UNICO I+D Project

6G-INTEGRATION 02 y 04

6G-INTEGRATION-04-E20

Distributed processing strategy

Financiado por la Unión Europea NextGenerationEU

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SECRETARÍA DE ESTADO DE TELECOMUNICACIONES E INFRAESTRUCTURAS DIGITALES

Plan de Recuperación, Transformación y Resiliencia

Document properties

Document number	6G-INTEGRATION-04-E20
Document title	Distributed processing strategy
Document responsible	Monica Villalobos, Yaima Fiallo (Capgemini Engineering)
Document editor	Yaima Fiallo, Ernesto Correa, Noel Ruiz, Alvaro Redondo, Miguel Juaniz (Capgemini Engineering)
Target dissemination level	Private
Status of the document	Final
Version	1.0
Delivery date	29/02/2024
Other delivery date	30/11/2023 (Partial)

Production properties

Reviewers	Noel Ruiz (Capgemini Engineering)

Disclaimer

This document has been produced in the context of the 6G-INTEGRATION 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.

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List of Acronyms

ACLs: Access control lists

AI: Artificial Intelligence

ANaaS: Aerial Network as a Service

ARM: Advanced RISC Machine

BS: Base Station

CPU: Central Processing Units

CSaaS: Crowdsourcing as a Service

CU: Centralized Unit

DL: Downlink

DLS: Data Link Switching

DU: Distributed Unit

EO: Electro-Optical

GaaS: Gaming as a Service

GEO: Geostationary Earth Orbiting

GPU: Graphics Processing Unit

HAPS: High Altitude Platforms

HF: Hard Float

HTAs: Heavier Than Air solutions

HTTPS: Hyper Text Transfer Protocol Secure

IaaS: Infrastructure as a Service

IF: Intermediate Frequency

IMT: International Mobile Telecommunications

IR: Infrared

ISL: Inter-satellite links

ITS: Intelligent Transport System

ITU: International Telecommunication Union

LAPS: Low Altitude Platform Stations

LEO: Low Earth Orbiting

LIDAR: Light Detection and Ranging

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LTAs: Lighter Than Air solutions

MBB: Mobile Broadband

MEO: Medium-Earth Orbit

MMaaS: Mobility Management as a Service

MSS: Maximum Segment Size

MTI: Moving Target Indicator

NTN: Non-Terrestrial Networks

O-RAN: Open RAN

PaaS: Platform as a Service

QoS: Quality of Service

RaaS: Routing as a Service

RAM: Random Access Memory

RF: Radio Frequency

RGB: Red, Green and Blue

RTT: Round-Trip Time

RU: Radio Unit

SaaS: Software as a Service

SAR: Synthetic Aperture Radar

SATaaS: Satellite as a Service

SECaaS: Security as a Service

SENaaS: Sensor as a Service

SLA: Service Level Agreement

SNaaS: Social Network as a Service

SNR: Signal-to-Noise Ratio

STaaS: Storage as a Service

TaaS: Transportation as a Service

TB: Tethered Balloon

TCP: Transmission Control Protocol

TNs: Terrestrial Networks

UAS: Unmanned Aircraft Systems

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UAVs: Unmanned Aerial Vehicle

UCs: Use Cases

UE: User Equipment

UL: Uplink

VHTS: Very High Throughput Satellites

WSNs: Wireless Sensor Networks

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1 Introduction

Non-Terrestrial Networks (NTN) have emerged as an innovative solution to overcome the limitations of traditional communication networks, extending connectivity beyond conventional terrestrial infrastructures. This introduction explores the architecture, processing layout, evaluation metrics, and fundamental enablers of these networks.

The architecture of NTN is based on the implementation of communication systems that do not depend exclusively on physical connections on land. These networks encompass various technologies, such as satellites, drones, stratospheric balloons and other aerial solutions, as well as underwater systems, which play a crucial role in expanding global connectivity.

In these architectures, the distribution of processing is essential to optimize the efficiency and speed of communications. Decentralization of processing allows for faster data transfer and processing as information is processed at multiple points in the NTN, decreasing latency and improving responsiveness.

The evaluation of these networks is carried out through specific metrics that address the quality, performance and reliability of the system. Metrics such as bandwidth, latency, availability, connection reliability, and data integrity are crucial for evaluating performance and determining the effectiveness of the NTN.

Key enablers driving these networks include technological advances in wireless communications, the development of more advanced satellite infrastructure, the miniaturization of devices and sensors, as well as progress in signal processing algorithms and the expansion of storage and processing capacity in Cloud.

Taken together, NTN represent a significant evolution in global connectivity, leveraging diverse technologies and distributing processing to ensure faster, more reliable and ubiquitous communications, thereby transforming the way we connect and exchange information in the modern world.

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2 Non-Terrestrial Networks

2.1. Overview

According to 3GPP [1] the typical scenario of a NTN providing access to User Equipment (UE) is depicted below:

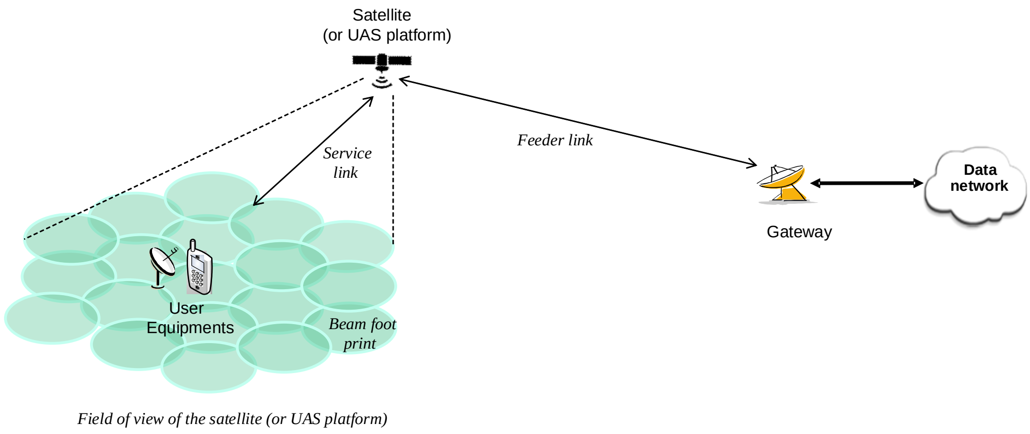

FIGURE 1 NTN TYPICAL SCENARIO BASED ON TRANSPARENT PAYLOAD [1]

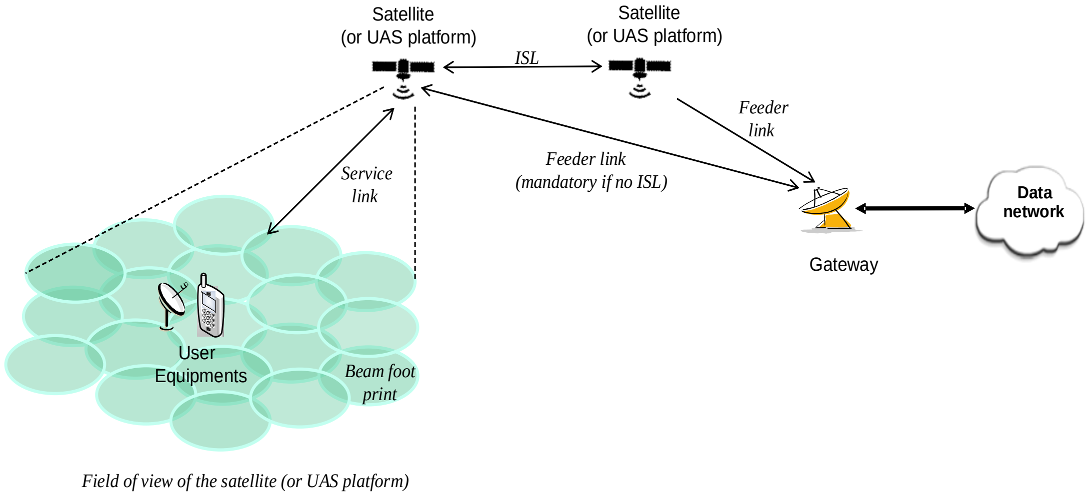

FIGURE 2 NTN TYPICAL SCENARIO BASED ON REGENERATIVE PAYLOAD [1]

Unmanned Aircraft Systems (UAS) operating in altitudes typically between 8 and 50 km, including High Altitude Platforms (HAPS).

NTN typically features the following elements:

- One or several sat gateways that connect the NTN to a public data network.
- A Feeder link or radio link between a sat gateway and the satellite (or UAS platform)
- A service link or radio link between the UE and the satellite (or UAS platform)

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- A satellite (or UAS platform) which may implement either a transparent or a regenerative (with on board processing) payload. The satellite (or UAS platform) generates beams typically generate several beams over a given service area bounded by its field of view. The footprints of the beams are typically of elliptic shape. The field of view of a satellite (or UAS platforms) depends on the on-board antenna diagram and min elevation angle.
    - A transparent payload: Radio Frequency filtering, Frequency conversion and amplification. Hence, the waveform signal repeated by the payload is un-changed.
    - A regenerative payload: Radio Frequency filtering, Frequency conversion and amplification as well as demodulation/decoding, switch and/or routing, coding/modulation. This is effectively equivalent to having all or part of base station functions (e.g., gNB) on board the satellite (or UAS platform)
- Inter-satellite links (ISL) optionally in case of a constellation of satellites. This will require regenerative payloads on board the satellites. ISL may operate in RF frequency or optical bands.
- UE are served by the satellite (or UAS platform) within the targeted service area.

2.2. NTN Architecture Integrating Terrestrial Networks

According to [2] extreme coverage extension aims to provide mobile communications coverage in diverse locations such as air, sea, and space. This expansion will benefit users who are currently outside the reach of conventional networks, utilizing technologies like drones, flying cars, ships, and space stations. To achieve such a coverage extension, it is requiring the development of highly efficient long-range wireless transmission technologies capable of spanning tens of kilometers.

As shown in Figure 3, employing Geostationary Earth Orbiting (GEO) satellites, Low Earth Orbiting (LEO) satellites, and HAPS, communication services can be extended to mountainous areas, remote regions, the sea, the sky, and even outer space.

GEO satellites are currently used to complement Terrestrial Networks (TNs) by providing a mobile backhaul, they offer global coverage but have long propagation delays (approximately 120 ms), while LEO satellites are used for satellite mobile phone systems and satellite sensing, have lower orbits and shorter delays.

HAPS, positioned at around 20 km altitude, offer coverage over large terrestrial cells with a radius of approximately 50 km or more. Since their altitude, it is possible to achieve a one-way radio wave propagation time of approximately 0.1 ms, depending on the cell radius. In addition, the 38.0-GHz to 39.5-GHz frequency band was specified for the HAPS system at the 2019 World Radiocommunication Conference (WRC-19). [3]

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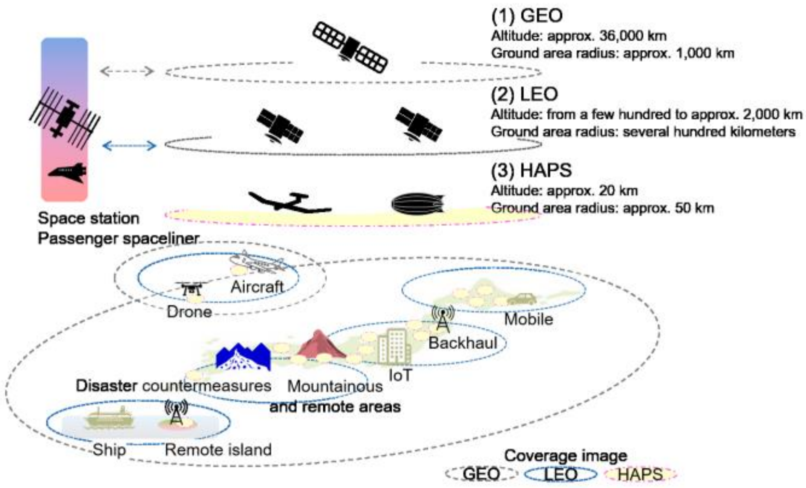

FIGURE 3 HOW SATELLITES AND HAPS EXTEND COVERAGE TO THE SKY, SEA, AND SPACE [2]

According to [2] HAPS are seen as a valuable solution for providing services in disaster-stricken areas and addressing various industrial needs in the context of 5G Evolution and 6G.

The next figure illustrates the multi-layered NTN system, where satellites and HAPS are integrated with the terrestrial 5G (or future 6G) core network, creating a significantly larger three-dimensional heterogeneous network compared to previous configurations. The expectation is that TNs, satellites, and HAPS will collaborate harmoniously to deliver seamless communications tailored to the specific location, encompassing air, sea, and space. This cooperative approach ensures optimal service provision with the required speed and latency.

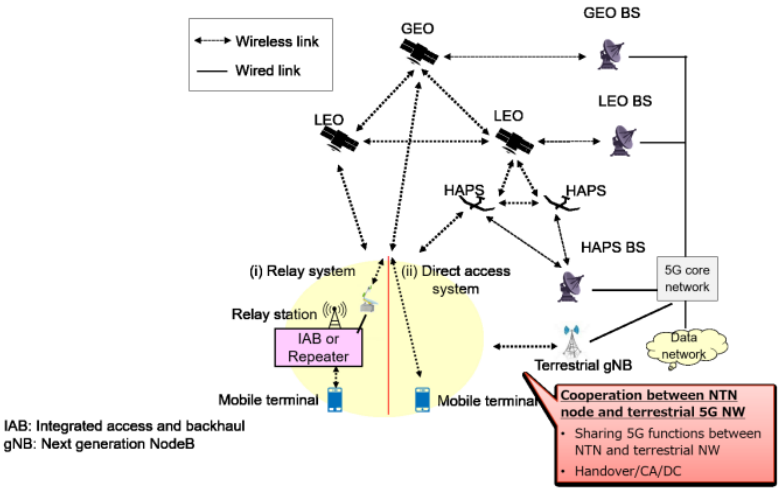

FIGURE 4 COOPERATION BETWEEN MULTI-LAYERED NTN SYSTEM AND TERRESTRIAL 5G NETWORK [2]

Challenges include expanding suitable radio interfaces for long-distance communications, optimizing frequency utilization, designing efficient network cooperation, and exploring wireless technologies like handover, carrier aggregation, and dual connectivity between NTNs and TNs. Each NTN platform has unique features, necessitating careful consideration in terms of routing and

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network construction. NTNs have the potential to cost-effectively expand 5G network coverage and optimize network development from the outset in the 6G era, with the sky serving as a starting point for future advancements.

2.3. HAPS Model

2.3.1. Overview

High-Altitude Pseudo-Satellites (HAPS) are advanced unmanned flying aircraft systems designed to operate in the stratosphere at altitudes typically ranging from 18-22 km (59,000-72,000 ft). These HAPS must endure challenging stratospheric conditions, including extreme temperatures as low as -90°C, high solar, UV, and cosmic radiation, and low atmospheric pressure.

According to [4] the stratosphere, where HAPS operate, is a distinct layer within the Earth's atmosphere characterized by several unique properties, important to consider:

- It experiences minimal weather disturbances, such as lightning or thunderstorms.
- The absence of clouds in this layer allows for efficient utilization of solar energy without causing atmospheric pollution.
- HAPS deployment in the stratosphere is safe, as it resides above the altitude of commercial air traffic.
- Two different types of stratospheric platforms, aerostatic and aerodynamic, can be deployed in this region.

The primary types of aircraft commonly used as HAPS are airplanes, airships, and balloons. These HAPS are specifically designed to execute flights at high altitudes and for extended durations, presenting complex challenges in maintaining human presence due to the extreme conditions involved. Consequently, since the year 2000, the majority of developed projects have focused on unmanned aircraft for HAPS applications.

Currently, HAPS applications can maintain stratospheric operation continuously for extended periods, with some solutions achieving flight times lasting several months, a duration that is expected to increase further.

The concept of HAPS can be categorized into two primary groups, according to [5]:

- Aerostatic or lighter-than-air solutions (LTAs): rely on buoyancy for their altitude control, there are two subcategories: balloons and airships.
- Aerodynamic or heavier-than-air solutions (HTAs): utilize aerodynamic lift forces to remain in flight.

Developing HAPS aircraft involves a complex balancing act for engineers, considering factors like flight performance, technological feasibility, economic viability, and regulatory constraints. While both HTAs and LTAs can serve similar purposes, each category is better suited to specific use cases, and the underlying technology for each solution is distinct.

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The following table summarizes the basic characteristics of a HAPS.

	LTA *(Balloons and airships)*	HTA *(Fixed winged aircrafts)*
Overview	• Lift generated by the light gas o usually, helium or hydrogen o no forward speed required for airworthiness • Power efficiency o Power used for payload and for station-keeping or directed flight • Higher payload capacity	• Lift generated by fixed wings driven by propellers[6]
Reusability	• Airships: Reusable[7] and powered • Balloons: Not reusable[8] and not powered	• Reusable and powered
Airframe	• Airframe varies with design; LTAs are filled with lifting gas (usually hydrogen/helium) • Within LTAs, airships usually have a larger volume compared to balloons. This creates a dynamic drag during flights leading to challenges during take-off/landing[9]	• Light-weight fixed-wing configuration with a large wingspan (25 m and more)
Height	• Constant, 18-22 km (59,000-72,000 ft)	• Volatile[10] - descending and ascending throughout the operation typically between 18-22 (sometimes rising up to 30 km or 98,000 ft)
Payload	• 15-300 kg	• 3-140 kg
Speed	• 36 km/h to 54 km/h (10 m/s to 15 m/s)	• 75-280 km/h[11] (20.8-33.3 m/s)
Flight	• Maintaining same altitude and position. Drifting on wind to stay over one location/region.[12]	• Flying up in a spiral during the day and down during the night (see footnote #10)
Ground operations	• Airships: varies by design o limited infrastructure required — remote areas or designated airfields, storing in containers, o require vast specialised hangars (as big as the Airbus A380 hangars) costing $50M+ o hangar and airfield required • Balloons: launching from remote locations to avoid incidents with air traffic	• Airport infrastructure - runway required for take-off and landing - can be grass field so very flexible on where they can operate • Stored in hangar - simple, low cost facilities • Can be transported anywhere in the world in containers

TABLE 1 BASIC CHARACTERISTICS OF HAPS [5]

2.3.2. System Components

A typical HAPS model features a flexible polymer-based composite hull structure that serves multiple purposes, including handling structural loads, signature control, and active and passive thermal control. The shape and size of the HAPS can vary, but it is always designed to facilitate active lift and drag control. Moreover, it is equipped with a photovoltaic array for primary power generation, stabilizers for directional control, thrust, active control thrusters, and sensors capable of capturing crucial information for the system's operation.

HAPS communications system consists of two parts, as show in the next figure.

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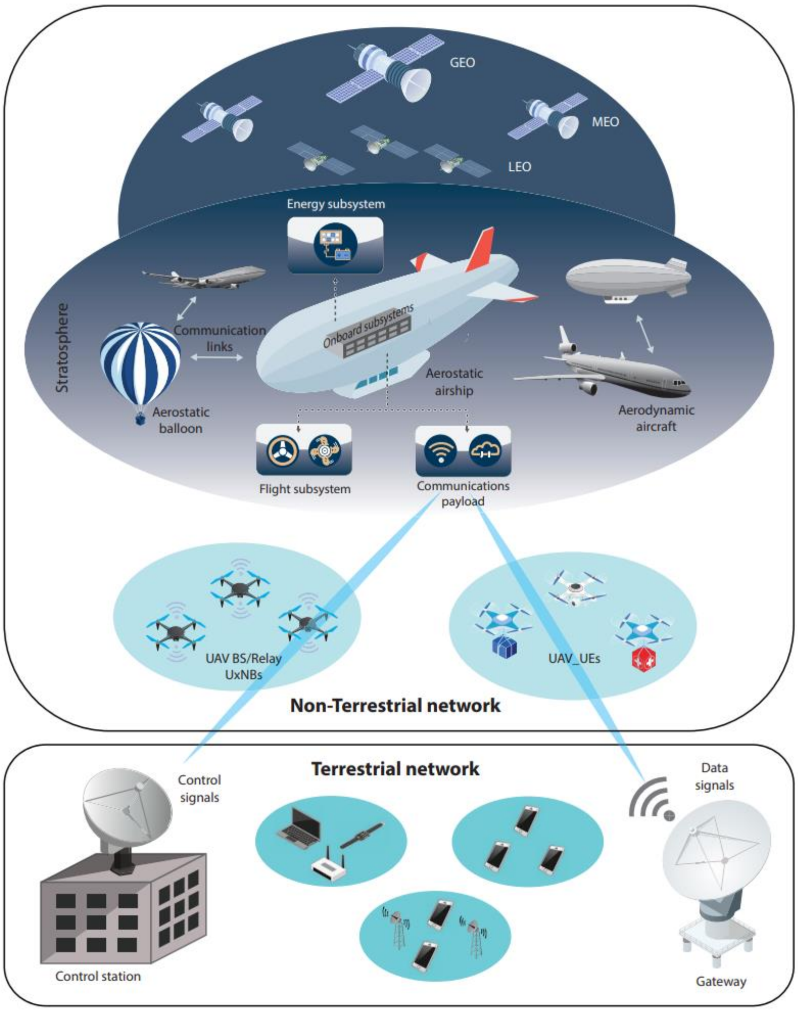

FIGURE 5 GENERAL VIEW OF THE HAPS SYSTEM AND ITS MAIN COMPONENTS [4]

1. **Non-terrestrial part:** this part encompasses the primary network components in both airborne and space environments, along with essential onboard subsystems crucial for successful HAPS deployment and an efficient communication system. It can be broadly divided into two segments.
    a. **Onboard subsystems**: mainly consists of three subsystems: flight control, energy management and communications payload.
    The **flight control subsystem** is responsible for stabilizing the platform, controlling its mobility, and directing it towards the intended direction. It utilizes sensors for altitude and direction measurement, a computing unit for decision making, and actuators for movement and orientation. Additionally, the flight control unit facilitates communication with the ground control station through telemetry, tracking, and command signals.
    The **energy management subsystem** handles energy generation, storage, and regulates the energy consumption of other subsystems.

The **communications payload subsystem** manages communications between the HAPS and other entities, and its configuration depends on the HAPS mission and targeted applications.

For more in-depth information on the energy and payload subsystems, refer to subsections **2** and **2.4**

b. **NTN**: In the aerospace domain, this segment represents all the non-terrestrial communication nodes potentially involved in HAPS communication systems, as shown in Figure 5 General view of the HAPS system and its main components . A HAPS has the capability to establish connections with other HAPS, creating a constellation or it can be integrated into a network comprising different layers of satellites. Additionally, the HAPS layer may be interconnected with various types of Low Altitude Platform Stations (LAPS), such as Unmanned Aerial Vehicle (UAVs) base stations or relays (UxNBs), or it can serve a swarm of diverse UAV users (UAV-UEs).

2. **Terrestrial part**: represents the ground elements and it can be divided into three segments.
   a. **Control station**: This component oversees communication operations between HAPS and various user types. It also orchestrates communication links and resource allocation among multiple HAPS nodes and other non-terrestrial or terrestrial networks. Furthermore, the control station is responsible for managing the takeoff/landing procedures, remotely monitoring the HAPS' position, and controlling its direction to optimize antenna efficiency and enhance overall performance.
   b. **Communications gateway**: This component establishes a connection between the HAPS and the core network via a wired backhaul infrastructure. Depending on the HAPS payload and the type of terrestrial network, communication can occur directly between the HAPS and terrestrial users, or data exchange may take place through the communications gateway. The control station and communications gateway can either be situated within the same building facilities or have separate locations. They primarily comprise amplifiers, processing units, and antennas. These antennas commonly feature parabolic dish reflectors to ensure high directivity gain.
   c. **Terrestrial networks**: This segment includes terrestrial BSs and different types of users, such as mobile users and IoT sensors, that is, all the terrestrial nodes or users involved in the HAPS communication systems.

2.3.2.1 Energy management subsystem

Effective management of the energy supplied to and consumed by a HAPS is of utmost importance as it significantly influences both flight duration and deployment costs. Given that HAPS systems are typically intended for prolonged operations in communication scenarios, meticulous energy management becomes a crucial aspect in ensuring the feasibility and cost-effectiveness of HAPS-based solutions. By implementing efficient energy management strategies, it becomes possible to optimize the utilization of resources, extend the operational time of the HAPS, and achieve economic viability for the deployment of such systems in various communication applications.

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Energy Sources: The use of energy sources in HAPS operations can be classified into three types:

- Conventional energy sources, such as fuel tanks and electrical batteries, have a limited flight duration of approximately 48 hours and require frequent landings for refueling. They are best suited for temporary or emergency use.
- Energy beams, from the ground, like microwave or laser beams, have been proposed as alternative energy sources for HAPS. An example is the SHARP project [5], utilizing a large ground antenna system to transmit microwave beams. Collectors with rectifier antennas convert the received energy to DC power. Similarly, laser beams have been experimented with for powering HAPS in Japan and the USA. However, due to high power irradiation risks, both microwave and laser-powered systems are considered unsafe.
- Solar energy is a renewable and safe option for powering HAPS, making it the primary energy source considered by most projects. Operate above the clouds where solar energy is abundant, and they can be equipped with large solar panels to generate significant energy. Solar-powered HAPS often have secondary energy sources, such as electrical batteries or hydrogen fuel cells, to support operations during nights or in winter. The integration of these energy sources requires a control unit to manage operations effectively.
  Researchers have extensively investigated effective HAPS solar energy designs and methods to improve solar energy conversion efficiency. Companies like MicroLink Devices produce high-efficiency solar sheets with a record-breaking solar energy conversion efficiency of 37.75% [6]. For secondary sources, Lithium-ion batteries and fuel cells have significantly improved in energy density over the years.

Energy Consumption: The energy consumption of HAPS is mainly attributed to two subsystems: the flight control and the communications payload subsystem.

The flight control subsystem's energy consumption is influenced by:

- Stability
- Propulsion power
- Control for altitude
- Direction
- HAPS's characteristics (type, weight, and size)

Aerodynamic platforms, which require continuous circular movement, tend to consume more energy compared to other types. Furthermore, larger and heavier platforms demand increased energy for their flight systems. As aerodynamic HAPS are relatively smaller than airships, their solar energy generation is lower, leading to a relatively limited capacity for payload power.

The remaining energy generated is allocated to the communications payload, which largely depends on its type and communication techniques. Payloads with more active components and computation processes are heavier and consume more energy in general.

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2.3.2.2 Payload subsystem

The payloads play a crucial role in seamlessly integrating HAPS into the existing security infrastructure. Achieving high resolution, reliability, low power consumption, and versatile operation modes are essential factors for the efficient and advantageous utilization of HAPS by European agencies.

In the table below are show the fundamental performance parameters for imagers, laser links, and radio frequency telecommunication payloads.

Parameters	
EO Image GSD	day operation - 8 - 15 cm[46] night operation - 100 cm footprint - 1000 m in diameter
Telecommunication	Extended footprint - 322 km (200 miles) radius[47] 3G, 4G in radius up to 100 km (62 miles) 5G in a radius up to 75 km (46.6 miles) Laser communication link can provide Gb/s in a radius of 100 km (62 miles) to the ground station.

TABLE 2 PAYLOAD SPECIFICATIONS

Payloads can be divided by the role they perform:

Active payload, the choice of payload type depends on the specific application and use-cases, includes various components:

- Antennas: devices used to transmit and receive electromagnetic signals. They play a crucial role in establishing communication links with ground stations or other communication nodes.
- Transponders: devices that receive incoming signals, amplify them, and retransmit them back to the ground stations or other receiving nodes. They help in extending the range and reliability of communication.
- Power amplifiers: component responsible for boosting the strength of signals while minimizing noise and interference. Low-noise amplifiers are essential for maintaining signal quality and improving communication performance.
- Frequency converters: used to change the frequency of signals. They can convert incoming signals to the desired frequency for processing and transmission.
- Intermediate Frequency (IF) processors: used to process signals at intermediate frequencies before further processing and transmission. They help in filtering, amplifying, and modulating signals to achieve better performance.
- Filters: used to separate desired signals from unwanted interference or noise. They ensure that only the required signals pass through the system, improving the quality of communication.

HAPS payloads can be categorized as:

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- HAPS-RS relay stations, requires an intermediate station to process users' signals, resulting in increased round-trip delay.
- HAPS-BS full base stations [4], has more active components and higher processing capabilities, making it suitable for direct signal processing and serving users.
  HAPS-SMBS equipped with a BS with superior caching, computing, and communication capabilities, capabilities to serve dense urban areas efficiently. However, the advanced capabilities of a HAPS-SMBS come with the trade-off of increased payload weight and energy consumption.

Therefore, careful analysis of the intended use-case, platform type, payload size, weight capabilities, and energy consumption is crucial for a successful and cost-effective HAPS deployment.

To optimize performance and energy consumption, mechanisms that balance computational costs should be developed. Since HAPS systems are meant to supplement terrestrial networks, computational loads can also be appropriately shared between HAPS systems and terrestrial networks.

Passive payload - HAPS-RSS, can be utilized in scenarios like backhauling signals from rural areas to the gateway and inter-HAPS communication links. It offers comparable capacity to radio relays, supports full-duplex communications, and reduces communication payload energy consumption, leading to extended flight duration and cost reduction. RSS-assisted communication systems are found to be 40% more energy-efficient than relay-assisted systems [7].

It has been shown to increase received Signal-to-Noise Ratio (SNR) and improve data rates, making it a promising technology for supporting wireless communications.

Overall, integrating passive RSS in HAPS systems can significantly enhance their performance, cost-effectiveness, and energy efficiency, making it a valuable technology for future wireless communication applications.

However, the choice of the HAPS platform type and its payload capabilities depends on the intended use-cases, such as temporary large events, IoT services, data centres, or inter-HAPS constellations.

The next figure illustrates two potential scenarios for utilizing HAPS-RSS, the first scenario involves backhauling signals from rural areas to the gateway, while the second scenario involves inter-HAPS communication links. In both cases, a ground control station is responsible for transmitting the necessary configurations to the onboard RSS controller. This enables the RSS to intelligently manipulate and direct the signals towards their intended destinations.

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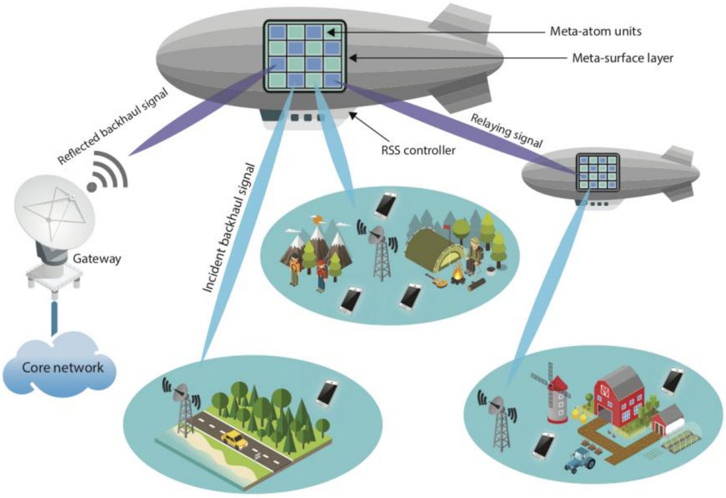

FIGURE 6 : HAPS-RSS FOR RELAYING SIGNALS AND SUPPORTING BACKHAUL FROM REMOTE BSS [4]

Computational payload, offers advantages in aerial network management and slicing due to the elevated position of HAPS, facilitating data collection and computations without overloading terrestrial communication links. Equipped with computational devices, HAPS enables efficient offloading from satellite and aerial networks, reducing response delays and interruptions caused by mobility. Strong collaboration between HAPS systems is essential for optimal use of distributed computational resources. Privacy concerns can be addressed using federated learning, maintaining user privacy without centralizing data. Collaborative coordination is crucial for future HAPS network optimization. Additionally, HAPS-based Multi-Access Edge Computing (MEC) clusters require intelligent scheduling considering energy, capabilities, and loads. Decisions on data processing location should be guided by efficient algorithms.

For more in-depth information on computational payload, refer to subsection **2.3.4 Computational**

2.3.3. Network Configuration

The next figure describes a network configuration involving HAPS stations which are essentially aerial platforms situated at high altitudes, and their integration with a 5G network, when HAPS is used for backhauling.

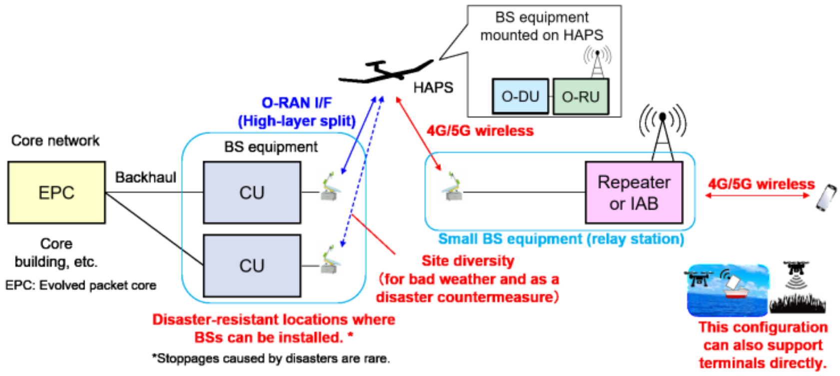

FIGURE 7 EXAMPLE OF COOPERATIVE CONFIGURATION WHEN HAPS IS USED FOR BACKHAUL [2]

Below a breakdown of the key components and concepts in this configuration:

- **HAPS Base Station (BS)**: the HAPS acts as a base station for the 5G network. It is equipped with a distributed unit (DU) and a radio unit (RU), both of which are part of the 5G BS equipment.
- **Open RAN (O-RAN) Alliance Specifications**: defines standards and specifications for open and interoperable radio access networks. In this configuration, the DU and RU on the HAPS adhere to these specifications, allowing for greater flexibility and compatibility in the network.
- **Centralized Unit (CU)**: is positioned at a ground location that is resistant to disasters. This CU plays a central role in coordinating and managing communication within the network.
- **Feeder Link and Service Link**: the CU communicates with the HAPS using a feeder link. Information from the CU is sent to the HAPS via this link. The HAPS then transmits the information through a 5G radio connection to a small terrestrial BS known as a relay station in the service link.
- **Portable 5G BSs**: the relay station receives the information from the HAPS and serves as a connection point for portable 5G BSs. These portable BS can provide 5G connectivity without the need for a wired backhaul, which is the traditional wired connection that links remote stations to the core network.
- **Direct Communications and Mobility Support**: the HAPS can also establish direct communication with 5G terminals, such as smartphones or other devices, without relying on relay stations. Moreover, if a terminal moves from one communication area to another, the network can seamlessly switch the communication target to a different HAPS, ensuring continuous connectivity as the terminal's location changes.
- **Site Diversity**: to mitigate the impact of adverse weather conditions and natural disasters, the network can implement site diversity. This involves using multiple CUs on the ground to communicate with the HAPS. If one CU is affected by bad weather or a disaster, the network can switch to another CU to maintain the network's functionality and availability.

In summary, this network configuration leverages HAPS to extend the coverage and capabilities of a 5G network. The HAPS serves as a base station, and its integration with ground-based components, including relay stations, centralized units, and multiple communication points, enables enhanced

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coverage, resilience to disasters, and the ability to provide 5G connectivity to portable base stations and devices.

The next figure describes an alternative network configuration involving HAPS within the context of a 5G network, when HAPS is used for direct access.

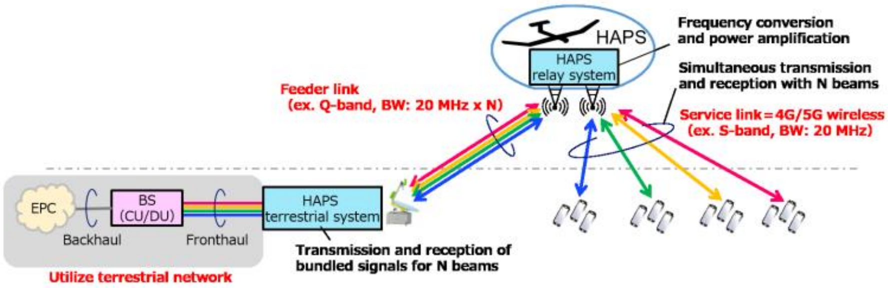

FIGURE 8 EXAMPLE OF COOPERATIVE CONFIGURATION WHEN HAPS IS USED FOR DIRECT ACCESS [2]

Below a breakdown of the main concepts:

- **Relay-Type Configuration with 5G Radio Repeater in HAPS**: the configuration being discussed involves using a relay-type setup. A 5G radio repeater is placed within a HAPS. This means that the HAPS acts as a relay station for the 5G network, boosting and retransmitting the 5G signals.
- **TNs and Fronthaul**: the TN is used to connect various elements of a telecommunications network. In this configuration, the TN is utilized to establish the connection between the core network and the fronthaul.
- **HAPS Terrestrial System with RU Function**: the HAPS terrestrial system is equipped with the RU function. This RU function handles the communication signals for multiple beams. Beams refer to focused and directional radio signals used to establish wireless connections.
- **Broadband Frequency in Feeder Link**: the feeder link, which is the connection from the HAPS to the ground network, uses a broadband frequency, specifically mentioned as the Q-band. The Q-band is a range of microwave frequencies commonly used for communication purposes.
- **Feeder Link Processing**: the HAPS relay system performs frequency conversion and power control as part of the signal processing in the feeder link. Frequency conversion involves changing the frequency of a signal, and power control ensures that transmitted signals are appropriately adjusted in strength.
- **Service Link Communications with Multiple Beams**: once the HAPS processes the signals received from the fronthaul, it can establish service link communications. This means that the HAPS uses multiple beams to simultaneously transmit and receive data with multiple endpoints.
- **Frequency Bands for Service Link**: the service link uses frequency bands below 2.7 GHz. These frequency bands have been identified for International Mobile Telecommunications (IMT) usage. IMT refers to global standards for wireless communications systems. The

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allocation of these frequency bands is based on decisions made in [3] and the planning for their usage continues with a focus on [7].

In summary, this configuration employs a HAPS as a relay station with a 5G radio repeater. The HAPS takes signals from the core network, processes them in its terrestrial system with RU function, and then transmits these signals using multiple beams in the service link. The Q-band frequency is used in the feeder link, and certain frequency bands below 2.7 GHz are used for the service link based on international specifications.

2.3.4. Computational role

Role A: Optical payloads, sensors and/or radar

According to [5] optical payloads and the use of sensors and/or radar are among the devices used for aerial mapping and Earth observation. In an optimal setup, sensors and radars complement optical systems by enhancing radar-derived information with colour data.

Optical payloads often equipped with stabilization systems (gimbals). They are designed to function effectively in low temperatures, thanks to specific thermal regulations. These come in various spectra, including visible, near infrared, and infrared, and are available in both RGB (colour: red, green and blue) and monochrome variants. Monochrome cameras offer superior light sensitivity, particularly during night-time operations, while RGB cameras are better suited for AI image recognition and machine learning due to the richer information they provide.

Image resolution achievable from the stratosphere ranges from 8 cm to 30 cm, depending on the image's swath or footprint. Swaths can vary from 1x1 km for 8 cm resolution to 3x3 km for 30 cm resolution. These payloads can cover large areas, up to 1000 km2, with 10m resolution for broad scanning purposes.

While live video feeds are possible, transmitting high-resolution video at 8 cm resolution can generate substantial data volumes, ranging from 2 to 5 gigabytes per second. A more efficient approach is to combine lower-resolution video feeds with occasional high-resolution images, providing superior data compared to current satellites with very high-resolution capabilities (around 30 cm).

Infrared (IR) imaging, which detects heat energy in the infrared spectrum, is independent of visible light. IR cameras display heat maps of surfaces and are useful for detecting hidden targets, troops, vehicles, or vessels, although their image resolution is typically lower compared to visible spectrum cameras.

Each platform employs **sensors and/or radars** to gather data about its surroundings. These sensors and radars serve multiple crucial functions, from detecting objects in the sky or on the ground for deconfliction to enabling applications like terrain mapping, target recognition, or validation. They operate effectively regardless of the time of day or prevailing weather conditions.

Some examples of the most used sensors and radars are:

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- Synthetic Aperture Radar (SAR)
- Moving Target Indicator (MTI)
- Light Detection and Ranging (LIDAR)
- Electro-optical infrared sensors

Role B: Cloud-Enabled HAPS

According to [9] HAPS is being extensively researched and considered for future deployment in communication projects, in addition to being used them as flying networks to enhance wireless communication systems in the next generation (6G) of technology. Are expected to provide robust data connectivity due to their stable location and favourable atmospheric conditions who this operates.

The idea focuses on harnessing the potential of HAPS as "flying data centers" or super-macro base stations for telecommunications. Considering the advantages of this approach, such as improving the quality, speed, and range of communication services. These services encompass various fields like satellites, Internet of Things (IoT), ad hoc networks (including sensor, vehicular, and aerial networks), gaming, and social networks.

Cloud providers could use HAPS to deliver these services, including data offloading to HAPS and enabling cloud customers to access them; considering the challenges associated with implementing practical cloud-enabled HAPS, such as energy efficiency, processing power, Quality of Service (QoS), and security.

It is important to highlight open issues in this area, including HAPS mobility and message routing, enhancing HAPS security through blockchain and machine learning, optimizing resource allocation using artificial intelligence (AI) in cloud-enabled HAPS, and integrating HAPS with heterogeneous networks.

The following are the opportunities where HAPS can be leveraged by integrating various cloud services and corresponding cloud-like applications that would be used by HAPS to improve the quality, range and type of services offered.

Traditional Cloud Computing Services

Traditional Cloud Computing Services is experiencing substantial growth, but presents challenges related to scalability and providing acceptable QoS in areas with weak internet connectivity. Solutions are being explored, including innovative data center locations and technologies, to address these issues.

Two critical questions emerge from this growth:

1. **Cloud Scalability**: Cloud scalability pertains to a cloud data center's ability to accommodate a growing number of customers. Factors like computing power, storage capacity, and bandwidth demand influence scalability. As organizations increasingly utilize the cloud for resource-intensive applications like big data and AI, as well as IoT devices, there is a growing

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need for cloud data centers to expand their capacity. This expansion, however, comes with challenges related to power consumption and cooling.

2. **QoS in Weakly Connected Areas**: Despite the cloud's widespread adoption, many regions, especially in developing countries, still suffer from poor internet connectivity. This connectivity gap poses a challenge as cloud services often cannot meet the QoS requirements, such as minimum bandwidth and maximum latency, in these areas. Thus, ensuring satisfactory QoS for users in poorly connected locations remains a significant challenge for cloud providers.

By deploying flying data centers on HAPS nodes, cloud providers can significantly expand their services, benefiting from the ample physical space available and the natural cooling at high altitudes (ranging from -15°C to 50°C). HAPS nodes, with their extensive coverage (up to a 500 km radius) and Line-of-Sight (LoS) connections, enable the provision of cloud services with reliable QoS to users in areas with limited ground connectivity.

In addition to specialized HAPS cloud services, traditional cloud offerings like: Platform as a Service (PaaS), Software as a Service (SaaS), Infrastructure as a Service (IaaS), Storage as a Service (STaaS), Security as a Service (SECaaS) can also be deployed on HAPS nodes.

HAPS cloud services are also proposed such as: Satellite as a Service (SATaaS), Sensor as a Service (SENaaS), Transportation as a Service (TaaS), Aerial Network as a Service (ANaaS), Routing as a Service (RaaS), Mobility Management as a Service (MMaaS), Gaming as a Service (GaaS), Social Network as a Service (SNaaS), Crowdsourcing as a Service (CSaaS).

An overview of HAPS cloud services and the environments in which they are offered and consumed is shown in the next figure.

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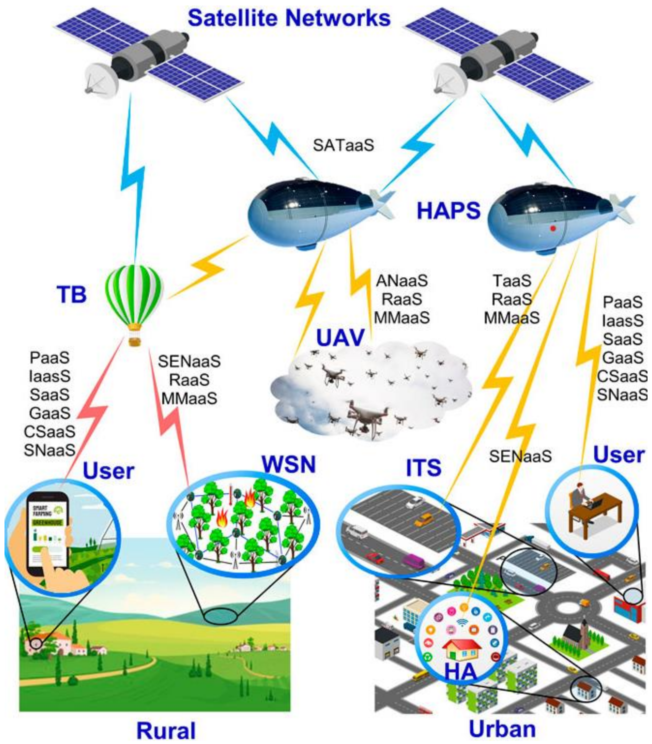

FIGURE 9 OVERVIEW OF THE PROPOSED SERVICES WITHIN THE CLOUD-ENABLED HAPS [9]

The table below compares the services proposed for the HAPS cloud services with those offered in traditional or mobile cloud platforms. Indicating the services that are similar, the advantages of the proposed service, and its limitations compared to the existing ones.

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HAPS cloud service	Existing services	Advantages	Limitations
SATaaS	• azure orbital • AWS ground station • spatial cloud for big earth observation data Yao et al. (2020) • satellite cloud computing Kanev and Mirenkov (2011) • cloud-based natural hazard modeling systems Ujjwal et al. (2019)	• lower delay • more accuracy • faster detection and response (natural hazards) • better quality (media and TV)	• less coverage per node • frequent maintenance and update requirements • possibility of disconnection to the HAPS network
SENaaS	• oracle IoT • google cloud IoT • SAP IoT • cisco jasper • altair SmartWorks • ubidots • SensorCloud	• ability to deploy in rural and isolated areas • monitoring the environment at the stratosphere layer • meeting the time requirements of delay-sensitive applications	• requiring dedicated HAPS gateways • requiring TBs in areas not covered by the HAPS network
TaaS	• AWS automotive • google connected vehicle platform • netrepid transportation cloud • AzureITS	• computational and storage capabilities for ITS big data applications • LoS connection • ability to consume services from mobile devices • few HAPS nodes can cover the whole vehicular network	• requiring dedicated HAPS gateways • disconnections in underground and hidden areas
ANaaS	• disaster sensing Luo et al. (2015) • object recognition Pinto et al. (2019) • UAV IaaS, UAV PaaS, UAV SaaS Mahmoud and Mohamed (2015) • drone as a service Loke (2015)	• ability to deploy in rural and isolated areas • LoS connection • connecting users in ground-disconnected areas or conditions • computational and storage capabilities for UAV big data applications	• requiring dedicated HAPS gateways • requiring TBs in areas not covered by the HAPS network • higher end-to-end delay between the user and the UAV (in some cases)
RaaS	• energy-aware multihop routing protocol (EASDN) Younus and Kim (2019) • routing protocol for low-power lossy networks (RPL) Ouhab et al. (2020) • secure routing protocol for internet of vehicles (SURFER) Mershad (2020b) • SDN-based UAV (SD-UAV) Secinti et al. (2018)	• ability to group all routing data from a huge network at a single HAPS node • stable and reliable connection between routing switches and controller	• requiring dedicated HAPS gateways • requiring TBs in areas not covered by the HAPS network • disconnections in underground and hidden areas • limited physical space within the HAPS node to support routing hardware
MMaaS	• free-flow model, queuing- up model Vijayarangam et al. (2018) • trajectory-following model, drone-following model Nguyen et al. (2021)	• computational and storage capabilities for traffic and mobility big data applications • meeting the strict delay requirements of mobility management applications	• requiring dedicated HAPS gateways • requiring TBs in areas not covered by the HAPS network • real-time connection is not always guaranteed
GaaS	• vortex • shadow • amazon luna	• meeting the strict delay requirements of gaming applications • stable LoS connection	• requiring dedicated connection between the user device anc the HAPS node • disconnections in underground and hidden areas
SNaaS	• social cloud Chard et al. (2011) • healthcare cloud services Sandhu et al. (2016) • social network educational services Thaiposri and Wannapiroon (2015) • multimedia as a service Nan et al. (2014)	• No handoff • lower delay • computational and storage capabilities for SN applications • connection to ground SN via the HAPS	• requiring dedicated connection between the user device anc the HAPS node • disconnections in underground and hidden areas
CSaaS	• crowdsourcing reference model Murturi et al. (2015) • crowdsourcing social enterprise service Tung and Jordann (2017)	• computational and storage capabilities for crowdsourcing applications • ability to reach users in disconnected areas	• higher delay than traditional crowdsourcing applications (in some cases)

TABLE 3 SUMMARY OF THE PROPOSED HAPS-CLOUD SERVICES [9]

In the next table it is describing the various requirements that are essential for the successful deployment of the proposed of HAPS cloud services.

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Requirement	Services
High-speed connection between the HAPS node and the service source/consumer	IaaS, SaaS, PaaS, SATaaS, SENaaS, TaaS, ANaaS, RaaS, MMaaS, GaaS, SNaaS
Reliable connection between the HAPS node and the service source/consumer	IaaS, SaaS, PaaS, SATaaS, SENaaS, TaaS, ANaaS, RaaS, MMaaS, GaaS, SNaaS, CSaaS
High data-rate connection between the HAPS node and the service source/consumer	IaaS, PaaS, SATaaS, SENaaS, TaaS, ANaaS, RaaS, MMaaS, GaaS, SNaaS
Secure connection between the HAPS and the service source/consumer and secure processing/storage within the HAPS node	IaaS, SaaS, PaaS, SATaaS, SENaaS, TaaS, ANaaS, RaaS, MMaaS, GaaS, SNaaS, CSaaS
Dedicated HAPS gateway that connects the service's source network to the HAPS	SENaaS, TaaS, ANaaS, RaaS, MMaaS
Dedicated communication module for connecting the HAPS to specific networks such as satellites or TBs	SATaaS, SENaaS, ANaaS
Dedicated connection between the consumer's device and the HAPS	GaaS, SNaaS
Sufficient physical space within the HAPS node	IaaS, PaaS, GaaS, SNaaS
High processing capability by the HAPS	SaaS, PaaS, SENaaS, TaaS, ANaaS, RaaS, MMaaS, GaaS
High storage capacity within the HAPS	SENaaS, TaaS, ANaaS, RaaS, MMaaS, GaaS, SNaaS, CSaaS
Intra-HAPS collaboration between the HAPS nodes to execute/offer the service	SATaaS, ANaaS, RaaS, MMaaS, GaaS, SNaaS, CSaaS
Tethered balloons (TBs) for connecting the service source/consumer with the HAPS	SENaaS, ANaaS, RaaS, MMaaS
Specialized hardware installed within the HAPS nodes for service-specific requirements (such as sensors, SDN controller, etc.)	SATaaS, SENaaS, RaaS
Support for real-time data transmission and sharing	SATaaS, SENaaS, TaaS, ANaaS, RaaS, MMaaS, GaaS

TABLE 4 REQUIREMENTS FOR THE HAPS CLOUD SERVICES [9]

2.3.5. General Use Cases (UCs)

In the context of 5G Beyond and 6G, the next figure shows a range of UCs of HAPS that it is used for relaying or emitting radio waves as a base station. These UCs encompass fixed systems for backhaul applications and mobile systems that provide services to terminals directly or through repeaters and relays. Broadband millimeter wave radio signals are expected to play a crucial role in delivering timely and high-speed connections with high capacity and low latency. This capability will be valuable across various applications, including industry and public events, regardless of the availability of ubiquitous wired networks like optical fibers.

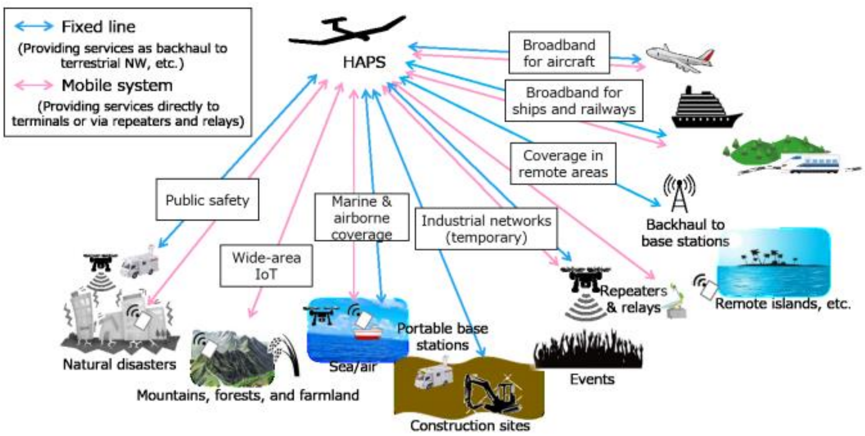

FIGURE 10 USE CASES FOR HAPS [2]

Requirements for each HAPS use case

HAPS systems have diverse requirements across different UCs, as depicted in next figure. Each use case demands specific communication speeds and bandwidths, necessitating flexible methods and systems to support both fixed and mobile applications. For backhaul applications to 5G base stations

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(BSs), a minimum speed of 1 Gbps per service link is anticipated. Additionally, to accommodate multiple concurrent service links, the feeder link must possess even faster and stable communication speeds ranging from several gigabits per second to several tens of gigabits per second, regardless of weather conditions.

Flexibility in controlling communication lines is crucial to seamlessly transition from regular business applications to public safety scenarios during disasters. Current disaster response focuses on providing basic communication services like voice calls and SMS, but future scenarios may require faster speeds for activities such as remote equipment control, video transmission, and drone communication. Developing network configurations and control techniques that enable system operation even when certain devices become unavailable will be essential for effective disaster preparedness.

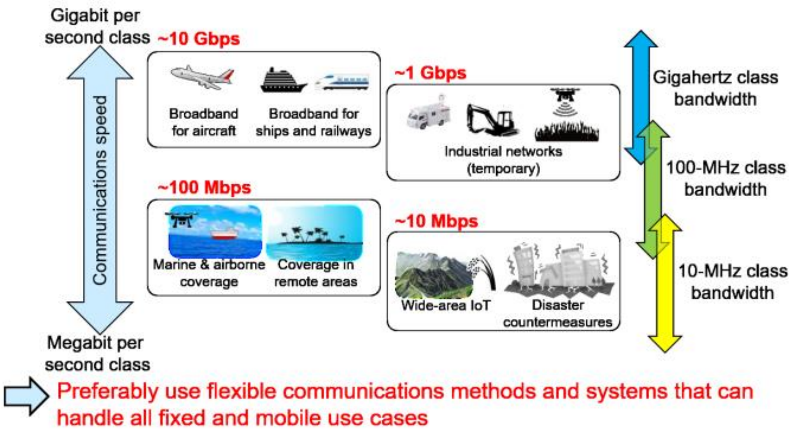

FIGURE 11 REQUIREMENTS FOR EACH HAPS USE CASE [2]

3 UCs for the exploitation of NTN+B5G technology

3.1. Fire detection and risk areas

The deployment of UAVs equipped with cameras is an innovative approach that enables early and accurate detection of fires in challenging or remote locations. These UAVs can provide real-time aerial surveillance, helping firefighters identify the source and spread of fires, as well as assess dangerous situations. This technology enhances the safety and effectiveness of firefighting operations and plays a crucial role in mitigating the devastating impact of wildfires and other emergencies.

It is proposed to use:

- UAVs with on-board IR cameras and NVIDIA
- Fire detection (AI)

3.2. Earth observation, Land use and cover

Earth observation might be the area where HAPS can bring the highest added value, it is providing advantages in continuous border monitoring, intelligence, reconnaissance, and surveillance due to their proximity to the ground. HAPS can offer high-quality images and even live video streams of areas of interest, surpassing satellite image quality and outlasting traditional unmanned aircraft systems (UAS). Image resolution can reach below 10 cm with current technology, with the main limitation being the platform's weight constraints.

HAPS are versatile, as one aircraft can serve multiple missions during a single six-month flight using the same payload. Depending on payload capacity, HAPS can carry various types of imagers and offer additional services like telecommunications or navigation. The Earth observation market, driven in part by satellites, is growing, and data processing solutions are available. Future developments are expected to improve data processing speed and quality while reducing data volume.

With HAPS, it's possible to discern small objects (below 50 cm) in multiple spectral ranges using current imagers and data processing, enhancing Earth observation capabilities for security applications.

According to [5] payload properties are often the key differentiator as to which HAPS to use for the given use case. For the Earth Observation they propose:

- High Resolution camera:
  0.08-0.18m resolution over 1km2 (3,000 ft) swath (sharp details can be detected)
- Intermediate camera:
  2m resolution over 80km^2 (50 miles) swath (moving objects, vehicles can be detected)
- Wide field camera:
  10m resolution over 1000km^2 (620 miles) swath (image-based geolocation)

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- <u>InfraRed camera or radars:</u>
  can be used for object identification during the night or when the images in visible spectra are not suitable or sufficient for precise object recognition.

For aerial vision it is proposed to use:

- UAVs with on-board hyperspectral cameras and NVIDIA
- Land use and land cover (AI/Deterministic)

3.3. Connected Vehicle Certificate Validation

The increasing use of navigation applications, from traditional GPS in everyday devices to autonomous vehicles benefits from HAPS due to their proximity to the ground. HAPS provide more precise and robust signals compared to satellites in orbit, especially in areas with obstacles like cities with tall buildings, mountain valleys, and forests. While satellite-based navigation raises safety concerns for autonomous vehicles, HAPS can offer both precise positioning and imaging capabilities, enabling complex tasks like identifying and steering a car to an available parking space in a city.

It is proposed to use:

- UAVs with minimal processing
- Real-time certificate review of vehicles in circulation (Deterministic)

3.4. Search and location of people

By equipping UAVs with cameras and implementing AI, it enables the efficient and accurate detection and tracking of individuals in real-time, even in challenging environments. This innovative approach has the potential to revolutionize the way we locate and assist people during emergencies, search missions, or security operations by providing aerial insights and data analysis that were once impossible to achieve. Also, combines cutting-edge technology to enhance search and rescue operations, surveillance, and various applications.

It is proposed to use:

- UAVs with on-board Electro-Optical (EO) cameras and Ground Node with NVIDIA
- AI for missing person detection
- Emergency equipment tracking

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4 Metrics and KPIs of NTN networks

In this part of the document, we want to show the quantitative way of measuring different parameters of the network, these measures are related to the performance, precision, and consumption of network resources, we also define the communication measures between the elements of the network that They will make it possible to deterministically define the distribution of the computation of processes or tasks depending on each use case.

We define two types of metrics, the first class models the parameters and corrections that must be considered, depending on the type of satellite platform used in the network, that is, they are metrics that measure the operation of the transmission of information between the agents of network. The second class of metrics measure the computing capacity of the network elements, considering the resources of each element and the processing volume of each request. These metrics will depend on energy, memory capacity, and latency times.

4.1. Satellite performance metrics

In general, NTN refer to networks that provide connectivity via spacecraft or airborne platforms, including satellites, HAPs and LAPs. These provide radio connectivity between the UE on the ground and the vehicle that, in addition, connectivity to TNs through Ground-Based Gateways (see Figure 12).

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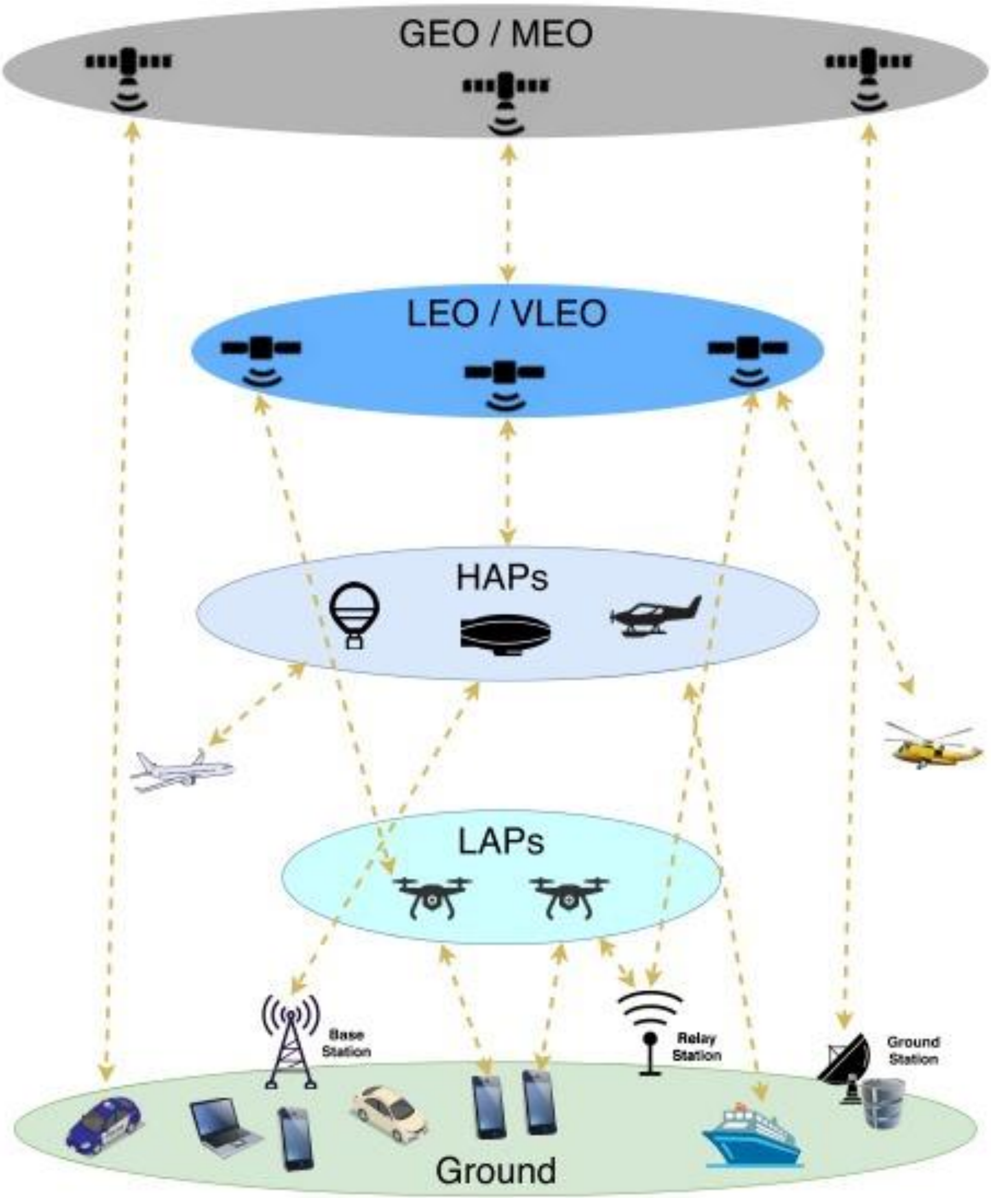

FIGURE 12 NTN ELEMENTS [10]

A HAPS network is made up of the following subsystems:

1) HAPS Stratospheric Platforms
2) User terminal stations
3) Head stations
4) Control centers (resources, configuration, regional sales).

This classification implies the possibility of numerous mobile and fixed subscriber stations; therefore, we can understand this type of network as a **federation**.

The following table summarizes the type of NTN options depending on the altitude of the spacecraft.

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NTN	Altitude	Characteristics
Stationary satellites placed in GEO	35876 km	GEO scenarios are often equipped with Very High Throughput Satellites (VHTS), providing tens or hundreds of Gb/s capacity each. In this case, Doppler effects are negligible, but propagation delays can reach up to several hundreds of milliseconds for transparent satellites.
Non-stationary satellites positioned in Medium-Earth Orbit (MEO) or LEO	7000-25000 km MEO 300-2000 km LEO	In relative motion to the earth. In these cases, latency values can be moderate, in the range of tens of milliseconds, but Doppler needs compensation. Satellite coverage and their cells may be stationary or not. The former requires the beams fixed on Earth, while the latter simply implies that the beams move at the same speed of the satellites (typically few km/s for LEO sats). In the case of non-stationary cells, methods for handover operations and roaming are required.
HAPS	20000 km	Like planes or balloons, operating like satellites but closer to the Earth, at about 20 km distance. HAPS latency values are often below 10 ms.
LAPS	1 km	Like drones or balloons

TABLE 5 TYPE OF NTN DEPENDING ON THE ALTITUDE

4.1.1. Transmission performance

The altitude of the space-borne has a clear impact on the round-trip time. In this regard, it is worth remarking that latency heavily affects Transmission Control Protocol (TCP) throughput in TCP/IP based networks, which for traditional TCP implementations is given by the Mathis formula [10]:

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$$Throughput_{TCP} < \frac{MSS}{RTT} \frac{C}{\sqrt{p_{loss}}}.$$

Where MSS is the Maximum Segment Size and RTT is the end-to-end Round-Trip Time; C is a constant that can be estimated from measurements (a number between 1 and 1.5 typically) and p_{loss} is the packet loss probability, due to any factor (packet corruption, collisions in shared media or buffer overflow due to congestion).

This table shows the maximum throughput in megabytes per second for a single TCP connection. (To improve readability, megabytes are used for the unit of measure.)

TCP window size (bytes)	RTT Latency (ms)	Maximum throughput in megabytes/second	Maximum throughput in megabits/second
65 535	1	65,54	524,29
65 535	30	2,18	17,48
65 535	60	1,09	8,74
65 535	90	0,73	5,83
65 535	120	0,55	4.37

TABLE 6 MAXIMUM THROUGHPUT IN MEGABYTES PER SECOND FOR A SINGLE TCP

If packets are lost, the maximum throughput of a TCP connection will be reduced while the sender retransmits data it has already sent.

4.1.2. Frequency bands

The table below summarizes the detailed information on the frequency bands assigned by the International Telecommunication Union (ITU) for communication satellites. As shown, the L and S bands do not offer much bandwidth (tens or hundreds of KHz to a few MHz typically) and are often intended for IoT applications with low bandwidth requirements. Ka and Ku bands provide much more bandwidth (tens or hundreds of MHz) and can be used to provide mobile broadband (MBB) connectivity, like that experienced on Data Link Switching (DSL) connections (say 20 Mb/s) even like fibre to the home (100 Mb/s and above), especially in cases with high antenna gains. Finally, the Q/V bands offer even higher bandwidth capacity values (hundreds of MHz to a few GHz) but are more subject to atmospheric losses and rain absorption. In this sense, some satellite companies are considering the V-band for Inter-Satellite Links (ISL), since they are above the clouds, offering mesh connectivity between satellites. Also, some experimental scenarios consider the W Band (between 75-110 GHz) which provides even more bandwidth than the Q and V bands and should also be used for ISL as this band suffers a lot due to problems. propagation and fading due to rain.

Sat Band	Downlink (DL)	Uplink (UL)

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L Band (GEO)	1518 – 1559 MHz	1626.5 – 1660.5 MHz 1668.0 – 1675.0 MHz
L Band (Non-GEO)	1613.8 – 1626.5 MHz	1610.0 – 1626.5 MHz
C Band	3400 – 4200 MHz 4500 – 4800 MHz	5725 –7025 MHz
S Band	2160 -2200 MHz 2483.5 - 2500 MHz	1980 - 2025 MHz
Ku Band	10.7 - 12.75 GHz	12.75 - 13.25 GHz 13.75 - 14.5 GHz
Ka band (GEO)	17.3 – 20.2 GHz	27.0 – 30.0 GHz
Ka band (Non-GEO)	17.7 – 20.2 GHz	27.0 – 29.1 GHz 29.5 – 30.0 GHz
Q/V band	37.5 – 42.5 GHz 47.5 - 47.9 GHz 48.2 - 48.54 GHz 49.44 - 50.2 GHz	42.5 – 43.5 GHz, 47.2 – 50.2 GHz 50.4 – 51.4 GHz

TABLE 7 ITU FREQUENCY ALLOCATIONS FOR SATELLITE COMMUNICATIONS

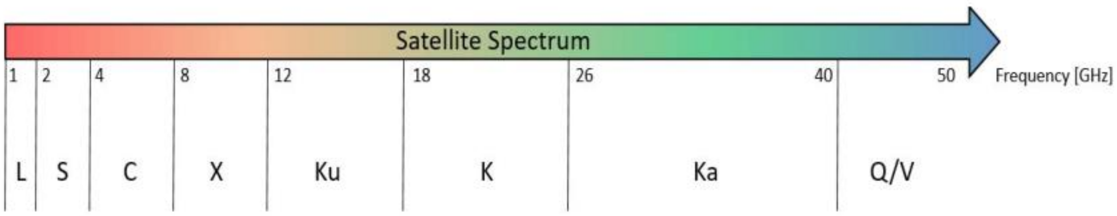

FIGURE 13 SATELLITE SPECTRUM [11]

4.1.3. Link-budget calculations

Classical link budget calculations for satellite communications follow the well-known **Friis propagation model**, where the power at the receiver antenna P_r (also referred to as signal strength S) is:

$$P_r = P_t \frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}$$

where P_t is the transmission power of the transmitting antenna, G_t and G_r are the transmission and reception gain of the two antennas, and λ and d are the transmission wavelength and slant range between the transmitter and receiver in the satellite link. Often, the product $P_t G_t$ is called the EIRP or Effective Isotropic Radiated Power.

The receiving antenna both collects the above signal power S and noise N. The amount of noise collected follows:

$$N = k_B T B_w$$

where k_B is the Boltzmann constant (1.380649 × 10−23 m2 · kg · s−2 · K−1 or −228.6 dBW/KHz), T is the noise temperature and B_w is the bandwidth of the receiving filter. Often, receiver systems and amplifiers are provided with noise figure (NF) values, which is a classical figure of merit used for both receivers and amplifiers (typically 5 to 9 dB of noise figure values).

4.2. Computing capacity of the network elements metrics

As we said previously, the second class of metrics measures the computing capacity of the network elements, considering the resources of each element and the processing volume of each request. These metrics are determined by the use cases that are intended to be developed.

NTNs are expected to play an important role in 5G & beyond systems by covering different fields and verticals, from transport to eHealth, energy and automotive, public safety, and many others (See Figure 14).

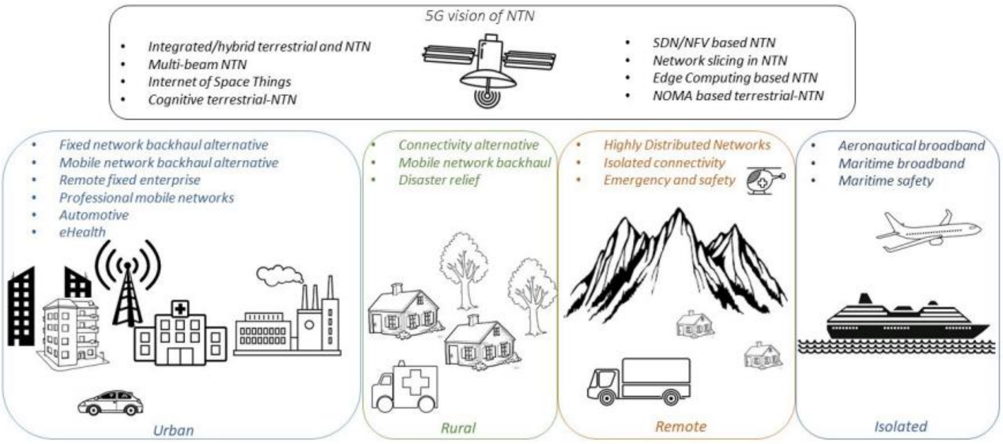

FIGURE 14 5G NTN USE CASES [12]

5G NTN use cases are divided into three categories:

- Service continuity to provide NTN access where it is infeasible through terrestrial networks.
- Service ubiquity to improve NTN availability in case of disasters that lead to the temporary outage or the destruction of terrestrial networks; and
- Service scalability to offload traffic from terrestrial networks, above all during busy hours.

Taking these parameters into account we can define the following operating metrics:

- Energy efficiency: The network performance and power consumption in the mobile networks are unimaginably complicated, involving intra/inter networks deployment and operation modes, the efficiency of media accessing mechanisms, processing of baseband signal and quality of analogue signal and RF devices and antenna efficiency. Future wireless system is expected to achieve low energy consumption for different network components, optimize network resource utilization, and provide quality network services with intelligent and energy-efficient solutions.
- Data Analytics: The effective utilization of the network resources improves the system performance and saves the energy used for mobile service. The utilization efficiency depends on the accuracy of the geo-temporal user behaviour and services models and predictions derived from the location, mobility, historic network deployment, and traffic record.
- Privacy and Security: Strengthening people's trustfulness and enhancing secure performance is especially the key point for situation awareness and reliability/resilience communication. Efficient security barriers become of paramount importance in the expanding cellular (or 6G) network. Meanwhile, as the extending coverage in future communication, the confidence mechanism of energy-sparse, resource-constrained communication networks will be the most important aspect of security and privacy considerations.

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5 Distributed processing strategy

5.1. Phase I. Admission Policy Analysis

Process Owner:

In a federated environment, where multiple entities collaborate to provide computing resources, it is essential to establish admission policies that regulate who have permission to deploy services on federated nodes.

To achieve this, robust authentication and authorization protocols such as OAuth or OpenID Connect can be employed, allowing process owners to securely authenticate and obtain access tokens to interact with federated resources.

Furthermore, identity federation systems can be implemented to enable process owners to use their local identity credentials to access federated resources without creating new accounts.

The goal is to ensure that only authorized owners can deploy services on federated nodes, thus safeguarding the integrity and security of the distributed environment.

1. Federation Authentication Policy:
   - Only federated organizations that have been authenticated and authorized are permitted to deploy services on federated nodes.
   - Each organization can decide what conditions the computing elements need to meet to be deployed on federated nodes (authorized owners, TLS security level).
2. Role-Based Access Control Policy:
   - Specific roles are defined within federated organizations, such as federator (able to add machines with their conditions and reports to the federation), deployer (capable of deploying services to be distributed in the federation according to a distribution strategy), and end user (who can access available services).
   - Only users with authorized roles are permitted to deploy services on federated nodes.
   - Access control lists (ACLs) or role-based authorization policies are used to control who can perform deployment actions on federated nodes.
3. Deployment Approval Policy:
   - An approval process is established for deploying services on federated nodes.
   - Before deploying a service, applicants must submit a deployment request that includes details about the service and its purpose.
4. Regulatory Compliance Policy:
   - Policies are implemented to ensure compliance with specific organizational regulations and regulations.

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- Before deploying a service, it is verified that it meets the security and privacy requirements established by applicable regulations.
- Regular audits may be conducted to ensure ongoing compliance with regulations and to prevent potential breaches.

Security Level:

In a federated environment, where computing resources may be distributed across different security domains, it is essential to establish admission policies that ensure an adequate level of security for deployed processes.

To achieve this, secure communication protocols such as Hyper Text Transfer Protocol Secure (HTTPS) can be used, which encrypt communications between processes and federated nodes, thus protecting the confidentiality and integrity of data. Additionally, certificate management systems can be implemented to verify the authenticity of processes and federated nodes, ensuring that only secure connections are established.

The goal is to ensure that processes deployed on federated nodes comply with established security standards, thereby minimizing the risk of vulnerabilities and attacks.

1. Container Image Integrity Verification:
   - Before admitting a process to a federated node, the integrity of the container image is verified using digital signatures or cryptographic hashes.
   - This ensures that the container image has not been compromised or maliciously altered before deployment.
2. Resource Isolation:
   - Resource isolation policies are implemented to ensure that processes deployed on federated nodes do not negatively affect other processes or the system as a whole.
   - This can be achieved by using container technologies or virtual machines to create isolated environments for each deployed process.
3. Audit and Logging:
   - A policy is established to audit and log all activities related to the deployment and execution of processes on federated nodes.
   - This allows tracking of who deploys what processes, when, and from where, facilitating the detection and response to potential security incidents.

Process Priority:

In a federated environment where multiple processes compete for shared resources, it is important to establish admission policies that define the execution priority of processes.

To achieve this, resource scheduling systems can be implemented to dynamically allocate resources based on process priority and resource availability. Additionally, scheduling rules can be established

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to ensure that high-priority processes have preferential access to resources, thereby minimizing wait times and improving system performance.

The goal is to ensure that computing resources are allocated fairly and efficiently, maximizing resource utilization and optimizing the performance of the federated environment.

1. Based on Service Criticality:

- Different priority levels are established based on the criticality of the service provided by the process.
- For example, processes providing essential services for critical infrastructure may have the highest priority, followed by important but non-critical services, and then complementary services.

2. Based on greed Service Level Agreement (SLA):

- Priority is assigned based on the agreed SLA between the service provider and the customer.
- Processes associated with stricter SLAs may have higher priority to ensure performance commitments are met.

3. Based on System Demand and Load:

- Process priority is dynamically adjusted based on real-time system demand and load.
- For example, processes experiencing high workloads may receive higher priority to ensure a prompt and efficient response, while non-critical processes may have lower priority.

4. Based on User or Customer Importance:

- Priority is assigned based on the importance of the user or customer associated with the process.
- For example, processes serving VIP clients or important users may receive higher priority to ensure an exceptional user experience.

5. Based on Specific Business Rules:

- Specific business rules are defined to determine the execution priority of processes based on certain criteria or conditions.
- For example, a process may receive higher priority during certain times of the day or in emergency situations according to defined business rules.

5.2. Phase II. Process Requirements Analysis

In the Phase II of the process requirements analysis for distribution, it is important to define the minimum hardware requirements needed to run the process efficiently and effectively on federated nodes.

Random Access Memory (RAM):

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This requirement indicates the minimum amount of RAM the process needs for its execution. For example, the process may require at least 8 GB of RAM to ensure optimal performance.

Hard Disk:

This requirement specifies the minimum amount of hard disk space needed to store the software and data associated with the process. For example, the process may require at least 100 GB of hard disk space to install and store temporary files.

Graphics Processing Unit (GPU):

This requirement indicates whether the process requires a GPU for specific calculations or processing. For example, if the process involves intensive 3D rendering or image processing tasks, it may require a dedicated GPU.

- **GPU Processing Capacity (High capacity / Normal):**
  This requirement describes the processing capacity needed to efficiently execute the process. For example, some processes may require high processing capacity to perform complex calculations in real-time, while others may function properly with normal processing capacity.

Peripherals:

This requirement specifies whether the process requires access to external peripherals, such as hyperspectral cameras, regular cameras, IR cameras, or thermal cameras to collect data. For example, an image analysis process may require access to a thermal camera to detect forest fires.

Processor Architecture:

This requirement defines the processor architecture compatible with the process. Processor architecture refers to the internal design of the processor and defines how instructions are executed and system resources managed. Some examples include:

- x86 (32-bit and 64-bit): Widely used in personal computers and servers. Common versions are 32-bit x86 and 64-bit x86_64 architectures. These architectures are compatible with a wide range of operating systems and applications.

- Advanced RISC Machine (ARM): Widely used in mobile devices, embedded devices, and embedded systems. It offers exceptional energy efficiency and is well-suited for applications requiring low power consumption and reduced space.

- ARM Hard Float (HF): A variant of the ARM architecture that uses hard floating-point format for floating-point calculations. This improves performance in applications that heavily use floating-point operations, such as signal processing and graphics.

- RISC-V: An open-source, modular instruction set architecture gaining popularity in various applications, from embedded devices to servers. It offers flexibility and customization, making it suitable for a wide range of applications and devices.

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- PowerPC: Primarily used in embedded systems and servers. It offers solid performance and is used in various applications, including video game consoles, medical devices, and communication systems.

Number of Central Processing Units (CPUs):

This requirement indicates the minimum number of CPUs needed to efficiently execute the process. For example, a process may require at least 4 CPUs for parallel calculations and accelerated performance.

5.3. Phase III. Distribution Optimization Analysis

To evaluate the process distribution in Phase III, it's important to define metrics that allow us to analyse the efficiency and performance of the distribution. Some relevant metrics could include in the next table.

Metrics	Objective	Unit
CPU_TIMES (CPU Times)	Measure the CPU time used by a process or set of processes	Seconds (s)
CPU_STATS (CPU Statistics)	Provide information about the CPU's performance and activity, such as the number of interruptions, context switches, etc	Variable, depends on the specific metric
VIRTUAL_MEM (Virtual Memory)	Assess the availability and use of the system's virtual memory	Bytes (B) or Gigabytes (GB)
SWAP_MEM (Swap Memory)	Measure the amount of swap memory used by the system	Bytes (B) or Gigabytes (GB)
BATTERY (Battery)	Monitor the device's battery charge level	Percentage (%)
DISK_USAGE (Disk Usage)	Evaluate the disk space utilization	Bytes (B) or Gigabytes (GB)
DISK_RW (Disk Read/Write Operations)	Account for the number of disk read and write operations	Number of operations and bytes

BYTES_TX_RX (Transmitted and Received Bytes)	Record the amount of data transmitted and received over the network	Bytes (B) or Gigabytes (GB)
NET_STATS (Network Statistics)	Provide information about the network's performance and activity, such as the number of packets, network errors, etc	Variable, depends on the specific metric
TEMPERATURE (Temperature)	Measure the system's temperature to monitor overheating	Degrees Celsius (°C) or Fahrenheit (°F)
POWERTOP (Power Consumption)	Assess the system's power consumption and optimize its efficiency	Watts (W) or Kilowatts (kW)

TABLE 8 METRICS TO EVALUATE THE DISTRIBUTION PROCESS

It will define computation distribution policies. These policies use different metrics to make decisions about service allocation in a distributed environment. By continuously monitoring and analysing these metrics, the system can dynamically adjust the distribution of services to optimize performance, efficiency, and system availability, as shown in the following table.

Computation distribution policies	Assignment rule	Metrics used
Load Balancing	Assign services to nodes with a balanced CPU and memory load	CPU_TIMES VIRTUAL_MEM
Resource Optimization	Assign services to nodes with sufficient available resources, such as RAM and disk space	VIRTUAL_MEM DISK_USAGE
Energy Efficiency	Assign services to nodes with low energy consumption to optimize the system's energy efficiency	POWERTOP
High Availability	Assign services to nodes with adequate battery to ensure service availability, especially in elements not connected to the power grid (attempts will be made to	BATTERY

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	ensure that aerial elements do not consume energy when possible)	

TABLE 9 COMPUTATION DISTRIBUTION POLICIES WITH YOUR ASSOCIATED ASSIGMENT RULES AND METRICS

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6 Distributed processing strategy for each UCs

6.1. UC1: Fire detection and risk areas

Objective:

To provide support to firefighting teams using UAVs equipped with integrated IR cameras and AI technology for early fire detection and improved efficiency in firefighting operations.

Actors:

- Fire Team:
  - Personnel specialized in fire suppression and rescue operations.
  - Responsible for receiving and responding to fire alerts generated by the advanced detection system.
  - Uses the information provided to direct extinguishing operations effectively and safely.
- Emergency Response Team:
  - Personnel specialized in responding to emergency situations, including fires and natural disasters.
  - Responsible for receiving and acting on fire alerts generated by the advanced detection system.
  - Works closely with the firefighting team to coordinate the response and provide logistical support during fire suppression operations.

Scenario:

In a mountainous region prone to wildfires, a team of firefighters is looking to improve their early fire detection capabilities to respond more efficiently and effectively to emergencies. To address this challenge, they decide to implement an Advanced Fire Detection system using drone technology equipped with IR cameras and artificial intelligence algorithms.

- The firefighting team establishes a network of drones equipped with IR cameras and AI systems, which will be strategically deployed in different areas of the mountainous region. These drones will perform periodic patrol flights to monitor the area for possible fire outbreaks.
- Once a drone detects a possible fire, it will send an alert to the Emergency Control Center, where the emergency response team is located. The Control Center will receive the alert, verify the information provided by the drone and coordinate the appropriate response.
- The emergency response team will quickly mobilize the necessary resources, including firefighting and wildland firefighting teams, to the location of the detected fire. Using the

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information provided by the Advanced Fire Detection system, the team will effectively direct their firefighting efforts, minimizing response time and maximizing operational efficiency.

6.1.1 Phase I. Admission Policy Analysis for UC1

Authentication and Authorization Policy:

- Authentication protocols, such as OAuth or OpenID Connect, will be implemented to allow authorized owners to securely authenticate and obtain permissions to interact with advanced fire detection system resources.
- Authorization mechanisms will be established to regulate access to systems and resources, ensuring that only authorized owners can deploy and operate the drones and associated infrastructure.

Identity Federation System:

- An identity federation system will be implemented to allow process owners to use their local identity credentials to access advanced fire detection system resources.
- This system will ensure that authorized owners can securely authenticate themselves and access the resources required to deploy and operate the drones and associated infrastructure.

Deployment Approval Policy:

- An approval process will be established for the deployment and operation of advanced fire detection systems.
- Prior to deploying the drones and putting the infrastructure into operation, applicants will be required to submit a deployment request that includes details on the planned operation and anticipated safety measures.

Regulatory Compliance Policy:

- Policies will be implemented to ensure compliance with regulations and standards applicable to the operation of drones and advanced fire detection systems.
- Prior to deployment and operation, systems will be verified for compliance with security, privacy and legal compliance requirements established by the relevant authorities.

6.1.2 Phase II. Process Requirements Analysis for UC1

The following services work to provide a complete solution for advanced fire detection, leveraging drone technology with IR cameras and AI algorithms to improve the efficiency and effectiveness of firefighting operations.

Drone Control and Management Service:

- This service is responsible for the centralized management of drones used in fire detection operations. Its functions include assigning and programming flight routes for the drones,

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monitoring the status and location of each drone in real time, and coordinating communication between the drones and the control center.

Image Capture and Processing Service:

- This service is responsible for capturing images using the IR cameras integrated in the drones, as well as processing these images for analysis. Its functions include capturing images in real time during drone flights, processing images to improve quality and resolution, and extracting relevant features from the images for further analysis.

Image Analysis and Fire Detection Service:

- This service uses AI algorithms to analyse the images captured by the drones and detect the presence of potential fires. Its functions include image analysis using computer vision and deep learning algorithms, fire detection in complex and varied environments, and the generation of alerts on the location of detected fires.

Data Management and Storage Service:

- This service is responsible for managing and storing data collected during fire detection operations, including images captured by drones and image analysis results. Its functions include secure and scalable storage of data in the cloud or on local servers, management of the integrity and availability of stored data, and controlled access to data by authorized users.

In the next table it shows the minimum hardware requirements necessary for its efficient and effective execution in the federated nodes.

Service	RAM	Hard Drive	Peripherals	GPU	Number CPU	Architecture
Drone Control and Management	At least 8 GB	At least 100 GB	No additional peripherals required	No	4	x86_64
Image Capture and Processing	At least 16 GB	At least 200 GB	Hyperspectral camera	At least 4 GB of VRAM	8	x86_64
Image Analysis and Person Detection	At least 32 GB	At least 200 GB	Hyperspectral camera EO Camera, IR Camera	At least 4 GB of VRAM	8	x86_64

Data Management and Storage	At least 8 GB	At least 500 GB	No additional peripherals required	Optional (Normal)	4	x86_64

TABLE 10 HARDWARE REQUIREMENTS NECESSARY FOR EXECUTION IN THE FEDERATED NODES FOR UC1

6.1.3 Phase III. Distribution Optimization Analysis for UC1

Considering the previous phases, it can define, in the next table, an optimal distribution strategy for the UC1.

Computation distribution policies	Assignment rule	Metrics used	Example of Application
Load Balancing	Allocate services to nodes with balanced CPU and memory load	CPU_TIMES VIRTUAL_MEM	If a node is experiencing high CPU and memory load, services can be redistributed to other nodes with available resources to maintain an optimal load balance. For example, if a drone is consuming a significant number of resources during a fire detection mission, the system can migrate some of the load to another drone with available resources
Resource Optimization	Allocate services to nodes with sufficient resources available, such as RAM and disk space	VIRTUAL_MEM DISK_USAGE	If a node has a limited amount of virtual memory and is close to reaching its maximum disk storage capacity, services can be allocated to other nodes with available resources. For example, if a node is running an image analysis service

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			and is using a large amount of virtual memory, the system can migrate some of the load to another node with more available resources
Energy Efficiency	Allocate services to nodes with low energy consumption to optimize system energy efficiency	POWERTOP	If a node is consuming a significant amount of energy and there are other nodes available with lower consumption, services can be migrated to those nodes to reduce the overall energy consumption of the system. For example, if a drone is using a high amount of energy during a patrol mission, the system can assign that mission to another drone with lower energy consumption
High Availability	Assign services to nodes with adequate battery to ensure service availability, especially on off-grid elements	BATTERY	If a node is using a significant amount of battery power and its charge level is low, critical services can be migrated to other nodes with a fully charged battery to ensure service availability. For example, if a drone is performing a fire detection mission and its battery level is

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			below a predetermined threshold, the system can transfer the mission to another drone with a fully charged battery

TABLE 11 DISTRIBUTION STRATEGY FOR THE UC1

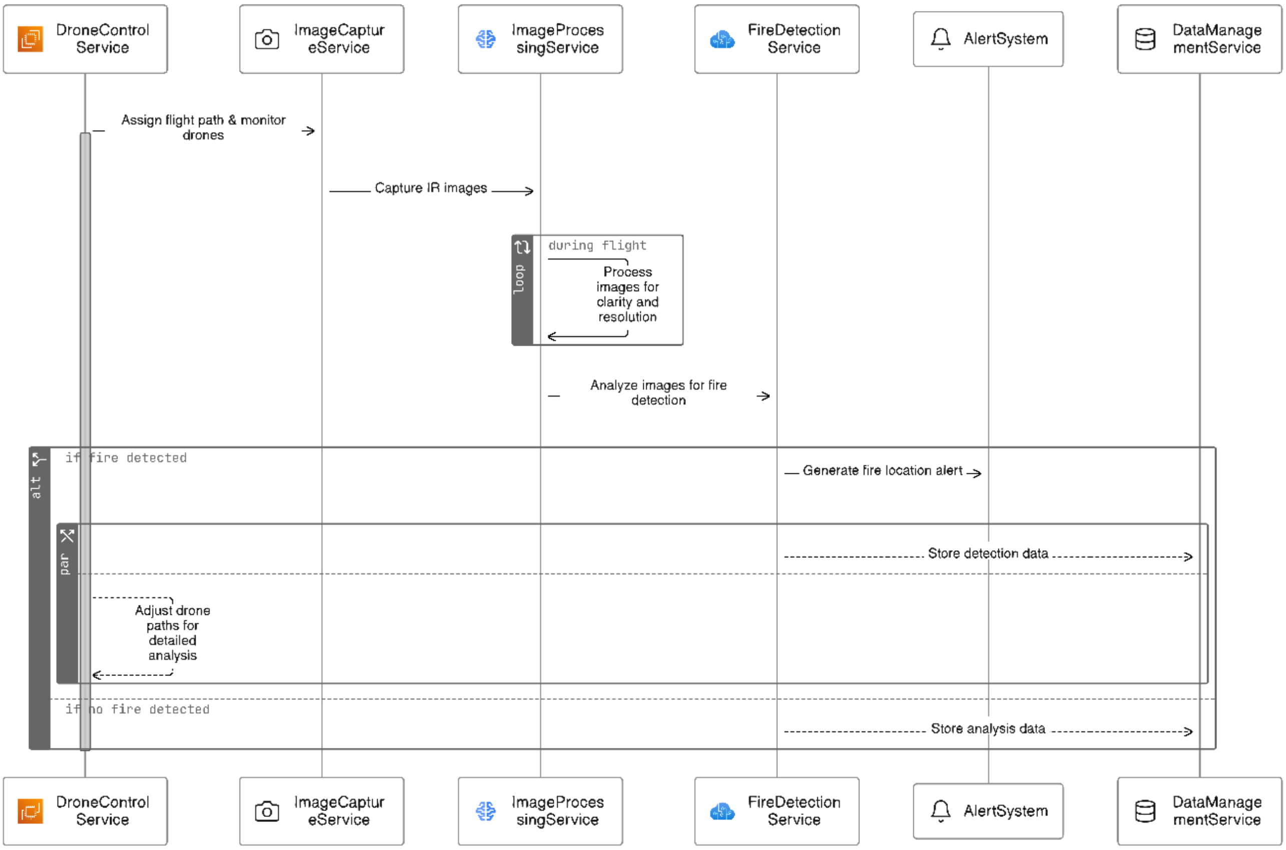

FIGURE 15 DISTRIBUTION STRATEGY FOR UC1

6.2. UC2 Land use and cover

Objective:

To use hyperspectral images obtained from a HAPS to determine land use and ground cover. This involves analysing the captured images to identify different types of terrain, such as urban areas, vegetation, bodies of water, etc. The resulting information can be used for various purposes, such as urban planning, environmental management, and monitoring changes in the landscape.

Actors:

- **HAPS**: Acts as the main actor by capturing hyperspectral images from a high altitude.

- **Data Processing Team**: This team is responsible for processing and analysing the hyperspectral images to determine land use and ground coverage.
- **End Users**: The end users are those who use the results of the image analysis to make informed decisions in their respective fields, such as urbanism, agriculture, environmental conservation, etc.

Scenario:

Suppose we are working on an environmental research project that uses hyperspectral images captured by a HAPS to analyse and determine land use and ground coverage in a specific region.

- The project is using a distributed system to process and analyse the captured images at different federated nodes.
- The federated nodes are distributed in different geographic locations to improve processing efficiency and reduce latency.
- The system is designed to support both high-priority processes, such as real-time analysis, and low-priority processes, such as background analysis.

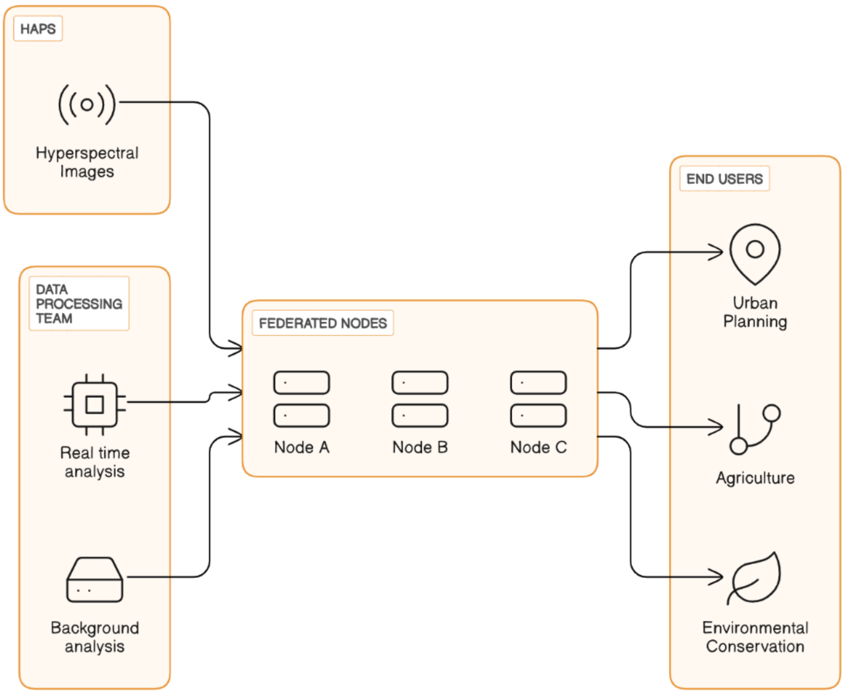

FIGURE 16 SCENARIO UC1 LAND USE AND COVER

6.2.1 Phase I. Admission Policy Analysis for UC2

Federation Authentication Policy:

- In this scenario, the organizations participating in the federation are those involved in the acquisition and analysis of hyperspectral images, such as governmental agencies, research institutions, or companies specialized in geospatial analysis.

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- To enable the deployment of services on federated nodes, these organizations must be authenticated and previously authorized. This implies that they must meet certain security requirements and be recognized as trustworthy entities within the federated environment.
- For example, a governmental agency responsible for environmental management can be authenticated through a secure authentication protocol, allowing it to deploy services related to the analysis of hyperspectral images on federated nodes.

Role-based Access Control Policy:

- Within the federated organizations, specific roles are defined for users participating in the service deployment and management process.
- For instance, roles such as "federation administrator," "image analyst," and "operations technician" can be designated.
- Each role has different levels of authorization and permissions to deploy services on federated nodes. Only users with the appropriate roles are permitted to perform deployment actions.

Deployment Approval Policy:

- Before deploying a hyperspectral image analysis service on federated nodes, an approval process must be followed.
- For example, an image analyst must submit a deployment request that includes details about the service, such as the region of interest, the analysis algorithms to be used, and the duration of the analysis.
- This request must be reviewed and approved by a federation administrator or a designated official before the service can be deployed on federated nodes.

Regulatory Compliance Policy:

- Policies are established to ensure that deployed services comply with the security and privacy requirements set by applicable regulations, such as the Data Protection Act.
- Before deploying a service, it is verified that it complies with these regulations to ensure the security and privacy of the processed data, especially those related to the observation of sensitive or protected areas.

6.2.2 Phase II. Process Requirements Analysis for UC2

Before defining the requirements for each process, it will define the list of services necessary to achieve the objective of the proposed scenario. These services are fundamental for acquiring, processing, and analysing the hyperspectral images and, ultimately, determining land use and coverage.

Image Acquisition Service:

- This service manages the acquisition of hyperspectral images from the HAPS during observation missions.

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- It must interact with the HAPS control systems to schedule and coordinate image capture operations.
- Additionally, it must ensure the secure transfer of the acquired images from the HAPS to the federated nodes for further processing.

Image Storage Service:

- This service is responsible for storing the acquired hyperspectral images in a secure and accessible repository.
- It must ensure the integrity and availability of the stored images, as well as manage access and permissions for authorized users to consult and retrieve images when necessary.

Image Processing Service:

- This service performs the initial processing of the hyperspectral images to prepare them for further analysis.
- It may include tasks such as distortion correction, image calibration, and noise removal.
- It must be executed on federated nodes and utilize appropriate hardware resources to ensure efficient and fast processing of the images.

Image Analysis Service:

- This service conducts advanced analysis of the hyperspectral images to determine land use and coverage.
- It uses algorithms and image processing techniques to identify and classify different types of terrain, such as urban areas, vegetation, bodies of water, etc.
- It must be executed on federated nodes and require appropriate hardware resources, such as powerful CPUs and possibly GPUs to accelerate processing.

Results Visualization Service:

- This service allows users to view the results of the image analysis, such as thematic maps and land use statistics.
- It must provide an intuitive user interface and advanced visualization functionalities to facilitate the interpretation of the results.
- It can be executed on federated nodes or client systems and communicate with the image analysis service to retrieve and display processed data.

In the next table it shows the minimum hardware requirements necessary for its efficient and effective execution in the federated nodes.

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Service	RAM	Hard Drive	Peripherals	GPU	Number CPU
Image Acquisition	At least 4 GB	At least 100 GB	Requires access to external peripherals, such as HAPS control systems, high-resolution spatial and spectral hyperspectral cameras, and data storage devices. Specifically, network connectivity is needed to communicate with the HAPS and additional storage space for temporarily storing captured images		
Image Storage	At least 8 GB	Several terabytes (TB) of storage needed, depending on data volume	No additional peripherals required		
Image Processing	At least 16 GB	At least 200 GB	No additional peripherals required	At least 4 teraflops	
Image Analysis	At least 16 GB	At least 200 GB	Depending on specific algorithms used for image analysis, access to peripherals like hyperspectral or thermal cameras may be needed to collect additional data during analysis		Powerful CPUs with multiple cores and high clock speed recommended
Results Visualization	At least 8 GB	At least 100 GB			

TABLE 12 HARDWARE REQUIREMENTS NECESSARY FOR EXECUTION IN THE FEDERATED NODES FOR UC2

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6.2.3 Phase III. Distribution Optimization Analysis for UC2

Considering the previous phases, in the following table, defines an optimal distribution strategy for the UC2.

Computation distribution policies	Assignment rule	Metrics used	Example of Application
Load Balancing	Image processing services will be assigned to nodes with a balanced CPU and memory load to ensure optimal performance	CPU_TIMES VIRTUAL_MEM	If a federated node has a moderate CPU and memory load and has the capacity to run more services, an image processing service will be assigned to that node
Resource Optimization	Image storage services will be assigned to nodes with sufficient available resources, such as RAM and disk space, to ensure smooth operation	VIRTUAL_MEM DISK_USAGE	If a federated node has a large amount of free disk space and enough available RAM, an image storage service will be assigned to that node
Energy Efficiency	Image acquisition services will preferably be assigned to nodes with low energy consumption to optimize the system's energy efficiency	POWERTOP	If there are several federated nodes available and some of them have lower energy consumption due to their energy efficiency, the image acquisition services will be assigned to those nodes
High Availability	Critical services, such as image storage, will be assigned to nodes with adequate	BATTERY	If it is detected that a federated node has a battery with enough charge to support the image storage service

	battery to ensure service availability, especially in elements not connected to the electrical grid		for an extended period, the service will be assigned to that node to ensure continuity of service in case of power outages or unexpected disconnections

TABLE 13 DISTRIBUTION STRATEGY FOR THE UC2

Theoretical Example of Nodes with Their Respective Resources:

As an application exercise for the UC2, it defines the following elements, as show in the next table.

Node 1 - HAPS Base Station

Features

- High processing and storage capacity
- Connection to the electrical grid and an alternative energy source (e.g., solar panels)
- High-speed network connection for communication with other nodes
- Built-in GPU for intensive image processing tasks
- Large amount of RAM and hard disk space for image storage

Role

- This node acts as the HAPS base station, responsible for receiving, processing, and storing the hyperspectral images captured by the HAPS. It can also perform coordination and resource management functions for the federated nodes

Federated Ground Nodes

Features

- Medium processing capacity.
- Connection to the electrical grid.
- Network connection for communication with other nodes.
- Sufficient RAM and disk space to run image processing and storage services

Role

- Node 2: Execution of image processing services.
- Node 3: Additional data storage.
- Node 4: Backup for critical services

Federated Nodes in Remote Areas

Features

Role

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▪ Medium processing capacity. ▪ Limited energy with backup battery and possibly alternative energy sources. ▪ Limited but available network connection. ▪ Sufficient RAM and disk space to run image processing and storage services	▪ Node 5: Acquisition and preprocessing of images. ▪ Node 6: Execution of specific analysis services for remote areas with built-in AI services. ▪ Node 7: Local data storage before transfer to the HAPS base station

TABLE 14 THEORETICAL EXAMPLE OF NODES FOR THE UC2

Based on these assumptions, it defines the following task distribution strategy, as show in the next figure.

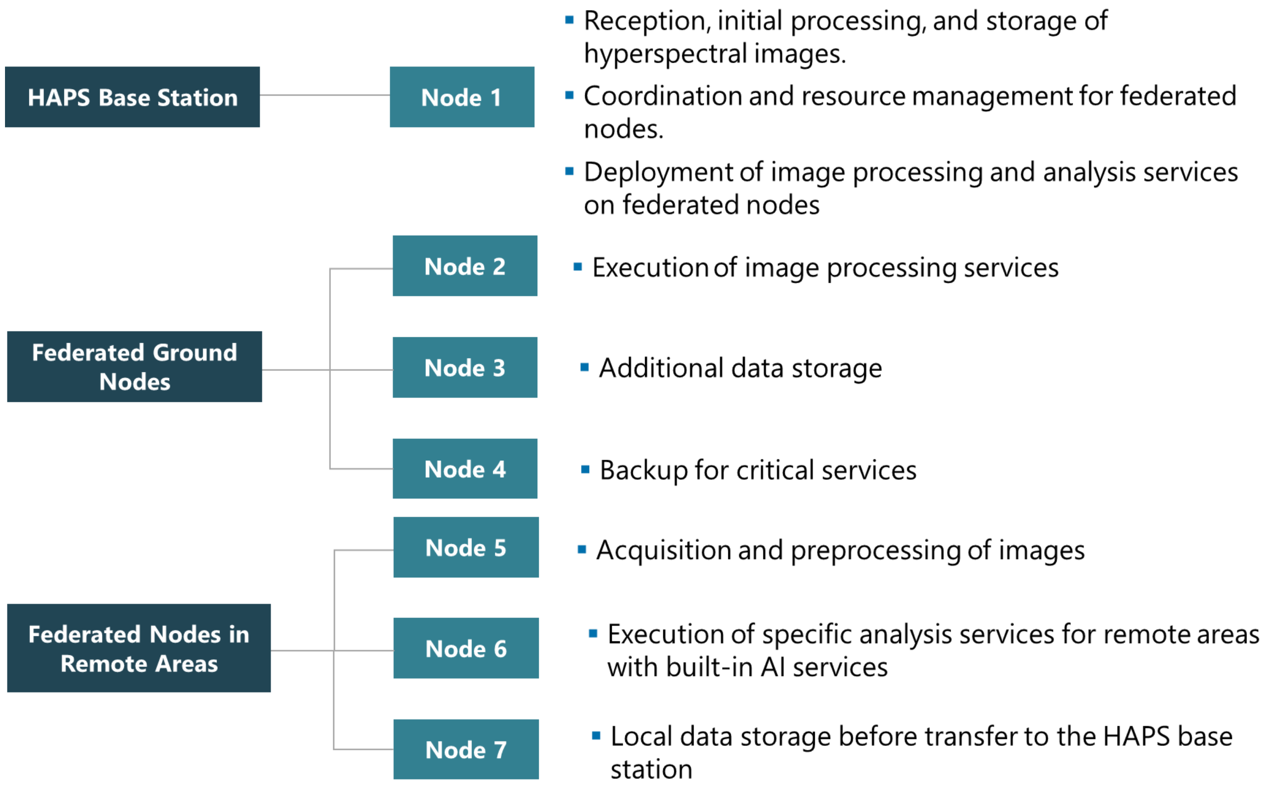

FIGURE 17 TASK DISTRIBUTION STRATEGY FOR UC2

Task-Based Distribution Policy:

- Each task will be assigned to the most suitable node based on its capabilities and geographical location.
- The distribution of tasks will be prioritized based on efficiency and the availability of resources at each node.
- A continuous monitoring system will be established to dynamically adjust the distribution of tasks in response to changes in system conditions.

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6.3. UC3: Connected Vehicle Certificate Validation

Objective:

To provide enhanced and accurate navigation capabilities for connected vehicles, including autonomous vehicles, using HAPS to improve navigation and positioning accuracy.

Actors:

- Connected Vehicle:
  - Cars, trucks, or other vehicles equipped with communication and navigation technology.
  - Responsible for receiving and processing navigation and positioning signals to guide their movement safely and efficiently.
- HAPS:
  - UAV equipped with communication and navigation technology.
  - It provides navigation and positioning signals to connected vehicles on the ground.

Scenario:

In an urban environment with tall buildings and obstacles that can interfere with satellite navigation signals, a HAPS-based navigation system for connected vehicles is implemented. This system takes advantage of the proximity of HAPS to the ground to provide more accurate and reliable navigation signals, especially in dense urban areas.

- HAPS deployment:
  - UAVs equipped with communication and navigation technology are deployed in strategic areas over the city.
  - HAPS establish communication with connected vehicles on the ground and provide them with navigation and positioning signals.
- Enhanced Navigation:
  - Connected vehicles receive navigation signals from HAPS and use this information to calculate routes and guide their movement.
  - The improved accuracy of navigation signals allows vehicles to avoid obstacles more efficiently and make safer navigation decisions.
- Real-Time Certificate Review:
  - Connected vehicles use communication technology to send and receive certification data in real time.
  - HAPS provide continuous review of in-vehicle certificates to ensure compliance with safety and mobility regulations.

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6.3.1 Phase I. Admission Policy Analysis for UC3

Federation Authentication Policy:

- Only authenticated and authorized HAPS are allowed to deploy navigation services in the urban region.
- Each HAPS must be authenticated using secure protocols before it can provide navigation signals to connected vehicles.
- Authentication and authorization criteria will be established to ensure that only trusted HAPS participate in the connected vehicle navigation system.

Role-Based Access Control Policy:

- Specific roles are defined for system actors, such as HAPS operators, connected vehicle fleet managers, and end users.
- Only authorized HAPS operators are allowed to deploy and operate the airborne platforms in the urban region.
- Connected vehicle fleet managers can access information on HAPS availability and performance, but do not have permission to modify its configuration or deployment.
- End users, represented by connected vehicles, have access to navigation signals provided by HAPS, but do not have control over the HAPS infrastructure.

Deployment Approval Policy:

- An approval process is established for the deployment of new HAPS in the urban region.
- Prior to deploying a new HAPS, operators must submit a deployment request that includes details on the intended location, technical capabilities, and safety procedures.
- A thorough review of each request will be conducted to assess its impact on the connected vehicle navigation system and ensure compatibility with local regulations.

Regulatory Compliance Policy:

- Policies are implemented to ensure compliance with safety and mobility regulations applicable to connected vehicle navigation.
- Before deploying a HAPS or providing navigation services, they will be verified to comply with safety standards set by regulatory authorities.
- Periodic audits will be conducted to ensure ongoing compliance with regulations and prevent potential violations.

6.3.2 Phase II. Process Requirements Analysis for UC3

Some examples of services that might be required to meet the objective of the proposed scenario are:

HAPS Communication Service:

- This service enables bi-directional communication between connected vehicles and HAPS.

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- It includes the transmission and reception of navigation signals, position updates and any other data needed for navigation.

Navigation Data Processing Service:

- This service is responsible for processing navigation data received from HAPS and calculating optimal routes for connected vehicles.
- It may include route optimization algorithms, vehicle position estimation and safe path calculation.

Security Certificate Validation Service:

- This service verifies the authenticity and validity of security certificates of connected vehicles in real time.
- It helps ensure that only authorized and secure vehicles have access to the HAPS-based navigation system.

HAPS Control and Monitoring Service:

- This service enables remote control and monitoring of HAPS deployed in the urban region.
- It includes functions such as power management, flight altitude adjustment and monitoring the status of sensors and communication equipment.

Connected Vehicle Fleet Management Service:

- This service provides tools for the centralized management of fleets of connected vehicles.
- It includes functions such as vehicle location tracking, route scheduling and the assignment of specific tasks to each vehicle.

Urban Environment Information Service:

- This service collects and provides up-to-date information about the urban environment, such as digital maps, traffic data and available parking locations.
- It helps improve navigation accuracy by considering real-time environmental conditions.

Incident Management and Safety Alert Service:

- This service is responsible for detecting and managing security incidents in the navigation system, such as unauthorized intrusions or equipment malfunctions.
- It generates alerts and notifications so that operators can quickly take corrective action.

In the next table it shows the minimum hardware requirements necessary for its efficient and effective execution in the federated nodes.

Service	Processor	RAM	Storage	Connectivity
HAPS deployment	Capable of handling communication and control of UAVs	At least 16 GB		Support for multiple communication interfaces such as Wi-Fi, 4G/5G or

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	equipped with communication and navigation technology is required.			other long-range communication technologies is required to establish connection with ground connected vehicles
Enhanced Navigation	Capable of processing navigation signals received from HAPS and calculating optimal routes for ground connected vehicles is required	At least 16 GB	Is required to temporarily store additional navigation data or records of navigation activities	A stable, high-speed network connection is required to receive updated navigation signals from HAPS and send position and route data to be connected vehicles
Real-time certificate review	Capable of processing real-time certification data and performing safety compliance checks is required	At least 16 GB	Is required to store certification records and compliance activities	A network connection is required to receive real-time certification data from connected vehicles and send compliance reports to relevant federated nodes

TABLE 15 HARDWARE REQUIREMENTS NECESSARY FOR EXECUTION IN THE FEDERATED NODES FOR UC3

6.3.3 Phase III. Distribution Optimization Analysis for UC3

Considering the previous phases, as show in the following table, it defines an optimal distribution strategy for the UC3.

Policy	Goal	Admission Rule	Metrics
HAPS Authentication and Authorization	Ensure that only authenticated and authorized HAPS can provide navigation services to connected vehicles	Only HAPS that have been previously authenticated and authorized by the competent authority shall be allowed to be deployed	HAPS Authentication Record, Authorization Status

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Navigation Signals Access Control	Control access to navigation and positioning signals provided by HAPS	Only authenticated connected vehicles shall have access to navigation signals issued by HAPS	Navigation Signal Access Log, Authenticated Connected Vehicle Authentication Status
Real-Time Certificate Monitoring	Continuously verify the validity of connected vehicle certificates to ensure compliance with safety and mobility regulations	Only vehicles whose certificates are valid and comply with established safety requirements will be allowed access to navigation signals	Certificate Validation Record, Regulatory Compliance Status

TABLE 16 DISTRIBUTION STRATEGY FOR THE UC3

6.4. UC4: Search and location of people

Objective:

To utilize UAVs equipped with integrated EO cameras, in conjunction with a Ground Node equipped with NVIDIA processors, to conduct efficient and effective search and rescue operations.

Actors:

- **Search and Rescue Team:** Individuals responsible for operating the drones and analysing the collected data.
- **Missing Persons:** Individuals who need to be located and rescued.

Scenario:

In a remote mountainous area, a group of hikers has gone missing due to harsh weather conditions. The search and rescue team has been notified and is ready to deploy using drone and AI technology.

- The hikers are lost in a mountainous region covered with dense vegetation and uneven terrain.
- Due to the bad weather, visibility is limited, and there is a risk of avalanches.
- The search and rescue team are comprised of trained drone operators equipped with advanced technology.
- A Ground Node equipped with NVIDIA processors has been deployed to process the data collected by the drones and run AI algorithms for person detection and localization.
- The drones are equipped with integrated EO cameras, which allow them to capture detailed images of the search area.

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- The search and rescue team uses a drone control application that enables them to plan flight routes, remotely control the drones, and visualize data in real-time.

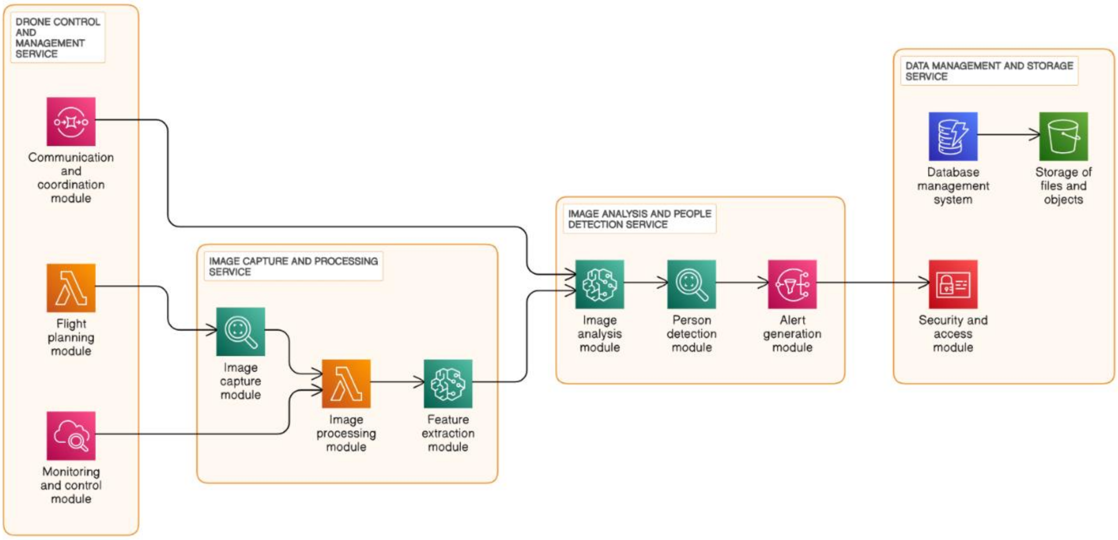

FIGURE 18 SCENARIO UC4 SEARCH AND LOCATION OF PEOPLE

6.4.1 Phase I. Admission Policy Analysis for UC4

Federation Authentication Policy:

- Only federated organizations that have been authenticated and authorized are allowed to deploy services on federated nodes.
- In this case, search and rescue organizations and the relevant authorities must be authorized to access the resources of the federated nodes.

Role-based Access Control Policy:

- Specific roles within federated organizations are defined, such as drone operators, data analysts, coordination staff, etc.
- Each role has specific permissions to access and deploy services on federated nodes.
- ACLs or role-based authorization policies are used to control who can perform deployment actions on federated nodes.

Deployment Approval Policy:

- A deployment approval process is established for deploying services on federated nodes.
- Before deploying a service, applicants must submit a deployment request that includes details about the planned search and rescue operation and its purpose.
- The request is verified against established criteria before approving the deployment of services on federated nodes.

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Regulatory Compliance Policy:

- Policies are implemented to ensure compliance with specific regulations and norms related to privacy, security, and the use of drones in search and rescue operations.
- Before deploying a service, it must be verified that it complies with the security and privacy requirements set by applicable regulations.
- Periodic audits may be conducted to ensure ongoing compliance with regulations and to prevent potential violations.

6.4.2 Phase II. Process Requirements Analysis for UC4

The following services provide the necessary technological infrastructure to carry out efficient and effective search and rescue operations using drones equipped with imaging technology and data analysis capabilities, as show in the next table.

Services	Description	Functions	Components
Drone Control and Management	This service is responsible for the centralized management of drones used in search and rescue operations	- Assignment and scheduling of flight routes for drones - Monitoring the status and location of each drone in real-time - Coordination of communication between drones and the ground base station	- Flight planning module - Monitoring and control module - Communication and coordination module
Image Capture and Processing	This service handles the capturing of aerial images using the integrated EO cameras on drones, as well as processing these images for analysis	- Real-time image capture during drone flights - Image processing to enhance quality and resolution - Extraction of relevant features from images for subsequent analysis	- Image capture module - Image processing module - Feature extraction module
Image Analysis and Person Detection	This service uses artificial intelligence (AI) algorithms to analyse images captured by drones and	- Image analysis using computer vision algorithms and deep learning	- Image analysis module - Person detection module

	detect the presence of people in areas of interest	- Detection of people in complex and varied environments - Generation of alerts and notifications about the location of detected individuals	- Alert generation module
Data Management and Storage	This service is responsible for managing and storing data collected during search and rescue operations, including images captured by drones and the results of image analysis	- Secure and scalable data storage in the cloud or on local servers. - Management of the integrity and availability of stored data. - Controlled access to data by authorized users	- Database management system. - File and object storage. - Security and access module

TABLE 17 DESCRIPTION OF THE SERVICES WITH THEIR FUNCTIONS AND COMPONENTS FOR UC4

In the next table it shows the minimum hardware requirements necessary for its efficient and effective execution in the federated nodes.

Service	RAM	Hard Drive	Peripherals	GPU	Number CPU	Architecture
Drone Control and Management	At least 8 GB	At least 100 GB	No additional peripherals required	No	4	x86_64
Image Capture and Processing	At least 16 GB	At least 500 GB	EO Camera	Yes (High capacity)	8	x86_64
Image Analysis and Person Detection	At least 32 GB	At least 1 TB	EO Camera, IR Camera	Yes (High capacity)	16	x86_64
Data Management and Storage	At least 16 GB	Variable, depending on the data volume	No additional	Optional (Normal)	8	x86_64

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		(Recommended: Cloud storage with elastic capacity)	peripherals required			

TABLE 18 HARDWARE REQUIREMENTS NECESSARY FOR EXECUTION IN THE FEDERATED NODES FOR UC4

6.4.3 Phase III. Distribution Optimization Analysis for UC4

Considering the previous phases, as show in the next table, it defines an optimal task distribution strategy for the UC4.

Computation distribution policies	Assignment rule	Metrics used	Example of Application
Load Balancing	Assign services to nodes with a balanced CPU and memory load	CPU_TIMES VIRTUAL_MEM	The Drone Control and Management Service, which requires a moderate CPU and memory load, would be assigned to a node that has balanced CPU time and virtual memory compared to other available nodes
Resource Optimization	Assign services to nodes with sufficient available resources, such as RAM and disk space	VIRTUAL_MEM DISK_USAGE	The Image Capture and Processing Service, requiring a significant amount of RAM and disk space, would be assigned to a node that has enough virtual memory and disk space available to efficiently run the service
Energy Efficiency	Assign services to nodes with low energy consumption to optimize the	POWERTOP	If there are nodes with similar processing capabilities but one consumes less energy according to

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	system's energy efficiency		POWERTOP metrics, services would preferentially be assigned to that node to optimize the system's energy consumption
High Availability	Assign services to nodes with adequate battery to ensure service availability, especially in elements not connected to the electrical grid	BATTERY	Critical services, like the Drone Control and Management Service, would preferably be assigned to nodes with adequate battery to ensure continuous service availability, even in situations where nodes are not connected to the electrical grid

TABLE 19 DISTRIBUTION STRATEGY FOR THE UC4

Theoretical Example of Nodes with Their Respective Resources

As an application exercise for the UC4, it defines the following elements, as show in the following table.

Centralized Control and Management Node (2 nodes)	
Features	**Role**
▪ High processing and storage capacity, connection to the electrical grid and an alternative energy source (e.g., solar panels), high-speed network connection	▪ These nodes act as centralized control and management centers for all search and rescue operations, each hosting the Drone Control and Management Service.

Image Capture and Processing Node (4 nodes)	
Features	**Role**
▪ Medium processing capacity, connected to the electrical grid	▪ These nodes are responsible for real-time image capture during drone flights and initial image processing

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Image Analysis and Person Detection Node (4 nodes)	
Features	**Role**
▪ Medium processing capacity, connected to the electrical grid	▪ These nodes use AI algorithms to analyse images captured by drones and detect the presence of people in areas of interest
Data Storage Node (3 nodes)	
Features	**Role**
▪ High storage capacity, connected to the electrical grid	▪ These nodes manage and store data collected during search and rescue operations, including images and analysis results

TABLE 20 THEORETICAL EXAMPLE OF NODES FOR THE UC4

Task Distribution Strategy:

- **Drone Control and Management Service:** Assigned to the HAPS Base Station (Node 1) for centralized coordination and real-time data processing.
- **Image Capture and Processing Service:** Distributed among Ground Federated Nodes (Nodes 2, 3, and 4) and Remote Area Federated Nodes (Nodes 5, 6, and 7), based on location and specific processing needs.
- **Image Analysis and Person Detection Service:** Executed on Ground Federated Nodes (Nodes 2, 3, and 4) due to their medium processing capacity and stable electrical connection.
- **Data Management and Storage Service:** Distributed between the HAPS Base Station (Node 1) and Ground Federated Nodes (Nodes 2, 3, and 4) to ensure data redundancy and availability.

In the next figure it show the distribution strategy for UC4.

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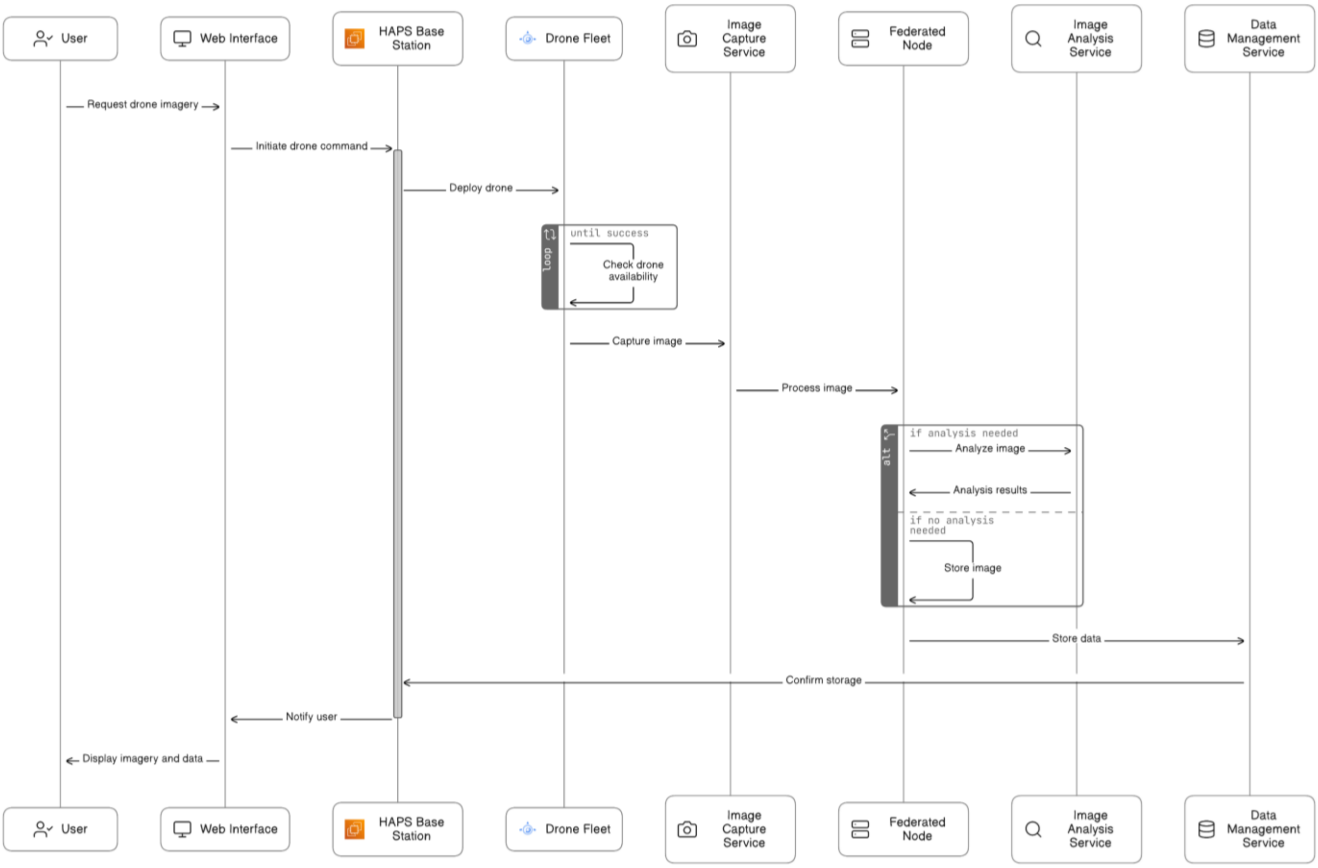

FIGURE 19 DISTRIBUTION STRATEGY FOR UC4

7 Conclusions

In conclusion, an overview of NTNs and their integration with B5G technology is provided, encompassing various dimensions such as architecture, use cases, metrics, and distributed processing strategies.

- NTN represents a significant leap forward in telecommunications, extending connectivity beyond conventional terrestrial networks.
- The seamless integration of terrestrial networks into NTN architecture ensures comprehensive coverage and connectivity.
- HAPS emerges as a promising solution for NTN, offering wide-area coverage and support for diverse applications.
- A range of use cases: fire detection, land use and cover, connected vehicle certificate validation, search and location of people; underscores the versatility and practicality of NTN technology.
- Metrics such as satellite performance and computing capacity are crucial for evaluating NTN network effectiveness and optimizing performance.
- A strategic approach to distributed processing, delineated through different phases, is vital for managing data processing efficiently. For this purpose:
    - An analysis of the admission policy is performed considering, process owner, security level, process priority and process priority.
    - Define minimum hardware requirements needed to run the process efficiently and effectively on federated nodes.
    - Define metrics to analyse the efficiency and performance of the distribution.
- The proposed distributed processing strategy allows for both horizontal and vertical scalability, that is, it can effectively adapt to changing demands and system growth. Horizontal scalability, by adding new federated nodes, facilitates rapid expansion of the system to handle larger volumes of data and workloads. On the other hand, vertical scalability, by improving the resources of each individual node, optimizes the performance and efficiency of the existing system.

  Combining both approaches creates a complete strategy that can be tailored to a variety of use cases and requirements. Horizontal scalability provides flexibility and agility to cope with sudden changes in demand, while vertical scalability optimizes the use of existing resources and improves performance at the node level.
- Tailoring distributed processing strategies to individual use cases allows for optimized resource utilization and effective handling of data processing requirements.

In essence, it highlights the multifaceted nature of NTN networks and their potential to revolutionize telecommunications through enhanced connectivity and versatile applications.

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8 References

[1] 3GPP TR 38.821, " Solutions for NR to support non-terrestrial networks," Release 16, March 2023. [Online]. Available: https://www.3gpp.org.

[2] Y. Hokazono, H. Kohara, Y. Kishiyama and T. Asai, “Extreme Coverage Extension in 6G: Cooperative Non-terrestrial Network Architecture Integrating Terrestrial Networks,” *IEEE Wireless Communications and Networking Conference,* 2022.

[3] "WRC–19, World Radiocommunication Conference 2019, Final Acts," *ITU Publications,* 2020.

[4] G. K. Kurt, M. G. Khoshkholgh, S. Alfattani, A. Ibrahim, T. S. J. Darwish, M. S. Alam, H. Yanikomeroglu and A. Yongacoglu, “A vision and framework for the high altitude platform station (HAPS) networks of the future,” *IEEE Communications Surveys and Tutorials,* 2021.

[5] F. E. B. a. C. G. Agency, “Technological Assessment Report - Frontex,” Member of the European Innovation Hub for Internal Security.

[6] “SHARP (Stationary High Altitude Relay Platform),” [Online]. Available: http://www.friendsofcrc.ca/Projects/SHARP/sharp.html.

[7] "MicroLink Devices," [Online]. Available: http://www.mldevices.com/index.php/news.

[8] “ WRC–23, World Radiocommunication Conference 2023, ITU-SG CL Contribution 55,” *ITU Publications,* 2020.

[9] K. Mershad, H. Dahrouj, H. Sarieddeen, B. Shihada, T. Al-Naffour and M.-S. Alouini, "Cloud-Enabled High-Altitude Platform Systems: Challenges and Opportunities," https://www.frontiersin.org/articles/10.3389/frcmn.2021.716265/full, 2021.

[10] J. S. J. M. a. T. O. M. Mathis, “The macroscopic behavior of the tcp congestion avoidance algorithm,” *ACM SIGCOM Computer Communications Review,* p. 27(3):67–82, 1997.

[11] E. L. N. M. S. K. S. B. S. J. F. M. M. J. C. M. D. D. S. S. C. S. K. J. Q. L. L. T. X. V. a. G. G. Oltjon Kodheli, “Satellite communications in the new space era: A survey and future challenges.,” *IEEE Communications Surveys & Tutorials,,* p. 23(1):70–109, 2021.

[12] F. Rinaldi, H.-l. Määttänen, J. Torsner, S. Pizzi, S. Andreev, A. Iera, Y. Koucheryavy and G. Araniti, "Non-Terrestrial Networks in 5G & Beyond: A Survey," *IEEE Magazine,* 2020.

[13] W. Jaafar and H. Yanikomeroglu, "HAPS-ITS: Enabling future ITS services in trans-continental highways," *IEEE Communications Magazine,* 2022.

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[14] G. K. Kurt and H. Yanikomeroglu, "Communication, computing, caching, and sensing for next generation aerial delivery networks: Using a high-altitude platform station as an enabling technology," *IEEE Vehicular Technology Magazine,* 2021.

[15] M. S. Alam, G. K. Kurt, H. Yanikomeroglu, P. Zhu and N. D. Dao, "High altitude platform station based super macro base station constellations," *IEEE Communications Magazine,* 2021.

[16] S. Alfattani, W. Jaafar, Y. Hmamouche, H. Yanikomeroglu, A. Yongacoglu and N. Dao, "Aerial platforms with reconfigurable smart surfaces for 5G and beyond," *IEEE Communications Magazine,* 2021.

[17] G. K. Kurt, M. G. Khoshkholgh, S. Alfattani, A. Ibrahim, T. S. J. Darwish, M. S. Alam, H. Yanikomeroglu and A. Yongacoglu, "A Vision and Framework for the High Altitude Platform Station (HAPS) Networks of the Future," *IEEE Communications Surveys & Tutorials ,* March 2021.

[18] C. Huang, G. C. Alexandropoulos, A. Zappone, M. Debbah and C. Yuen, "Energy efficient multi-user MISO communication using low resolution large intelligent surfaces," *IEEE Globecom Workshops (GC Wkshps),* pp. 1-6, 2018.

[19] F. &. M. H.-L. &. T. J. &. P. S. &. A. S. &. I. A. &. K. Y. &. A. G. Rinaldi, "Non-Terrestrial Networks in 5G & Beyond: A Survey," *IEEE,* pp. Access. 8. 165178 - 165200., 2020.

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