6G for Connected Sky
"6G-SKY"

Work Package 5

Integration, Demonstrations and Lab Emulations

Task 5.1 – Development of dedicated hardware modules (UAVs, antennas)
Task 5.2 – Lab Emulation
Task 5.3 – Multi-technology network integration
Task 5.4 – 3D network demonstration with multiple drones flying as a swarm in coordination (avoiding accidents)
Task 5.5 – Demonstration sense and avoid mechanisms
Task 5.6 – Demonstration of HAPS networking

Deliverable 5.1.

Demo concept and planning

6G-SKY Project
14.9.2023

for full publication

Abstract

The D5.1 deliverable document contains concepts and procedures for defining and conducting the demonstrations.

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6G-SKY, Work Package 5: Integration, Demonstrations and Lab Emulations

D5.1 Demo concept and planning

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[6G-SKY]

[D5.1 - Demo concept and planning]

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CELTIC published project result

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Document History

Version	Date	Author(s)/Reviewer	Comment
V0.0	18.04.2023	Andreas Kercek (LAKE)	Document Structure
V0.1	16.07.2023	Andreas Kercek (LAKE)	Document for external review (part 1)
	27. 07. 2023	Gergely Biczok (AITIA)	Review (Chapters 1-3 and 5-6)
	28.07.2023	Aygün Baltaci (Airbus)	Review
V0.2	31.07.2023	Andreas Kercek (LAKE)	Adaption according to reviewer's comments. Completion of chapter 4
V0.3	14.8.2023	Thomas Schlichter (FHG)	New chapter 4 inserted.
V0.4	16.8.2023	Andreas Kercek (LAKE)	Chapter 4 cleaned up.
V0.5	16.8.2023	Andreas Kercek (LAKE)	All figures in the document numbered and referenced. Ready for chapter 4 review.
v0.6	16.8.2023	Gergely Biczok (AITIA)	Review (Chapter 4)
v0.7	24.08.2023	Jan Grävendieck (EAG)	Review, mainly chapter 5
v0.8	05.09.2023	Jan Grävendieck (EAG)	Review chapter 5
V1.0	14.09.2023	ANdreas Kercek (LAKE)	Final version

Executive Summary

This document details the demonstration cases as roughly sketched in the proposal under WP5 and in D1.1. The demonstrations serve to show the functionality of the 6G-SKY architecture in different use cases underlying the demonstrations. The use cases are described in further detail in D1.1. The demonstrations shall particularly show what features beyond 5G+ are needed to fulfill use case requirements. The majority of demonstrations will target TRL5 and also show sustainability aspects (e.g. enhanced energy efficiency, greenhouse gas reduction, safety aspects, etc.). We also include schedules for setting up the demonstrations and we assign responsibilities for different contributions to the demonstrations.

Note: As planning and setting up the demonstrations are ongoing processes where new insights will be coming up periodically, we consider this as a living document which will be constantly updated due to adaptions during the course of the project. We therefore plan to periodically submit updated versions of this document after submission of its first version on the D5.1 due date.

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Glossary

List of acronyms with alphabetical order.

Abbreviation	Description
(D)A2A	(Direct) Air-to-Air
(D)A2G	(Direct) Air-to-Ground
D2D	Device-to-Device
D2I	Device-to-Infrastructure
EASA	European Union Aviation Safety Agency
EMC	Electromagnetic compatibility
FR1, 2, 3	Frequency Range 1, 2, 3 corresponding to frequencies up to 410MHz—7.125 GHz, 24.25—52.6 GHz, and 7.125—24.25 GHz
FSS	Fixed Satellite Services
HALE	High Altitude Long Endurance
HAPS	High Altitude Platform
GEO	Geostationary (satellite)
gNB	“gNodeB”, 5G base station
LEO	Low Earth Orbit(satellite)
LOS	Line-of-Sight
MALE	Medium Altitude Long Endurance
MEO	Medium Earth Orbit (satellite)
MU-MIMO	MultiUser Multiple Input Multiple Output
NLOS	Non-Line-of-Sight
NTN	Non-Terrestrial Network
PoC	Proof-of-Concept
RPAS	Remotely Piloted Aircraft Systems
SDR	Software Defined Radio
TDoA	Time Difference of Arrival
TRL	Technology Readiness Level[1]
UAV	Unmanned Aerial Vehicle - Drone
UE	User Equipment (e.g. smart phone)
UGV	Unmanned Ground Vehicle
USRP	Universal Software Radio Peripheral
UTM	Unmanned Aircraft System Traffic Management
V2V	Vehicle-to-Vehicle

1 Introduction

Objective of the document

[1] https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

The D5.1 Demo concept and planning document describes the demonstration cases, specifically of Task 5.2—5.6 in WP5 in further detail. For each of the demonstration cases, a motivation is given along with a description of the setup, and goals in terms of performance metrics, success criteria, TRL-level to be reached and particular 6G-features to be demonstrated. For each demo case, we describe the procedures how the demonstrations will be conducted and in which environment/testbed and which organization is going to contribute to which components in HW and/or SW for the demonstration. Each demo case is supplemented by a preliminary schedule. For each demonstration, a description of sustainability aspects is given.

Structure of the document

The further structure of the document is as follows: In Chapter 2 we give a short overview of WP5. Chapter 3 is dedicated to HW components such as drones and antennas that will be used for the demonstrators. Chapter 4 to Chapter 8 describe the demonstration cases in detail:

- Chapter 4: Task 5.2 ─ Lab Emulation
- Chapter 5: Task 5.3 ─ Multi-technology network integration
- Chapter 6: Task 5.4 ─ 3D network demonstration with multiple drones flying as a swarm in coordination (avoiding accidents)
- Chapter 7: Task 5.5 ─ Demonstration sense and avoid mechanisms
- Chapter 8: Task 5.6 ─ Demonstration of HAPS networking

Each chapter describes motivation, setup, goals (including metrics and success criteria), schedules and procedures. Additionally, contributions to sustainability aspects are explained for each demo case, where applicable.

Chapter 9 concludes the document briefly summarizing how the demonstrations show 6G-SKY's beyond-5G- and 5G+- features, TRL levels reached and contribution to sustainability.

2 WP5 Overview

The overall goal of WP5 is to integrate the components developed in WP1 - 4 into functional demonstrators as well as to demonstrate the functionality of these components and the 6G-SKY architecture on a system level. This will be accomplished in different environments depending on the underlying use cases. We will further develop dedicated hardware necessary for the tests (i.e., UAVs, antenna modules). Test procedures, performance metrics and success criteria for each test/demonstration as predefined in WP1 will be detailed in the beginning of WP5. These will be applied to the testing and demonstrations. Particular objectives with associated tasks within WP5 are outlined as follows:

- Development of dedicated UAV hardware for swarming and antenna modules for use in the tests (Task 5.1).

- In-lab interoperability testing and validation of communication links and applications as used in Tasks 5.3 and 5.6 (Task 5.2).
- Evaluation and Proof-of-Concept of the results from WP2, WP3 and WP4. Multi-Technology Connectivity Links and the resilience of the adaptive multi-technology network will be tested (Task 5.3).
- Proof of concept demonstration of networking and swarming technology with a real swarm of UAVs applied to the mobility use case defined in WP1 (Task 5.4).
- Demonstration of safety in Urban Air Mobility and U-space by providing "see & be seen" capability to all types of low flying aircraft including manned aircraft, collaborative drones and non-collaborative drones (Task 5.5).
- Test and demonstration of HAPS-Ground, HAPS-low altitude UAV, HAPS-HAPS and HAPS – Satellite links (Task 5.6).

3 Task 5.1: Development of dedicated hardware modules (UAVs, Antennas)

Lead: Twins, **Contributors:** Lakeside Labs, Meshmerize

Subtask 5.1.1: UAV platform

Two already-existing and highly-adaptable UAV platforms provided by Twins GmbH will be utilized. Multiple medium-sized multicopters of type twinFOLD GEO will be used for low-altitude operation, whereas one large multicopter, twinFOLD KAT, is planned to take over command and provide higher altitude observation.

Based on artificial intelligence, the UAV swarm is supposed to jointly execute missions and exchange information allowing for a correct and efficient workflow. For the implementation of such a system, selected sensors, antennas and other payloads will be integrated on both types of drones. In order to mount the planned exterior, the existing frame needs to be adapted to a certain extent. Several mountpoints are foreseen on the arms of the copters to allow the integration of communication modules which are sensible to electromagnetic fields induced by components of the UAVs. As most EMC inducing components are close to the center point of the UAV, mountpoints on the arms allow for a beneficial buffer zone to shield the communication modules. Also, electromagnetic shielding is considered. Furthermore, the bottom baseplate needs to be redesigned for both UAV platforms to allow mounting of the active sensor payload.

Additionally, a custom gimbal camera mount for the twinFOLD GEO is being designed and developed, in order to provide sufficient image stability during flight operations. On the software side, a primary communication interface to the drones’ flight controller will be implemented allowing fully autonomous control of the UAV from an on-board companion PC.

The primary communication protocol is MAVLink[2], while the autopilot software used is Arducopter/Ardupilot[3].

All adaptions to the existing design and concept of the drone will be iteratively tested to ensure and maintain stable and safe flight characteristics. We will adapt two basic concepts of UAVs, a drone for smaller payloads of up to 1.650g incl. batteries (twinFOLD Geo) and a heavy lifter for payloads up to 5kg (twinFOLD KAT) to account for different hardware settings depending of the UAV's tasks (see e.g. Chapter 6 for details). The two concepts are described in the following:

3.1.1 twinFOLD GEO

The basic design is shown in Figure 1. The features of the design are itemized as follows:

Registration options

- EASA Category OPEN
- Category SPECIFIC (only Austria)

Technical Data

- Maximum take off weight (MTOW): 5.000g
- Maximum payload: 1.650g (incl. battery)
- Maneuverability: Bank of max. 30°
- Maximum speed: Horizontal: 10m/s, vertical: 5m/s
- Maximum altitude (MSL): 3.000m
- Flight time: Average 20min, Maximum 30min

  (Dependent on temperature, payload, altitude and batteries)

- Maximum wind speed: 7m/s laminar flow
- Operating temperature: Ideal: 18—40°C, with battery pre-heating down to -20°C
- Primary interface: MAVLink

[2] https://mavlink.io/en/

[3] https://ardupilot.org/copter/

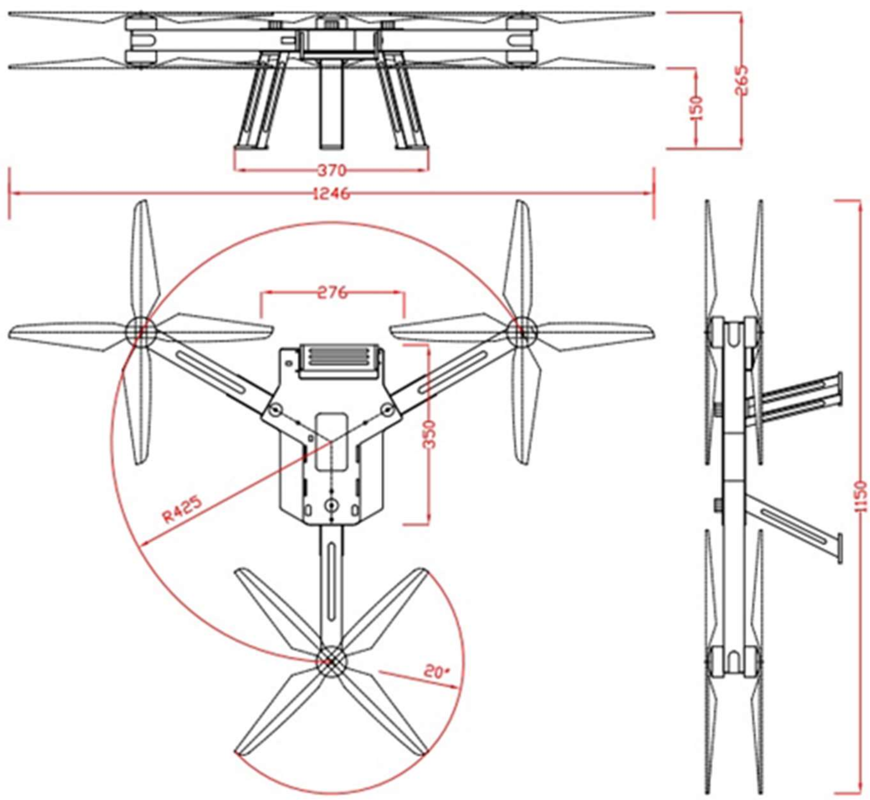

Figure 1: Basic design of the twinFOLD GEO for use in the demonstrations, esp. Task 5.4.

3.1.2 twinFOLD KAT

The basic design is shown in Figure 2. The features of the design are itemized as follows:

Registration options

- EASA Category OPEN
- Category SPECIFIC (only Austria)

Technical Data

- Maximum take off weight (MTOW): 12.000g - 14.000g
- Maximum payload: 5.500g—7.500g (incl. battery)
- Maneuverability: Bank of max. 20°
- Maximum speed: Horizontal: 7m/s, vertical: 5m/s
- Maximum altitude (MSL): 3.000m
- Flight time: Average 30min, Maximum 45min

  (Dependent on temperature, payload, altitude and batteries)

- Maximum wind speed: 6m/s laminar flow
- Operating temperature: Ideal: 18—40°C, with battery pre-heating down to -20°C
- Primary interface: MAVLink

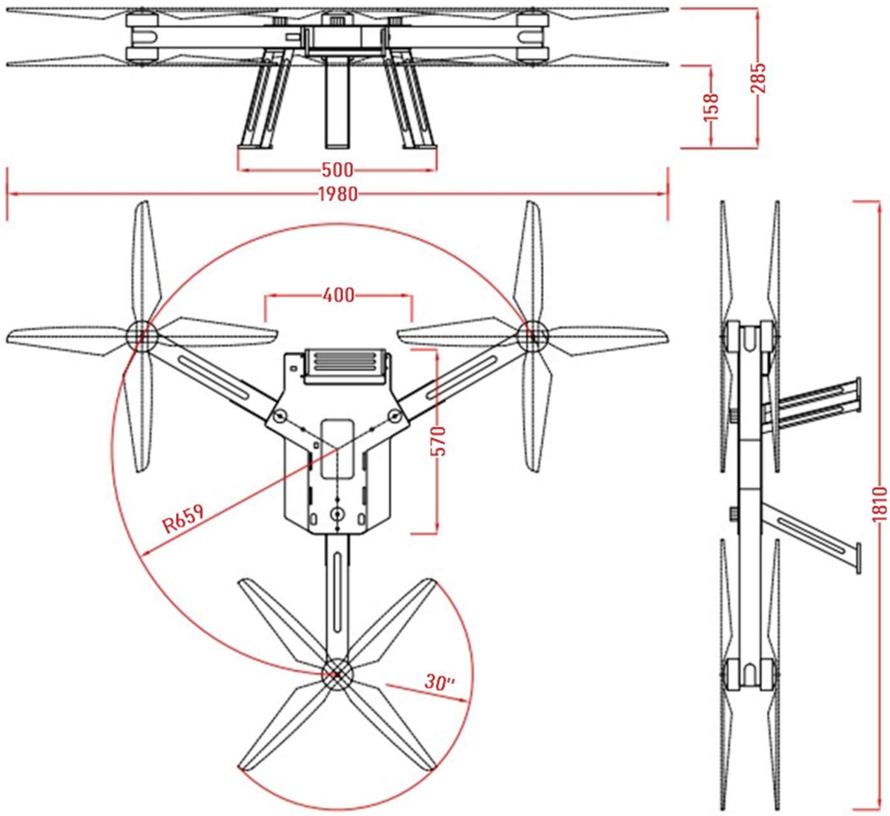

Figure 2: Basic design of the twinFOLD KAT for use in the demonstrations, esp. Task 5.4.

Subtask 5.1.2: Communication and antenna module design

The goal of this subtask is to design and develop a communication and antenna module to enable efficient and reliable wireless communication between the agents of a drone swarm.

As the first step towards the design of the module and antenna is to identify unique communication challenges for the drone swarm use-case which have a strong implication on the design. The three-dimensional spatial distribution of communication agents within the swarm poses a significant hurdle. Additionally, the high mobility and density of communication agents within the swarm, along with the weight limitations imposed by the drone's carrying capacity, needed to be considered. And lastly, the limited power available due to battery constraints, the vibrations and physical stress endured by the module when mounted on a drone, and the exposure to harsh environmental conditions further complicate the design process.

To address these challenges, a multitude of solutions were devised, leading to the adoption of an external Wi-Fi communication module based on 802.11b/g/n/ac standards. While C-V2X is integral to the system, its limited availability in devices prompted the decision to conduct tests with accessible hardware. This decision enables seamless integration of diverse hardware modules with the UAV, significantly expanding the range of compatible options. To ensure a smooth integration of the module with the drone's computing unit, an Ethernet connection will be established through a bridged interface, between the communication module attached to the UAV and the UAV itself. Facilitating a seamless integration of the UAV into the network as shown in Figure 3.

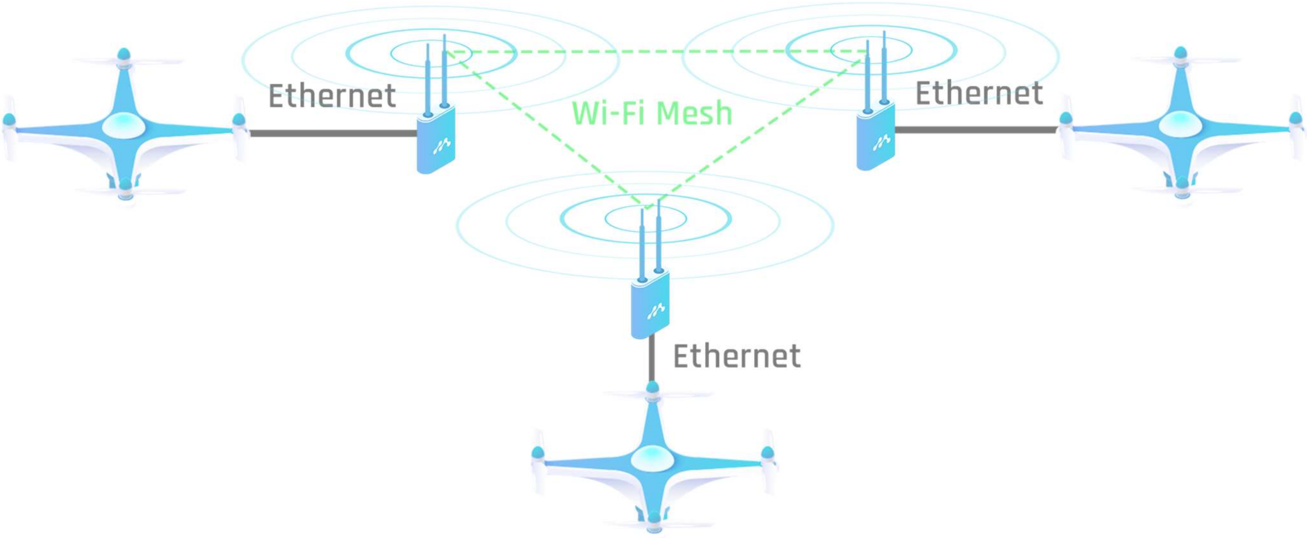

Figure 3: External Wi-Fi module integration with a UAV.

To identify the most efficient module, firstly, a thorough evaluation process will be undertaken, involving extensive testing of different industrial communication modules based on 802.11b/g/n/ac standards to determine the optimal choice for the drone swarm. This assessment considers the specific limitations of the drones themselves, as well as the environmental factors that could impact performance such as weather conditions, temperature extremes, heavy vibrations, battery efficiency, carrying capacity of the drones, etc.

The devices chosen for the initial tests are a subset of industrial Wi-Fi routers, selected for their ability to offer high reliability in diverse environmental conditions while adhering to the weight limitations of the drone payload.

Initial laboratory tests and evaluations have begun with the Gl.iNet AR-150[4] device, assessing its suitability for integration into the drone swarm communication system. Device offered a good weight- to -performance ratio, but has unsatisfactory absolute performance in terms of throughput. The next steps for the lab tests would be to extend range of tested devices, including but not limited to Doodle Labs wearable[5], Acksys Airbox[6], and GL.iNet Collie[7].

The exploration of multi-directional antennas is considered as another promising solution to enhance network reliability. By employing antennas capable of transmitting and receiving signals in multiple directions simultaneously, the module could mitigate the challenges posed by the three-dimensional spatial distribution of the drone swarm. Additionally, the concept of

[4] https://www.gl-inet.com/products/gl-ar150/
[5] https://doodlelabs.bitbucket.io/design-in-docs/wearable-design-in/wearable-2450/
[6] https://www.acksys.fr/en/product/56-airbox/
[7] https://www.gl-inet.com/products/gl-x300b/

overhearing is crucial to the design of an opportunistically- routed network, which enables agents within the swarm to passively monitor and utilize signals transmitted by neighboring drones, further enhancing the network's reliability.

Also, the feasibility of employing multiple antennas with diverse positions and angles will be investigated. This approach aims to optimize coverage across multiple planes within the drone swarm. By strategically positioning antennas at varying angles and locations, the communication and antenna module could effectively address the high mobility and density of the agents, ensuring robust and consistent wireless connectivity. Utilizing multiple antennas will naturally lead to higher energy consumption in the communication module. However, given the typically modest transmission power of 802.11 devices, the distinction between employing a single antenna and multiple antennas can be considered insignificant.

To validate the performance in real-world scenarios, outdoor tests will be conducted to evaluate different hardware modules, as well as the effectiveness of different antennas and antenna positions/angles.

In Chapter 43Antennas and Satellites, two types of antennas for UAVs suitable for 6G-SKY are presented.

4 Task 5.2: Lab Emulation

Overview

Lead: Fraunhofer, **Contributors:** Deutsche Telekom, Airbus, Meshmerize, EAB, EAG

4.1.1 Motivation

The scope of Task 5.2 is the in-lab interoperability testing and validation of communication links and applications as used in Tasks 5.3 and 5.6.
The lab emulation task has the goal to integrate, test, and validate the communication equipment and the applications in the lab under reproducible conditions, before performing the over-the-air tests with drones, HAPS and satellites within Task 5.3 and Task 5.6.

4.1.2 Setup

The principal setup is depicted in Figure 4. The lab setup is based on a commercial channel emulator (Keysight F64 incl. aerospace option for GEO, MEO and LEO satellites) for hybrid scenarios which reproduces the propagation conditions from various links (satellite, HAPS, A2G, A2A, V2V) in real-time. Integration and interoperability testing of the communication links (e.g., based on OpenAirInterface or other commercial wireless devices) is possible in-lab without the need for expensive satellite or HAPS capacity or drone operations, because all link characteristics like delay and frequency drifts, multi-path transmissions and interference can be emulated. Additionally, testing equipment, e.g., a cellular communication tester (Keysight UXM 5G Wireless Test Platform), for detailed analysis of a UE regarding performance and specification compliance, is available. The test site is located in Erlangen, Germany.

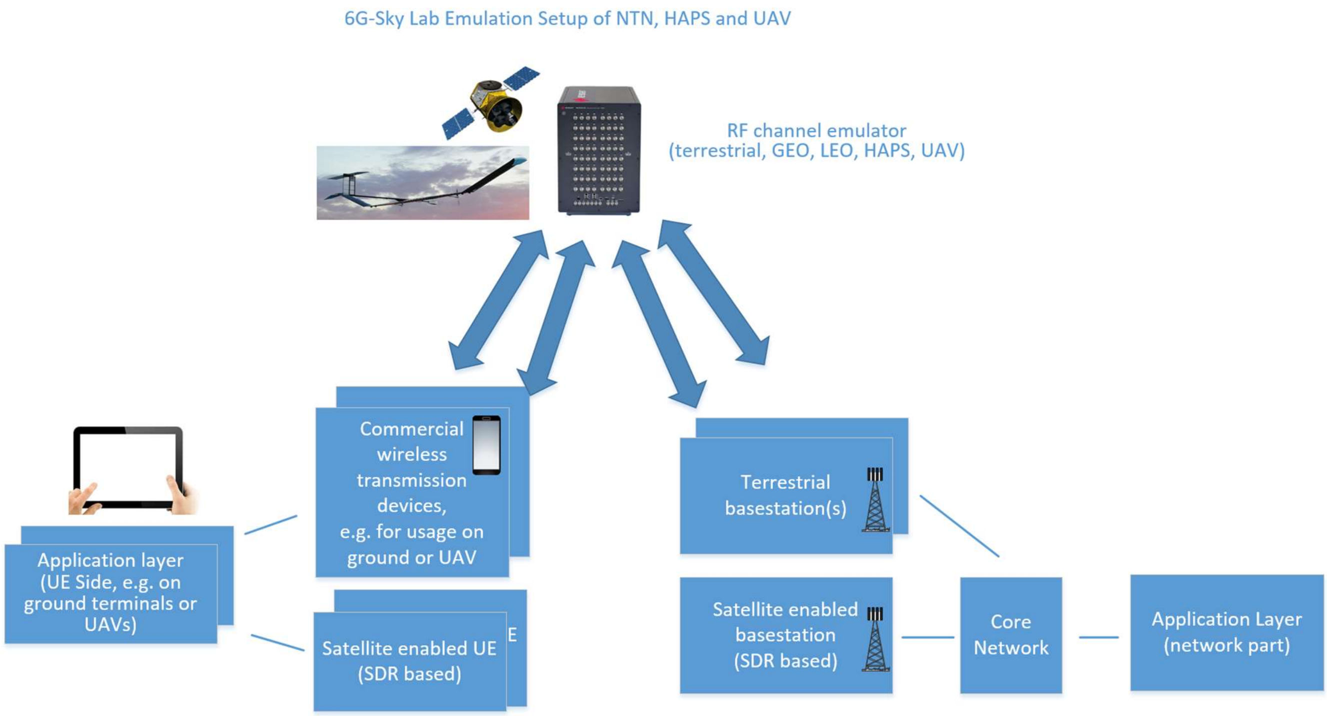

Figure 4: Overview of the lab setup for interoperability testing.

Goals

4.1.3 Goals, Performance Metrics and Success Criteria

The first test setup for T5.3 is designed for testing the communication within a swarm of drones, and the communication of the drone swarm with the ground network via an NTN satellite connection. Several drones use Wi-Fi modems to communicate with the other drones, and, additionally, one dedicated drone is equipped with an NTN satellite modem allowing communication with the ground network.

Therefore, the lab test setup consists of Wi-Fi modems, an NTN UE modem, an NTN gNB, the 5G core network and applications on the client and network side.
Additional 5G-NR Sidelink modems allow comparisons between 5G-NR Sidelink and Wi-Fi in the challenging environment of highly mobile drones. The interconnections between the drones are emulated by the channel emulator and enables RF connections with virtual flight paths and mainly Line-of-Sight propagation conditions including interference.

This lab setup is shown in Figure 5**Fehler! Verweisquelle konnte nicht gefunden werden.**.

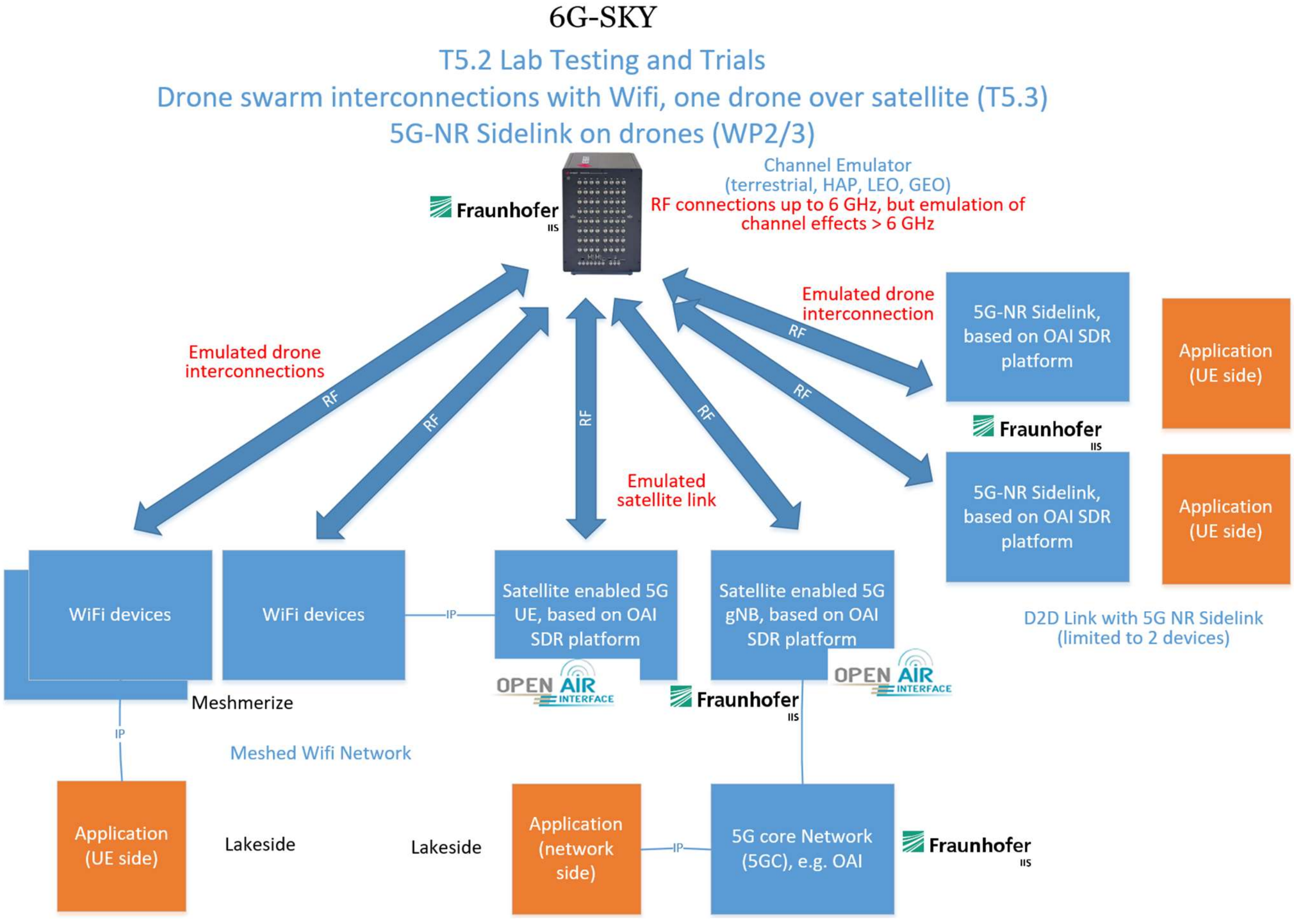

Figure 5: Detailed lab setup for testing drone swarm communications (T5.3).

Challenges for this task are itemized as follows:

- High mobility of UAVs,
- Uplink requires higher link capacity than downlink as data from application sensors are usually sent from the UAVs.

Potential fields for assessment can be outlined as follows:

- 5G-based (UAV to satellite) link emulation (latency, link capacity, etc.)
- Sidelink D2D emulation for communications among UAVs (latency, link capacity, interference). Comparison of Sidelink and meshed, probably complementary usage
  - Note that licensed and unlicensed frequency bands are currently specified by 3GPP for the 5G NR Sidelink. It has to be defined later-on in the project, which scenario(s) shall be emulated in the lab.
- DA2A connectivity for the UAV mesh network is also planned, for this purpose Wi-Fi will be used.

For direct 5G-NR NTN communication, OpenAirInterface will be used for the 5G-NR UE NTN modem, for the 5G-NR NTN gNB, and for the 5G core network. In addition, the 5G-NR Sidelink modems will be based on OpenAirInterface, allowing extensions towards 6G and reducing the dependency on commercial equipment availability.

The second test setup (T5.6) is designed for testing communications between terrestrial UEs and a base station located on a high-altitude-platform (HAP). This base station is connected (backhauled) to the ground-network using a satellite connection. The terrestrial UE can perform handovers between the HAP and a terrestrial base station. Both base stations (terrestrial and on the HAP) are connected to a common terrestrial core network. Mostly commercial equipment is used in this test setup.

This lab setup is detailed in Figure 6.

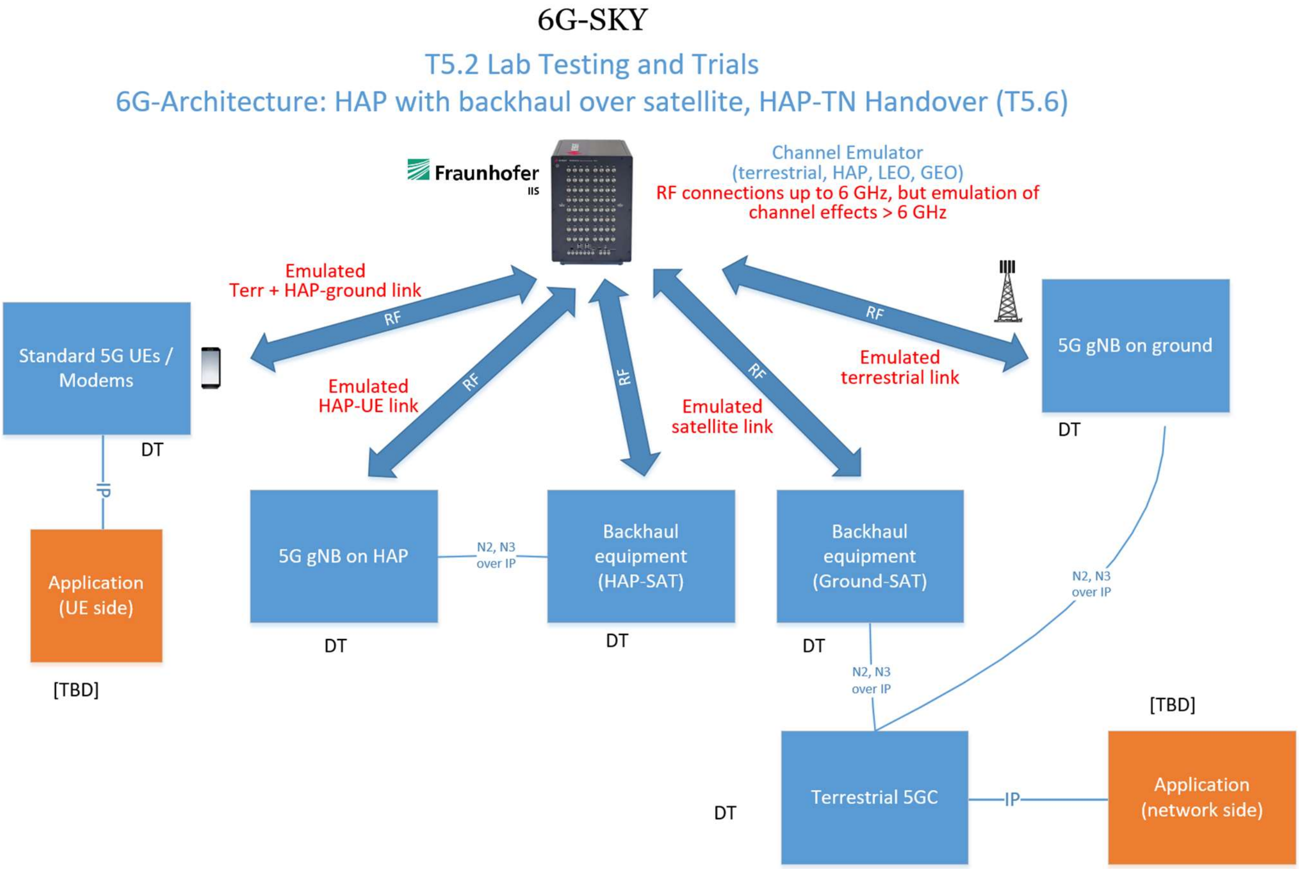

Figure 6: Detailed lab setup for testing integrated terrestrial/non-terrestrial networks with HAPs and Satellite-Backhaul (T 5.6).

Challenges of the communication architecture, to be evaluated in the lab setup:

- Long distance between HAPS-ground, HAPS-low altitude and HAPS-satellite nodes will be always challenging in terms of overall link budget

Potential fields for assessment:

- 5G (UE to HAPS and/or terrestrial network)-based link emulation (handover times, latency, link capacity,etc.)
- Channel emulation of HAPS links in Frequency Range 3, especially from 6-10 GHz
- Emulation of HAPS coexistence with terrestrial networks assuming in-band operation

- Connectivity of UAVs as UE (DA2G) to dedicated ground base station on FR3 with scenario handover to Satellite if connection to base station is lost

Using emulation with the channel emulator and real equipment allows assessing different KPIs, e.g.:
- timing effects of initial log-on to satellite and cellular networks
- timeouts (e.g. tunnel especially for satellite communications)
- re-setup of links
- switching times

4.1.4 TRL reached by the demonstration
The lab setup enables TRL5, because the channel emulator creates a realistic environment for the communication devices, including wireless propagation conditions and antenna characteristics.

4.1.5 Particular 6G-features of the use case
There is no specific functionality of the lab environment itself going beyond 5G-Advanced, which is more upon Tasks 5.3 and 5.6. Certainly, the lab setup supports 6G scenarios towards 3D-network architecture.

Procedures
Figure 5 and Figure 6 indicate which partner contributes which component to the test setups. Besides that, further procedures for integration and evaluation will be coordinated with Tasks 5.3 and 5.6.

Schedule
The lab environment is already available and well established by other terrestrial and non-terrestrial research projects.

Contributions to sustainability
Regarding sustainability, the lab setup helps to avoid lengthy field trials, requiring higher energy consumption by traveling, operation of ground equipment, UAVs, and HAPS.

5 Task 5.3: Multi-technology network integration

Overview

Lead: EAG, **Contributors:** Fraunhofer, Meshmerize, Airbus, Motius, Lakeside Labs, Deutsche Telekom, KTH, EAB, Skysense

5.1.1 Motivation
The scope of Task 5.3 is to combine the components developed in the WP1-4 into a functional demonstration of wireless communication links over-the-air. The demonstration is being tested with the dedicated hardware under various real environments conditions. The dedicated hardware for the test includes drones, antenna modules for ground station,

antennas for the flying vehicle, and dedicated radios or a Software-Defined Radios (SDRs) setup that are able to support the specific requirements are needed. With this setup, we intend to test the technologies we have investigated, in particular the capabilities on the new 7 GHz to 15 GHz frequency band for which this new RF front-end component is needed.

5.1.2 Setup

The field-demonstration is planned on the site of Airbus in Ottobrunn/Munich. There is a helipad with sufficient free space for drone flights and antenna masts can be setup nearby or on the rooftop of one of the buildings, where we can test our experimental setups. We intend to set up our special ground base stations there and test our setup with several UAV platforms that are equipped with dedicated communications and antenna modules flying around the terrain. Figure 7: Airbus Helipad in Ottobrunn, Munich, Germany shows the area.

Figure 7: Airbus Helipad in Ottobrunn, Munich, Germany.

The demonstration in Task 5.3 can be grouped into four main areas.

- First, we plan to test the connectivity of UAVs as end-user devices. For this purpose, several drones are equipped with hardware that provides the connection to the ground station, represented as network link 1 in Figure 8. Furthermore, in our planning, one UAV would be equipped with an additional satellite connectivity hardware (Figure 8, network link 4). The network traffic to the individual UAVs will be steered either through the terrestrial base stations directly in link 1, or through the satellite connection 4. For the terrestrial base station, we plan to run in the 7 to 10 GHz frequency range so that specific prototype hardware will have to be developed for this work package. This is where the new Phased-Array-Antenna for the gNB on ground are used to demonstrate beamtracking and MU-MIMO, see Figure 9.
- A Direct Air-to-Air (DA2A) connectivity for the UAVs mesh network is also planned to be implemented, for this purpose Wi-Fi 6 technology is used (network link 2).
- At least one mobile handset will be used in the demonstration, link 3 in Figure 8. Here, we want to demonstrate how the connectivity, to a ground base station and to a flying gNB attached to a drone, works. In particular, the quality of service during handover between terrestrial and non-terrestrial networks is of interest.
- Additionally, key components for safe and explainable AI will be integrated in the demonstration. An AI-based algorithm, which adapts to changing channel and network

situations during flights will be demonstrated. This algorithm shall improve the end-to-end communications quality by operating on network system parameters. Moreover, a system that explains the AI decisions should be added, in case of connectivity malfunction.

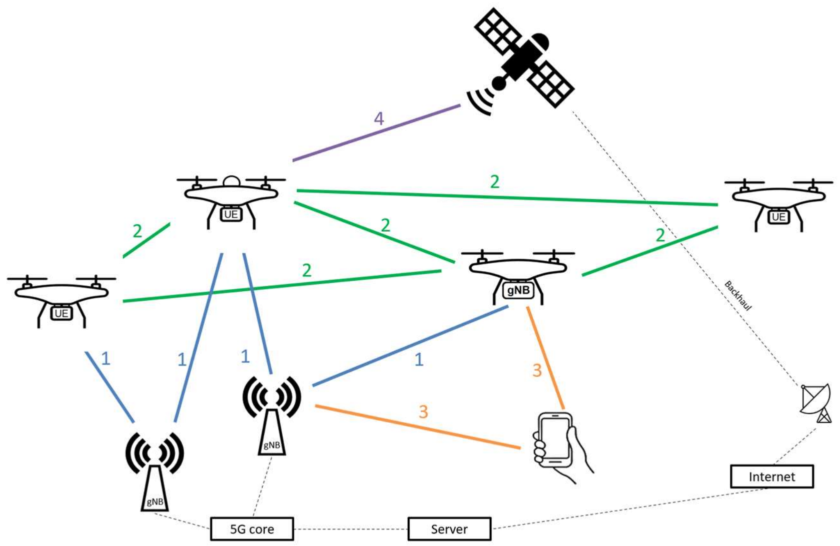

Figure 8: Overview of the planned connectivity.

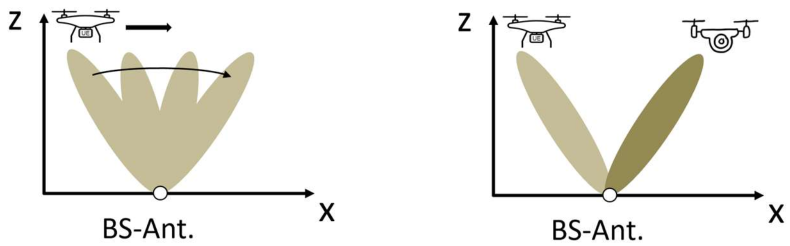

Figure 9: Illustration of beamtracking (left) and MU-MIMO (right).

Goals

5.1.3 Goals, Performance Metrics and Success Criteria

Evaluation and PoC of the resultsfrom WP2, WP3 and WP4. Multi-Technology Connectivity Links and the resilience of the adaptive multi-technology network will be tested.

During the demonstration, we intend to get insights into the following key technical aspects:

- Resilience of the adaptive multi-technology network by switching between networks, terrestrial network and satellite + mesh network.
- Timing effects of initial log-on on satellite and cellular networks, timeouts (e.g. tunnel, especially for satellite communications), re-setup of links, switching times, etc.

- Achieved robustness when switching between networks.
- Constant quality of the Multi-Technology Connectivity Link for the user.
- Throughput and connection coverage.
- Performance under different channel conditions, e.g., LOS/NLOS propagation
- Knowledge regarding realistic tower grid and cell shape for ground station.
- Initial investigation into interference issues, if applicable

5.1.4 TRL reached by the demonstration

TRL5 refers to “technology validated in a relevant environment”. In this PoC, the hardware experimental setup and software architecture are to be tested under real environmental conditions. This applies as far as realistically feasible. Not all possible scenarios can be reproduced, as the necessary hardware and regulatory approvals are not available for all scenarios.

Limitations are to be applied to the following example:

- For the Demonstration setup in the field, we are only allowed to operate on licensed frequency bands and with the approved power level.
- There are limitations regarding the availability of the required hardware of the RF-front-end and SDRs. E.g., the number of RF-ports necessary for beamtracking and MU-MIMO, and the available frequency range.
- Not all flying objects mentioned in the 6G-SKY project are available for demonstration. There are no flying taxis available yet and we will also not able to show the radio link to commercial aircraft.
- Additionally, there is also the altitude limitation of 120 m for UAV flights in open category.

5.1.5 Particular 6G-features of the use case

The PoC should justify the feasibility of 6G frequency candidates, e.g., 7 GHz—15 GHz, for 3D-aerial networks with focus on a base station which ensures airspace coverage. The focus in WP3 is AI-based mobility management, which accounts for both horizontal and vertical handovers, thanks to the 6G-SKY AI-native architecture. Hence, an additional main aspect in this task (Task 5.3) is the handover between different network technologies, especially between TN and NTN networks. Finally, the aspect of embracing AI is a key element of 6G.

Procedures

The planning of the demonstration has started recently, so there are still many details to be clarified. In general, there will have to be some adjustments to the PoC plans during the project.
Currently, the following main points have been identified:

1. We need a test license for outdoor demonstration in the 7 GHz to 15 GHz band. Clarification with the Bundesnetzagentur is needed. We must think of sufficient guard time for the license time period. (DT, Airbus).
2. The planned 6G frequencies 5.9—8.4 GHz or 10.0—10.5 GHz for DA2G are still under discussion. The frequencies 6425—7025 MHz and 7025—7125 MHz are also used for FSS up-link, therefore it is less suitable for sky applications with up-tilt antenna pattern. As far as we know, today 10.0—10.2 GHz range looks facilitating for aerial use. The results of the ITU World Radiocommunication Conference 2023 (WRC-23) are interesting in this respect.
   As a fallback, there is also the option to work in the usual mobile radio frequency range FR2. In this case, the use of traditional remote radio units would be possible, for example.
3. For the demonstration, location the Helipad at the Airbus site in Munich is settled. (Airbus).
4. The antenna for ground station for the demonstration of the DA2G link will be provided by EAG. It still needs to be clarified whether EAG will also provide antennas for UAVs or commercial aircraft. (EAG)
5. For the ground station, the used SDRs, Radio, RF-Fronthaul, gNB, antenna requirements and number of ports for MU-MIMO and beam targeting capabilities have to be clarified. (Fraunhofer, EAB)
6. There is the idea to extend the demonstration by one mobile handset. In this case, we probably have to add an Up/Down conversion to the phone so that we can work in the proposed frequency range FR3. (DT)
7. Connection from the UE to commercial network for handover scenarios are under discussion. (DT, Airbus)
8. As a flying taxi is not yet available for the test set-up, we plan to show these investigations also using the drones here with realistic air-taxi flight heights. Here, we still have to define which drone carries what technology for the PoC. We also need the right persons with the pilot licenses for the flights. (Airbus, Meshmerize, Twins)
9. For the DA2A mesh network between drones the Wi-Fi 6 technology is planned. It is important to consider that the four drones are remotely controlled by the pilots through a Wi-Fi interface. In this case, the Wi-Fi control channels can interfere with the drone mesh network channels and limit the performance. (Meshmerize, Airbus)
10. For the demonstration, also a satellite link to a UAV is planned. For this, we need the antenna and radio which is carried by the drone. Here, for the SatCom link Heinrich Hertz in the Ka-Band is under discussion. Antenna options are shown in 8.1.3. (Airbus FDH, Lakside, Fraunhofer)
11. For the demonstration, we also need a gNB and NUC mounted on a drone. (Fraunhofer, Airbus)
12. The specific 5G core network to be utilized is still under discussion, this also depends on the used SDRs. (EAB, DT, Fraunhofer)

In the demonstration of Task 5.3, there are possible overlaps with the other tasks such as Task 5.4 (3D network demonstration with multiple drones flying as a swarm incoordination),Task 5.5 (Demonstration sense and avoid mechanisms), and Task 5.6 (Demonstration of HAPS networking).
Here, it has to be checked and coordinated whether the demonstration-setup in Munich is compatible and can be extended or parts can be reused.

- For example, there was a discussion on an additional demo in Munich with Skysense regarding Task 5.5.
- The use of the Drone swarm network technology from Task 5.4.

Schedule

The investigations on the overall concept with considerations to the architecture, software and hardware components have already started in WP1 to WP4. From WP2, there are already first simulations on hardware for a base station radiator and antenna array at approx. 7 GHz.

An approximate timeline is as follows:

1. Currently, a more detailed definition is being worked on for what will be shown in Task 5.3. There are still coordination tasks among the project participants.
2. By the end of 2023, we will have clarified the frequency band and regulatory conditions on which we are allowed to launch the demonstration.
3. From the beginning of 2024, the necessary hardware for the demonstration must be defined in detail, including the responsibilities of involved partners for each component and their interactions. This refers to all aspects and interconnections within the demonstration set-up.
4. Once the previous item has been settled, in Q2 2024 the missing hardware must be arranged. If necessary to reduce risk, the first initial tests of sub-components will already have been completed.
5. Before the summer holidays of 2024, it must be checked whether all responsibilities, approvals, software, hardware prototypes and test vehicles are in place.
6. The Demonstration environment is planned to be ready by late summer 2024 followed by the first trial of demonstration.
7. Experimental demonstration of the holistic network integration and evaluation of KPI as well as optimization and tuning of system components from Q4 2024 to Q1 2025. It is preferred to have the hardware earlier in 2024, e.g., in Summer.
8. April 2025 is set as the conclusion of the documentation and the end of the project.

Contributions to sustainability

With a non-massive MIMO ground station antenna, the power consumption of the ground station is kept low and the amount of material necessary to build the antenna is not excessive, promoting a lean and sustainable demonstration.

6 Task 5.4: 3D network demonstration with multiple drones flying as a swarm in coordination

Overview

6.1.1 Motivation

Lead: Lakeside Labs, **Contributors:** Twins, Meshmerize, RED Bernard, LCA.

Task 5.4 is mainly concerned with the UAV (swarm)-level of the 6G-SKY architecture and ground users. UAVs are a flexible carrier that can move the communication network towards users into areas with sparse network coverage and close the link to the rest of the network architecture. At the same time, UAVs can act as flying sensors collecting data and sending them over the network, sometimes do on-board pre-processing of data. They are therefore also highly (3D) mobile users that have to be coordinated within the 6G-SKY architecture. This means swarm coordination, collision avoidance, obstacle detection etc. may be seen as 6G-SKY network services that run partly directly on UAVs and partly offloaded to nearby edge centers within the 6G-SKY architecture. Control data for UAV coordination as well as processed data or offloading of raw data from application sensors must be handled by the 6G-SKY architecture. Very different requirements in terms of massive broadband, real time aspects and D2D communication at the same time must be met, which are not realized with current 5G technology implementations. This calls for a combination of different communication technologies as proposed by the 6G-SKY project.

Task 5.4 is to analyze the performance of a drone swarm serving as a means to extend the communication network to remote areas, and, on the other hand, also performing sensing tasks (combined sensing and communication).

The potential applications of such a UAV-based network are plenty: supporting autonomous mobility in rural areas, periodic inspection of infrastructure (mobility, transportation, energy, water supply, pipelines), precision farming, environmental monitoring, disaster management, etc.

We opted for use cases that will show 5G+ features in connection with goods mobility as a first test case in a rural cargo terminal where cargo containers are shifted from rail to road and back. Details can be retrieved from the D1.1 document. We can already show the benefit of 6G-SKY for the transportation and logistics branch. Another advantage is that we can operate in a “secured, lab-like” area for these particular use cases. This is vital for such early-stage UAV-swarm tests as regulatory frameworks still inhibit the use of autonomously operating UAVs and UAV swarms in real outdoor target environments. Once the functionality and performance are shown in these use cases, we can extend the 6G-SKY approach to any of the aforementioned applications to use UAV swarms in the 6G-SKY architecture for supporting them.

This task comprises two related scenarios/use cases, namely,

– Use Case 1 (UC1): Logistics centers supported by swarms of drones
– Use Case 2 (UC2): UAV swarm to support autonomous mobility and infrastructure in rural areas

UC1: Logistics centers supported by swarms of drones

UC1 is about supporting the cargo terminal of the Logistik Center Austria Süd in Fürnitz, Austria (Partner LCA) with 6G-SKY-enabled UAV-swarms. In the hub, containers come in via train or truck and are shifted from one modality to the other and often stored in dedicated areas. So called „cargo lifters“ or „reach stackers“ (basically diesel trucks with container lifting mechanisms/cranes) or cranes load or unload containers on/from trucks or wagons or storage areas. The containers carry a unique container-ID written on different outside container enclosures and sometimes on top of the containers.

The processes in the terminal come with some challenges. To avoid unnecessary routes and unnecessary shifts of containers (so called „dispo lifts“), it is necessary to know about the location of the containers in the storage areas. Currently, the reach stacker drivers select a particular container (with particular ID). The reach stackers are equipped with GPS modules on the lifting crane that register the position of the containers when they are again released in the storage areas (position in a grid and level of storage). The information on stored containers (location and container ID) is then used by a central system to show the drivers the way to a particular container the driver selects to handle next.

However, the current route planning does not include other traffic information (location of trucks, jams, accidents, etc) and relies on the “integrity” of the drivers, meaning that they really pick the container they report to the system (container ID). Corresponding improvements can further reduce unnecessary routes and unnecessary shifts of containers with respect to the current solution. This also holds for the paths of the trucks entering the cargo terminal.

<u>The long term vision is that the 6G-SKY enabled UAV swarm will improve the situation by</u> periodic state estimation of the cargo terminal using UAV-based cameras and image analysis. The UAV-swarm periodically (e.g. every 30 minutes) assesses the cargo terminal. The information gathered is then used to locate the containers, locate stackers and trucks and assess the traffic situation in the terminal in case of jams or accidents etc.). The information will then be used to calculate the best routes for stackers and trucks and will be compared to the current solution. The information will also be used to check integrity of the positions and container-IDs created by the existing GPS-system. Later on (outside the scope of 6G-SKY) other use cases in connection with stock-keeping or asset/container maintenance (cleaning, repair, painting) can be addressed.

As the situation with containers, trucks and stackers is hard to simulate in a lab environment, we decided to do first test and measurements as well a minor part of the demonstrations in the cargo terminal itself which is geographically limited. Nevertheless, the vision is that the information of the terminal (and of other terminals in the trans-modal transportation chain will be accessible to a (global) cargo booking system where delivery of goods can be ordered with time of arrival guarantees and real time tracking. Here, the other elements of the 6G-SKY architecture are important. The information will be transmitted using a reliable and redundant mixture of communication technologies (5G cellular, HAPs-, satellite communication, etc.).

The demonstration has a simulation part and an experiment part. The experiment part will show the coordinated flight of the UAVs (one UAV for overview, other UAVs for container-ID assessment), data acquisition and communication within the 6G-SKY architecture. This can only be done at LCA as this is the only way to have containers, trucks and stackers at one place to be detected. Here, we will mainly assess all communication and coordination-related parameters relevant for the performance of the UAV-part of the 6G-SKY architecture (described below) and the performance of data acquisition and pre-processsing.

The simulation part consists of a number of components. First, we will show the coordination and communication of the UAVs closely accompanying the experiments. We plan to perform an OMNeT++-based simulation study. Communication will be modelled using the Simu5G and INET frameworks. For the coordination of the drone swarm we plan to use an artifical bee colony (ABC) algorithm. The ABC algorithm is a metaheuristic optimization technique inspired by the foraging behavior of honeybees. It can be adapted to solve various optimization problems, including route planning and resource allocation keeping in mind the communication requirements, which align well with the challenges presented in the logistics centers scenario. These simulations will prepare the UAV flights for data acquisition in the terminal. The second component of the simulations will refer to the improved routing for the stackers and trucks together with dispo-lifts based on the information gathered by the drones (container-, truck-positions, etc.). The corresponding simulation environment is based on the AIMSUN[8] traffic-simulation bundle together with dedicated Python scripts and a GIS software tool to create the models. We will derive benefits and application-related metrics only from such simulations (e.g. reduction of paths and energy consumption compared to current route planning, etc., see Section 6.1.3). These metrics directly correspond to benefits for the terminal and to its goals (see below). Experimental tests or demonstrations of these metrics are out of scope for this project as it would require a full-fledged integration of the technology into the processes of the terminal, which would demonstrate TRL5 to TRL6. The 6G-SKY related tests and demos in the terminal are more or less data acquisition campaigns for testing networking related parameters, not directly the use case-related metrics. The test and demo campaigns at LCA Süd will be the basis for lab-simulation-based assessment of the application related metrics and benefits for the cargo terminal. All in all, the demonstrations therefore only reach TRL 4 as they will involve lab simulations to a large extent.

The information created from the UAV-swarm will show that the 6G-SKY architecture can support this particular application and an improvement of dispo lifts and reduction of routes by simulation. The results can be exploited via further integration into follow-up projects.

UC2: UAV swarm to support autonomous mobility and infrastructure in rural areas

UC2 is related to UC1 in the sense that the application is exactly the same. The big difference is that the manned diesel-driven reach stackers will be replaced by autonomous electrical vehicles performing the same task.

The UAVs and ground vehicles will be forming a mixed swarm of robots that will be coordinated jointly and will exchange sensor- and telemetry information. The information generated will be used to define the mission goals of the ground vehicles, to perform the cargo shifts efficiently, as well as redefining the UAV mission if necessary.

Adding another mobile (user-)component to the network comes with additional challenges that lie in the further enhanced 3-dimensionality of the problem, the high mobility and even more strictly real-time relevant data that has to be transported through the network. We will show the performance of the 6G-SKY architecture in away similar to UC1 (simulation and experiments). The relevance of 6G-SKY goes far beyond automated cargo terminals towards any form of operation of collaborating autonomous vehicles (personal mobility, farming, disaster management, etc.).

[8] https://www.aimsun.com/

As such vehicles are not going to be in place by the end of the project, we will demonstrate the mixed swarm with ground robots from our subcontractor ALP.Lab to assess the network performance. The demonstration will take place in parallel via simulations and in a testbed for autonomous mobility and UAVs. As the technology will be demonstrated in a lab environment it reaches TRL4 at the end.

6.1.2 Setup

UC1: Logistics centers supported by swarms of drones

The demonstration setup is as follows. A UAV at higher altitudes (70-100m) to locate container islands, trucks, cargo lifters and traffic events will be used (based on a twins FOLD KAT drone design). The information on the location of container islands will be sent to other UAVs operating at lower altitudes (17m) to identify containers, namely, finding and reading their container IDs with on-board cameras and image processing. At the time of finishing this document, we expect to use up to three UAVs based on the twins FOLD GEO design. The pre-processed and also raw image data will be offloaded to a local server. Based on the gathered information, re-planning of routes of vehicles (trucks,cargo lifters, etc.) will be simulated. The basic setup is shown in Figure 10.

Figure 10: Experimental setup for UC1 at Logistik Center Austria Süd.

The communication within the UAV swarm will be realized by Wi-Fi (mesh) and cellular technologies, redundantly. Other technologies (redundant) will also be assessed for enhancing robustness in the UAV-network. All UAVs will carry sensors and data analysis HW from RED as well as a companion board (LAKE) as a UAV-control center handling swarm coordination algorithms as well as the communication protocols. The twins FOLD KAT UAV can carry payloads of up to 5kg and has therefore some headroom for additional sensors or communication HW. All UAVs will be registered.

Regarding the software side, the UAVs will run an Ardupilot flight controller communicating with the companion board via the MAVLink protocol. We will use the Robot Operating System (ROS) environment for implementation (version to be defined). Onboard telemetry sensors will be used for flight control. The companion board runs the coordination algorithms (based on e.g., the artificial bee colony swarm algorithm) and also controls communication to fellow drones, base station and other entities. It will initiate and stop data recording and is responsible for sending raw or processed data (e.g. container IDs, container locations, stacker locations, etc.) to a server.

The server will also include a mission control component to define and control the mission of the UAV swarm. The information gathered will be used for (offline) simulations of best routes for the trucks and stackers.

There are two options for the ground based server: Option B is a local server that is located at the terminal and connected to the UAV swarm via Wi-Fi (mesh) and/or cellular. In Option A, the same will be deployed on a remote server that will be placed in the premises of RED in Vienna. The connection to the UAV swarm will be over cellular or technologies residing on HAPs or Satellites to show how the UAV swarm is embedded in the 6G-SKY network.

UC2: UAV swarm to support autonomous mobility and infrastructure in rural areas

The setup of UC2 comprises the same UAVs and servers as in UC1 with the same HW and SW setup. To this setup, autonomous robots/vehicles on the ground will be added playing the role of the stackers in the terminal (or general autonomous means of ground transportation). The aim of UC2 is not to show a particular use case but to validate the performance of the 6G-SKY architecture to support coordination of autonomous ground and aerial vehicles as a heterogeneous swarm. The network itself provides sensing, information-creation, communication and coordination services at a time. Joint sensing and communication is a beyond 5G aspect. The basic setup of UC2 is shown in Figure 11.

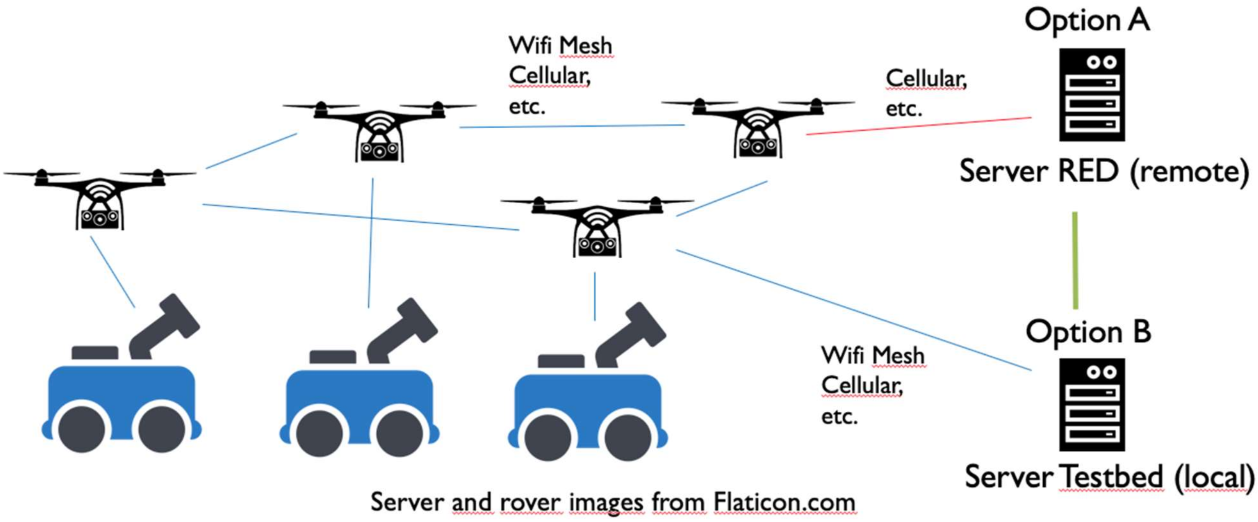

Figure 11: Experimental setup for UC2. The demonstration is going to be performed in testbed for autonomous mobility with our subcontractors AIRlabs Austria and ALP.Lab.

The additional autonomous ground robots/vehicles will be connected to the UAVs via Wi-Fi (mesh) or cellular. UAVs and ground vehicles will exchange telemetry data (position, velocity, etc.). In the demonstration, UAVs and UGVs will follow mobility patterns that are typical for a cargo terminal. While doing so, network performance (e.g., throughput, latency, packet error rate) will be evaluated. The tests and demonstrations will be performed in dedicated testbeds.

Goals

6.1.3 Goals, Performance Metrics and Success Criteria

UC1: Logistics centers supported by swarms of drones

The goal of the demo is twofold. It has a target application dimension (optimization of a cargo terminal via simulation) and a 6G-SKY network performance dimension (via both, simulations and experiments) both of which come with particular goals, performance metrics and success criteria. We will use simulations with environments prepared in WP3 as well as experiments in target environments and testbeds.

Technology related goals (networking/coordination/detection):

This task is to show

– Appropriate coordination of UAVs (Overview—UAV, UAVs for details). This means that the region of interest is well covered by the UAVs.
– Proper communication of information on container islands to the UAVs for container-ID reading.
– Detection of stackers, container islands, trucks via UAV-based image processing.
– Identification of containers in a container island via UAV-based image processing.
– Exchange of control- and payload data in the UAV network.
– Communication of payload data to local and remote server.

Technology related performance metrics and success criteria (networking/coordination/detection):

These metrics will be finally assessed in the tests/demos. What shall be reached is the following:

– Min. data transfer rate > 5Mbit/s
– Packet error rate < 1%
– Max. delay for control data < 100ms.
– Positioning accuracy for containers, stackers, and trucks <= 5m.
– Detection of stackers, container islands, trucks (mean average precision > 0.8)
– Recognition accuracy of container IDs > 95%.

The result is a technical PoC for the 6G-SKY-enabled UAV swarm.

Application related goals (simulation only):

– Showing that the data (info on positions of containers, trucks, etc. derived from image data) can be used to re-plan routes.
– Showing that the re-planned routes yield better energy efficiency and reduction of CO_2-footprint wrt. current solution.
– Demonstration via simulation with data captured at LCA Süd.

Application related metrics and success criteria (simulation only):

- Reduction of anticipated number of dispo-lifts by 5%.
- Reduction of per diem travel distance of the vehicles (stackers, trucks) by 5%.
- Reduction of energy consumption and CO_2-emission by 5%

The result is a PoC demonstrating that the 6G-SKY-enabled UAV swarm can improve the processes in a cargo terminal.

UC2: UAV swarm to support autonomous mobility and infrastructure in rural areas (use case 2)

The goal of UC2 is to show whether real time control of the UGVs together with UAVs in a heterogeneous swarm is possible within the 6G-SKY-architecture. The assessment will focus on the technical aspects of networking performance and swarm coordination. We aim at characterization of properties and limitations of machine type communication in simulation and experiment. We will characterize metrics such as

- Min. data transfer rate: 200kbps (UL)/300kbps (DL)
- Packet error rate < 1%
- Max. Delay: 140ms (UL)/10ms (DL)

However, the exact values will be determined during the experiments.

This will lay the groundwork for a later integration of autonomous reach stackers into the LCA environment and give necessary insights for the corresponding design of the communication and coordination framework at LCA.

6.1.4 TRL reached by the demonstration

The activities and demonstrations related to UC1 and UC2 mostly refer to TRL4. In UC1, the target environment will only be used to gather data and show swarm communication and coordination. A large part will be done via simulations, especially regarding all application related metrics. The majority of the developments happen on a lab scale. Technology-wise, we show functionality of technical components (communication, swarm-coordination, data collection and pre-processing, simulation of routes). The components are still subject to ongoing research and far from any level close to a product. Also, the level of integration is still low. A full-fledged integration to show the technology on a system level in a target environment is out of scope for the project and will be the objective of follow-up projects. Therefore, a maximum TRL level of 4 will be reached in these demonstrations.

6.1.5 Particular 6G-features of the use case

The demonstration cases feature particular 6G aspects that are beyond 5G. For swarming, low latency direct D2D communication without involving base stations is vital. Current 5G implementations do not allow for this. Therefore, we have to rely on multi-technology links to include both D2D and D2I communication.
Another aspect going beyond 5G is joint sensing, communication and computation in 3D with respect to the drone swarm. Beyond exchange and transmission of payload and control data,

each drone represents a sensor node with computational abilities for sensor data processing and local decision making influencing the behavior of the swarm based on the computation results. Since the UAVs act in 3D space with considerable mobility, 3D features of the communication network have to be taken into account.
For robustness in communication, we will also rely on redundant communication technologies (e.g., meshed WiFi and mobile broadband).

Procedures

UC1: Logistics centers supported by swarms of drones

Figure 12: Example procedure for data acquisition in UC1 at LCA Süd. A region of the cargo terminal will be assessed by the overview drone. The location of container islands (beside other objects like trucks, etc.) will be identified and reported to the detail drones which read individual container IDs of containers in the islands.

How will the demonstration be performed?

- Simulation of setup.
- One day at LCA.Overview UAV + 3 Detail-UAVs for data collection and UAV swarm coordination (see Figure 12
  Local Server + Server at RED (remote data analysis)
  UAV meshed Wifi network + 5G connection
- Permissions/Clearances
  Only permission by LCA/TSA/ÖBB, Drones will be in the Specific Category
- Locations
  LCA for data capturing, LAKE and RED for simulations, offline data analysis and evaluation

Components and contributors:

- Drones: twins
- Wifi Mesh: Meshmerize
- Cellular modules: Lakeside Labs
- Sensors, Data reduction HW, Evaluation Servers: RED
- Simulation environment: Lakeside Labs+Meshmerize

- Route optimizazion and dispo-lift optimization routines: RED (offline)
- Testbed: LCA

UC2: UAV swarm to support autonomous mobility and infrastructure in rural areas

How will the demonstration be performed?

- Simulation of setup.
- 2-3 days at testbeds defined together with Airlabs Austria and Alp.LAB Overview UAV + 3 Detail-UAVs for data collection and UAV swarm coordination, 2 UGVs included in the mesh network.Local Server + Server at RED (remote data analysis)
  UAV meshed Wifi network + 5G connection
- Preparations
  2 UGVs will be prepared by ALP.lab for integration into the robot network.
- Permissions/Clearances
  Drones will be in the Specific Category, Permission will depend on the final location.
- Locations
  to be defined, e.g. testbeds proposed by Airlabs Austria and ALP.lab, LAKE and RED for simulations, offline data analysis and evaluation

Components and contributors:

- Drones: twins
- Wifi Mesh: Meshmerize
- Cellular modules: Lakeside Labs
- Sensors, Data reduction HW, Evaluation Servers: RED
- UGVs: ALP.Lab
- Simulation environment: Lakeside Labs+Meshmerize
- Route optimizazion and dispo-lift optimization routines: RED (offline)
- Testbed: e.g. AIRlabs or ALP.LAB test areas or other, tbd.

Schedule

The development of components for the demonstrations based on simulations and experimental setups take place in WP3. In the following, we present a rough WP5-timescale how to get from the components to the demonstrations:

1. Start of the integration processes for UC1 and UC2 (early 2024) and continuous testing with feedback loops to WP3. In parallel, simulations on component- and system level will take place in order to prepare the demonstrations. In parallel, data gathering e.g. at LCA will take place with individual components/UAVs, etc.
2. Demonstration setup is planned to be ready by Summer/Fall 2024.
3. Experimental demonstrations and data gathering Fall 2024.
4. Evaluation of experimental data of the demonstrations in Winter 2024 and tuning of system components until the end of the project.

Contributions to sustainability

Sustainability related aspects were already mentioned above. The 6G-SKY architecture especially the UAV-swarm-based monitoring in a cargo terminal pursue the goal of reducing energy consumption and CO_2-emissions. The proposed state estimation with 6G-SKY can help reduce unnecessary dispo-lifts and extra miles for trucks and stackers once fully implemented. 6G-SKY also supports the transition to autonomous electrified mobility by providing the necessary ICT framework for including autonomous stackers. This can serve as an example for any kind of coordination of electrified autonomous transportation means such as road trucks.

7 Task 5.5: Demonstration sense and avoid mechanisms

Overview

Lead: Skysense, **Contributors:** Lakeside Labs, Airbus.

7.1.1 Motivation

This task is devoted to the fortification of low-altitude aerospace security, a critical component to ensure the safe operation of 6G-powered UAV applications. From an Unmanned Traffic Management (UTM) perspective, UAVs can be classified into two categories: authorized and unauthorized drones. The origins of UAV applications bring about two primary security concerns that require diligent attention.

The first category, authorized drones, are those registered and managed under a UTM system. Despite their authorized status, it is crucial to maintain rigorous real-time monitoring and tracking of these drones throughout their operational timeline. The heterogeneous nature of the air-interface protocols utilized by these drones presents a challenge, as these protocols may lack mutual communication compatibility or recognizability. In response, an integrative UAV sensing network, capable of detecting and tracking all UAVs, should work in concert with the UTM system to elevate the overarching safety standards.

The second category, unauthorized UAVs, necessitates immediate detection and swift dissemination of relevant information to all proximate authorized UAVs to circumvent potential collisions. It is critical to underscore that collisions may manifest physically or occur within the frequency domain. A robust UAV sensing network plays a pivotal role in identifying and locating any intrusive UAVs, both spatially and spectrally, irrespective of the drones' intended purpose.

7.1.2 Setup

Figure 13 below shows the setup to be employed during the demonstration. Within this framework, several (at least three) Skysense Validrone Time Difference of Arrival (TDoA) sensors are deployed around the protected area. It is of note that the effective surveillance region is represented by the convex area encapsulated by the sensor network with a certain extension, and sensors can be deployed out of the protected area for better coverage. Placement of these sensors at elevated positions, such as rooftops or local high points, is instrumental in amplifying the detection range and enhancing the precision of the localization and tracking performance. The system is engineered to identify the distinctive digital signatures inherent in the wireless communications exchanged between targeted UAVs and their remote control devices. This capability facilitates the pinpointing of UAVs and pilots alike, even from distances extending multiple kilometers outside the boundaries of the protected area. The results obtained from this detection process can then be transmitted to the UTM system managing the protected area, where they can be used to guide and inform UAV operations further.

In the context of the demonstration, the detection system boasts two primary capabilities: it can either authenticate the flight status of authorized UAVs or identify unauthorized UAVs, consequently initiating a warning sequence within the security system. All detection-related information is subsequently dispatched to the UTM system of the protected area. To illustrate, an unauthorized UAV may be identified as one originating from a brand that has not been granted permission to operate within the airspace of the protected region.

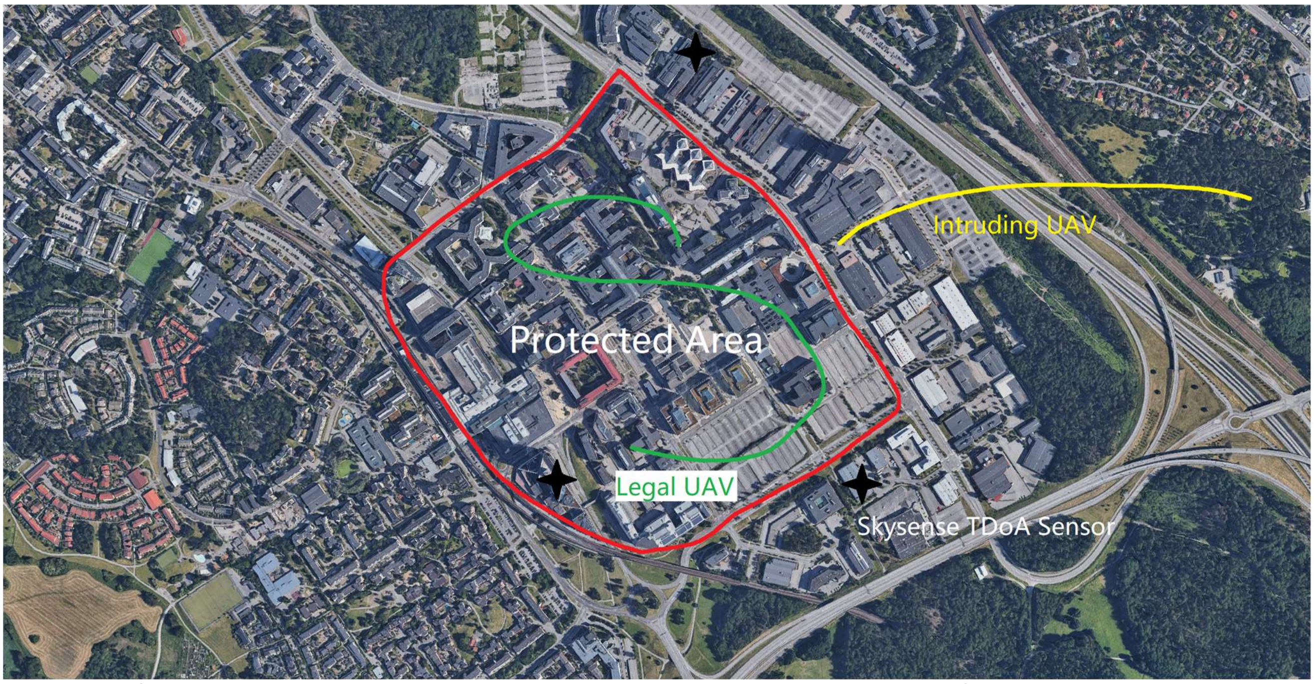

Figure 13: System setup. Red line marks the protected area, black star are the location of sensors. Yellow and green line are examples of intruding UAV and legal UAV, respectively.

Goals

7.1.3 Goals, Performance Metrics and Success Criteria

The goal of the demonstration is to show that the drone detection system is capable of providing reliable drone detection and tracking services to support legal UAV operations and also secure the protected area from threats coming from intruding UAVs. Considering the operating area of 6G-based UAV applications such as flying taxis or air transportation are large, one key goal of the demonstration is to showcase that the system can cover an area of multiple kilometers at least. We break down the performance metrics into the following list:

1. Show that the system can detect drones from 5 km away from the protected area.
2. Show that the system can localize drones inside the protected area.

3. Show that the tracking rate of the UAV is at least one per 3 seconds.

Considering that the detection rate may vary a lot depending on the deployment and also the surrounding environment of the protected area, the above performance metrics may vary depending on the size, terrestrial condition, and radio environment of the demo site. To achieve the targeted metrics, the location of the deployment needs to be agreed upon with Skysense.

7.1.4 TRL reached by the demonstration

The forthcoming TDoA sensor will be constructed leveraging the existing hardware of the Skysense Validrone sensor, a device already commercially available and utilized by numerous customers throughout Sweden, including notable establishments such as the Port of Wallhamn and other governmental sites. This sensor has earned the endorsement of Swedish authorities, having been successfully employed to monitor and intercept illicit UAV activities.

The advanced TDoA feature has undergone extensive verification and testing in Kista, Sweden. Empirical evidence from these tests indicates that a solitary sensor, optimally located, can furnish a detection range exceeding 10 kilometers, capable of detecting a drone traversing half the expanse of Stockholm city. Meanwhile, a configuration of three sensors can comprehensively cover the Kista area, encompassing the premises of universities and many global companies including the Ericsson headquarters. The planned demonstration presents a formidable opportunity to showcase the advanced maturity of the Skysense TDoA system, surpassing TRL5. This demonstration will also illustrate the system's capability to integrate seamlessly with the UTM systems of partnering entities, thereby delivering substantive value to prospective clients.

7.1.5 Particular 6G-features of the use case

6G can provide ultra-low latency and high data rate communications to the UAV system that would drive the UAV application to another level in terms of the size and operating speed of the UAVs. Moreover, UAVs may operate in the form of large swarms in many applications. At the same time, security is becoming a more critical thing for future UAV network applications when the UAVs will not only be a flying camera but also airborne transporters and flying taxis. Therefore, a powerful and fully integrated UAV sensing network becomes a necessity.

Procedures

Outlined below are the procedural steps for conducting demonstrations:

1. Sensor Network Planning: The positioning of sensors is the most pivotal element in determining the system's ultimate performance.
2. Sensor Installation at Demonstration Site: Essential requirements for this step include both internet and power supply. We highly recommend using a mast to elevate the sensor off the ground even if the sensor is deployed on a roof of a building.
3. Sensor Activation and Internet Connection: Ensure that all sensors are powered and successfully connected to the Internet.

4. Integration with Partners' UTM System: Link the sensors to the Unmanned Traffic Management (UTM) system of our partners.
5. UAV test: Launch UAVs both within and outside the protected areas. Based on the identification data supplied by the sensor network, the UTM system may categorize detections as authorized or unauthorized UAV.

Schedule

Skysense initiated the development phase of its system at the project's inception. The initial prototype sensor was constructed in January 2023, showcasing its functionality for the first time in Kista, Sweden by April 2023. Subsequently, the TDoA prototyping network was successfully established in Kista in June 2023.
Moving forward, our strategic roadmap involves the augmentation of our signal library with additional UAV protocols and manufacturers, prioritizing those that our partners utilize.

Moreover, we intend to incorporate our system into our partners' Unmanned Traffic Management (UTM) frameworks. This integration aims to underscore the value of a UAV sensing network in tangible industrial scenarios.

Contributions to sustainability

The majority of upcoming large-scale UAV applications, encompassing UAV transportation and industrial swarm utilization, require a significantly elevated threshold of safety and security compared to present-day UAV applications. Ensuring such a high degree of security and safety, without a comprehensive awareness of the skyward situation, might necessitate manufacturers and users to implement additional precautions and redundancies.

Skysense's UAV sensing technology provides an effective solution, enabling surveillance of drone operations and detection of potential threats. Consequently, UAV applications can primarily focus on their core objectives. We firmly believe that the cost savings resulting from optimizing UAV operations can be substantial.

8 Task 5.6: Demonstration of HAPS networking

Overview

Lead: Deutsche Telekom, **Contributors:** Airbus, Fraunhofer.

8.1.1 Motivation

HAPS concept combines advantages of both terrestrial and satellite networks - distance between HAPS platform and User Equipment in the range of tens of kilometers and high line of sight probability supporting usage of higher frequency bands not that much convenient for terrestrial network deployment in rural and deep-rural areas.
The purpose of this test is to use a Remotely Piloted Aircraft System (RPAS), provided by a subcontractor Grob H3, as a very flexible HAPS platform able to integrate any payload system, for a proof-of-concept demonstration in the low stratosphere with a focus on new 6G frequency band candidate in the Frequency Range 3 (7-24 GHz) and different types of back-haul solutions like air-ground and/or satellite to HAPS. A pressurized container with a liquid cooling system capable to accommodate any prototypical payload originally not optimized for stratospheric thermal and pressure conditions can be also provided. The main site for testing will be in Germany.

8.1.2 Setup

HAPS-Ground, HAPS-low altitude UAV, HAPS-HAPS and HAPS – Satellite links are under consideration to be tested. System Integration into live or isolated 5G mobile network would be also possible (Germany). Test Scenarios will reflect use cases defined in WP1. The main focus will be on KPI's critical for 6G network differentiation – link quality, capacity, reliability, delay, etc.

There are also two backup scenarios under consideration if HAPS platform or 5G+ system supporting FR3 frequency bands would not be available.

- Channel sounding test in FR3 with RPAS system or stratospheric balloon (in-house or subcontracted).
- Channel characterization test in FR3 with RPAS system or stratospheric balloon

8.1.2.1 *A donor aircraft as a flexible payload carrier*

The GROB G 520 is one of the world's largest fully composite manned and unmanned aircraft, providing an ideal system platform for OPV/UAV applications (Optionally Piloted Vehicle). The flexible payload-bay concept of the G 520 can accommodate multiple mission systems for both civilian and military applications and operations with a minimum of integration and modification lead time. Possible payload areas are illustrated in Figure 14. Illustration of past test configuration is shown in Figure 15.
Based on its proven airframe and systems reliability, the G 520 mitigates development risks for future UAV and/or system developments. The G 520 is the cost efficient performance platform for the UAV and OPV requirements of the 21st century, both in the HALE and MALE performance/application sector.

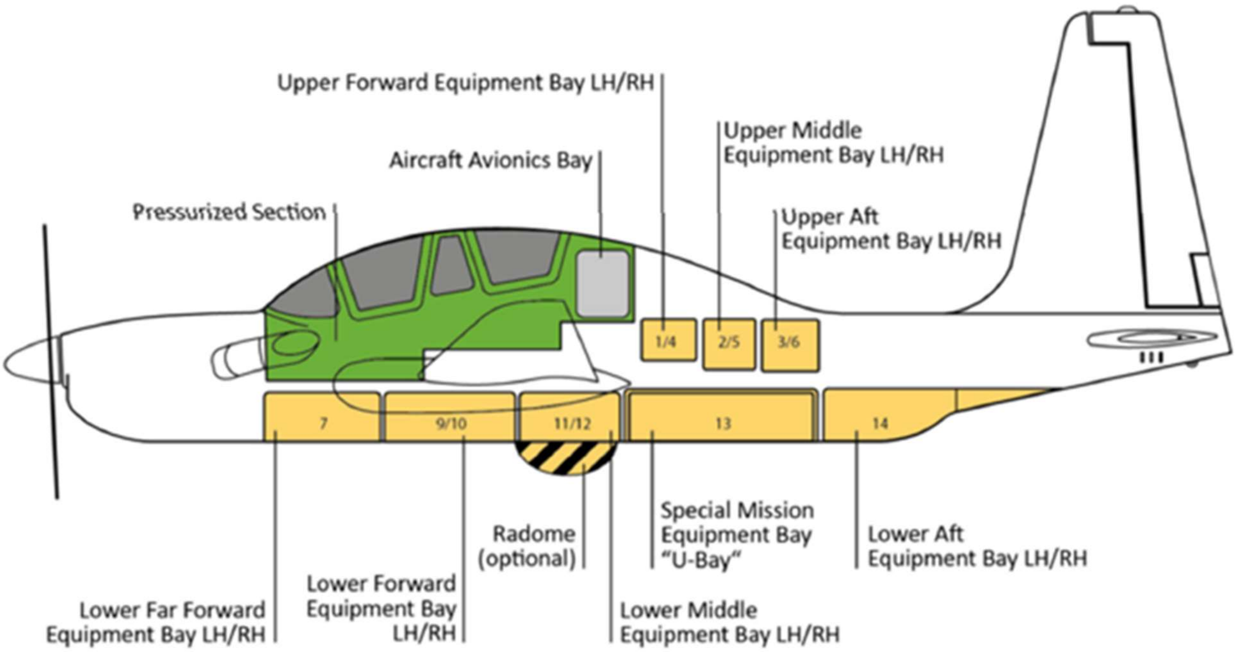

Figure 14. Aircraft U-Bays for payload integration.

Figure 15. G-520 during the test.

G 520 available for 6G-SKY HAPS testing in the low stratosphere (FL450) has following features:

- Full Composite Fuselage
- Wingspan: **33m**
- Maximum Payload Volume: 3.85m^3
- Electrical Power for Payload - 7kW DC + 6kW AC
- Max Payload 1100kg (**238kg** for any typical mission)
- Mission Time: **8h**
- Max Flight Level: 450 (**13.7km**)

DTAG has developed and built an unique „Strato-Lab“ with Grob Aircraft SE for experiments from the low stratosphere. It enables testing of any terrestrial even laboratory equipment from the low stratosphere which does not have to be certified for operation in stratospheric environmental conditions.

Utilizing the G520 Strato-Lab, it is possible to test and demonstrate various system topologies comprising a HAPS layer, such as ones depicted in Figure 16 and Figure 17.

Figure 16. Demonstration system topology draft.

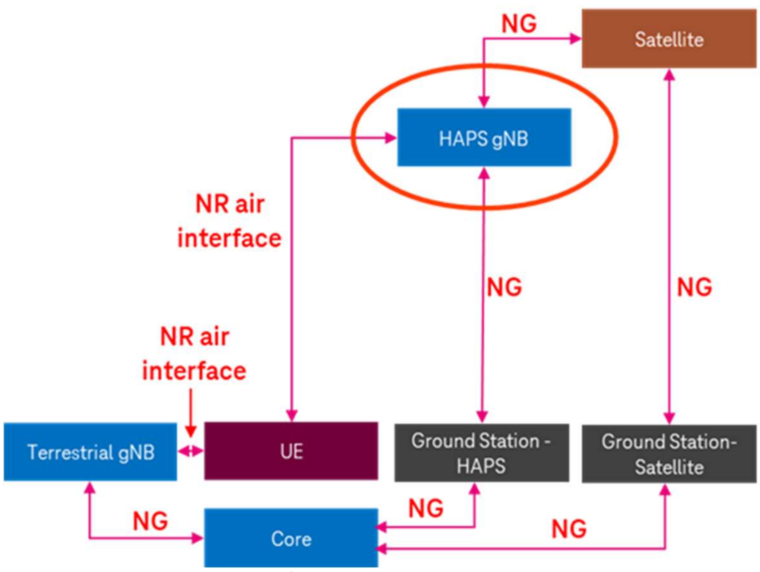

Figure 17. System architecture example.

8.1.2.2 Stratospheric balloon as a back up

As a backup plan (in the case G520 would not be available for the test), channel characterization of FR3 with stratospheric balloons is also under consideration. Illustration of the balloon test objectives and results are depicted in Figure 18.

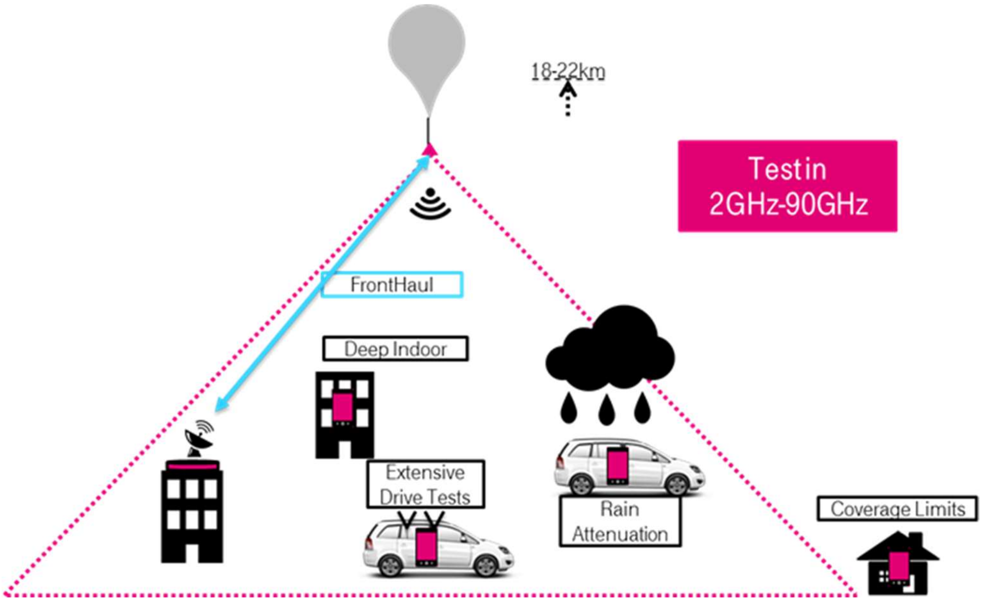

Figure 18. Balloon test high level architecture.

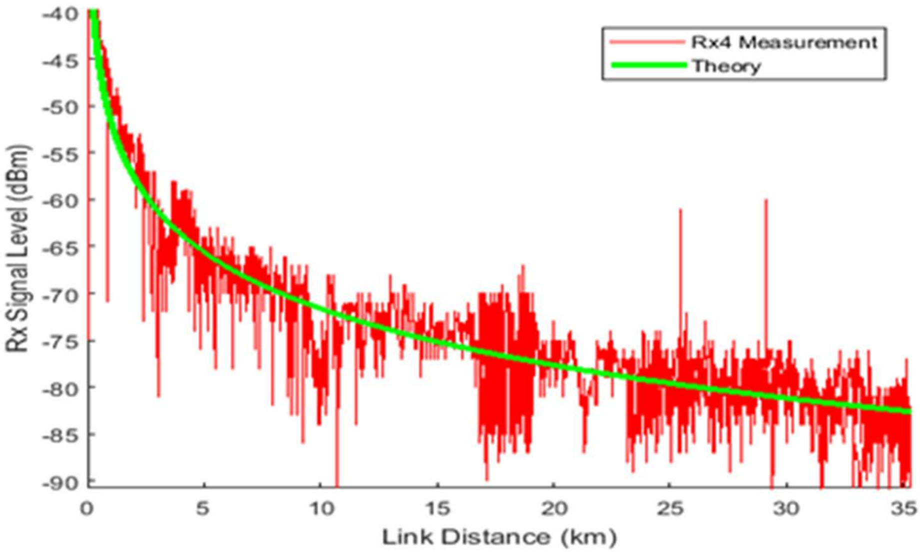

Figure 19. Test results example in FR1.

8.1.3 Antennas and Satellites

In Table 1four high performance antennas for applications with mobile satellite applications in Ka band and Ku band for the 6G-SKY are introduced.

Table 1 Possible high performance antenna options for 6G-Sky.

	KYMETA HAWK u8 Antenna	**ThinKom ThinSat Ka500**	**StarLink Mobility**	**MILLI SAT H LW**
Antenna type	Electronically scanned array, Rx and Tx combined, 82cm active diameter	Ka-band Phased Array Antenna technology (for AC and other vehicles) for GSO and NGSO, flat panel array	Electronic phased array	Milli SAT H LW is a lightweight, portable on-the-move satellite communication terminal solution.
Terminal	yes	no	yes	yes
Frequency band	Ku	Ka	Ku	Ku
Polarization	Linear, software-defined (circular with software update)	Switchable circular (R/L, L/R, R/R, L/L)		Linear (V/H) Automatic Skew Control
G/T [dB/K]	9.5 to 12	14		7.2 dB/K
EIRP [dBW]	45 (20W BUC)	49		45.7 dBW (50 W BUC)
Scan angle	Az: 360°, El:+15° to 90°	Az: 360°, El : +10° to 90°	FoV 140°	
Size [cm]	89.5×89.5×14	83.8×83.8×12.7	57.5×51.5×4.1	33×37
Weight [kg]	33	34	9.2	10.2
Power [W]	70 (avg)	300	110 to 150	35 (250W Psat)

The KYMETA HAWK u8 terminal is a well-established product for mobile satellite applications. It comes with a terminal, reasonable power consumption of 70W and operates in the Ku band. Kymeta has a cooperation with OneWeb so the terminal is compatible with the OneWeb constellation. They work together as a black box with no or almost no inside for the user into technical aspects like a detailed link budget, satellite tracking etc.

The ThinSat Ka500 antenna is designed for the use on aircraft. It is a phased array antenna which operates in Ka band. It weighs 34 kg but has no terminal. This antenna has a good compatibility to a wide range of modems.

Another option is the StarLink mobility terminal. StarLink is a proprietary system which acts like a black box. It has reasonable size and weight, and has a power consumption up to 150W.

The last proposed solution for HAPS-satellite link is MILLI SAT LW, a small lightweight portable on-the-move satellite terminal solution. It is optimal for airborne connectivity, for compact installations, and for fully autonomous operation for transmit and receive of high bandwidth data rates of more than 10 Mbps.

Table 2 Very lightweight mobile antenna options for 6G-SKY.

	Hughes 4510 (EchoStar)	ara 0349-820	Cobham aviator UAV 200 (Inmarsat)
Antenna type	Omnidirectional	Rugged, lightweight, proven flight endurance antenna, horn omni	LGA antenna array, omnidirectional
Terminal	yes	no	yes
Frequency band	S	Ka (or Ku)	L
Polarization		Right-Hand Circular	
G/T [dB/K]			
EIRP [dBW]	3.5		
Size [cm]	24.8×17.8×11.5	9.1×10.4	24×16×6
Weight [kg]	1.5		1.45
Power [W]	16	10	28

In Table 2 are three very light mobile antenna options for 6G-SKY shown which can be used for Task 5.3.

The Hughes is a lightweight antenna which is compatible with GEO satellites from Echostar. It operates in S band and has a down link capacity of 200kbps. Like other options, there is a probability that this is a black box system where the user has no knowledge about certain parameters.

The ara antenna is an example of range of similar antennas. The antenna with the name 0349-820 is a representation of one example antenna of this range. It is a rugged lightweight horn omnidirectional antenna. It is relatively small and is able to operate in the Ka band. Even so that not many parameters about this antenna are publicly known, it looks like a good candidate for an UVA antenna.

Another lightweight antenna could be the Cobham Aviator UAV 200, it is a terminal which is able to communicate with Inmarsat with a data rate about 200kbps. It consumes 28W of Power is 24 cm long and weights 1.45kg.

Two terminals mentioned in Table 1 are also an option for larger drone. The StarLink mobility terminal and the MILLI SAT H LW terminal are relatively light and could fit on a larger drone.

The type of antenna to be used in this project depends on the aircraft or drones and their equipment bays used in this project, as well as their size, weight, power and cost constraints.

Table 3 Satellite options for the 6G-SKY

	OneWeb	StarLink	Intelsat	Inmarsat	Echostar	H2Sat
Frequency band	Ku	Ku	Ku	L	S	Ka
Orbit	LEO	LEO	GEO	GEO	GEO	GEO
Comment	Compatible with Kymeta (black box, 200Mbps)	Proprietary, black box 220Mbps	Compatihle with MILLI SAT H LW	Compatible with Cobham aviator (200kbps)	Compatible with Hughes (probably black box, 200kbps)	Regenerative and transparent payload

There are already a few satellite constellations for communication purposes available. However, it is yet to be determine what satellite service could be used. The depending factors are frequency band, satellite type, availability and also other link properties such as latency, CNR or robustness due to handover.

All satellite constellations except the Heinrich Hertz satellite (H2Sat) in Table 3 are operational and consisting of transparent satellites.

OneWeb is a British company which already cooperating with several 5G projects. It is a LEO constellation which operates in the Ku band and consists of more than 500 satellites. O3b is a MEO constellation which consists of 20 satellites with transparent payload. It operates in Ku and Ka band.

Starlink is US based, the biggest constellation yet and it consists of over 4100 LEO satellites at 550km above the surface of the Earth. Like already mentioned StarLink is a proprietary system which acts like a black box which both come with advantages and disadvantages.

Intelsat, Inmarsat and Echostar are GEO constellations. They have higher latency but do not depend on complicated handover protocols.
The H2Sat was launched in July 2023 to GEO and could already be operational when the demonstrations of the 6G-SKY are starting. It has a regenerative payload and operates in Ka band.

Goals

8.1.4 Goals, Performance Metrics and Success Criteria

The goal of the demonstration is to show HAPS operating in new frequency bands from 7-10GHz in the low stratosphere can provide the mobile service to different nodes in 3D network architecture (UAV, drone, terrestrial customer) and can be back-hauled via both ground-air and air-space links.

8.1.5 TRLlevel reached by the demonstration

The E2E demonstration of 5G+ system operation in 6G frequency candidate bands from 7-10GHz in relevant environment (TRL 5).

8.1.6 Particular 6G-features of the use case

The PoC should prove 6G frequency candidates in FR3 for 3D NTN network with focus on a base station operating in the low stratosphere.

Procedures

The demo setup will be integrated into G520 in Grob H3 premises (Tussenhausen, Germany). Ground test and low altitude (FL100) tests will be conducted around aircraft supplier airfield during the preparation phase.

Schedule

The demo setup is under the preparation targeting the demonstration in H2 2024.

Contributions to sustainability

Large part of rural terrestrial sites are deployed for providing coverage and not for capacity need. HAPS can reduce grid energy of a mobile network by 10% to 50% by switching off terrestrial base stations. HAPS can replace such towers in wide sparsely populated areas. Furthermore, novel hydrogen based power solutions are promising carbon free network operation.

9 Conclusion

We have described the demonstration cases for the 6G-SKY architecture regarding their motivation, setup, goals and planning. They particularly show aspects where the 6G-SKY architecture exceeds the current 5G features regarding, e.g.,

- 3D network architecture,
- 6G frequency candidates, e.g., 7 GHz – 15 GHz, FR3, for 3D-Aerial networks with focus on a base station operating either on the ground and in the low stratosphere.
- Handover between different network technologies.
- Joint sensing, communication and computation in 3D e.g. with respect to a drone swarm,
- Drone/UAV detection system capable of providing reliable drone detection and tracking services to support legal UAV operations and securing the protected area from threats coming from intruding UAVs
- redundant communication technologies for robustness.

The majority of the demonstrations reach or even surpass TRL5 and include sustainability aspects such as avoiding unnecessary field trials via prior emulation and therefore reduce traveling and operation of fuel intensive carriers (HAPs, etc.), reduction of CO2-consumption in transportation, enhancing safety of aerial operations (e.g. via surveillance of UAVs in the airspace), using HAPs in rural areas while reducing grid energy of base stations that do not need to be installed.

All in all, the demonstrations will show the benefit for the targeted use cases as well as how they are enabling them via features beyond 5G+.