator and allows frequency conversions, amplification, and filtering to be carried out. A microcontroller and a section for power control and monitoring are also always present on the boards.

Each transponder board is boxed in an aluminum container with basic dimensions of 82.1x96 mm and varying height depending on the board. Each aluminum container has connectors on the front side, mounting holes for screws at the four corners, and properly sized wall thickness to provide proper radiation shielding (TID).

Table 2. Transponder main features and performances briefly summarizes all the features of the transponder, and Figure 4 photos of the transponder.

Table 2. Transponder main features and performances

Receiver Frequency	27.6 - 30 GHz
Transmitter Frequency	17.8 - 20.2 GHz
Maximum output RF power	7 W
RF connectors	Female coaxial 2.92 mm connectors
Command interface	RS422
Debug and programming interface	RS485 (+ GPIO)
Mass	• 921 g (with IF board) • 685 g (without IF board)
Dimensions	• 82.1 x 96 x 62.69 mm (with IF board) • 82.1 x 96 x 45.59 mm (without IF board)
Input supply voltage	12 V to 18 V

DC Power consumption	• IDLE: 2 W
	• TRANSPONDER (not receiving): 23 W
	• TRANSPONDER:
	  ○ Low gain: 30 W
	  ○ High gain: 35 W

DC Power peak	45 W (duration 200 ms) - only when switching to transponder mode with RF signal already applied to the RX antenna
Temperature range	• Operating: -20°C to +70°C • Non-operating: -30°C to + 90°C

Figure 4. Transponder

3.3 Ground Segment

The Ground Segment associated to the LIDE mission architecture can be divided into:

- LIDE Ground Terminals
- TT&C Ground Segment

3.3.1 LIDE Ground Terminals

The Ground Terminals consists of a transmitting Gateway antenna, and a receiving User Equipment described below.

Gateway

The below figure corresponds to the Gateway Block diagram and architecture description.

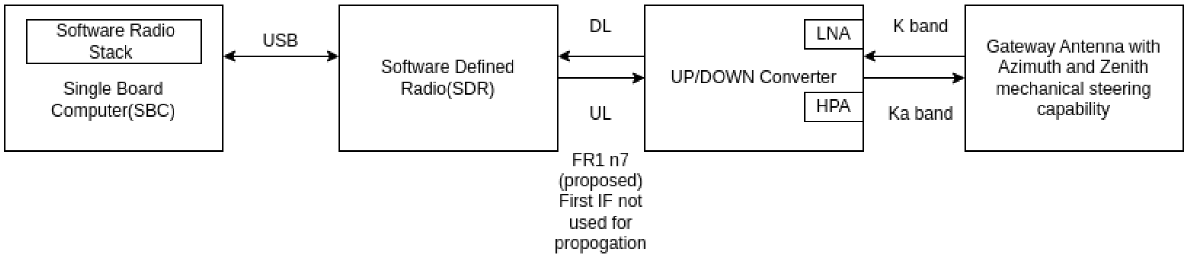

Figure 5. Gateway architecture block diagram

A 1.2 m Sheet Molding Compound-composite (SMC) antenna has been selected which incorporates precision-assembled reflector panels, back structures and a hub that allows easy placement on a pole and a match with the identified motor solution (the SPX-01).

The antenna is fixed on a standard azimuth-over-elevation pedestal which provides a solution for ground or roof installation guaranteeing stiffness, stability, full orbital arc coverage, pointing and tracking accuracy.

Figure 6. 1.2m K/Ka band antenna and K/Ka band OMT

The 1.2m SMC antenna comes with OMT waveguide feeds to transmit and receive applications in Ka and K bands with RHCP or LHCP polarization. The electrical performance is compliant with FCC and ITU-RS-580 sidelobes specifications.

The antenna transmits in the operating frequency range between 27 and 31 GHz, and receives in the range from 18.7 to 21.2 GHz. The pedestal of the antenna guarantees both azimuth pointing ranges from 0° to 10° with fine tuning and an elevation pointing range between 30° and 90°. In the assembly with the motor system, a fixed position for elevation and azimuth will be used to make the system compliant with the full terminal tracking requirements.

User Equipment

The figure below corresponds to User Equipment architecture.

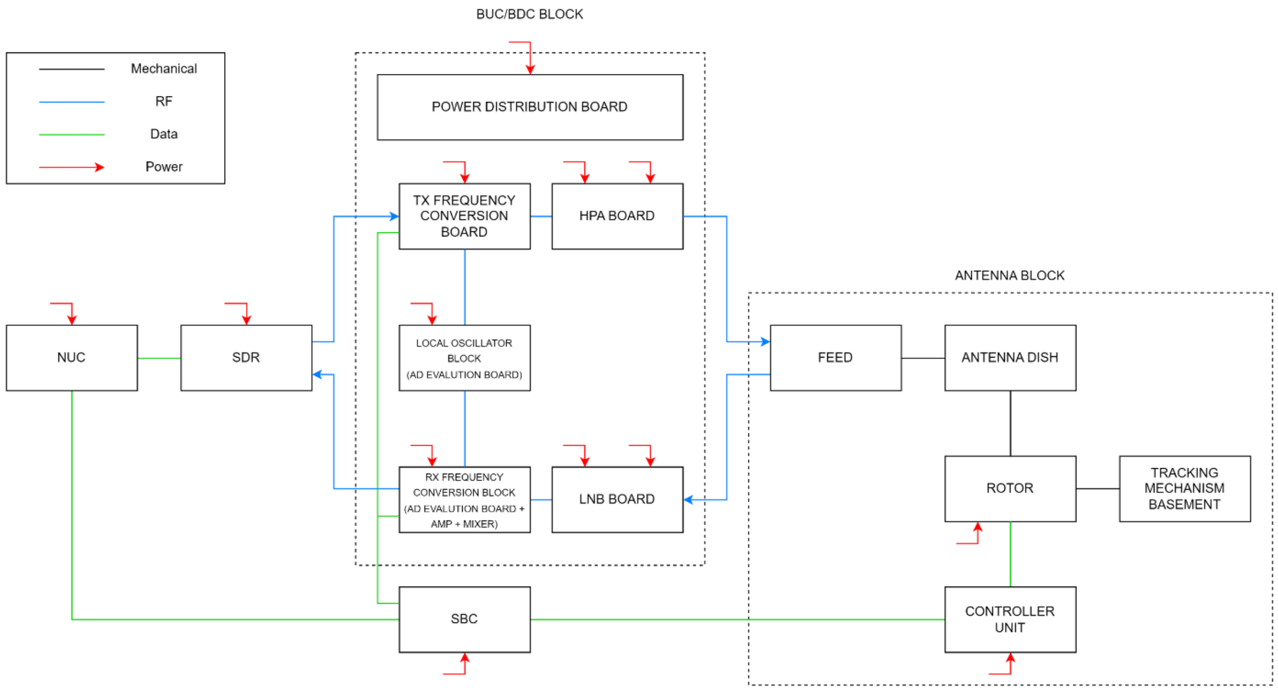

Figure 7. UE segment block diagram

For the UE antenna block selection, the preferred approach has been (in analogy with the GW) to identify on the market a COTS integrated solution, compatible with the technical requirements (maximum diameter, TX power limit, frequency range) and the programmatic constraints (lead time, cost and supplier responsiveness), without requiring an ad-hoc development.

The antenna block is characterized by:

- The COMAG - SK38-5 as antenna dish provided by Satgear (figure below)
- The same OMT feeder selected for the GW terminal

Figure 8. COMAG - SK38-5 by Satgear

4 MISSION PROFILE AND CONCEPT OF OPERATIONS (CONOPS)

The spacecraft is designed to serve as a comprehensive testbed and validation platform for demonstrating direct 5G broadband access from LEO satellites to small aperture mobile terminals. It integrates advanced technologies and subsystems to fulfil its functional requirements effectively while complying with regulatory standards and ensuring reliable and efficient operation in space.

The LIDE mission can be divided into four main phases, presented in the figure below:

- Launch and Early Operations Phase
- Commissioning
- Nominal Operations
- Decommissioning

During the Launch and Early Operation Phase, targeted between Q3 2024 and Q1 2025, the spacecraft is initially integrated in the Tyvak designed deployer system. Once reached the operative orbit, the satellite will be deployed from the launcher, and will start the automatic power-on sequence including the OBDH startup, the appendices deployment (e.g. solar arrays, UHF antenna) and the attitude stabilization the spacecraft.

The Commissioning Phase foresees a series of checks to verify the health status of the spacecraft, that will last for at most one month, in particular:

- Appendices deployment verification
- Platform telemetry collection and analysis
- ADCS modes test
- S-band communication test
- Payload health check

The commissioning finalization will kick-start the Nominal Operations Phase which foresees the alternance between four sub-phases.

- Sun Pointing: where no payloads operations are ongoing (Payloads turned OFF) and the vehicle will control its attitude pointing the solar panel to the Sun to maximize the power generation.

- S-Band Communication: this sub-phase required for the secondary payload, a Spectrum Monitoring analyzer not part of the ARTES mission and not presented in this paper, will occur when the spacecraft is in visibility with a Tyvak Ground Station assigned to the mission. During the access the spacecraft will perform ground target pointing the two S-Band antennas dedicated to the TMTC toward the ground station, the on-board S-Band radio is activated establishing a full duplex link dedicated to command and telemetry transfer. Each S-Band communication window is scheduled uplinking and executing on-board a daily operations schedule. Once the S-Band pass is over, the spacecraft automatically turns off the S-Band communication subsystem and moves back to a sun pointing subphase. In this subphase an S-Band link is established with the aim of:

- Commanding and uplink data from the ground
- Downlink Bus telemetry, Payload telemetry and Spectrum monitoring data

- Primary Payload Operations: this sub-phase will occur when the spacecraft is in visibility of the two LIDE ground terminals. To establish a forward and return link between the GW and the UE, the two transponders will be powered ON and the spacecraft will perform ground target pointing the K/Ka Payload antennas toward the UE (located less than a km far from the GW). Before and after the access over the two LIDE terminals, the Payload is set in an idle mode, where only the control electronics is powered ON.

- Secondary Payload Operations: when the secondary payload (a spectrum monitoring anlayzer not part of the ARTES mission) is operative, and the spacecraft is pointing the S-Band Payload antenna toward Nadir performing the spectrum acquisition. These acquisition windows will be schedule on-board uplinking and executing a daily schedule. Once finished a spectrum acquisition window, the spacecraft will automatically move back to the sunpointing sub-phase.

During the Primary PL in-orbit operations, multiple experiments will be scheduled when the 12U spacecraft is in line-of-sight with the two ground terminals, with the aim to establish a bidirectional K/Ka band link (K band uplink, Ka band downlink) through the 2 bent-pipe Payload transponders. Each of the two ground terminals will run a dedicated Software Radio Stack solution compatible with the latest 3GPP standard introducing the NTN scenario (Release 17).

To evaluate the 5G broadband communication link established via spacecraft, a closed link characterization is performed at ground terminal level, focusing on the assessment of KPI such as: C/N, latency, and throughput with data rates of at least 1 Mbps in uplink and 10 Mbps in downlink. The operative mission foresees two different phases: a first period where the Gateway and User equipment will be installed in Italy at Leonessa site (Rome), and a second phase where the terminals will be relocated and installed at ESA ESTEC site in the Netherlands.

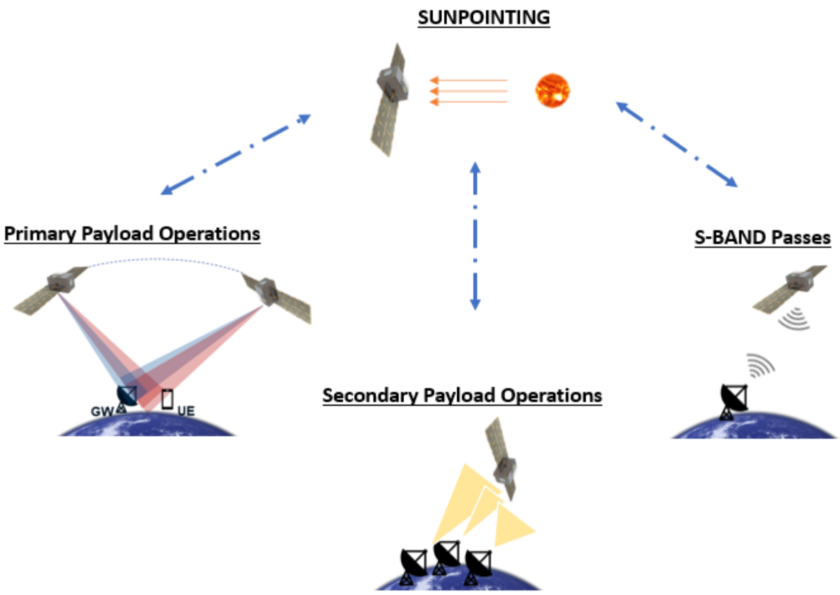

Figure 9. Nominal Operations Sub-Phases

5 CONCLUSIONS

In conclusion, the "Demonstration of Direct 5G Broadband Access from LEO to Small Aperture Terminals" project marks a significant advancement in space-based communication systems. Through innovative technologies and collaborative efforts, the project showcases the feasibility of establishing direct 5G broadband access from LEO satellites to small terminals. These findings lay the foundation for future developments in connectivity, including the evolution towards 6G technology.

The project not only enhances European technological autonomy but also paves the way for ubiquitous high-speed broadband connectivity, shaping the future of telecommunications and satellite-based services.