A1 Telekom Austria AG – Business Unit Enterprise

A1November 22nd 2022

A1 Austria

Drones in business – overview of selected use-cases

Regulations & U-Space

Role of TELECOMs in UAV business - A1 Telekom Austria Projects

Commercial drone market – trends and developments

A1 Austria

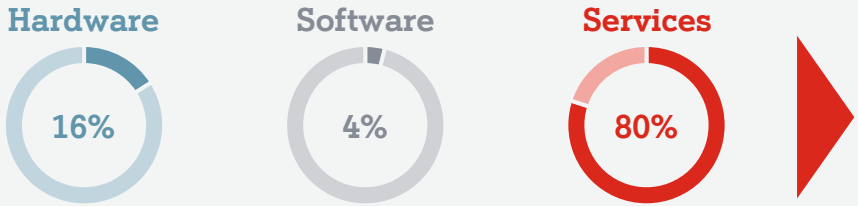
- **1.190 commercial drones** sold in Austria in 2019 (+6,3% compared to 2018)[1]
- **30.000 drone operators** registered via Austro Control by May 2022[2]

- **Number of commercial drones** expected to **grow by 560% to 125K** (2020-2030)[3]
- Market size over **1,5 billion Euros** by 2025[3]
- **Demand** for commercial drones expected to **grow by 16%** per year until 2025[3]

Example drone use cases:

- Aerial measurement
- Asset inspection
- Videography
- Mapping & monitoring
- Various data gathering
- Transportation
- Delivery etc.

Market share by segment:



Currently most commercial drone flights are provided to customers as a service e.g.

→ **Drone as a Service (DaaS)**

1: Branchenradar Drohnen in DACH 2020 (2020) | 2: Austro Control (2022) | 3: Bundesverband der Deutschen Luftverkehrswirtschaft (2021)

DaaS use-case example: Drones in construction

- Inspection & Documentation of the construction site
- Measurements & Digital Twins
- Quantity surveying and Mapping
- Asset Tracking
- Work safety monitoring
- Security monitoring

Source: Big Rentz

DaaS use-case example: Drones in agriculture

- Every 10th farmer in Germany used drone to gather data
- Plant health analysis
- Pest control (Bark beetle detection) – Co-operation with **AirXBig**
- Counting and rescue of wildlife
- Targeted crop management for increased yields
- Large area surveying (e.g. forest management)

Source: Deutscher Bauernverband, Bundesinformationszentrum Landwirtschaft

DaaS use-case example: Drones in asset inspection

- Inspection of cell towers, wind turbines, power lines, solar panels, rails, buildings, etc.
- Maintenance cost reductions up to 90%
- Reduction of occupational accidents
- AI assisted asset damage detection
- Standardized condition documentation
- Data-based decision-making

Source: Air&More, Skyability, Power Engineering

BVLOS opportunities example: Drones in search and rescue

- Enhanced search and rescue missions
- 1st aid kit / defibrillator delivery
- Ski resort patrol / avalanche search and rescue
- Remote monitoring of rescue missions
- Ground-sky situational awareness for better mission co-ordination

Image Source: Austrian Red Cross

Drones in business – overview of selected use-cases

Regulations & U-Space

A1 Telekom Austria Projects

VLOS vs. EVLOS vs. BVLOS

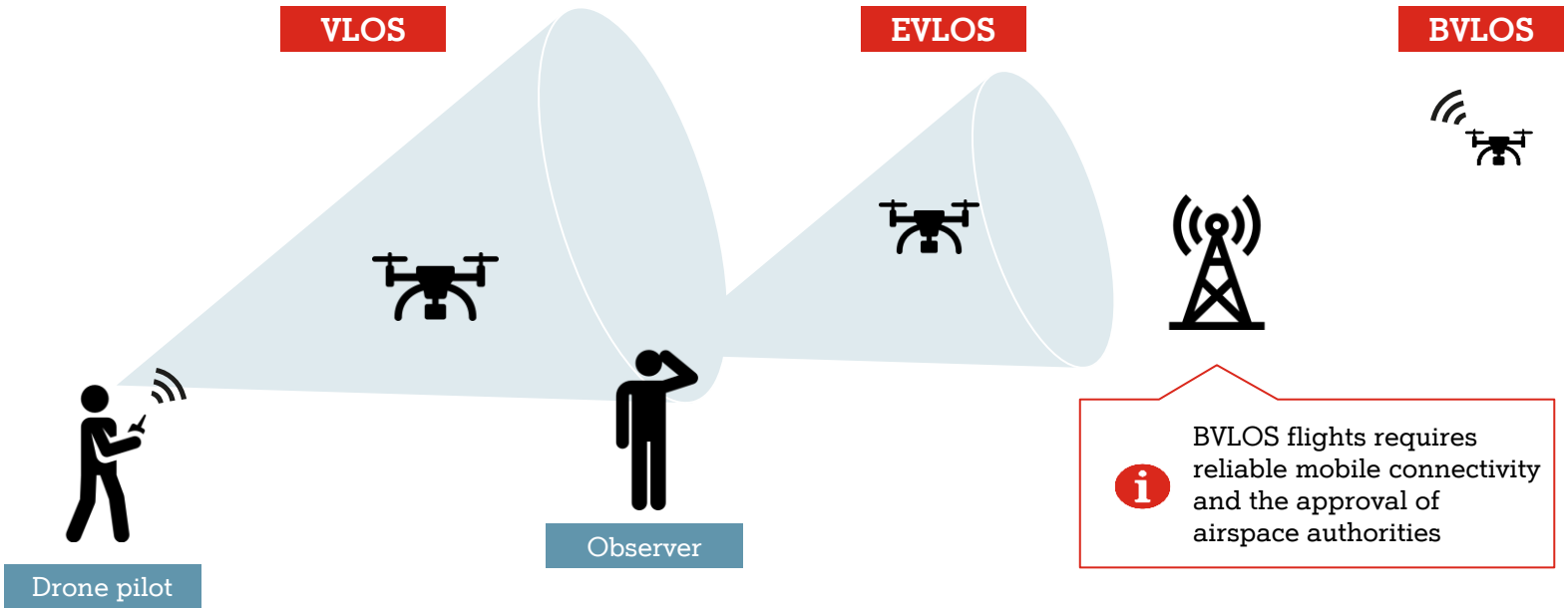
A1 Austria

BVLOS growth projected at **17% yoy** with the support from new **EU regulations** by the European Aviation Safety Agency (EASA)

Eye contact with the drone
Visual Line of Sight

Proxy eye contact with the drone
Extended Visual Line of Sight

No eye contact with the drone
Beyond Visual Line of Sight



The EASA has developed regulations for three distinct categories of drone operations

Open category

Leisure and low-risk commercial drone operations

Specific category

Riskier operations mostly for **commercial use VLOS and BVLOS**

Certified category (BVLOS)

Operations with **highest level of risk** – case by case assessment by regulator e.g. passenger drones, cargo drones etc.

Most current commercial applications are expected in open and **specific category**

Source: European Aviation Safety Agency

Each category comes with its own set of guidelines

Open

Leisure and low-risk commercial drone operations

- **Registration** of drone and operator
- Online **license** and practical training
- **Compliance with rules** for A1, A2 and A3 subcategories
- Weight dependent C category rules apply

Specific

Riskier operations mostly for commercial use

- Additional requirements to **notify Aviation Authorities**
- **Operational risk assessment** required to request authorization
- Max. takeoff weight 25 > kg

Certified

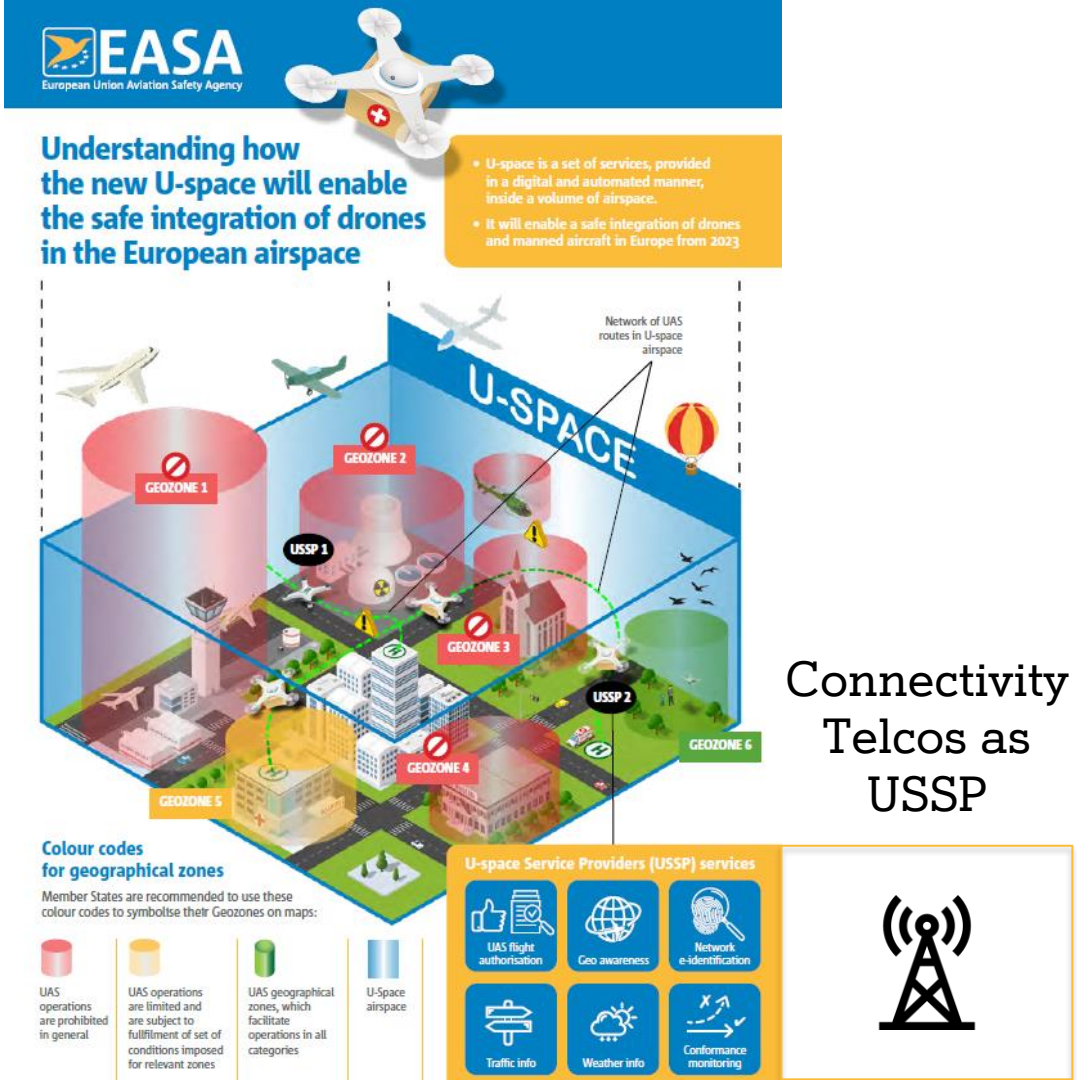
Operations with **highest level of risk**

- Development of regulations still **in progress**
- Involves cargo and passenger drones
- Mostly applies to BVLOS flights

Connectivity is currently not a requirement, however due to creation of national UTM systems, we expect this to be added as requirement soon.

EASA U-Space

Source: European Aviation Safety Agency



Connectivity Telcos as USSP

Drones in business – overview of selected use-cases

Regulations & U-Space

Role of TELECOMs in UAV business - A1 Telekom Austria Projects

A1 Telekom Austria Drone Project

2023 ~

Retail / B2C2B Drone bundles

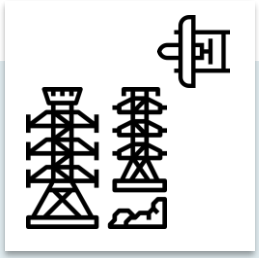
Leveraging our retail infrastructure and our Telco resources to offer end-to-end b2c2b UAV bundles for customers such as sole proprietors, videographers, small DaaS operators etc.

Bundle Example:

Drone + **Connectivity** + **Cloud** + SaaS + Insurance

Small-medium clients

VLOS & EVLOS



2023 ~

BVLOS platform

With expected growth of BVLOS market A1 Telekom is in a strong position to provide infrastructure and services critical for developing and operating end-to-end BVLOS use-cases.

BVLOS is heavily dependent on:

Safety Data (provided by A1 & partners) + **Connectivity** + **Cloud services**

Large Enterprise clients

BVLOS

A1 Telekom Austria offer for small business clients

A1 Drone Bundles

Drone* + Connectivity + Cloud + SaaS + Insurance

A1 Telekom drone bundle is a product package aimed at small-medium business clients.

Drone LTE bundle is a unique proposition that packages most recent mid-segment commercial drone technologies together with A1 core services to enable next generation of DaaS flights – i.e. more reliable control via LTE and data streaming directly from drone to cloud.

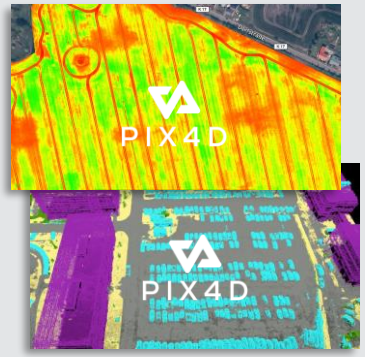
LTE / 5G prioritized drone connectivity

Cloud storage

SaaS & other added value services

LTE connectivity available on some models such as Parrot Anafi AI with LTE streaming latency up to 300ms for 1080p/30fps video.

EXOSCALE

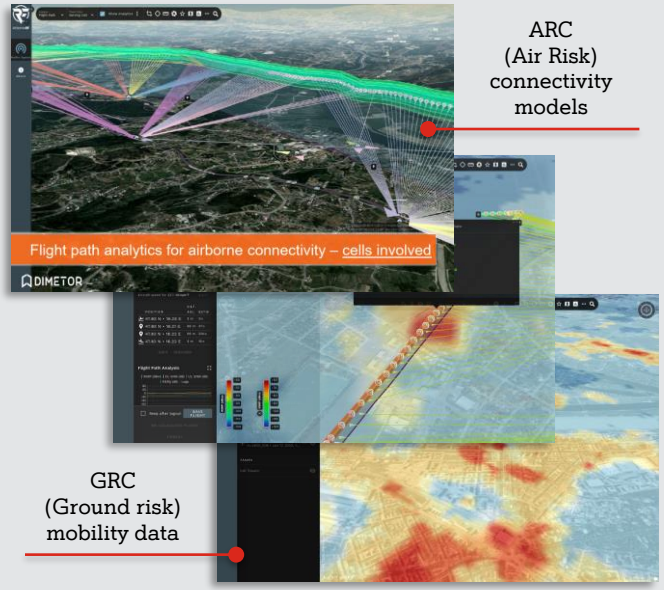


A1 Telekom Austria offer for enterprise clients

A1 BVLOS Platform

A1 Telekom is in strong position to play a pivotal role in providing dedicated 5G connectivity for BVLOS UAV use-cases.

Leveraging our relationships with leading hardware providers, combined with A1's cloud offering and ability to provide risk assessment services to clients for SORA, A1 is a strong partner for our enterprise clients in developing BVLOS UAV use-cases.



ARC (Air Risk) connectivity models

GRC (Ground risk) mobility data

5G dedicated UAV connectivity & cloud storage

5G standalone slice for autonomous vehicles. Talk to us about POC

Thank you!

peter.kozar@a1.at

Unoccupied aerial vehicles in applied research: Technological and data-related aspects

Gernot Seier

Within the framework of the workshop
Possible use cases of drones for companies
DIH Süd, Klagenfurt,
22.11.2022

Photo: G. Seier, 09/2021

AIRlabs* Austria GmbH

***Aeronautical Innovation & Research Laboratories Austria**

- Austrian BMK-innovation laboratory
- Multisite-concept with specialized infrastructure
  - Research and development
  - Validation
  - Integration
- For users, industry, research institutions and the public sector

AIRlabs Austria consortium

SHAREHOLDER

CONSORTIUM PARTNER

PARTNER

SUPPORTED BY

Development according to technology readiness level (TRL)

Aerial vehicles

Testing and approval

Social acceptance

Infrastructure

Operational levels

Level	1	2	3	4	5	6	7
Name	**Research, Development** *Technological fundamentals* Engineering and Simulation	**Research, Development** *Application-oriented tests* Specialized laboratories, climatic wind and icing tunnels, indoor flight halls	**Validation** *Airspace small* Civil R/TSA areas	**Validation** *Airspace large* Civil R/TSA areas	**Integration** *Operational environment UAM* CTR areas	**Integration** *Specific operational environments* External and internal aerial survey of specific infrastructures	**Integration** *Effective airspace* Regulated by ACG beyond the innovation laboratory
TRL	TRL 1 - 5	TRL 2 - 5	TRL 5 - 7	TRL 5 - 7	TRL 5 - 7	TRL 5 - 7	TRL 7 - 8
							

Temporary Restricted Area
LO R 9 STEINALPL, Effective date 31.08.2022

REPUBLIK ÖSTERREICH

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REPUBLIC OF AUSTRIA

AIP SUP 020/22
31 AUG

Dieses AIP SUP umfasst 3 Seiten.
Durch dieses AIP SUP wird AIP SUP 012/22 ersetzt.

This AIP SUP includes 3 pages.
This AIP SUP replaces AIP SUP 012/22.

INKRAFTTRETUNGSDATUM / EFFECTIVE DATE: 31 AUG 2022 - 31 DEC 2024, 2300

ENR

LO R 9 STEINALPL
ZEITWEILIGES FLUGBESCHRÄNKUNGSGEBIET
(CTA S)

1. Seitliche Begrenzung:

47 46 23N 015 30 14E - 47 47 35N 015 41 06E - 47 43 05N 015 40 26E - 47 42 35N 015 29 46E - 47 46 23N 015 30 14E.

2. Obergrenze/Untergrenze:

7500 FT AMSL
GND

3. Zeitliche Beschränkung:
Aktivierung wird mittels NOTAM kundgemacht.
MON - FRI maximal von Beginn der bürgerlichen Morgendämmerung (BCMT) bis Ende der bürgerlichen Abenddämmerung (ECET), ausgenommen gesetzliche Feiertage.

4. Art der Beschränkung:
Der Ein-, Aus-, Durchflug und der Betrieb von Luftfahrzeugen, unbemannten Luftfahrzeugen oder selbständig im Fluge verwendbarem Luftfahrtgerät in das bzw. im bzw. aus dem zeitweiligen Flugbeschränkungsgebiet ist verboten.

Ausgenommen hiervon sind:
a) Einsatzflüge gemäß § 145 Luftfahrtgesetz;
b) Militärischer operationeller Flugverkehr gemäß § 145a Luftfahrtgesetz;
c) Such-, Ambulanz- und Rettungsflüge;
d) Flüge mit unbemannten Luftfahrzeugen, welche zu sicherheitspolizeilichen oder strafprozessualen Zwecken eingesetzt werden;
e) Flüge mit folgenden unbemannten Luftfahrzeugen, unter Einhaltung der Bedingungen betreffend Anmeldung und Aktivierung (siehe Punkt 5),
   1) Drehflügler, Starrflügler und Hybrid UAS der Betriebskategorie „speziell" gemäß Art. 5 der Durchführungsverordnung (EU) 2019/947 im Rahmen der erteilten Betriebsgenehmigung und
   2) der Betriebskategorie „offen" gemäß Art. 4 der Durchführungsverordnung (EU) 2019/947.

LO R 9 STEINALPL
TEMPORARY RESTRICTED AREA
(CTA S)

1. Lateral Limits:

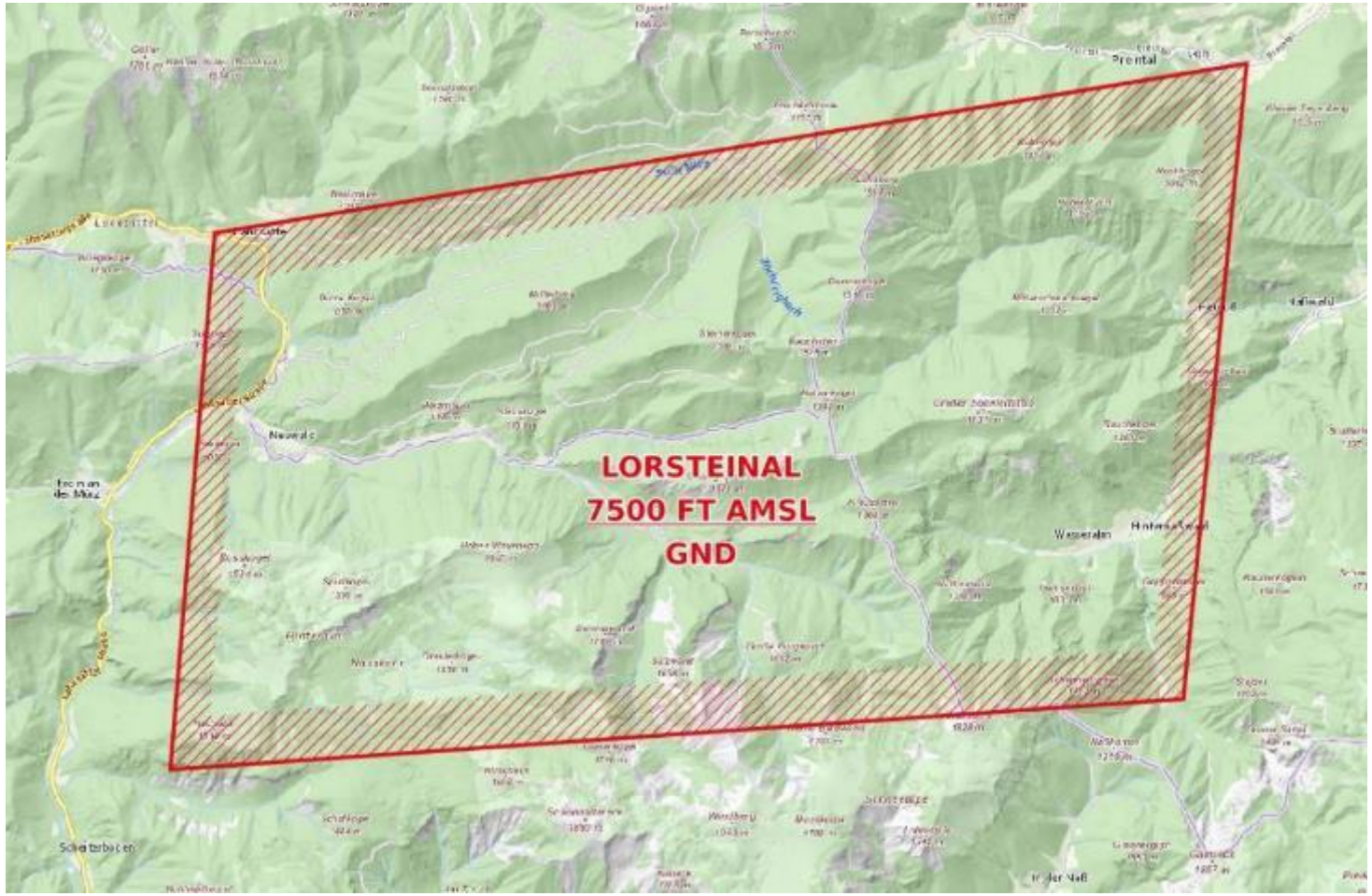
2. Upper Limit/Lower Limit:

3. Time constraint:
Activation promulgated by NOTAM.
MON - FRI maximum from Beginning of Civil Morning Twilight (BCMT) to End of Civil Evening Twilight (ECET), except legal holidays.

4. Type of restriction:
Entry, exit, transit and operation of aircraft, unmanned aircraft or aeronautical equipment that can be used independently in flight into or within or out of the temporary restricted area is prohibited.

This restriction does not apply to:
a) flights according § 145 aviation act;
b) military operational air traffic according § 145a aviation act;
c) search-, ambulance- and rescue flights;
d) flights with unmanned aerial vehicles engaged for police or judicial purposes;
e) flights with the following unmanned aircraft, subject to compliance with the conditions regarding registration and activation (see item 5),
   1) Rotorcraft, fixed-wing aircraft and hybrid UAS (Unmanned Aircraft System) of operational category 'Specific' according Article 5 of Commission Implementing Regulation (EU) 2019/947 as part of the operating license granted and
   2) of operational category 'Open' according Article 4 of Commission Implementing Regulation (EU) 2019/947.

- 1 -



Operational levels

Level	1	2	3	4	5	6	7
Name	**Research, Development** *Technological fundamentals* Engineering and Simulation	**Research, Development** *Application-oriented tests* Specialized laboratories, climatic wind and icing tunnels, indoor flight halls	**Validation** *Airspace small* Civil R/TSA areas	**Validation** *Airspace large* Civil R/TSA areas	**Integration** *Operational environment UAM* CTR areas	**Integration** *Specific operational environments* External and internal aerial survey of specific infrastructures	**Integration** *Effective airspace* Regulated by ACG beyond the innovation laboratory
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Cities selected for the survey

- Barcelona
- Budapest
- Hamburg
- Milan
- Paris
- Øresund cross-border region between Denmark and Sweden

URBAN AIR MOBILITY 10 KEY SURVEY RESULTS

Urban Air Mobility (UAM) is a new mode of air transport of goods and passengers in urban environments, using electric aircraft taking off and landing vertically, with or without a pilot on board. First operations will be a reality 3 to 5 years from now.

https://www.easa.europa.eu/en/uam-10-key-findings

Click for more details

1 A POSITIVE INITIAL ATTITUDE TO UAM THROUGHOUT THE EU

83% express an initial positive attitude towards UAM

64% and 49% ready to try out drones and air taxis respectively

Very homogeneous replies and no major differences across cities and respondent groups

https://www.easa.europa.eu/en/uam-10-key-findings

Emergency and/or medical transport use cases receive greatest public interest. Top three use cases:

41% transport of injured person to hospital

41% drone delivery of groceries of medical supplies to hospitals

36% transport of emergency medical personnel

STRONG SUPPORT FOR USE CASES THAT ARE VALUABLE TO ALL

2

https://www.easa.europa.eu/en/uam-10-key-findings

AIRlabs Austria Unmanned Traffic Management

Source: G. Seier

Glaciological UAV-based research: Case study Austerdalsbreen, Norway

Fieldwork 2021, JOSTICE (jostice.no)

Technological and data-related aspects

3 days (September 2021) of fieldwork

Two different multirotor UAVs

~4,400 photographs

Visible and TIR spectrum

Direct and indirect georeferencing

Photo: G. Seier, 05.09.2021

UAVs in (glaciological) research …

- are a great opportunity for high-resolution and tailored mapping or other surveys/measurements.

- require in-depth preparation and a lot of effort (time, hardware, intellectual work) during and after the fieldwork.

- are in many cases beyond a cost-effective mission (requirements, TRL), but entail personal involvement.
- However, the hardware and software components are in most cases developed and produced by companies, which is why there are a lot of research-related use cases of drones for companies.

Drones, 5G and Examples of Current Funding Opportunities

POSSIBLE USE CASES OF DRONES FOR COMPANIES

Klagenfurt, 22 Nov 2022

DI Dr.-Ing Holger Friehmelt

Institute Director FH JOANNEUM Luftfahrt/Aviation and Technical-Scientific Director AIRlabs Austria GmbH

Federal Ministry
Republic of Austria
Climate Action, Environment,
Energy, Mobility,
Innovation and Technology

FFG
Promoting Innovation.

The projects AIRlabs and EMoTe have received funding from the Austrian research funding programme Take Off. Take Off is a Research, Technology and Innovation Funding Programme of the Republic of Austria, Ministry for Climate Action. The Austrian Research Promotion Agency (FFG) has been authorised for the Programme Management.

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- Die Projekte AIRlabs und EMoTe werden gefördert bzw. finanziert im Rahmen des FTI-Programms Take Off durch das Bundesministerium für Klimaschutz und von der Österreichischen Forschungsförderungsgesellschaft abgewickelt.

Federal Ministry
Republic of Austria
Transport, Innovation
and Technology

FFG
Promoting Innovation.

The Bright Future of Drone Delivery Services

Drone Delivery Services Market Snapshot (2022-2032)

[300 Pages Report] The global **drone delivery services market** is anticipated to be valued at **US$ 322.2 Million** in 2022. During the forecast period ranging from 2022-2032, sales of Drone Delivery Services market are expected to grow at a CAGR of **33.0%,** to be valued at **US$ 5,596 Million**. During the historical period 2016-2021, Drone Delivery Services demand inclined at a **5.8%** value CAGR.

Data Points	Key Statistics
Expected Market Value (2022)	US$ 322.2 Million
Anticipated Forecast Value (2032)	US$ 5,596.0 Million
Projected Growth Rate (2022-2032)	33% CAGR

With rising demand for drone delivery services, numerous governments are relaxing restrictions to enable drones to fly in their airspace, which is projected to boost the growth of drone procurements to supply new delivery routes for remote places throughout the projection period. As a result, the market for drone delivery services has expanded.

Source: https://www.futuremarketinsights.com/reports/drone-delivery-services-market

The Bright Future of UAS Services

DIGITAL JOURNAL WORLD TECH & SCIENCE SOCIAL MEDIA BUSINESS ENTERTAINMENT LIFE SPORTS

Drone Service Market Growth – at a CAGR of 46.8% | Increasing demand for drone service due to development of urban air mobility services

By GetNews Published September 16, 2022

Drone service market size was USD 9.60 Billion in 2021 and is expected to register a revenue CAGR of 46.8%

Source: Drone Service Market Growth – at a CAGR of 46.8% | Increasing demand for drone service due to development of urban air mobility services - Digital Journal

Wireless Technologies in UAS Services

Moving drones forward in leaps and bounds

Drone technology is still developing quickly across multiple fronts. "Drones are extremely interesting products because there's about 25 relevant technology subsystems under the hood," says Joe Enke. These subsystems include the cameras, the positioning systems, the sensors, the wireless technologies, the batteries as well as advanced materials and thermal management.

Source: Drones | GSMA 5G Business Accelerator Hub

Examples of 5G and Drones Applications

DRONE INDUSTRY INSIGHTS

How 5G Leverages Drone Applications

Establishing Unmanned Traffic Management (UTM) Systems

Challenge: How do we manage the growing number of drones in the air?
Role of 5G: Support low-altitude drone communication and surveillance.
Key Hurdles: Regulations, Integrating Drone Operations with Manned Airspace.

Improving and Scaling Flights Beyond the Visual Line of Sight

Challenge: How do we conduct scalable BVLOS flights for crucial drone applications?
Role of 5G: High-quality and widespread connectivity enabling secure BVLOS flights.
Key Hurdles: Regulations; Establishing a Sufficiently Wide Network.

Data Transmission

Challenge: How do we most effectively transmit the vast amounts of data from and to ground stations?
Role of 5G: Offering a stable and widespread data connection with large bandwidth capacity and low latency.
Key Hurdles: Establishing Stable Network Connections also in Rural Areas.

Source: DRONEII.com Date: April 21st 2020

DRONEII.COM DRONE INDUSTRY INSIGHTS

Current National Research Strategy

Bundesministerium
Klimaschutz, Umwelt,
Energie, Mobilität,
Innovation und Technologie

Service Themen Ministerium Recht DE

Themen > Innovation > Aktivitäten > Luftfahrttechnologie > FTI-Strategien für Luftfahrt

- Energie
- Innovation
  - Aktivitäten
    - Digitale Technologien
    - Energie und Umwelt
    - Innovationsfördernde öffentliche Beschaffung (IÖB)
    - Innovative und wettbewerbsfähige Unternehmen
    - Kooperation von Wissenschaft und Wirtschaft
    - Luftfahrttechnologie
      - ERA-NET Air Transport Net
      - **FTI-Strategien für Luftfahrt**
      - Take Off
    - Menschen, Qualifikation und Gender
    - Mobilität

FTI-Strategien für Luftfahrt

Die Österreichische Gesamtstrategie 2040+ für den Luftfahrtsektor besteht aus zwei Teilstrategien, die zusammenwirkend den Weg zur Dekarbonisierung gemäß Mobilitätsmasterplan 2030 weisen:

- Die Luftfahrtstrategie 2040+
- Die FTI Strategie für Luftfahrt 2040+

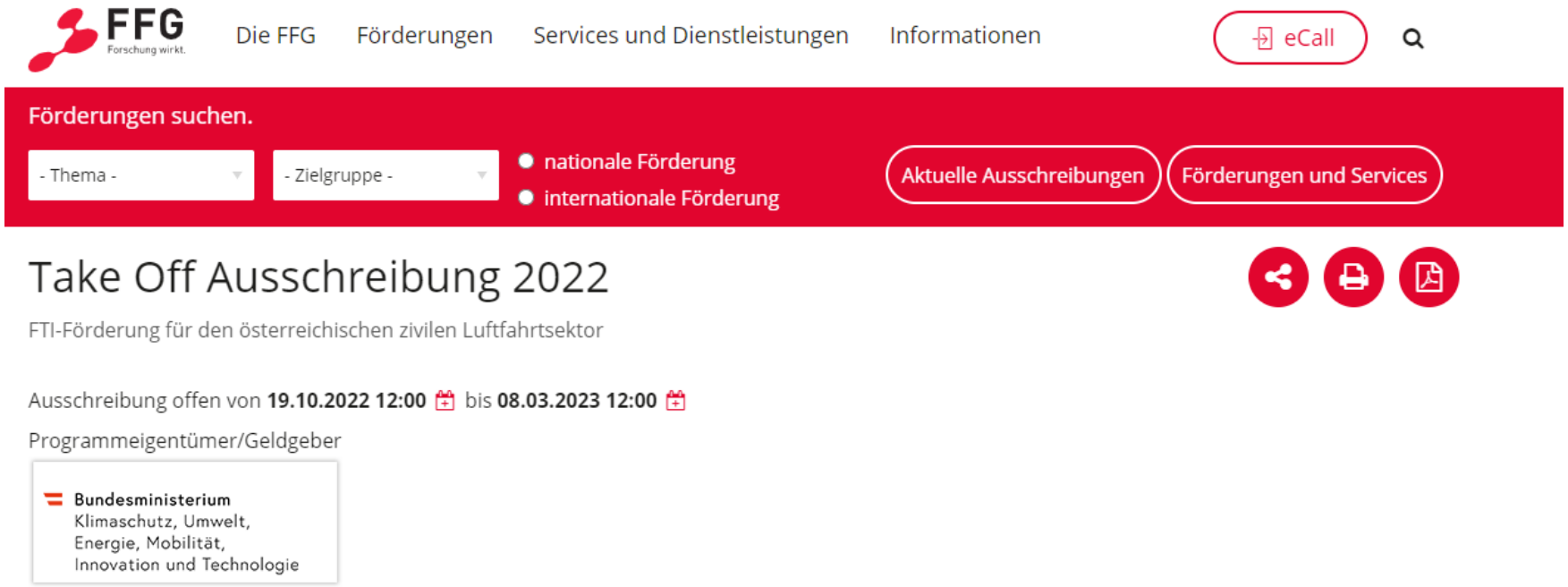
Sie sind in ihrer Umsetzung eng miteinander verwoben und sollten daher stets gemeinsam betrachtet werden.

Mit der Forschungs-, Technologie- und Innovationsstrategie für Luftfahrt formuliert das BMK in Zusammenarbeit mit den Stakeholdern der heimischen Luftfahrt(zuliefer)industrie, universitären und außeruniversitären Forschungsorganisationen sowie Vertreter:innen des österreichischen Luftverkehrs die gemeinsame Stoßrichtung um österreichische Akteure als Innovationstreiber für klimafitte und wegweisende Lösungen für ein zukunftsfähiges Luftfahrtsystem zu positionieren. Die Strategie gilt als Grundlage für die österreichische Forschungs- und Innovationsagenda Luftfahrt deren Umsetzung wesentlich zum ökologischen und digitalen Systemwandel beitragen soll.

- FTI Strategie für Luftfahrt 2040+ (PDF, 1 MB)

More at : FTI-Strategien

Current National Research Call



More at : [Take Off Ausschreibung 2022 | FFG]

Zukunftsträchtige Forschungs- & Innovationsthemen

	Luftfahrzeug	Produktion	Lufttransportsystem
Energiewende	• Alternative Antriebe & Treibstoffe (Batterie, SAF, Brennstoffzelle, H2-direkt, hybrid) • Energieeffizienz durch Leichtbau, Design, Aerodynamik, … • Konfigurationen • All-Electric Aircraft	• Energieeffizienz im Fertigungsprozess • Energieoptimierter Materialmix • Tanksysteme	• klimaneutrale Flughäfen und -plätze • Infrastruktur (H2) • Umweltoptimierte Höhen- und Routenführung • Formationsflug
Kreislaufwirtschaft	• Wiederverwertung • Wiederverwendung • Wiederproduktion • Reparierbarkeit	• Materialauswahl • CE-Design/5 R's • Kreislauforientierter Fertigungsprozess • Lebenszyklusanalyse	• Kreislauforientierter Betrieb • as-a-Service Modelle/ • shared economy • MRO am Boden
Mobilitätswende	• Anwendungsspezifische Transportkombinationen • Anpassung an nutzungsbasierte Geschäftsmodelle • Lärm und emissionsreduzierte Konzepte	• Nachhaltige Logistikkonzepte • Generative, bedarfskonforme Fertigung	• Flughafen als Mobilitätsknoten • Intermodalität, durchgängige Mobilitätskonzepte • Barrierefreiheit • Klimaoptimierte Flugführung
Digitale Transformation	• unbemannte/automatisierte Luftfahrzeuge • Steuerung (automatisiert, Single Pilot, …) • Simulation • Virtuelle Zulassung • MRO	• Vernetzte Produktion • Digitaler Zwilling • KI/Blockchain/Quantentechnologie • as-a-Service Modelle	• Cybersicherheit • Aufbau Datenpool • Integration von UAVs • digitale Infrastruktur für U-SPACE • Operationelle Effizienz • Human Factors

Ausblick Take Off Ausschreibung 2022

- Ausschreibung offen von **20.10.2022 12:00** bis **08.03.2023 12:00**
- **8.1 M€** Österreichische Marktsegmente: Strukturen, Komponenten und Innenausstattung, Sys
  Cockpitausrüstung, Avionik, Flugzeug-Basissysteme, Vernetzte Luftverkehrsinfrastruktur, Intelligent
  Fluggeräteinfrastruktur, Nachhaltige Flughafeninfrastruktur, Bodentest-, Prüf- und Trainingsgeräte
- **1.4 M€** Klimaneutrale Urban Air Mobility - Erforschung und Integration Unbemannter Luftfahrtsysteme (UAS)
- **2.6 M€** Sustainable Aviation Fuels (SAF) - Biotreibstoffe, synthetische Treibstoffe, Wasserstoff - Entwicklung und Systemfähigkeit
- **Aviation Forum Austria – 20 Jahre Take Off 19.10.2022** ab 9 Uhr, Erste Campus Wien

Ausblick Take Off Ausschreibung 2023

- Ausschreibung voraussichtlich offen von **Oktober 23** bis **März 24 12:00**

- **7,8 M€** Innovative, ressourcen- und klimaschonende FTI-Lösungen, die einen wesentlichen Beitrag und Anschub zur Transformation des Luftfahrtsystems leisten.
- **3.2 M€** Sustainable Aviation Fuels inkl. Wasserstoff
- **1.0 M€** Missionsfeld Regionen: umweltfreundliche Mobilitäts- und Transportalternativen im Vor- und Nachlauf von Langstreckenflügen

AIRlabs Vision

Our vision for AIRlabs Austria GmbH is to establish and operate a nationwide innovation laboratory in Austria which unites all key stakeholders from industry, research, and users to address all current and future needs from research, development, and validation of UAS in a sustainable way.

Die Vision der AIRlabs Austria GmbH ist der Aufbau und Betrieb eines österreichweiten Innovationslabors, das alle Schlüssel-Stakeholder bestehend aus Anwendern, Industrieunternehmen und Forschungseinrichtungen im Konsortium eint und damit nachhaltig die aktuellen und zukünftig absehbaren Anforderungen aus Forschung, Entwicklung und Validierung von UAS adressiert.

AIRlabs Summary and Key Facts

- Well balanced consortium with 25 partners from all over Austria
- ANSP, i.e. AustroControl, as integral partner
- Unique multisite concept with six levels covering all TRL
- Synergies to other autonomous testing regions and topics
- Non-profit scientifically focused project within the framework of the BMK/FFG TAKEOFF Program
- Collaboration potential to German LuFo program
- Considerable additional partners‘ contributions
- 17 LoI partners with a multitude of innovative applications

Federal Ministry
Republic of Austria
Transport, Innovation
and Technology

FFG
Promoting Innovation.

AIRlabs Value Proposition

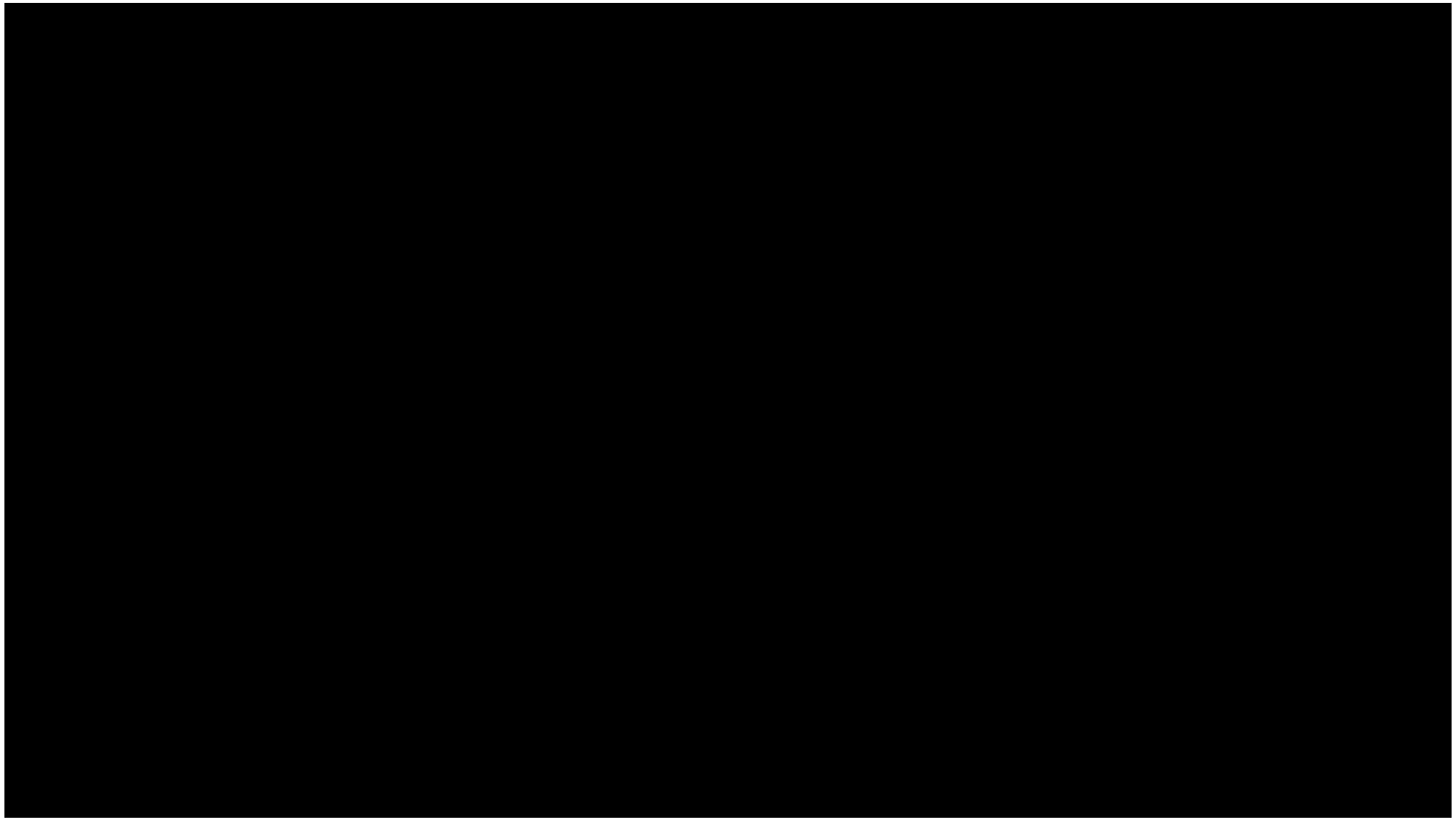
Level	1	2	3	4	5	6	7
Description	**Research, Development** *Fundamentals* Laboratories, simulation, engineering	**Research, Development** *Applied Research* Indoor test range (AAU), climate wind tunnel (RTA) and other Infrastructures	**Validation** *Airspace small* Small civil R/TSA airspaces	**Validation** *Airspace large* Large civil R/TSA airspaces	**Integration** *Application Area UAM* Propably within CTR	**Integration** *Application Spec. Operations* Specific infrastructures	**Integration** *Real Airspace* Covered by Austro Control outside of the innovation laboratory
TRL	TRL 1 - 5	TRL 2 - 5	TRL 5 - 7	TRL 5 - 7	TRL 5 - 7	TRL 5 - 7	TRL 7 - 8
							

Partners

Konsortial-PartnerInnen

LoI-PartnerInnen

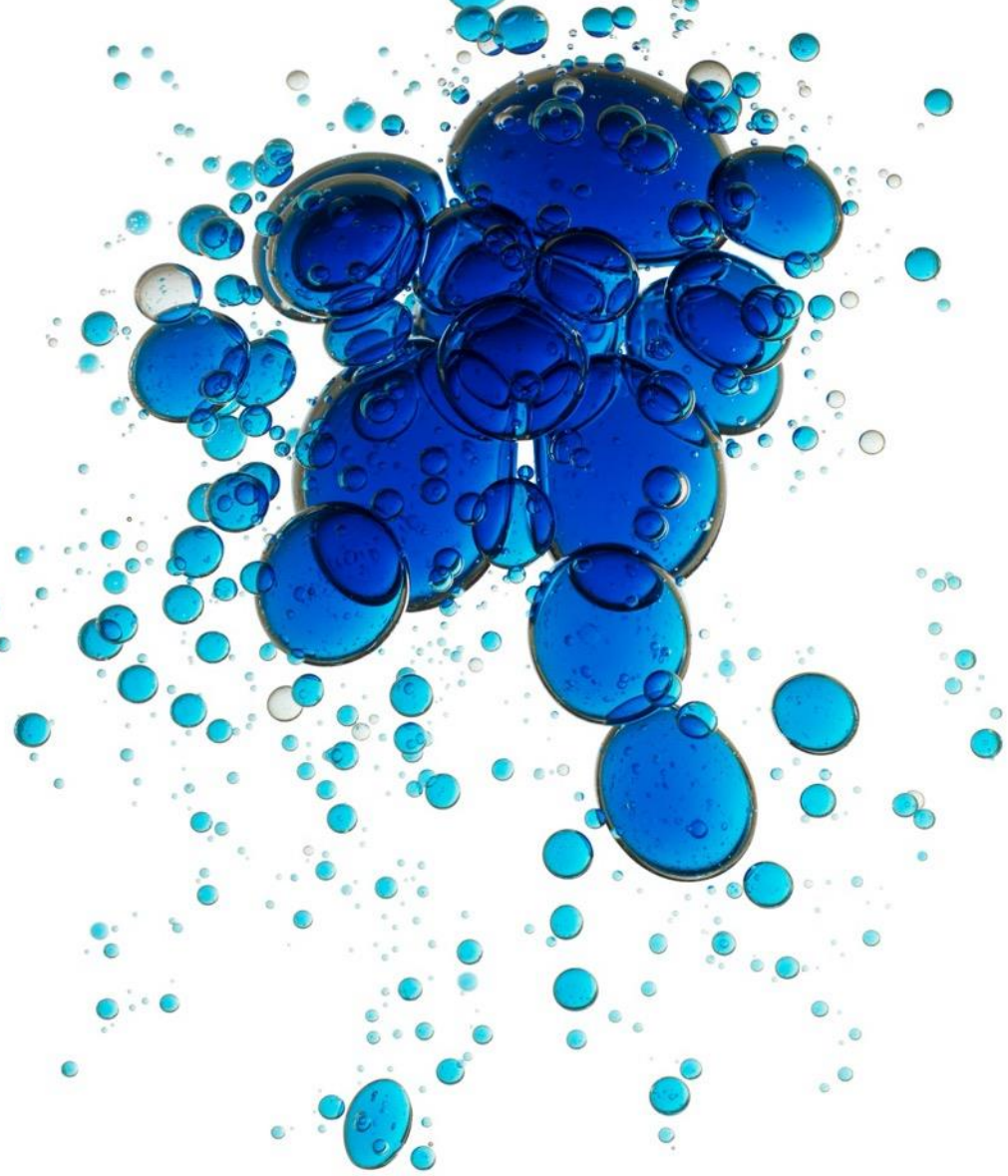
AIRlabs Value Proposition



AIR labs
AUSTRIA

Collaboration partners are always highly welcome!

www.airlabs.at



Lakeside Labs

6G for Connected Sky

Andreas Kercek
Research Manager

UAV-Workshop, DIH-Süd, Nov. 22nd, 2022

Powered and financed by:

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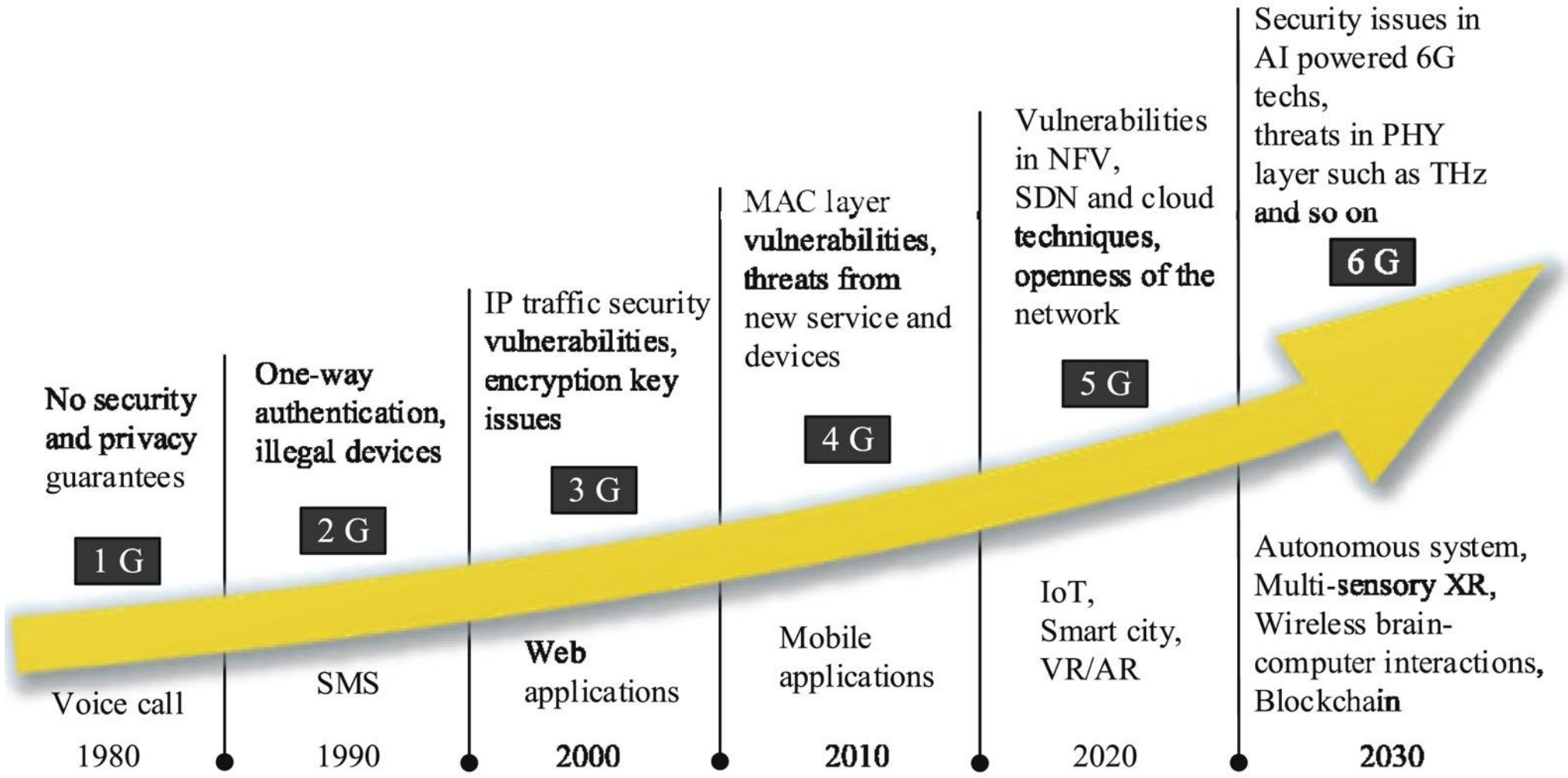
5G‘s „Killer App“ Will Be 6G!

THEODORE S. RAPPAPORT, New York University (h-index: 120)

Why 6G?



Wang et al., Digital Communications and Networks, 08/2020

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Why 6G?

Use Case (capability)	5G	6G	
Augmented Reality for Industry (peak rate & capacity)	Low resolution / high level tasks	High resolution, multi-sensory/detailed tasks, co-design	Enhancement to 5G services
Telepresence (capacity)	High video quality, limited scale	Mixed reality/Holographic	
Security surveillance, Defect detection (positioning & sensing)	Manual	Automated	
Distributed computing, Automation (time synchronization)	Micro-seconds level tasks	Higher precision nano second level tasks	
Dynamic digital twins and virtual worlds (real-time multi-sensory mapping and rendering)	Limited	Yes	New services introduced in 6G
Wireless in Data Center (peak rate and capacity)	No	Yes	
Zero Energy devices (back scatter communications)	No	Yes	
Swarms of robots or drones (low latency D2D)	Limited	Yes	
Bio sensors and AI	Limited	Yes	

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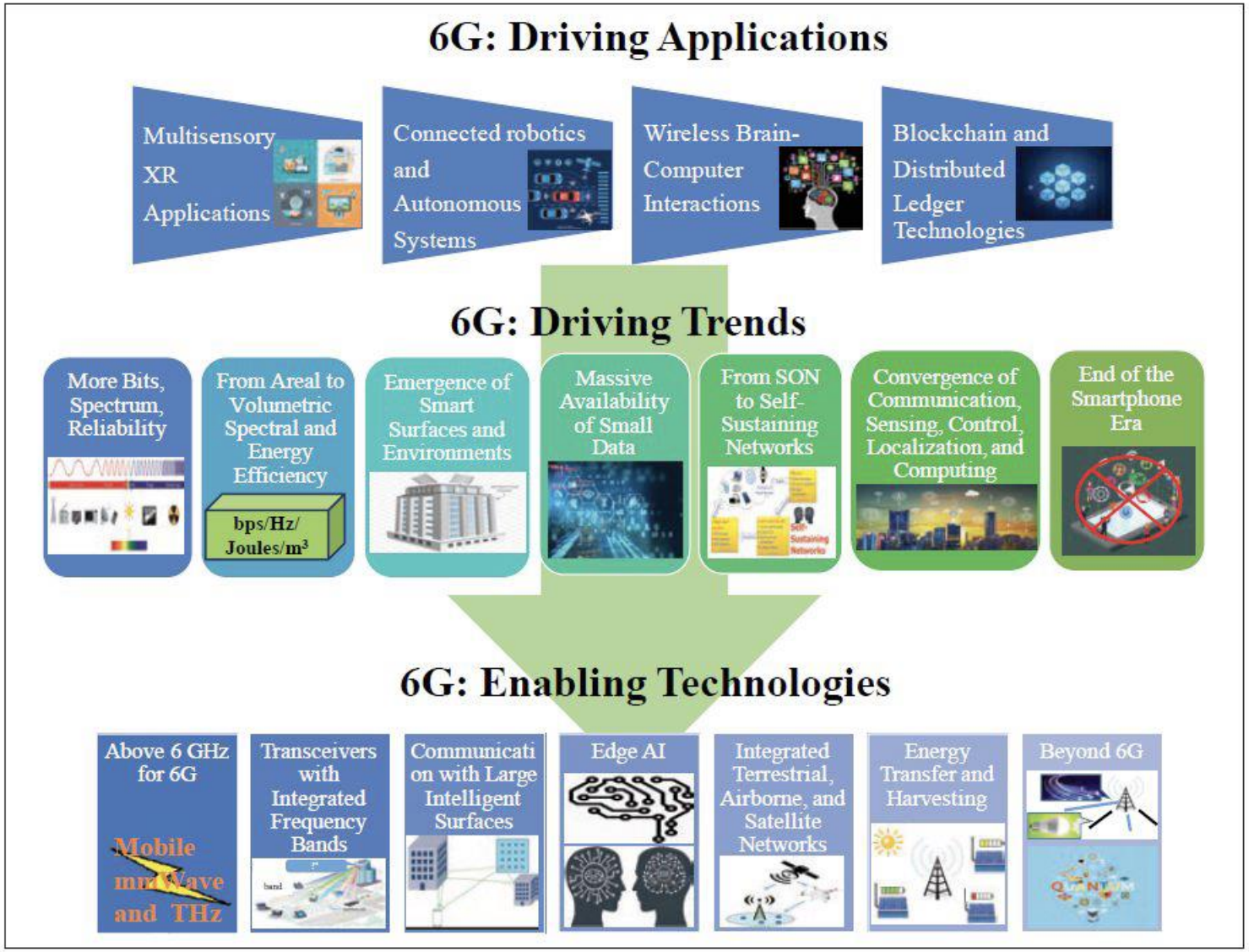
Why 6G?



Saad et al., IEEE Network, 05-06/2020

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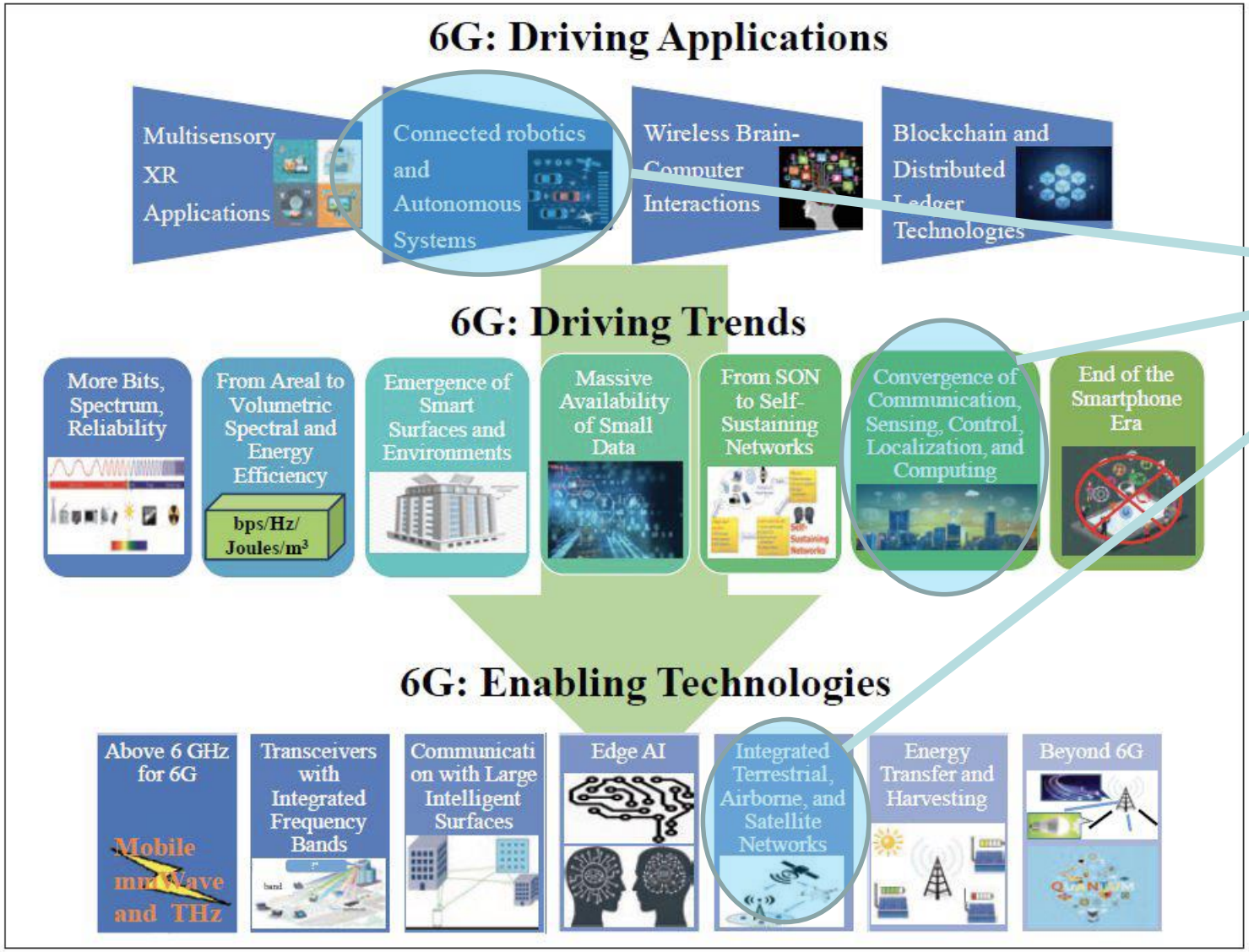
Why 6G?



Saad et al., IEEE Network, 05-06/2020

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6G-Sky Key Data

CELTIC-NEXT project with the planned framework: Technical Focus: 6G Multi-Layer Architecture

- Duration: 05/2022-04/2025
- Project budget: ~9m€
- Effort in person years: ~60

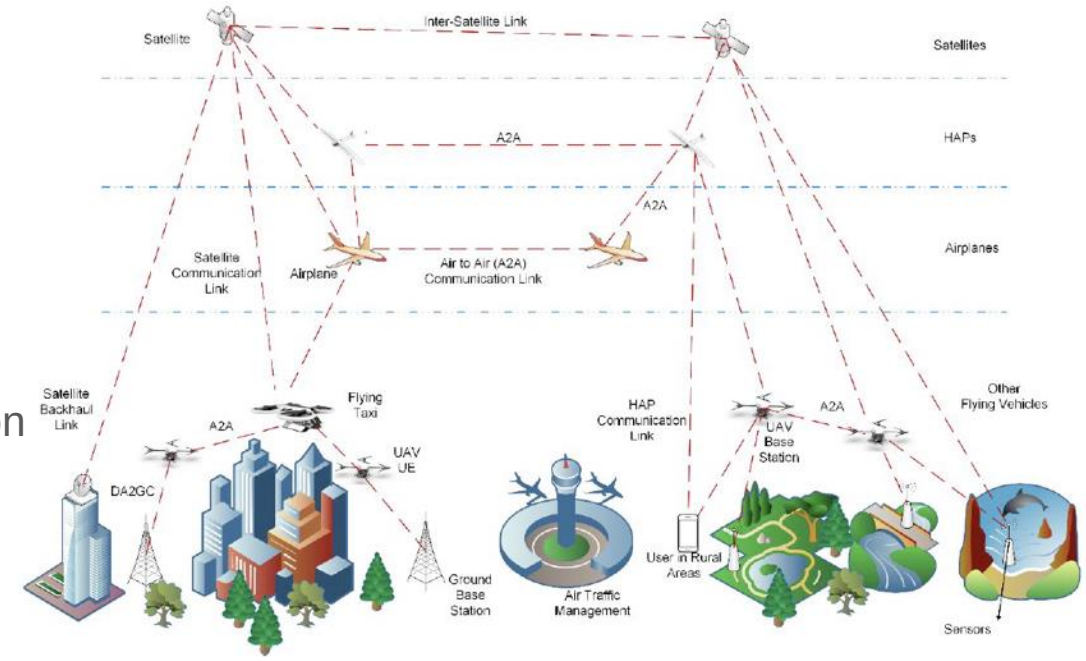
Countries and funding bodies:

- **Austria:** Austrian Research Promotion Agency
- **Germany:** Federal Ministry for Economic Affairs and Climate Action
- **Hungary:** Nemzeti Kutatási, Fejlesztési és Innovációs Hivatal
- **Sweden:** Ministry of Enterprise and Innovation

Partners:

- **Coordinator: Airbus**. Germany
- **Technical Coordinator: KTH** Royal Institute of Technology, Sweden
- **17 legal-entity partners** from industry (5), SMEs / startups (7), research institutes (2), government (2), universities (1)

Technical Focus: **6G Multi-Layer Architecture**



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6G-Sky Consortium

Industry

S

G H S

G

G

SMEs / Startups

A

S

A

G

G

H

University

S

Research Institutes

A

G

Government Related

S

A

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6G-Sky Objectives

Technical Focus: **6G Multi-Layer Architecture**

Reliable and robust **connectivity for aerial and ground** users

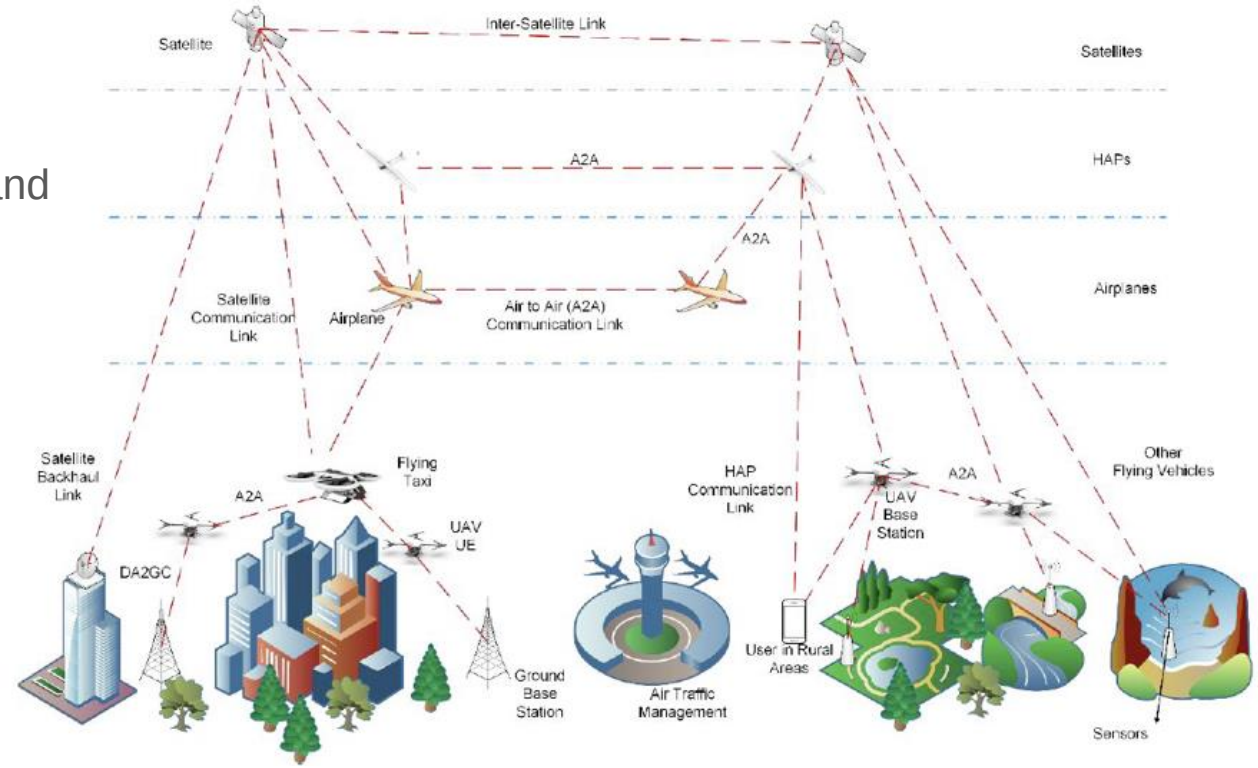
- flexible and adaptive **network architecture**
- **multiple communication technologies** such as satellite and direct air to ground communication

Novel wireless **network design and management schemes** in 3-dimensional (3D) space

- different types of **aerial vehicles** with their unique requirements

Providing **robust, low latency and/or high-capacity** communications to **ground** users

- **rural areas** without any infrastructure via Non-Terrestrial Networks (NTNs)



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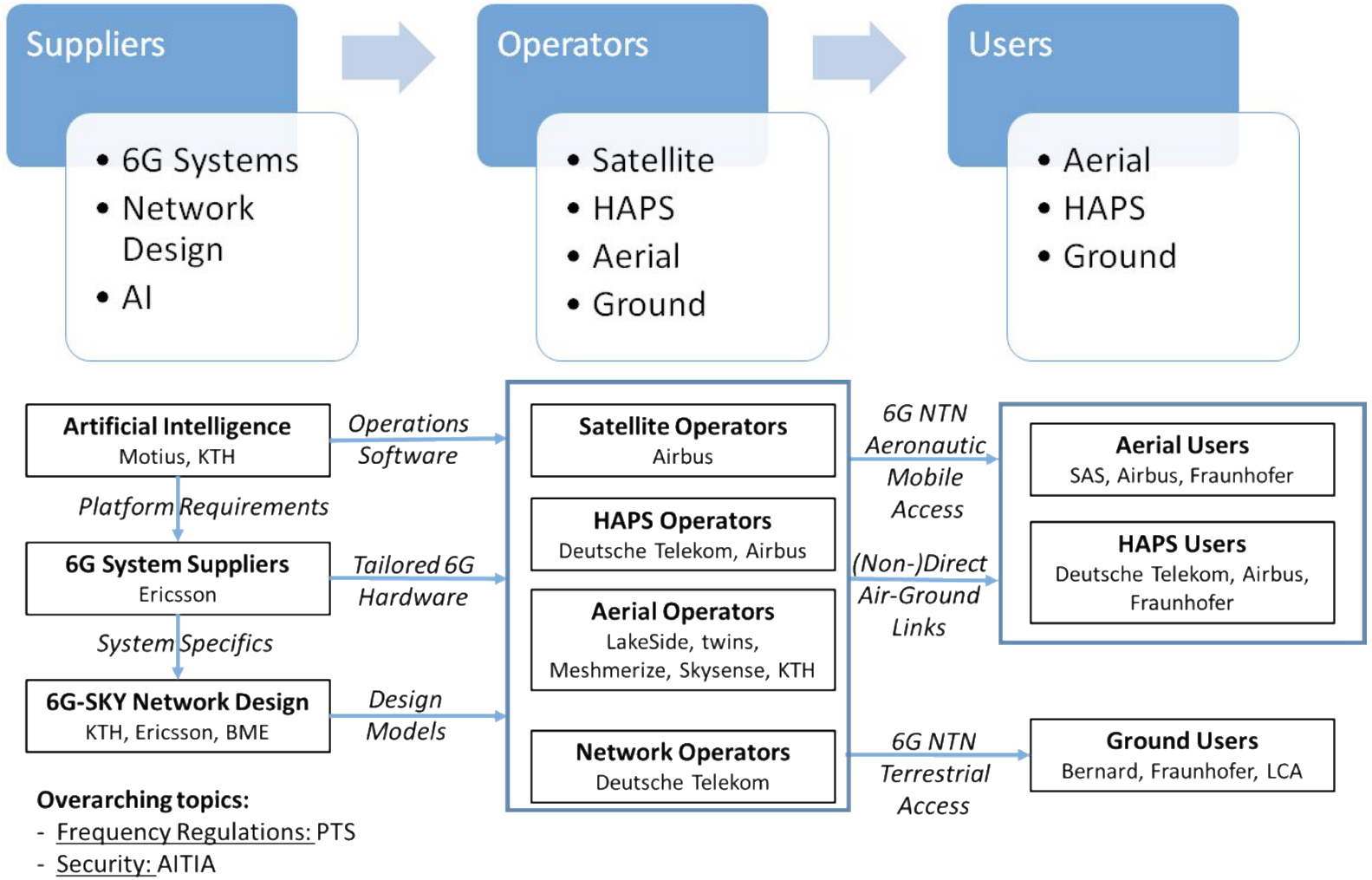
6G-Sky Value Chain



Overarching topics:

- Frequency Regulations: PTS
- Security: AITIA

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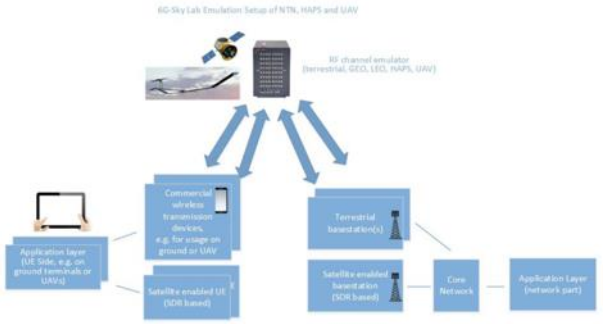
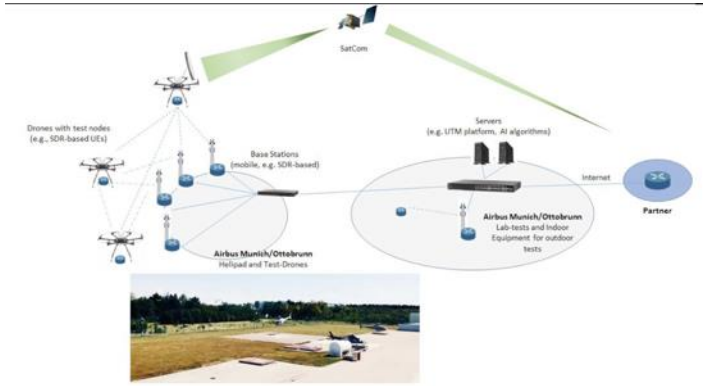
6G-Sky Demonstrations

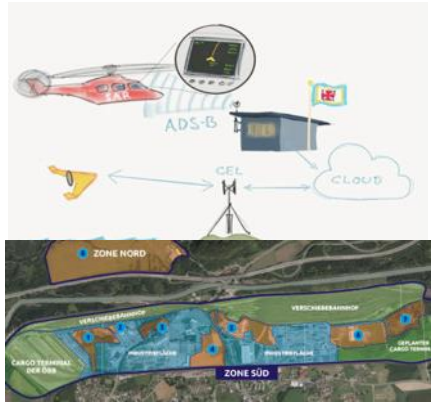
1.) Lab Emulations



2.) Multi-technology Network Integration



3.) 3D Network Demonstration with Drone Swarm + Sense & Avoid



4.) Demonstration of High Altitude Platform networking

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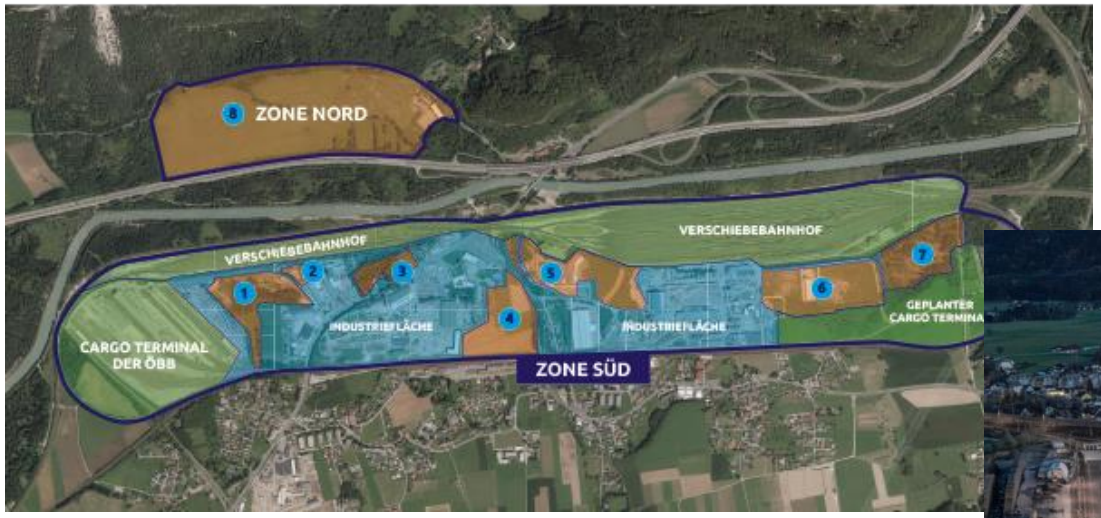
6G-Sky Logistics Use Case

LOGISTIK CENTER Austria Süd



Intermodal logistics:
trains, trucks,
autonomous vehicles (on-site)

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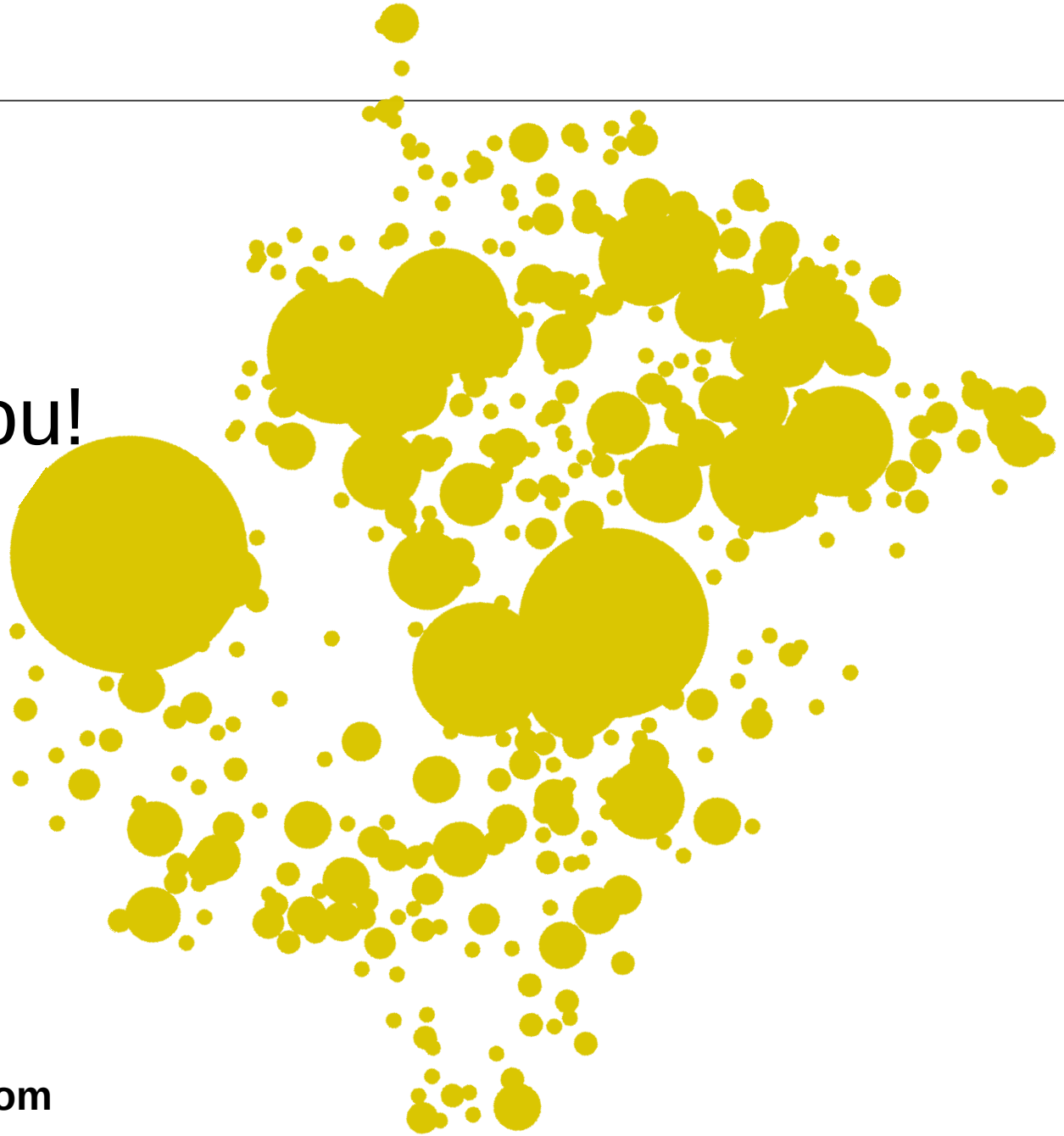
Thank you!



www.Lakeside-Labs.com

Use Case "Demo of Blood Transport in Lilienfeld, NÖ"

POSSIBLE USE CASES OF DRONES FOR COMPANIES

Klagenfurt, 22 Nov 2022

DI Dr.-Ing Holger Friehmelt

Institute Director FH JOANNEUM Luftfahrt/Aviation and Technical-Scientific Director AIRlabs Austria GmbH

Federal Ministry
Republic of Austria
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The project AIRlabs has received funding from the Austrian research funding programme Take Off. Take Off is a Research, Technology and Innovation Funding Programme of the Republic of Austria, Ministry for Climate Action. The Austrian Research Promotion Agency (FFG) has been authorised for the Programme Management.

Mission

- Place: Lilienfeld, Lower Austria (NÖ)
- EVLOS Flight in Specific Category with UAV with less than 25 kg total mass
- Transport of donor blood bettween Red Cross Site and Hospital of Lilienfeld
- Only during civil daytime (sun less than 6° below horizon)

Parameter	Value
Maximum altitude	120 m
Maximum speed	60 km/h
Operating temperature	+5 °C to +50°C
Mode of operation	Automatic
Type of operation	EVLOS with Observer (Never done before)
Population	49 / km²
Airspace class	G

UAV

- Mission flight time 10 min
- Empty mass 11.5 kg
- Maximum takeoff mass 17 kg
- Max payload 5 kg (~ 3.74 kg in demo case)
  - Transportation box 0.74 kg
  - NaCl “donor blood” 0.420 kg
  - Cooling pads 0.66 k
- Operating temperature -10 °C to +50 °C
- Maximum climb rate 2.5 m/s
- Maximum sink rate 3.5 m/s
- Maximum horizontal speed 60 km/h

Ehang‘s Falcon

GRC

Route

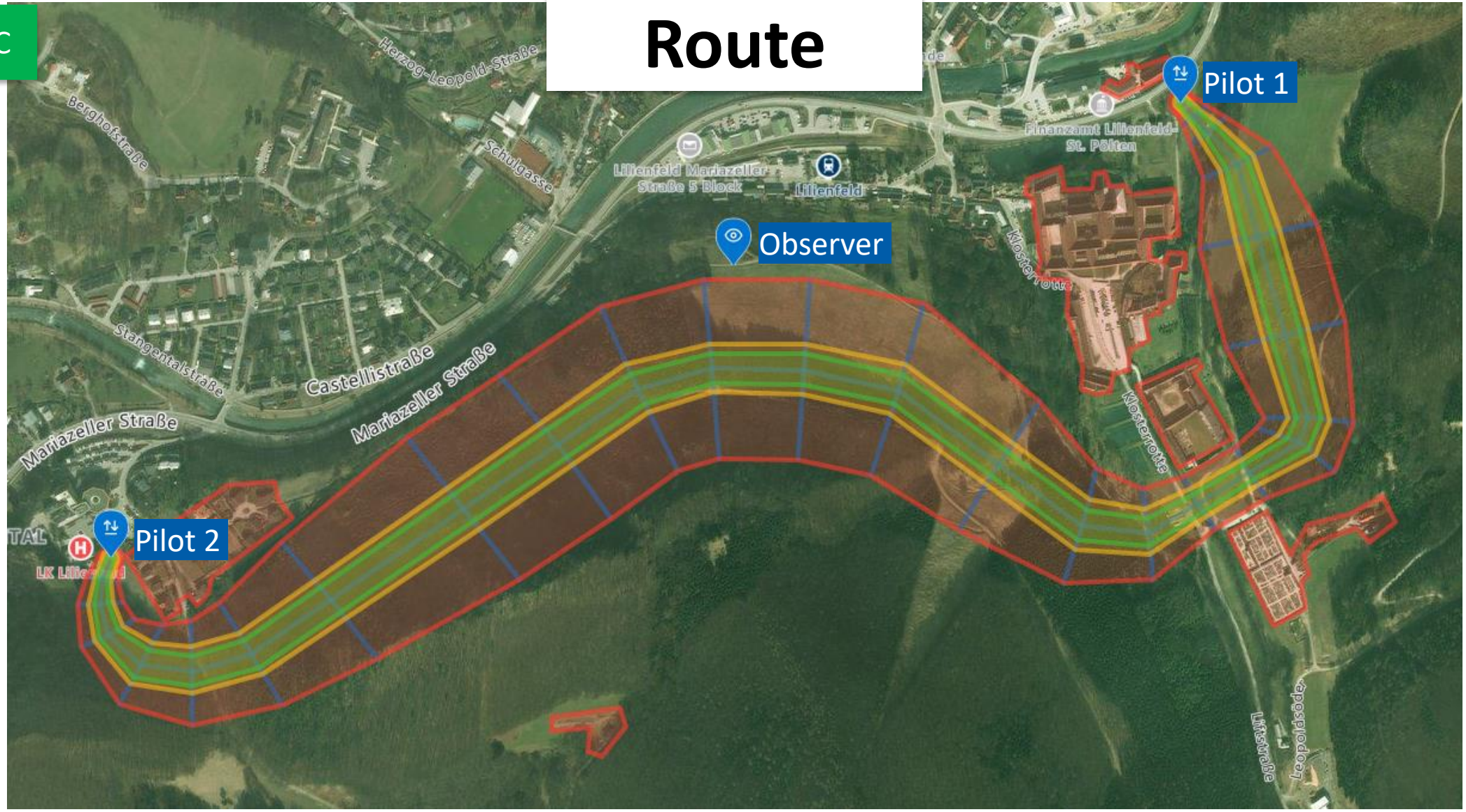


Figure 3: Lilienfeld in SOARIZON [1]

GRC

Ground Risk Buffer (GRB)

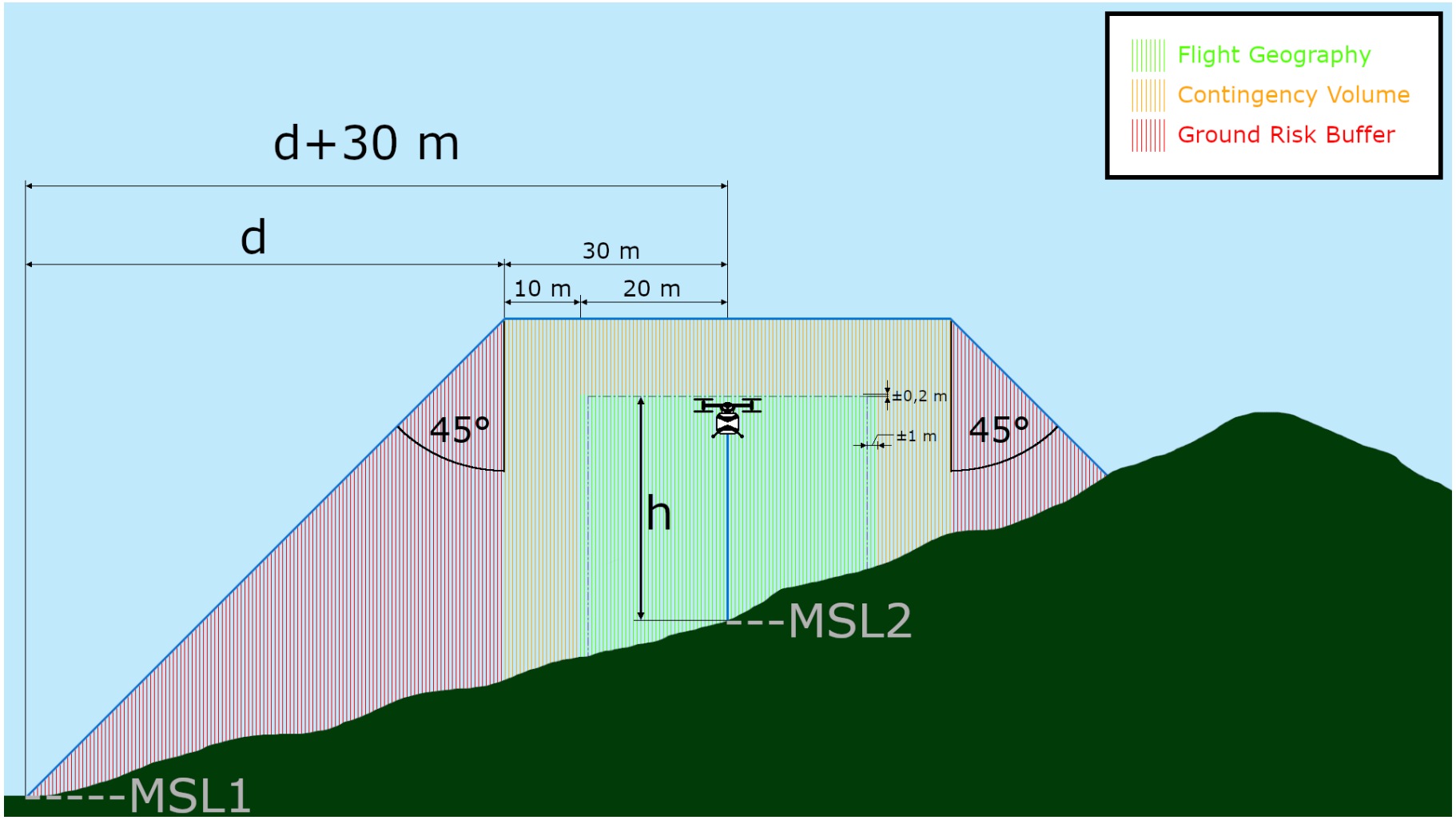


Figure 5: Ground Risk Buffer calculation for one specific waypoint

GRC

ARC

Vertical Profile

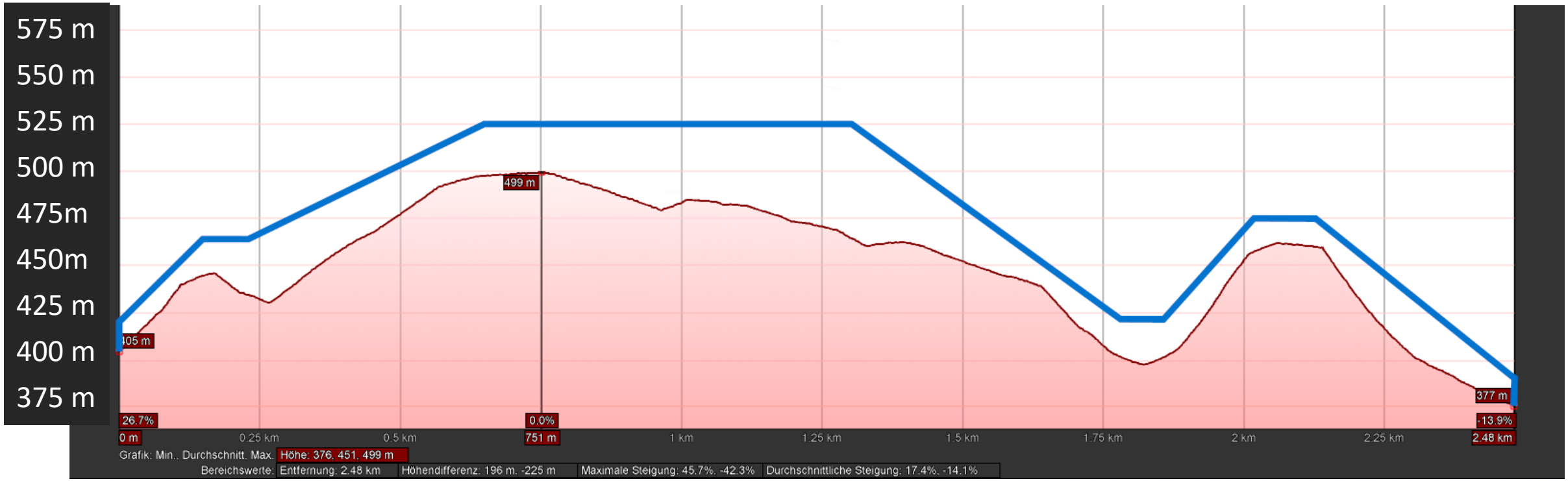


Figure 4: Altitude diagram[4]

EVLOS Concept with Observer

VLOS from drone to pilot 1

VLOS from drone to Observer

Photos from the SORA document

Test flight in open category with a DJI Mavic Pro

VLOS from drone to pilot 2

FH JOANNEUM University of Applied Sciences

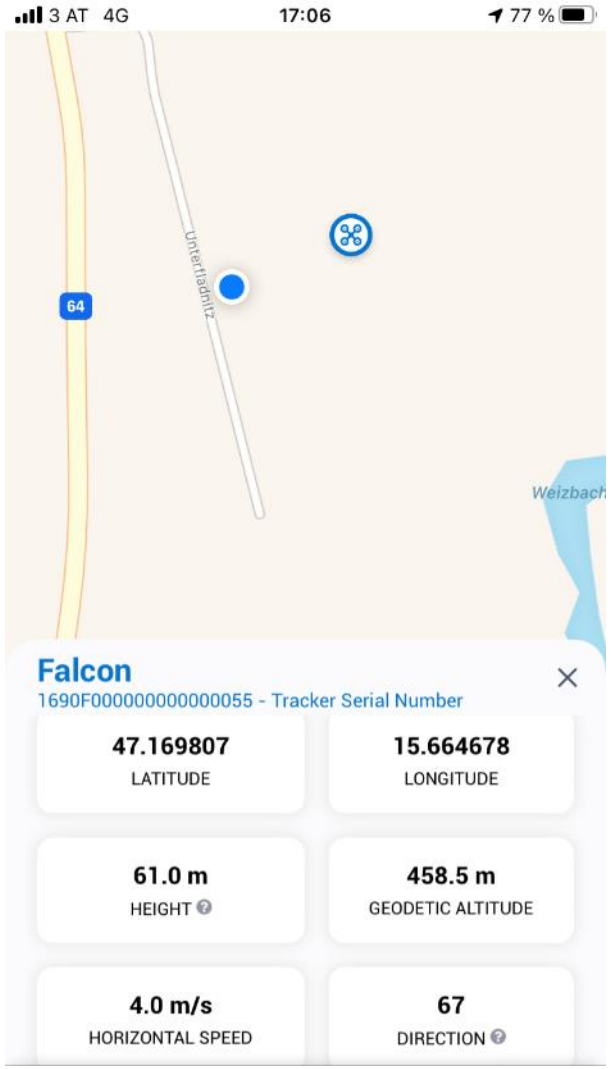
Thales Scaleflyt Remote ID

Additional Position Information

- Dimensionen 50 mm x 50 mm x 30 mm
- Gewicht 60 g
- Batterie (aufladen mit USB-C)
- Global Positioning System (GPS) und mobiles Netz
- Abbildung auf Handy-App

App Display:

- UAS on map
- Fluíght duration
- Take off time
- Coordinates of tracker
- Height above ground
- Height above sealevel
- Horizontal speed
- Flight heading



Screenshot from Scaleflyt Remote ID

FH JOANNEUM
University of Applied Sciences

Media Response

Man wolle sich nun in weiteren Schritten und Demonstrationen an eine Serienanwendung herantasten. Dabei spielt auch die **AIRlabs Austria** … eine gewichtige Rolle. Dieses vom BMK geförderte Innovationslabor stellt nämlich geeignete Testinfrastrukturen rund um die Drohnenfliegerei zur Verfügung.

»OBSERVER«

Kleine Zeitung im Fokus
Verlagsbeilage
Graz, am 13.10.2021, Nr: Innovat. Mobilität, 2x/Jahr, Seite: 16-17
Druckauflage: 169 797, Größe: 91,89%, easyAPQ: _
Auftr.: 2598, Clip: 13894616, SR: FH Joanneum

Blutkonserve aus der Luft

Das Rote Kreuz hat erstmals eine Blutkonserve per Drohne ausgeliefert, und zwar völlig automatisch. Die FH JOANNEUM hat das Projekt wissenschaftlich begleitet.

Alle 90 Sekunden braucht ein Mensch in Österreich eine Blutkonserve. Wenn ein Krankenhaus Nachschub bestellt, setzt sich ein Auto mit Fahrerin oder Fahrer in Bewegung, um das lebensrettende Blut zu liefern. Das Rote Kreuz und die FH JOANNEUM erprobten jetzt neue Wege, um dabei Zeit und Ressourcen zu sparen: Erstmals wurde am 22. September 2021 eine Blutkonserve per Drohne ausgeliefert. Und zwar vollautomatisch. Die Aktion ist symbolisch, der Flug von der Rotkreuzbezirksstelle Lilienfeld (Niederösterreich) ins nahegelegene Landesklinikum dauerte nur wenige Minuten, aber sie zeigt, wie Drohnen in Zukunft das Helfen erleichtern können.

Versprechen für die Zukunft. „Bereits jetzt verwenden wir Drohnen, etwa bei Personensuchen oder zur raschen Lageerhebung nach großen Unfällen", sagt Gerry Foitik, Bundesrettungskommandant des Roten Kreuzes. „Blutkonserven mit Drohnen auszuliefern ist eine weitere vielversprechende Anwendung. Drohnen sind kein flüchtiges Spielzeug, sondern gekommen, um zu bleiben. Die Blaulichtorganisationen hoffen, dass bei ihrem Einsatz künftig mehr möglich sein wird und die rechtlichen Rahmenbedingungen dafür geschaffen werden." In Ruanda würden zum Beispiel bereits Blutkonserven von Drohnen ausgeliefert. Auch in der Schweiz werden bereits medizinische Produkte auf diese Art transportiert.

FH JOANNEUM begleitete das Projekt. Eine Änderung der EU-Vorschriften hat in Österreich erste Erleichterungen gebracht, doch das nationale Luftfahrtgesetz ist streng. Flüge wie [illegible] in Lilienfeld müssen aufwendig beantragt werden. Holger Friehmelt, Leiter des Instituts Luftfahrt/Aviation an der FH JOANNEUM, hat das Projekt wissenschaftlich begleitet. „Die nötigen Technologien sind weltweit vorhanden. Hier konnten wir aber mit österreichischem Know-how erstmals demonstrieren, wie man in engem Zusammenspiel mit der Zulassungsbehörde in einer Realumgebung einen sinnhaften Transport ermöglichen kann", sagt er. „Ganz essentiell für diese Integration im wahrsten Sinne des Wortes war ‚frisches Blut', nämlich junge Studierende der Luftfahrtstudiengänge an der FH JOANNEUM. Nur durch deren tatkräftige Mitarbeit wurde dieses Projekt erst möglich."

Und auch inhaltlich war diese Flugdemonstration hochspannend. Erstmal wurde in einer sogenannten Realumgebung geflogen. Dabei war nichts abgesperrt oder über einem abgeschlossenen Areal geflogen, sondern in einem realen Einsatzgebiet. Die Drohne musste bei ihrem 2,4 km langen Flug zusätzlich mehrere Hundert Höhenmeter zurücklegen und mit den Windverhältnissen in einem solchen Tal zurechtkommen. „Flach über einen See oder das Meer kann jeder, mit unserem dreidimensionalen Flug in Lilienfeld aber haben wir eine Weltpremiere hingelegt" freut sich Holger Friehmelt für das gesamte Team.

„Man wolle sich nun in weiteren Schritten und Demonstrationen an eine Serienanwendung herantasten. Dabei spielt auch die AIRlabs Austria, eine Ausgründung der FH JOANNEUM, eine gewichtige Rolle. Dieses vom BMK geförderte Innovationslabor stellt nämlich geeignete Testinfrastrukturen rund um die Drohnenfliegerei zur Verfügung. Neben dem Firmensitz in Eggenberg beteiligten sich eine ganze Reihe von steirischen Partnern an AIRlabs – nicht nur im technisch-wissenschaftlichen Bereich, sondern auch im Netzwerken durch das Luftfahrtcluster ACstyria, ergänzt Friehmelt.

Richtige Software gibt Sicherheit. „Wir freuen uns über das Projekt. Unser eingesetztes Modell „Falcon L" gehört zu den führenden Logistikdrohnen weltweit und ist unter anderem bei DHL in China im Einsatz. Damit können wir Pakete bis zu fünf Kilogramm, mit einer Geschwindigkeit von 80 km/h rund 90 km weit transportieren – und das vollautomatisiert. Unsere Lösung lässt sich auf beliebig viele Drohnen skalieren", sagt Andreas Perott, CMO Europe von Elitag.

Das Rote Kreuz würde lieber heute als morgen Blutkonserven per Drohnen ausliefern

PIXELMAKER

Eine Mitarbeiterin am Luftfahrtinstitut der FH Joanneum zeigt die Blutkonserven-Drohne

PIXELMAKER

Seite: 1/2

Zum eigenen Gebrauch nach §42a UrhG. Digitale Nutzung gem PDN-Vertrag des VÖZ vorbehalten. Anfragen zum Inhalt und zu Nutzungsrechten bitte an den Verlag (Tel: 0316/875-3308).

Seite: 2/2

Discussion of Mobile Communication Requirements of Demo Case

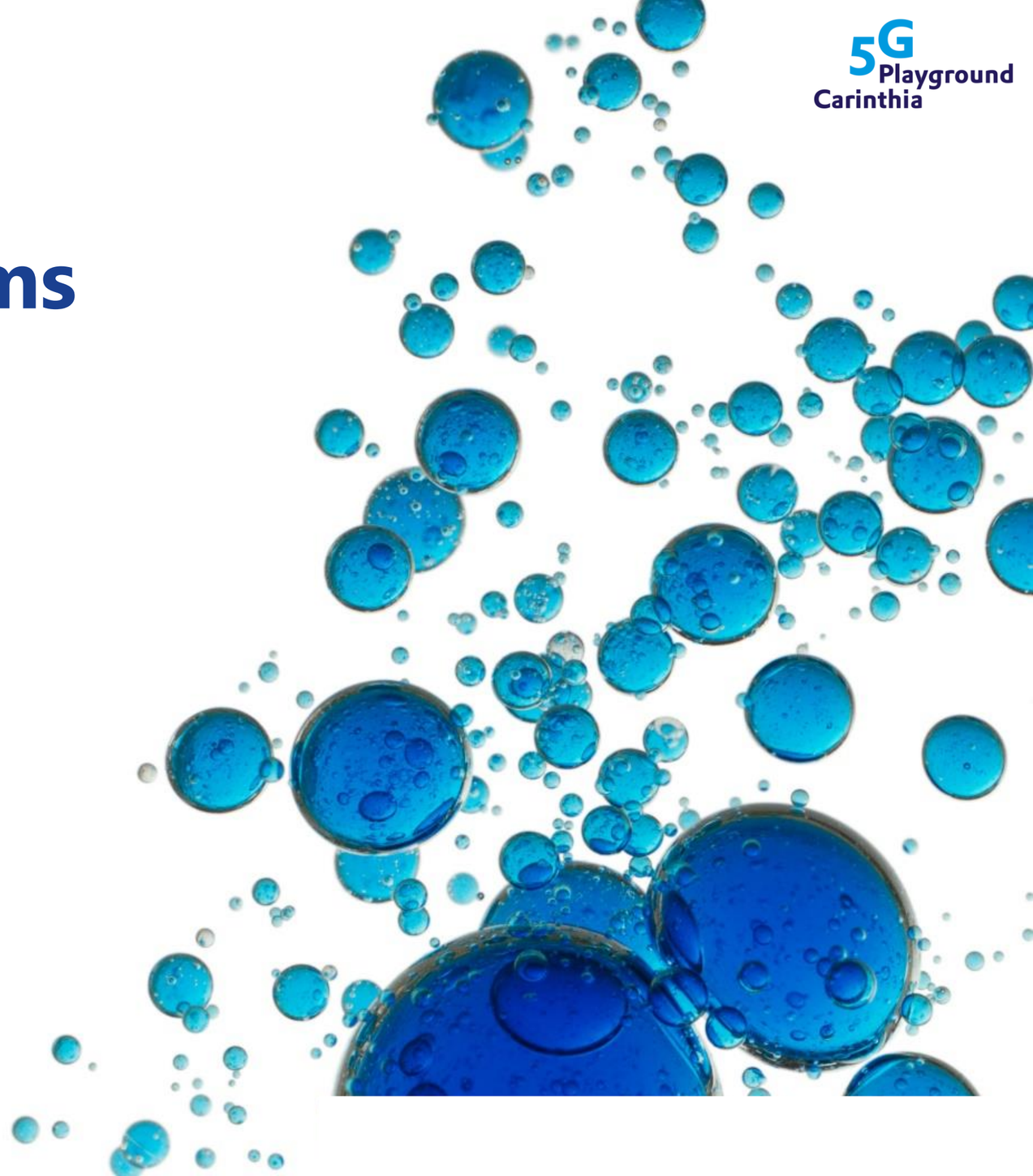
• Team to Ops Center in China	**VoIP** (WeChat via 4G LTE 5G)
• Ops Center in China to Drone	**Datalink** (Internet via 4G LTE 5G)
• Pilot 1, Observer, Pilot 2	**Cellphone** (Mobile Network 4G LTE 5G)
• FIC Wien to local pilot	**Cellphone** (Mobile Network 4G LTE 5G)
• Remote ID (Thales)	**Datalink** (Internet via 4G LTE 5G)
• Communication local team to ÖRK Christopherus Ops	**Radio** (Ultrashort Wave Terrestrial and Trunked Radio Digital BOS Radio (380 to 400 MHz)
• Local team to potential air traffic	**Air Traffic Radio** (VHF 117,975 to 137 MHz)

Thank you very much for your attention!

Lakeside Labs
SELF-ORGANIZING NETWORKED SYSTEMS

5G Playground Carinthia

Communication in Swarms
Use Case Presentation



Christian Raffelsberger
Senior Researcher

Lakeside Labs

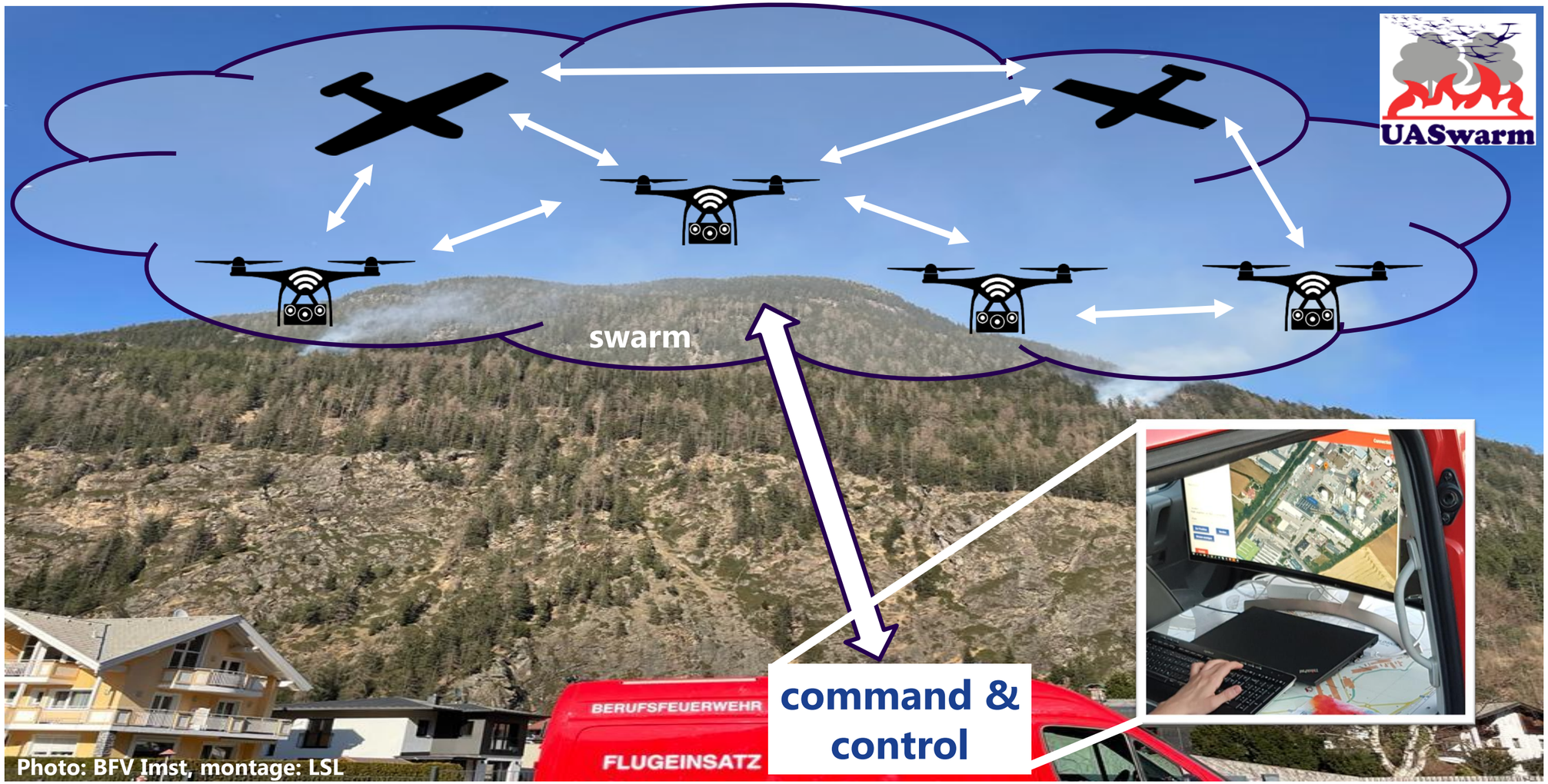
SELF-ORGANIZING NETWORKED SYSTEMS

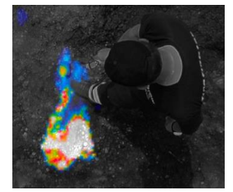
Key Facts: Non-profit research organization on self-organizing, networked systems
currently 17 researchers
research topics: swarm intelligence, wireless communication, multi-robot systems (focus on drones), sensor networks

Cellular Connected drones: Introduction

Application example

S&R and monitoring in forest fires





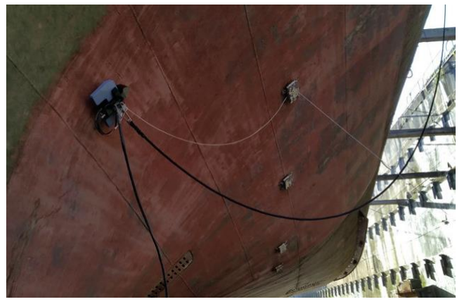
Lakeside Labs
SELF-ORGANIZING NETWORKED SYSTEMS

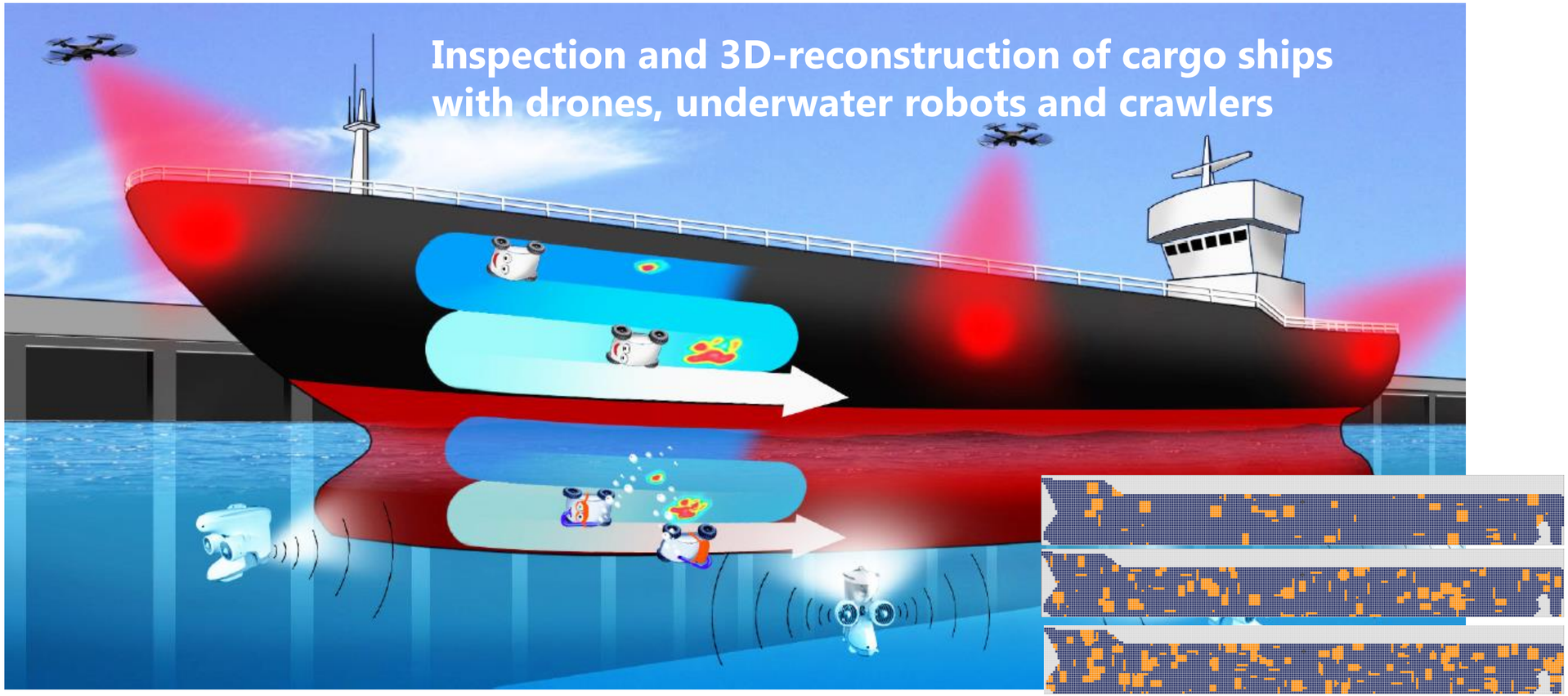
5G Playground Carinthia

Application example

Ship maintenance

BugWright2





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blueye · RINA · NTNU Norwegian University of Science and Technology · ROBOPLANET · Trondheim Havn · In Extenso Innovation Croissance · WMU World Maritime University · danaos · Alpen-Adria Universität Klagenfurt | Wien | Graz

Cellular-connected drones

Ad-hoc vs cellular

Ad-hoc communication

mainly IEEE 802.11 WiFi

+ COTS hardware
- communication range (LOS)
- scalability
- antenna orientation (3D)
- interference (ISM bands)
+ adaptability/modifciations

Cellular-connected drones

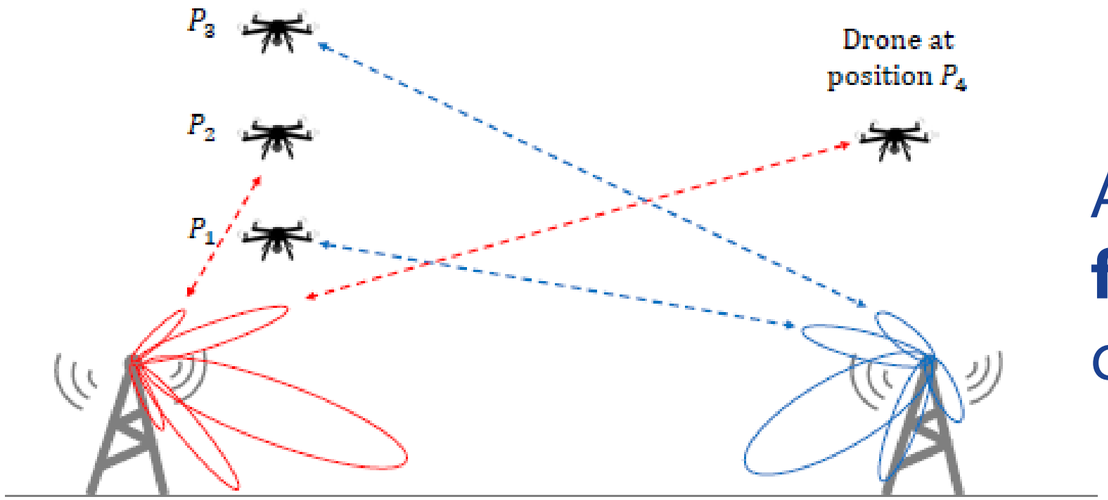
LTE, 5G

+ COTS hardware
+ communication range (BVLOS)
+ scalability
~ data rates in the uplink
~ antenna orientation
~ interference
- adaptability/modificiations

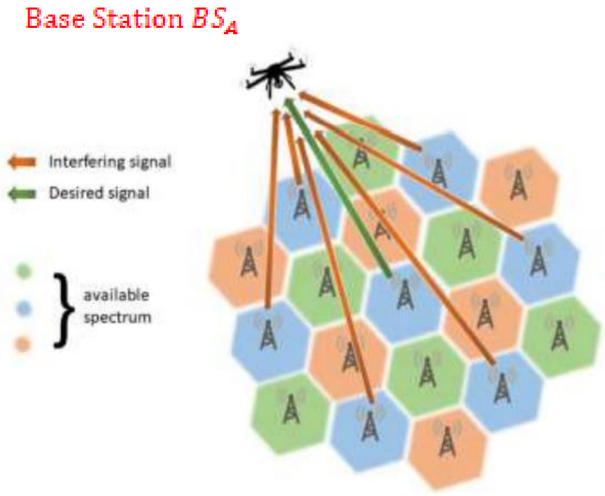
Cellular Connected drones: Integration Issues

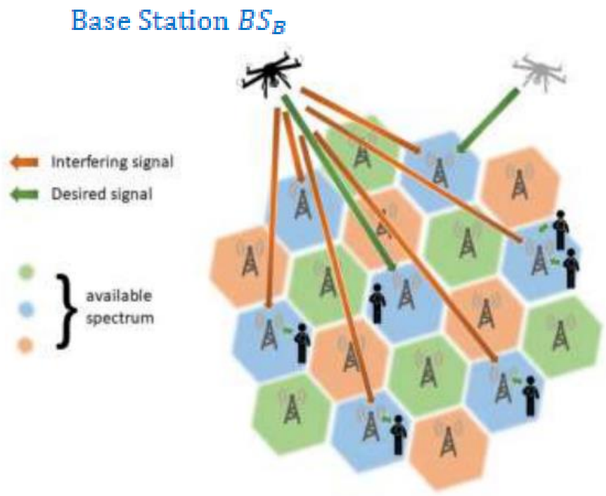
Cellular-connected drones

Interference and handover issues



Antennas oriented towards ground, **frequent handovers** due to connectivity via side lobes

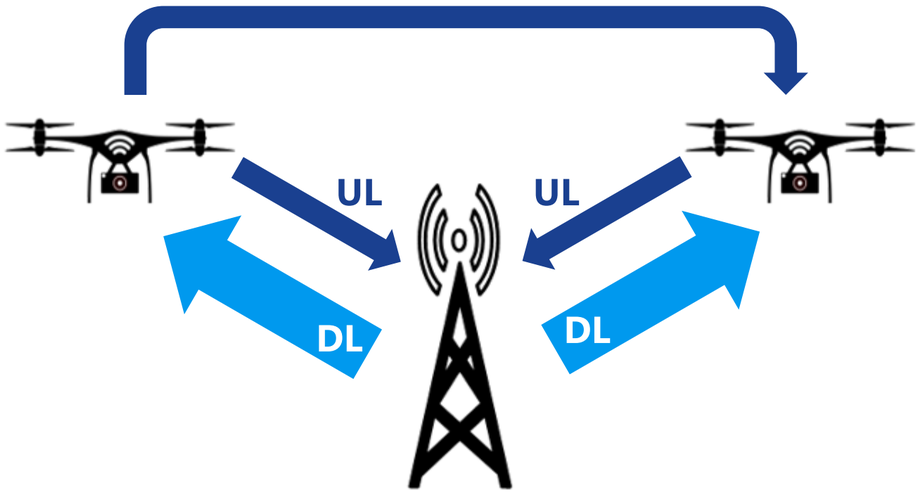




LOS connectivity to distant base stations, **increased interference** in cells using the same frequency

Cellular-connected drones

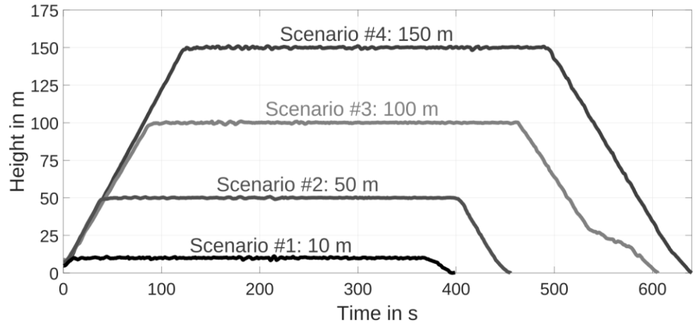
Uplink limitations

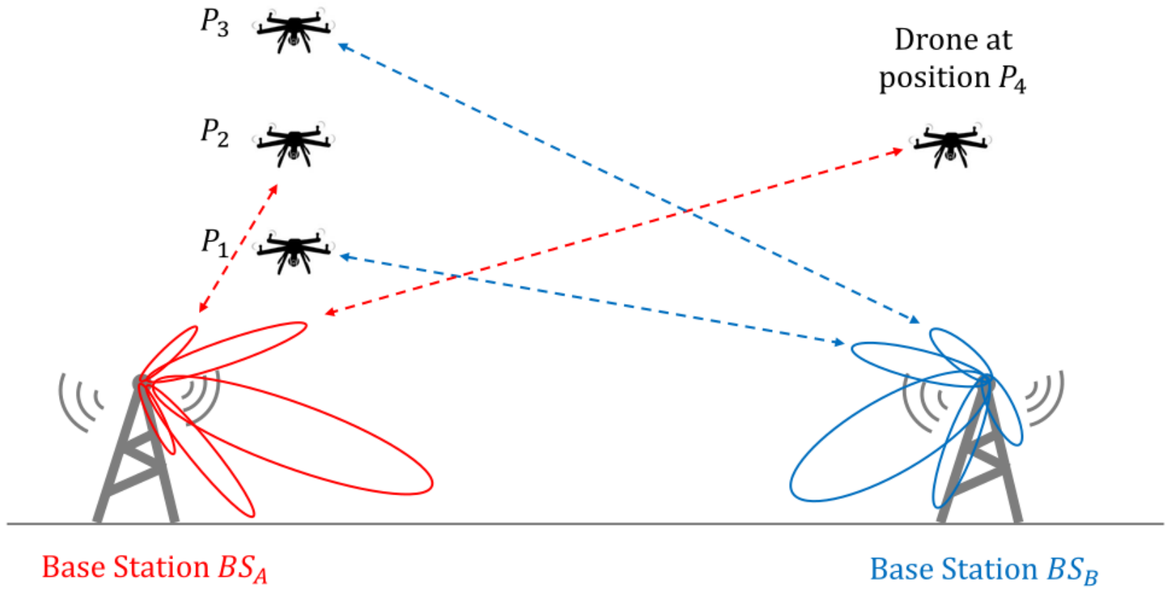


current cellular architectures **do not provide direct device-to-device communication**, hence drones are **limited by uplink**

Cellular-connected drones

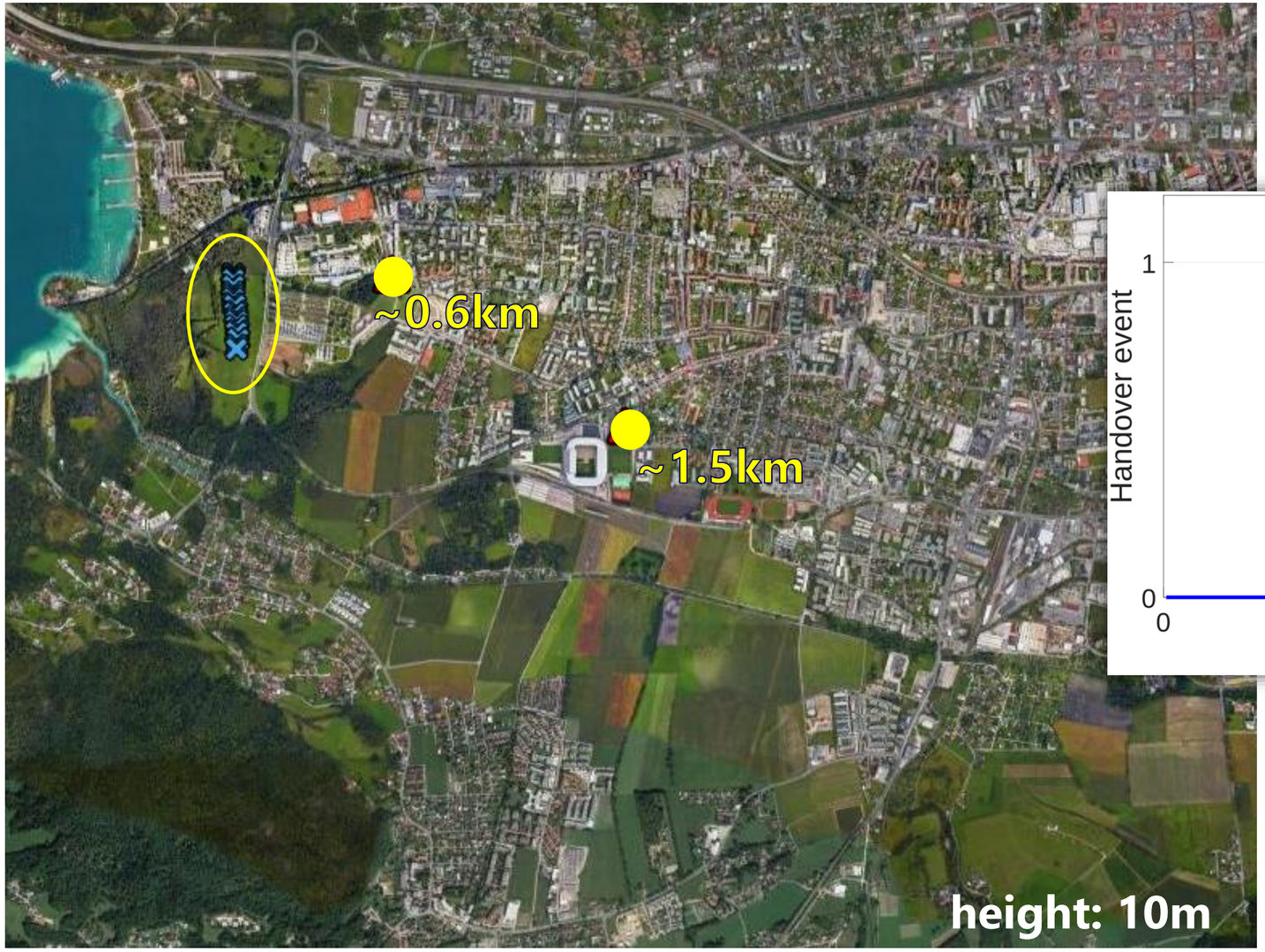
Real-world evaluations (LTE-A)

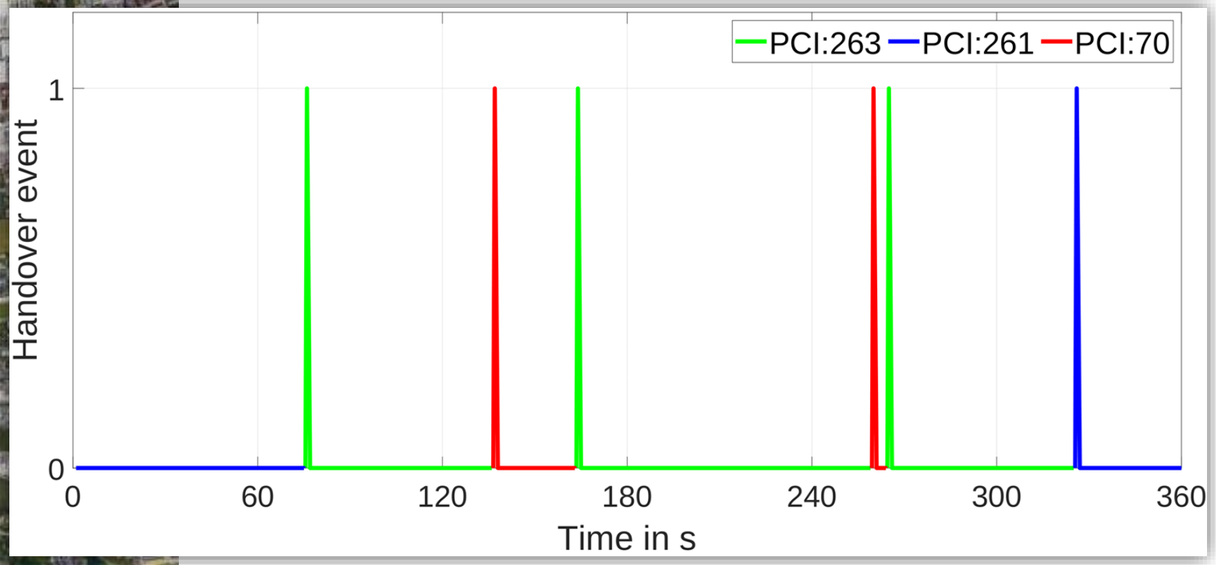




Cellular-connected drones

Handovers @ 10m

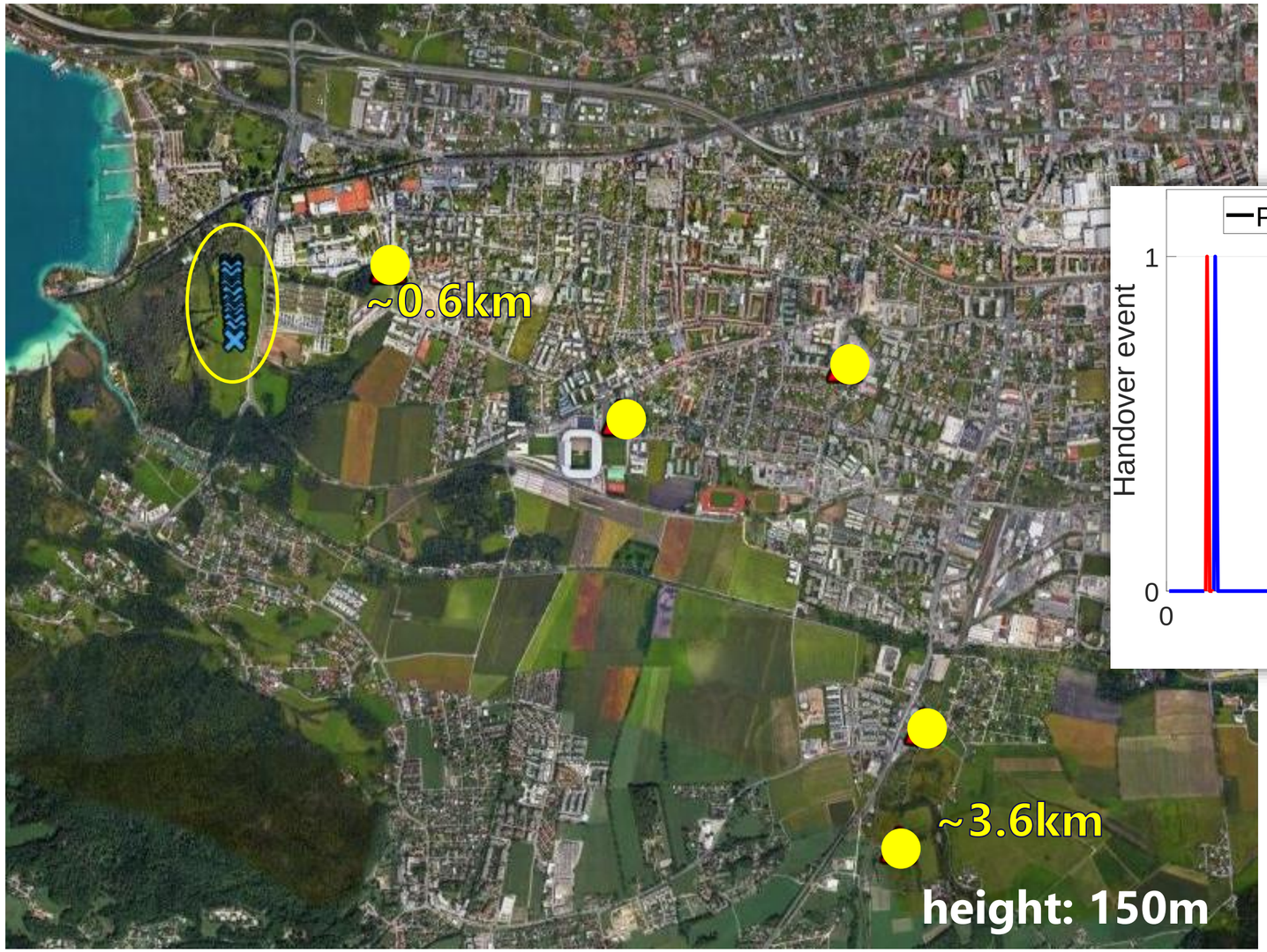


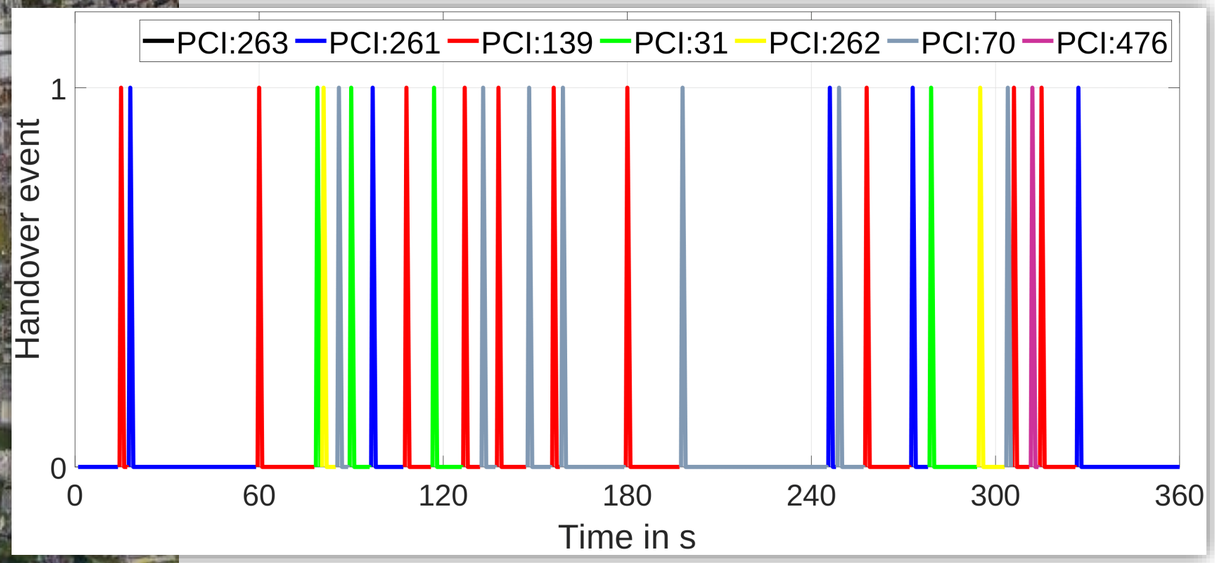


1 handover per minute

Cellular-connected drones

Handovers @ 150m



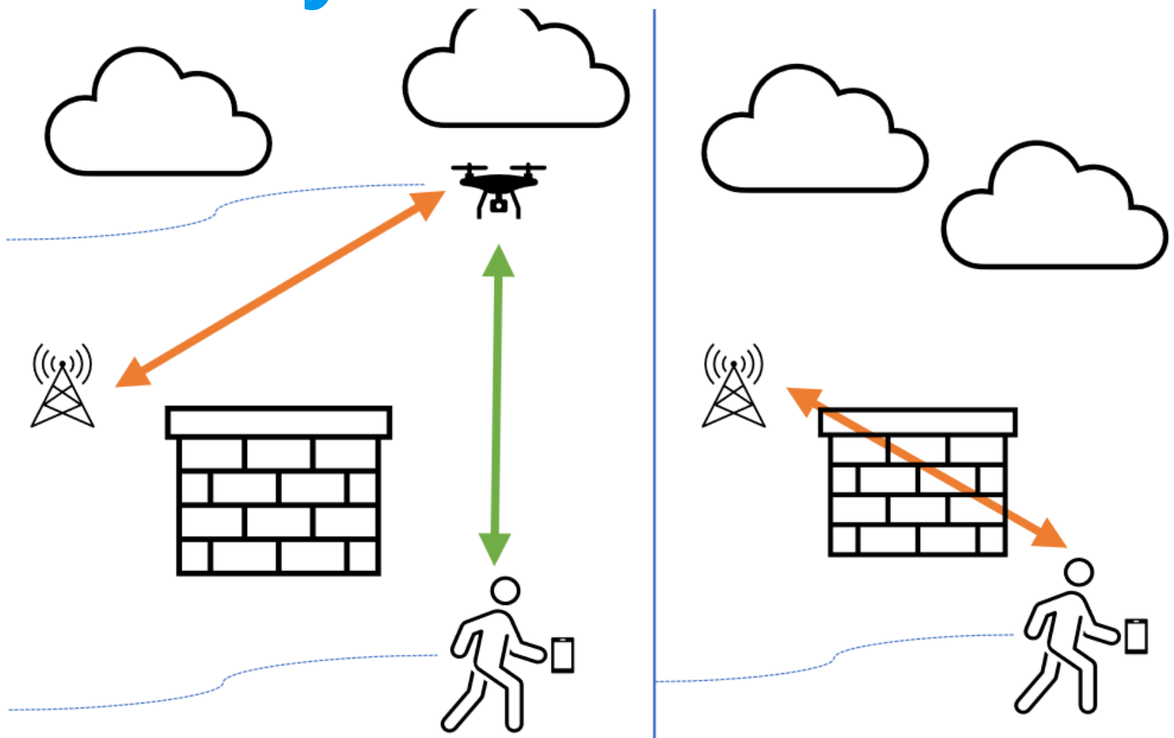


4 handovers per minute

Cellular Connected drones:
Drone Small Cell

Drone Small Cell (DSC)

Drone as LTE-WiFi relay

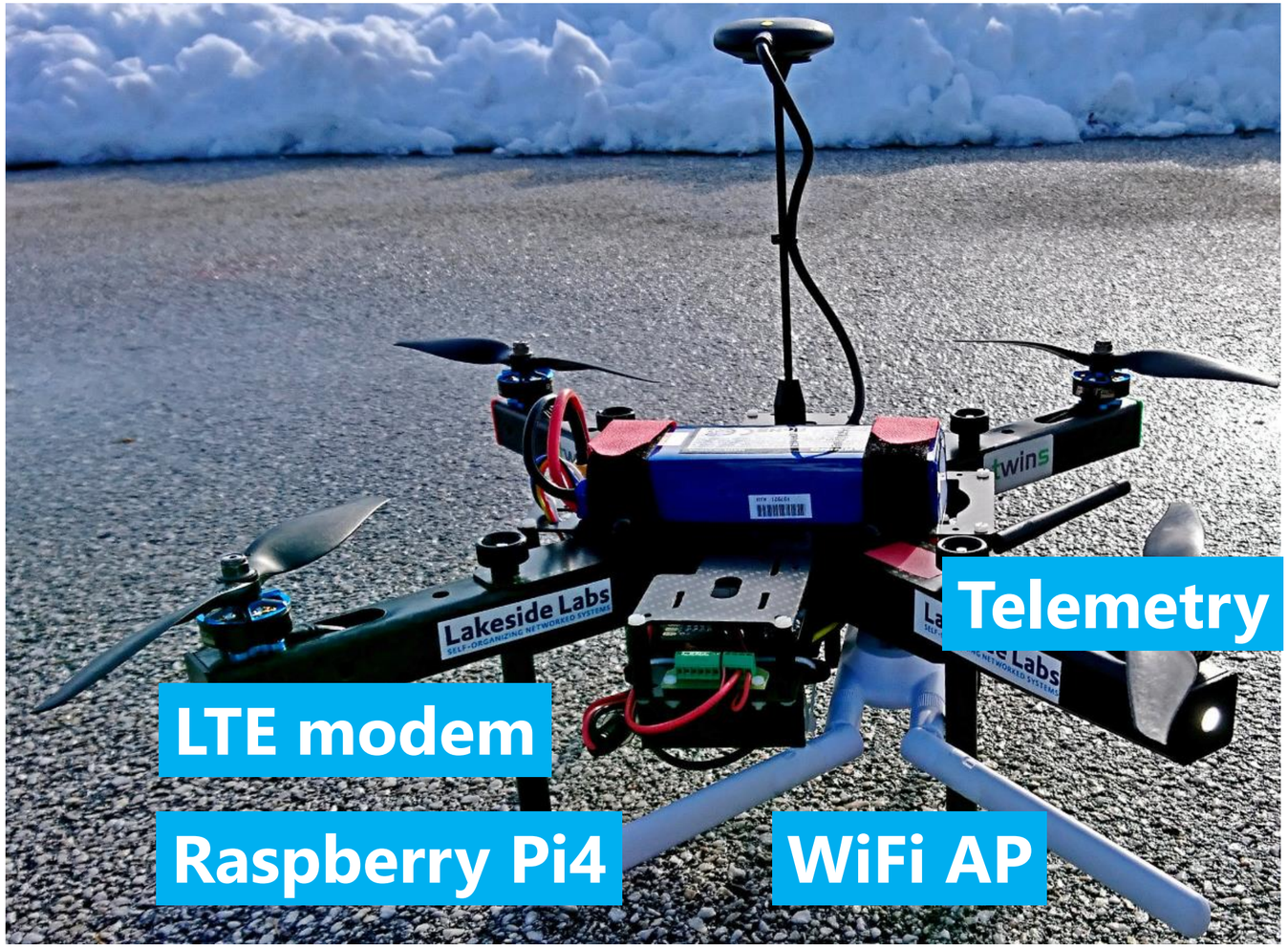


LTE to UAV, Wi-Fi to user

LTE only

Drone Small Cell (DSC)

Hardware setup



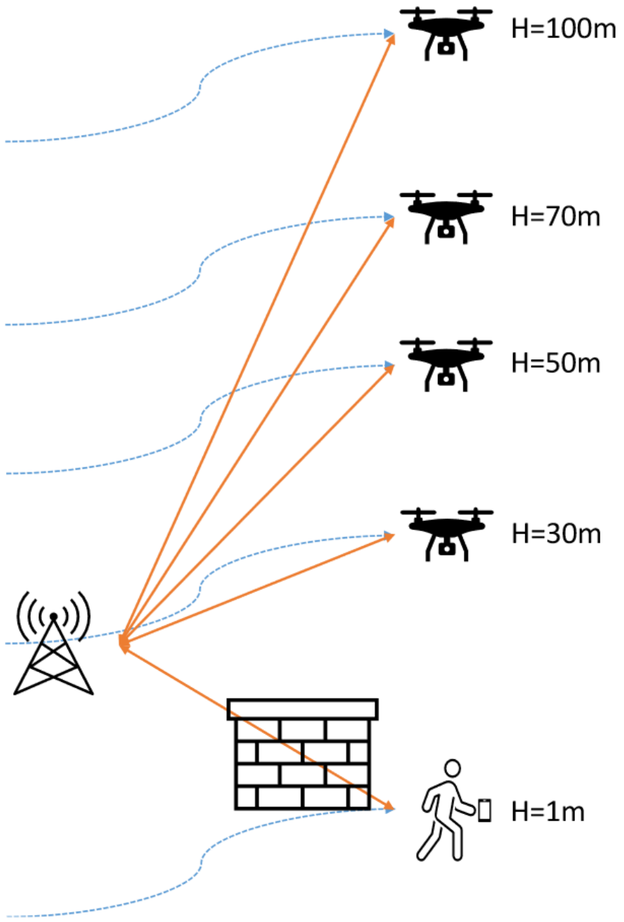
Huawei E3372 LTE modem (LTE Cat4)

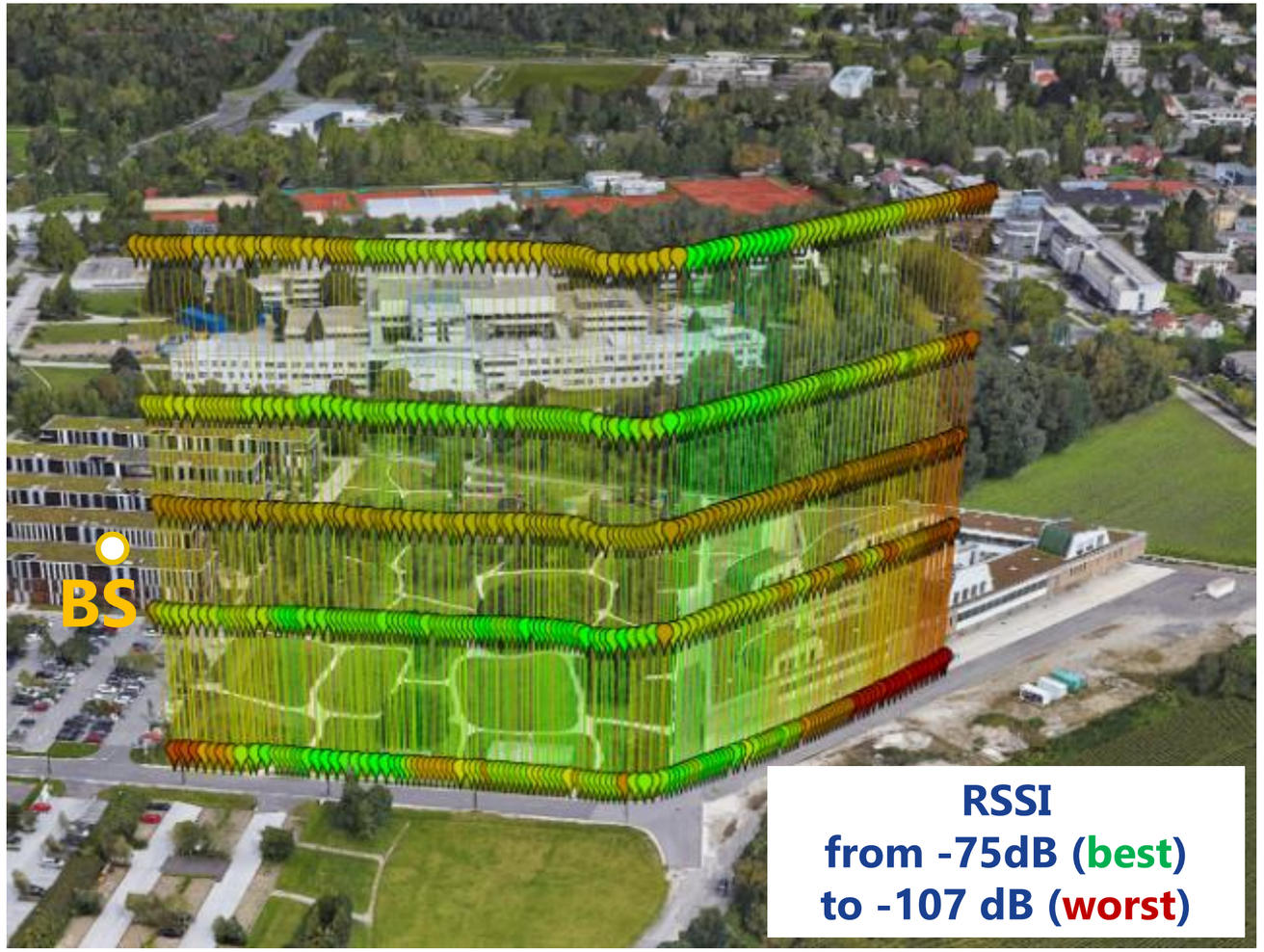
UniFi UAP-AC-m 802.11 ac Wi-Fi AP, 2x2 dual band

Samsung S20 5G: 802.11ac with VHT80 MU-MIMO; LTE Cat20 with 4x4MIMO

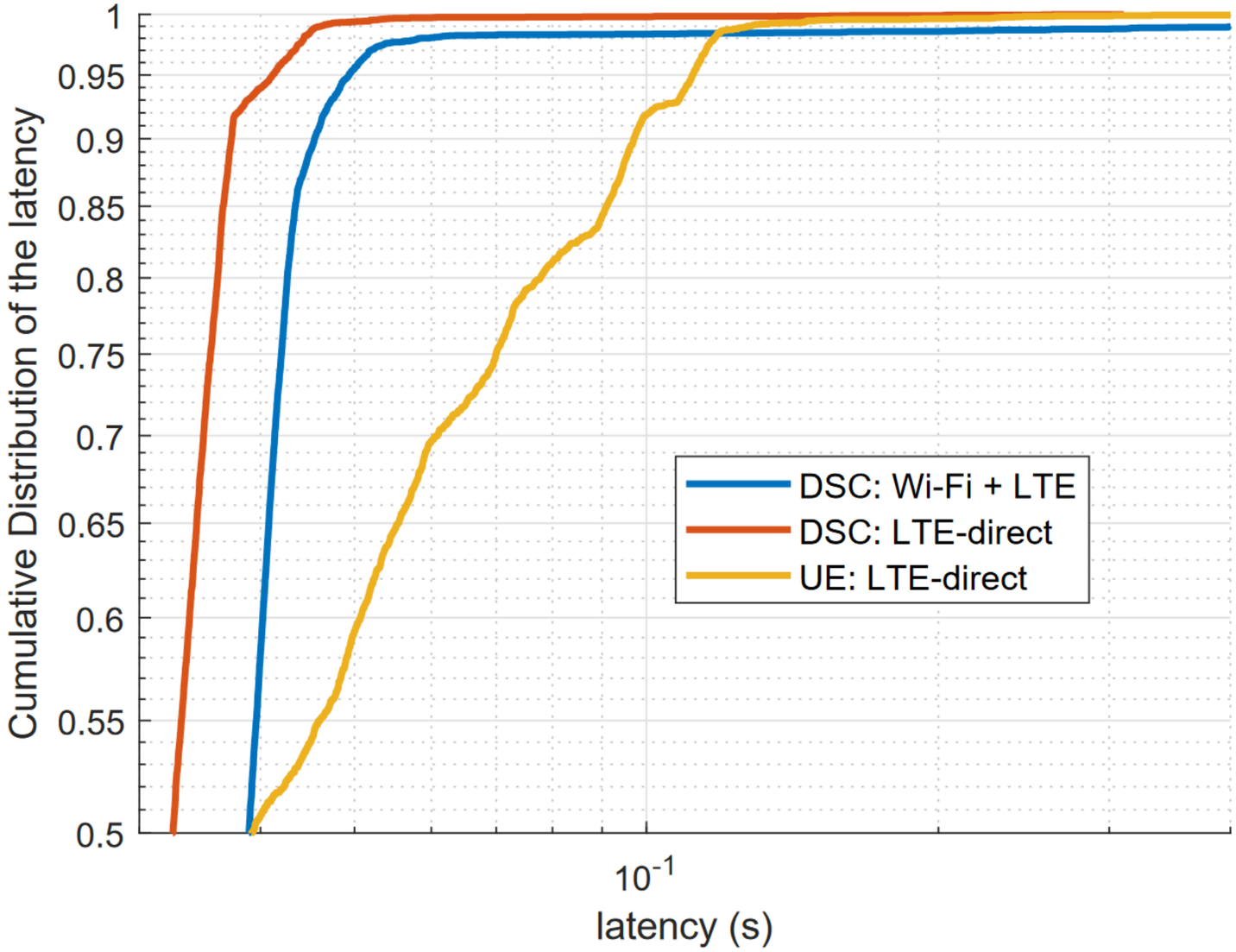
Drone Small Cell (DSC)

RSSI measurements





DSC latency results



average **latency**:
LTE-direct: 54ms
DSC: 53.7ms

DSC provides **better latency consistency** (low jitter)

Cellular Connected drones: Collision Avoidance

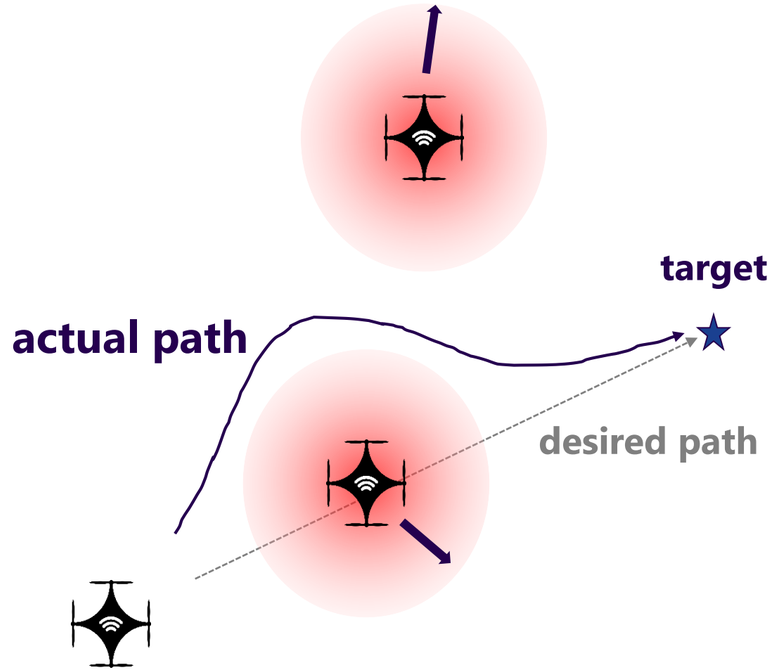
Collision avoidance

In a cellular-connected swarm of drones

Multiple drones fly in a “free flight” zone, clear of obstacles and are connected via a **5G network**

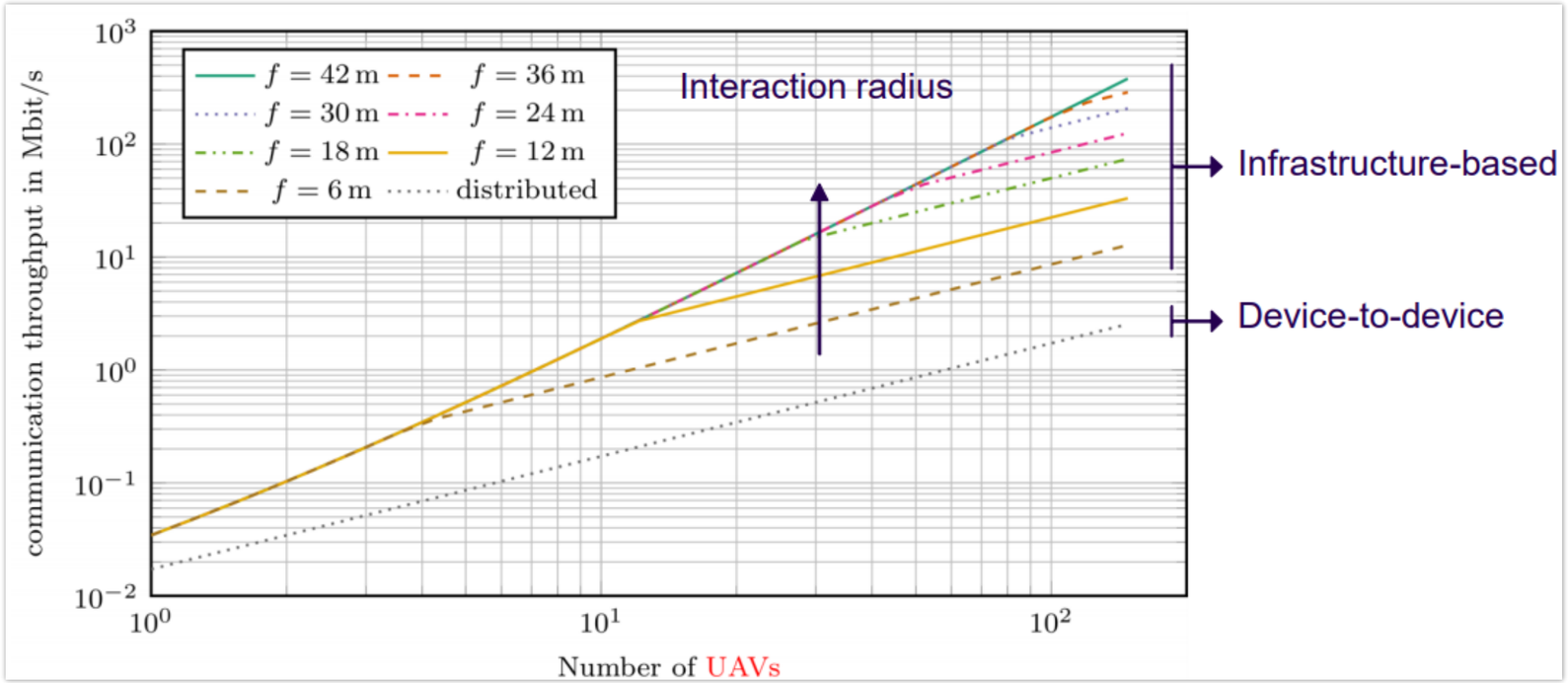
distributed (on-board) collision avoidance path planning algorithm based on potential fields

each drone **attracted** by its target and **repelled** by other drones



Collision avoidance in a swarm of drones

Scalability of communication



payload data: ~3.1 kbit/s per drone, at an update rate of 10 Hz

(a) position

Content	Size (Byte)
Position	24
Orientation	32
Headers	135
Total	**191**

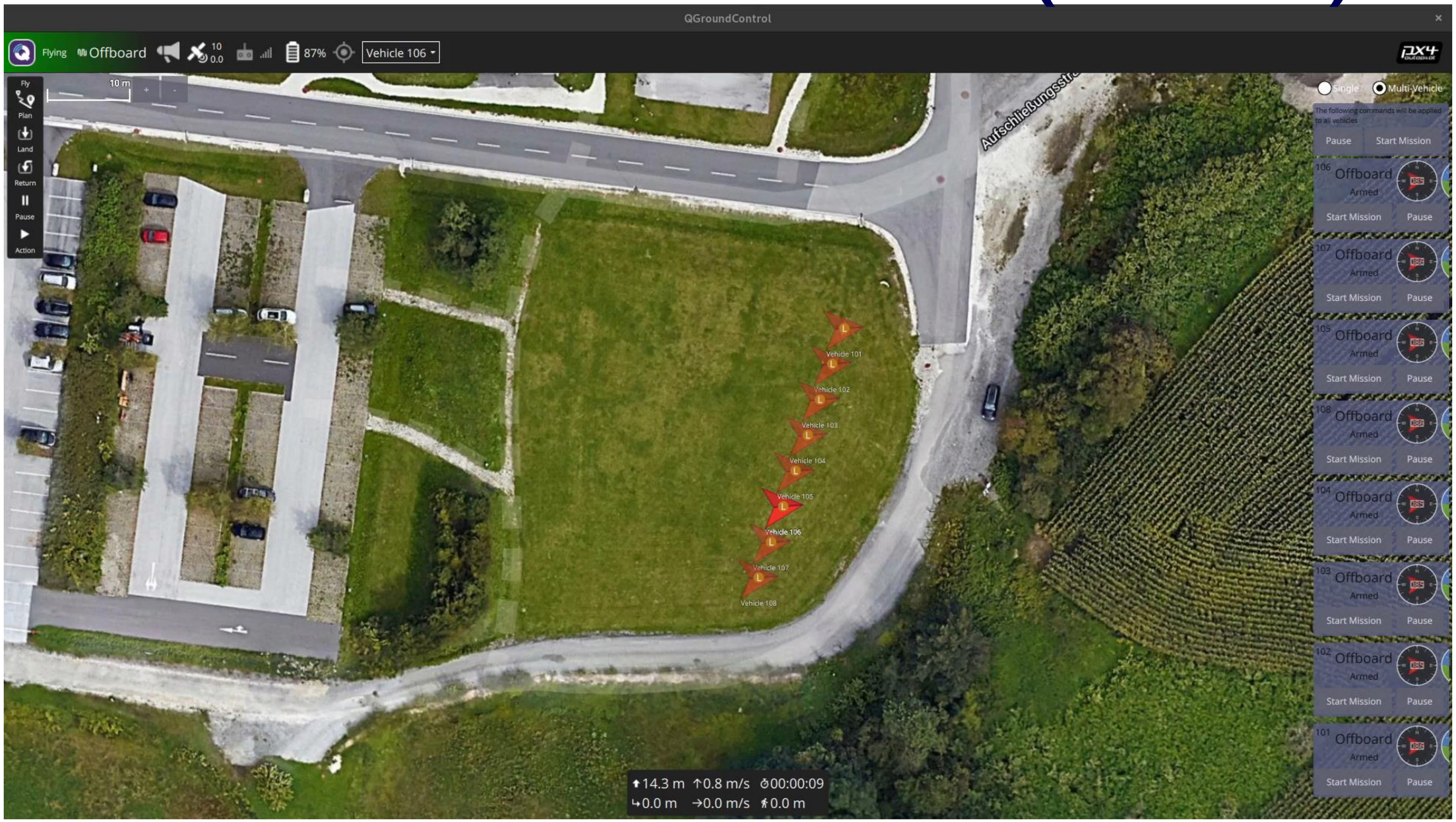
(b) velocity

Content	Size (Byte)
Linear	24
Angular	24
Headers	135
Total	**183**

interactions in centralized architecture: **quadratic increase** (with neighbour count)

interactions for D2D: **linear increase** (with swarm size)

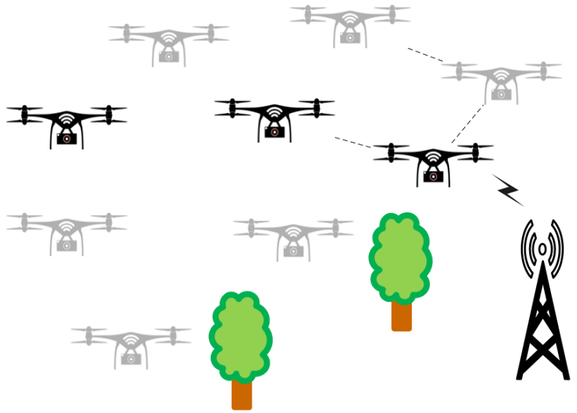
Demo Video: Collision avoidance (8 drones)



Mixed real/virtual swarm environment

Architecture

outdoor antenna

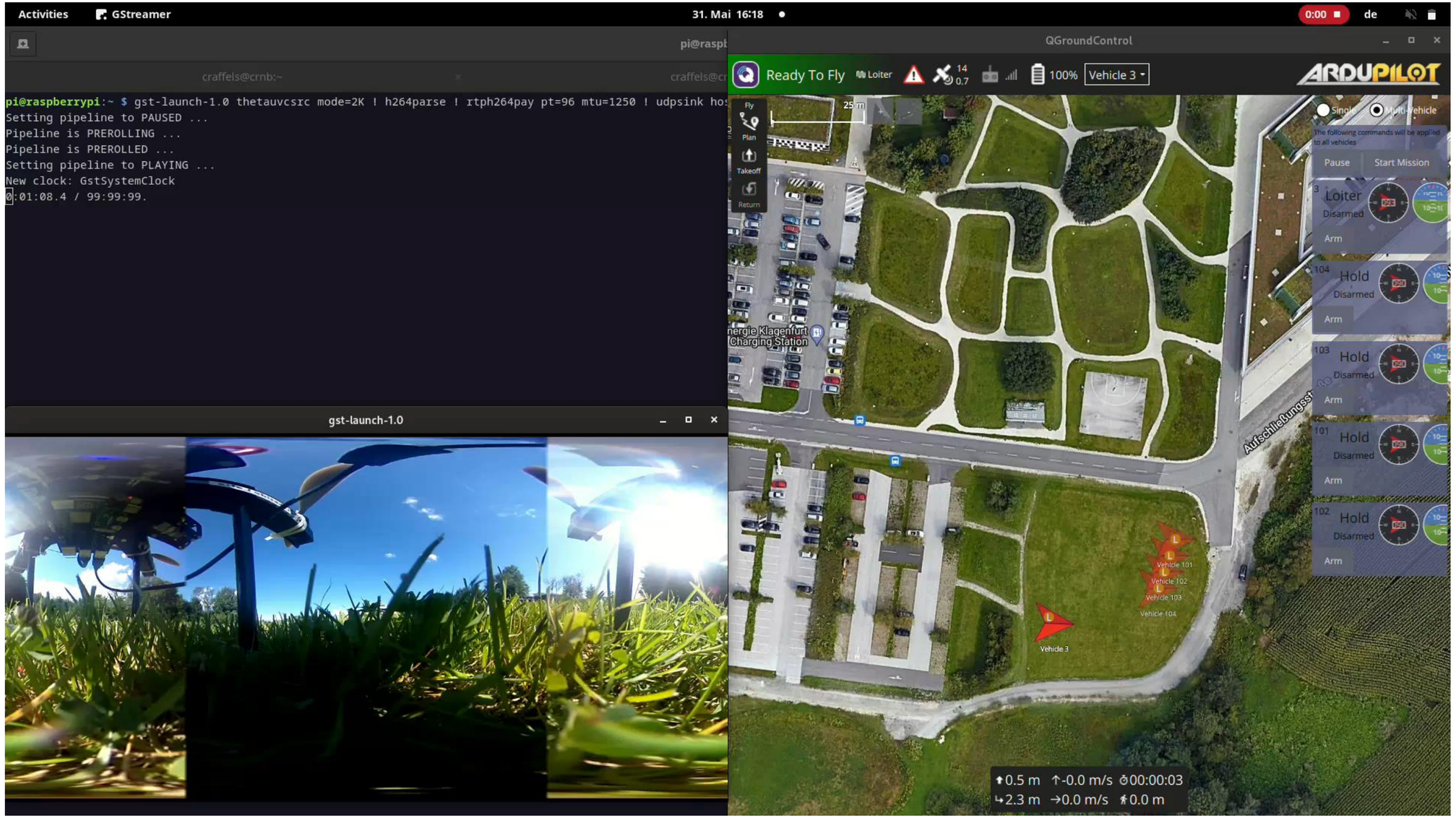


ground control station @B14

edge server @B08

facilitates scalable **evaluations and demonstrations**

Hybrid demo: Ground Control Station



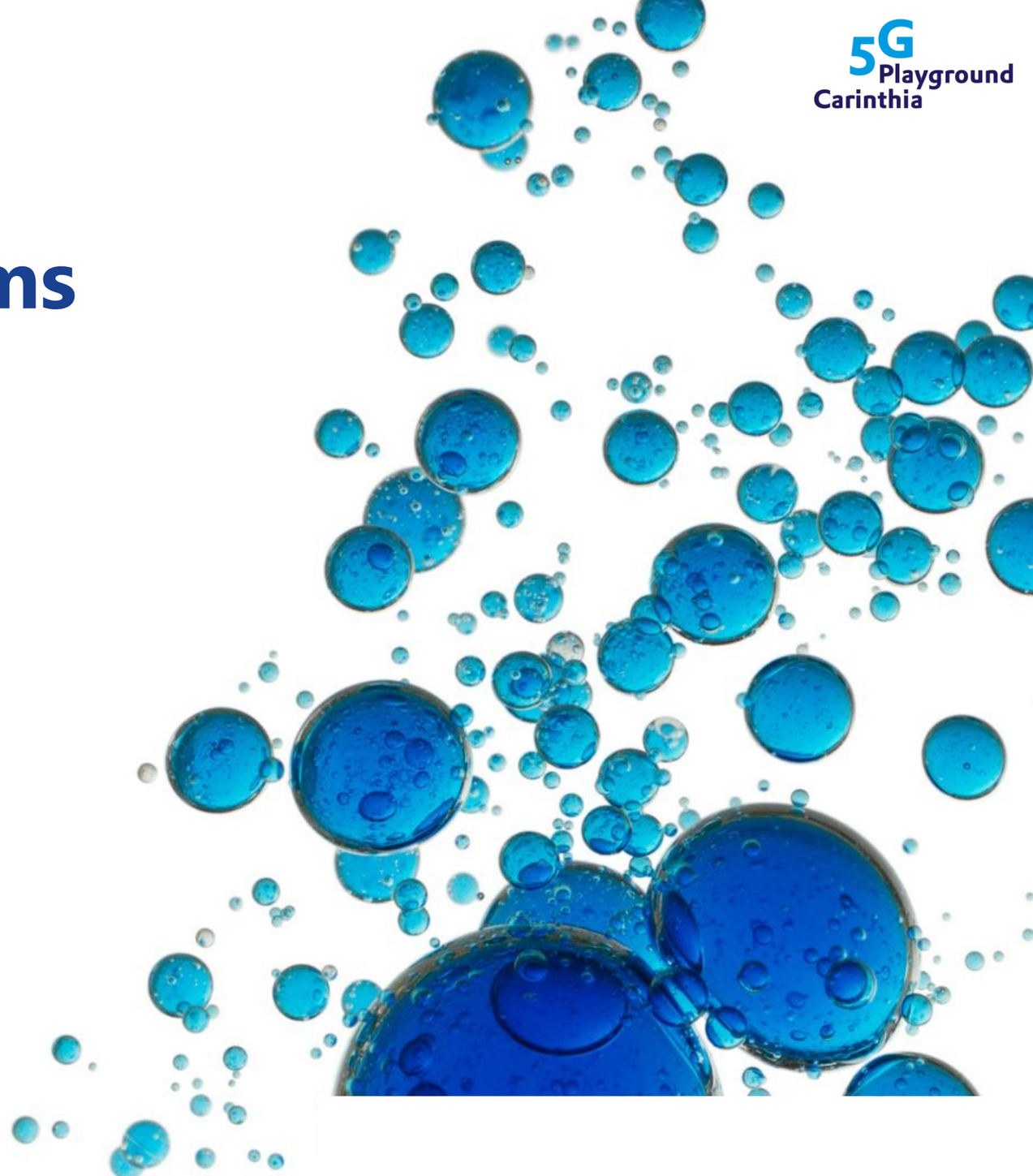
Hybrid demo: 360° video stream

Lakeside Labs
SELF-ORGANIZING NETWORKED SYSTEMS

5G Playground Carinthia

Communication in Swarms

Use Case Presentation



Kontakt:

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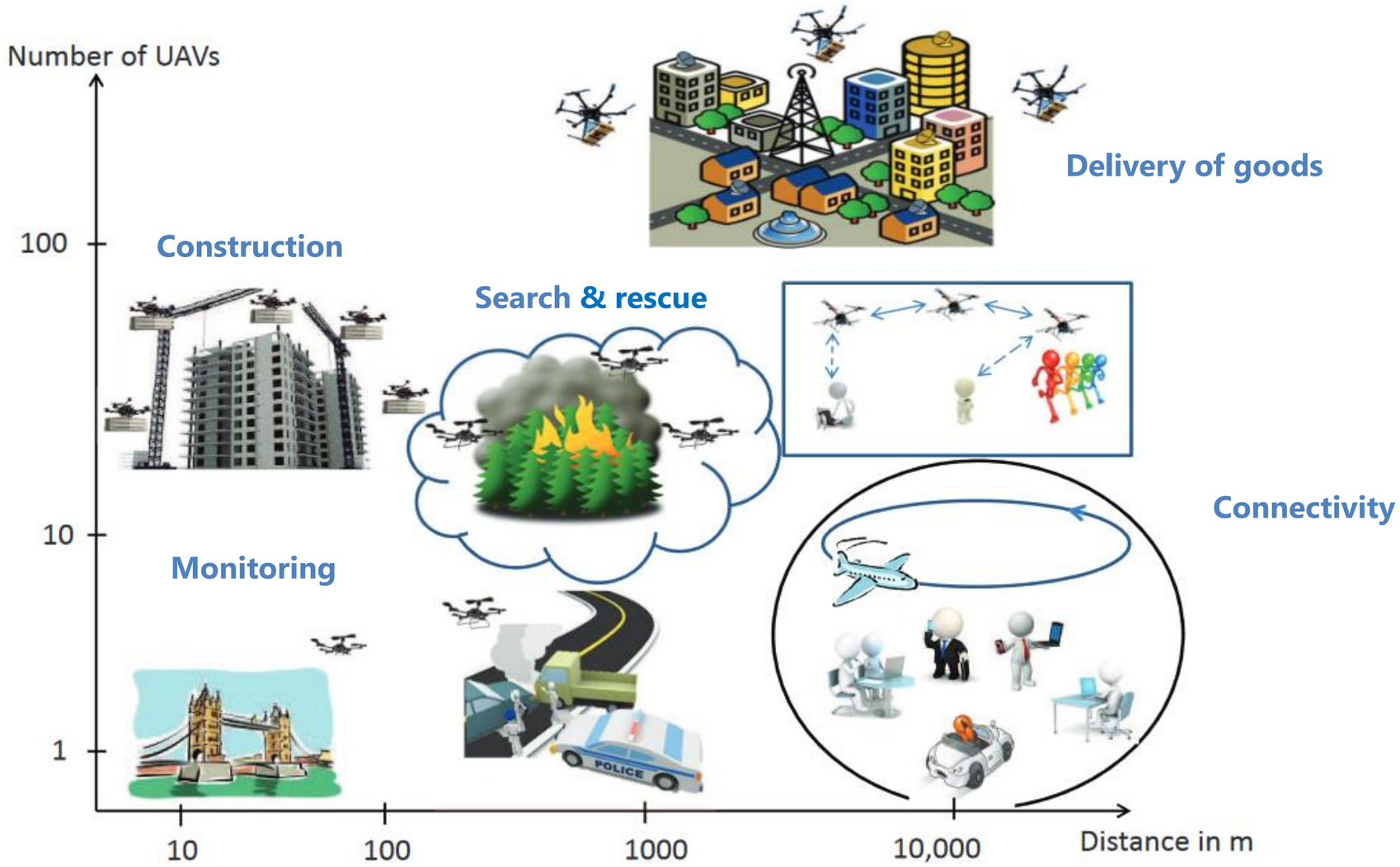
T: +43 463 287044 77

References

- S. Hayat, C. Bettstetter, A. Fakhreddine, R. Muzaffar, and D. Emini, "**An experimental evaluation of LTE-A throughput for drones**," in Proc. ACM Workshop on Micro Aerial Vehicle Networks, Systems, and Applications (DroNet), (Seoul, Korea), pp. 3–8, June 2019.
- A. Fakhreddine, C. Bettstetter, S. Hayat, R. Muzaffar, and D. Emini, "**Handover challenges for cellular-connected drones**," in Proc. ACM Workshop on Micro Aerial Vehicle Networks, Systems, and Applications (DroNet), (Seoul, Korea), pp. 9–14, June 2019.
- R. Muzaffar, C. Raffelsberger, A. Fakhreddine, J. López Luque, D. Emini, and C. Bettstetter, "**First experiments with a 5G-connected drone**," in Proc. ACM Workshop on Micro 17 Aerial Vehicle Networks, Systems, and Applications (DroNet), (Toronto, Canada), June 2020.
- A. Stornig, A. Fakhreddine, H. Hellwagner, P. Popovski, and C. Bettstetter, "**Video Quality and Latency for UAV Teleoperation over LTE: A Study with ns3**," in IEEE Vehicular Technology Conf. (VTC), online conference, April 25–28, 2021.
- I. Donevski, C. Raffelsberger, M. Sende, A. Fakhreddine, J. J.Nielsen, "**An Experimental Analysis on Drone-Mounted Access Points for Improved Latency-Reliability**," in Proc. ACM Workshop on Micro Aerial Vehicle Networks, Systems, and Applications (DroNet), (Online), June 2021.
- A. Fakhreddine, C. Raffelsberger, M. Sende, C. Bettstetter, "**Experiments on Drone-to-Drone Communication with Wi-Fi, LTE-A, and 5G**", To appear in Proc. IEEE Globecom Workshops (Dec 2022)

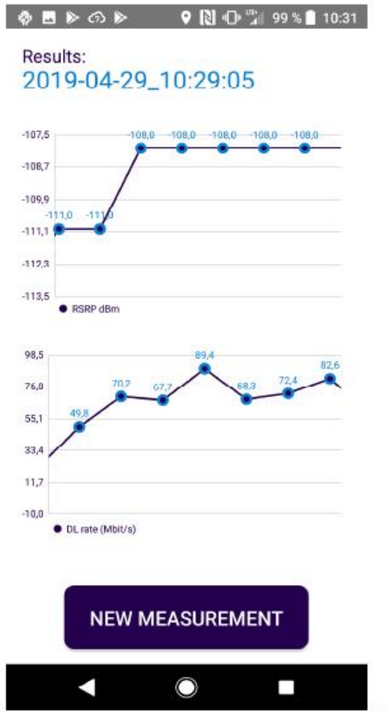
Backup Slides

Application areas for (swarms of) drones



Cellular drone measurement tool (CDMT)

- Received power (RSRP)
- Received quality (RSRQ)
- Signal-to-noise ratio (RSSNR)
- Channel number (EARFCN)
- Cell identifier and neighboring cell information
- Throughput (UDP/TCP)
- Latency
- GPS coordinates



Available for academic use:

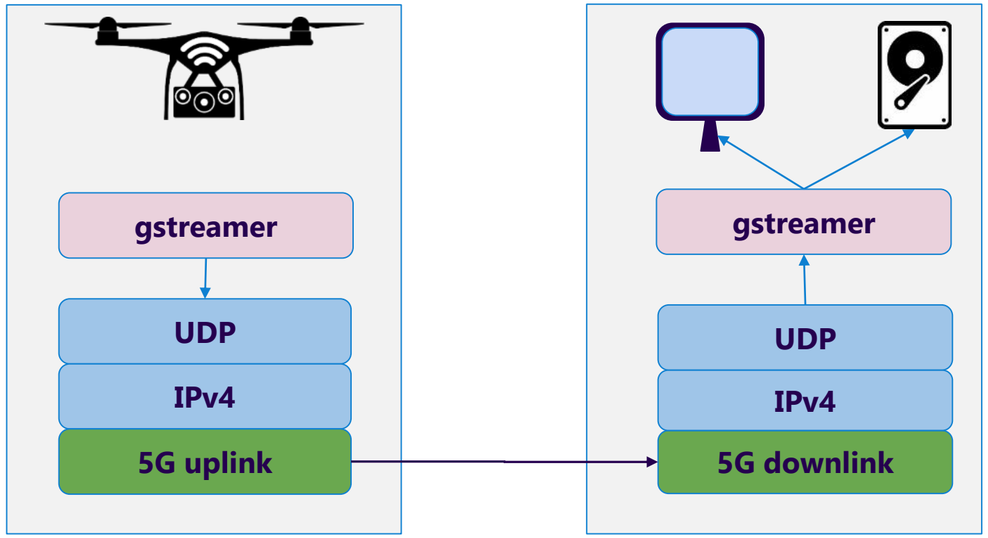
www.lakeside-labs.com/cdmt

360° video streaming from a drone

gstreamer-Pipeline for real-time transmission (**delay <1s**)

(H264, **2K**, **~45Mbit/s**, Real-time Streaming Protocol over UDP/IP)

Ricoh Theta
360° camera

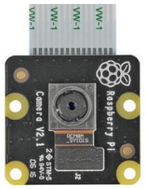


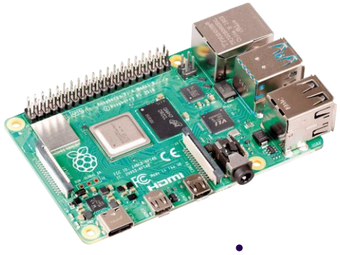
UAV Hardware/Software

flight controller

GPS

visual sensors





companion board

power supply

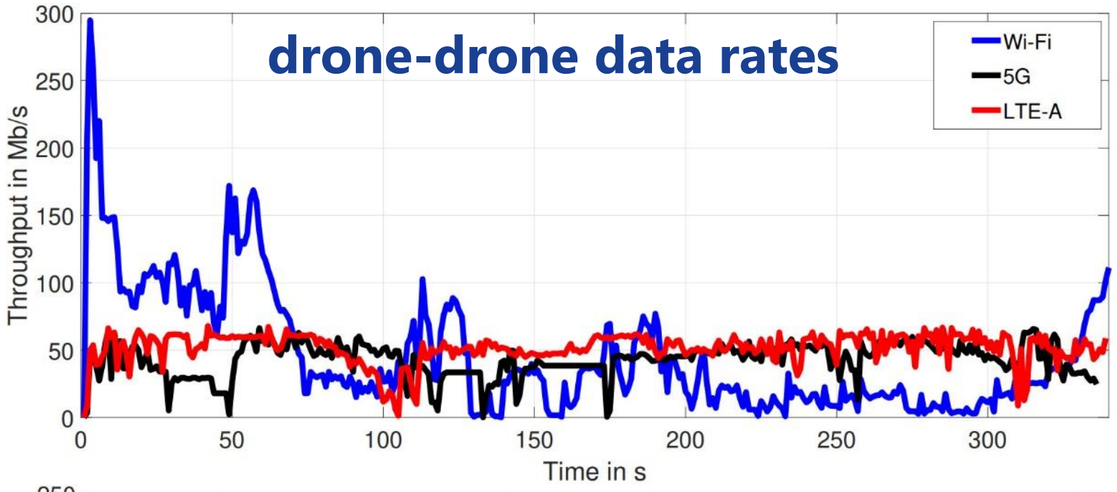
communication

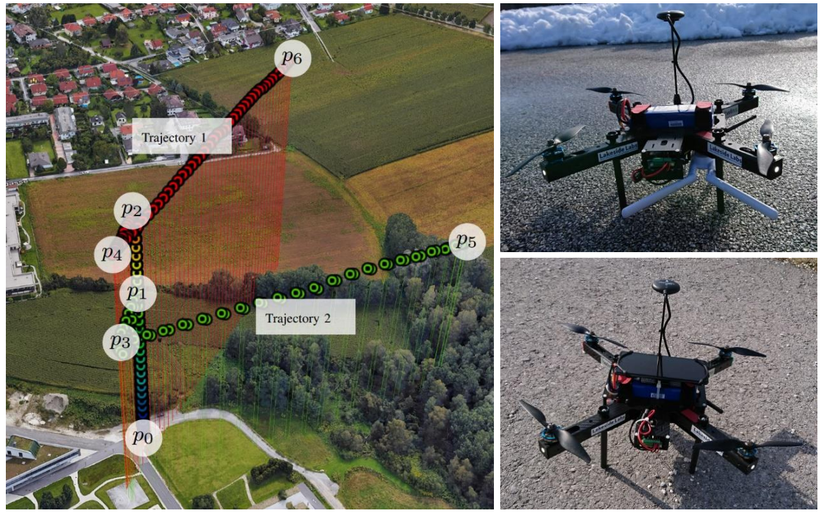
Phy. UAV

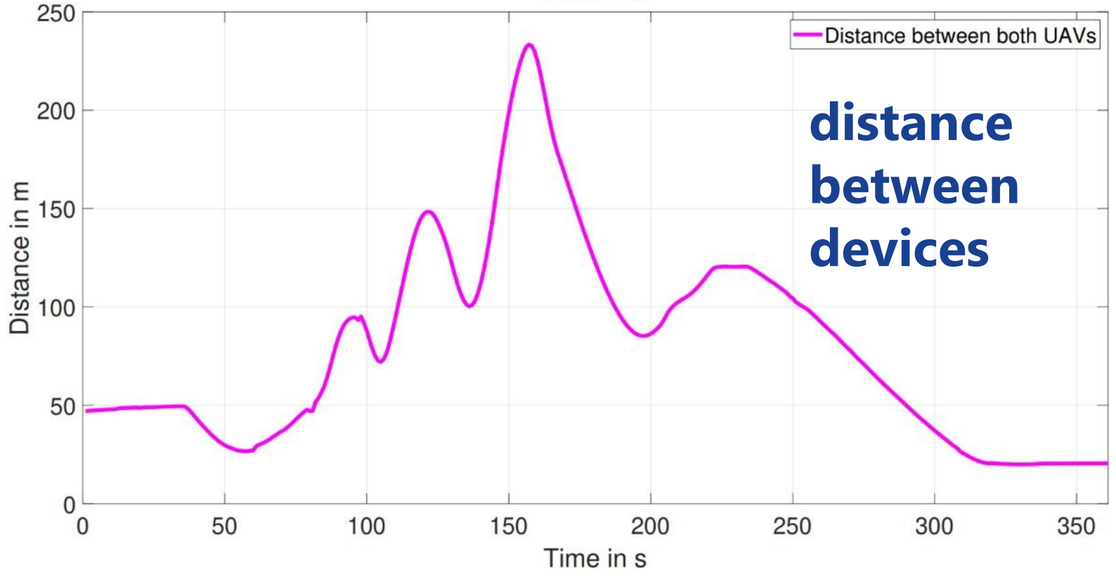
- swarm libs
- ROS
- swarmio
- discovery client
- PX4 | RPi

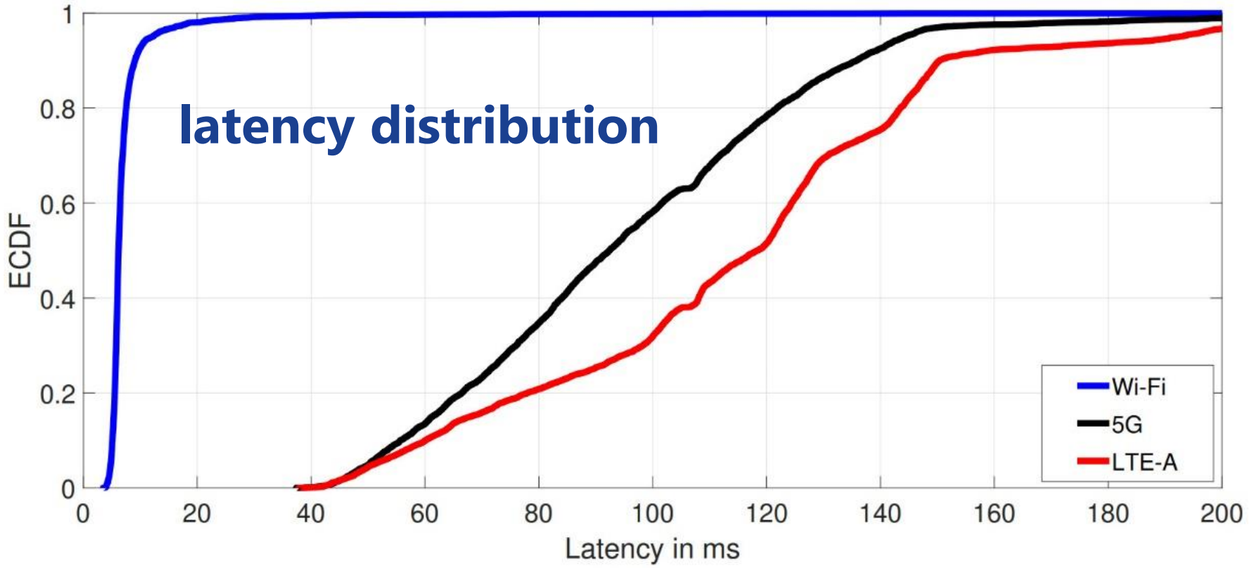
Cellular-connected drones

Drone-to-Drone evaluation (4G/5G/Wi-Fi)

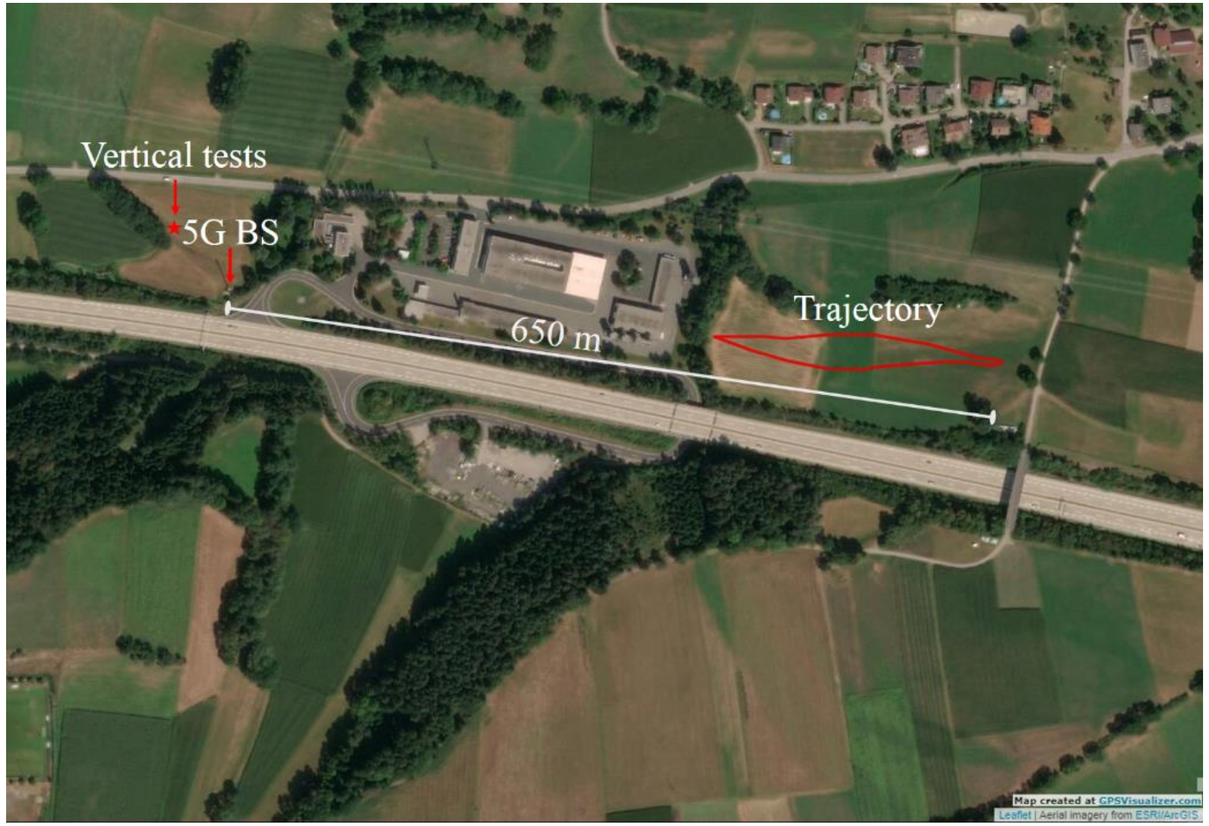


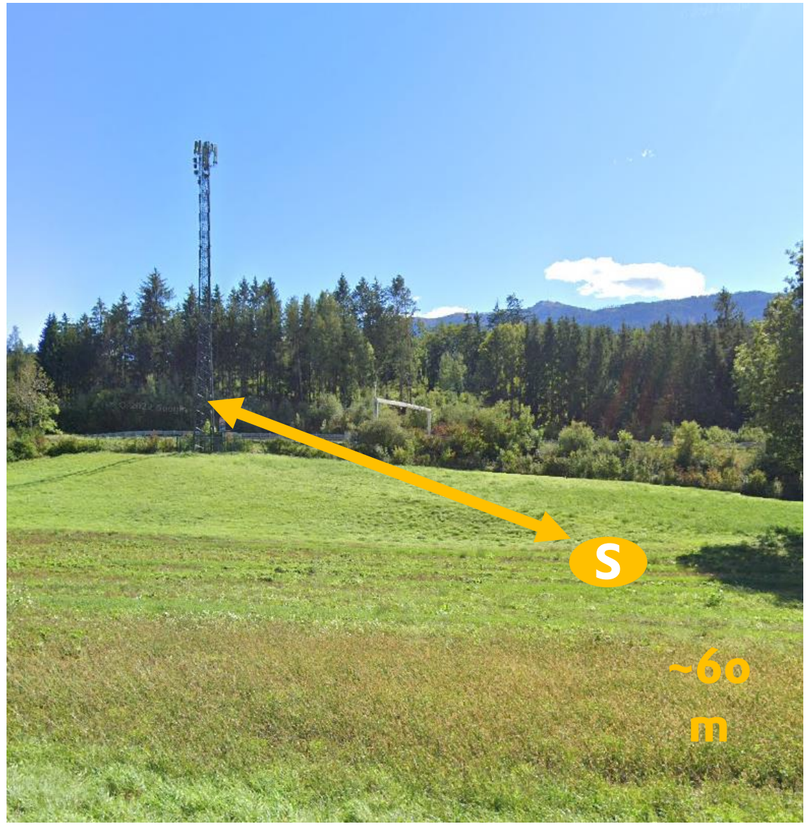






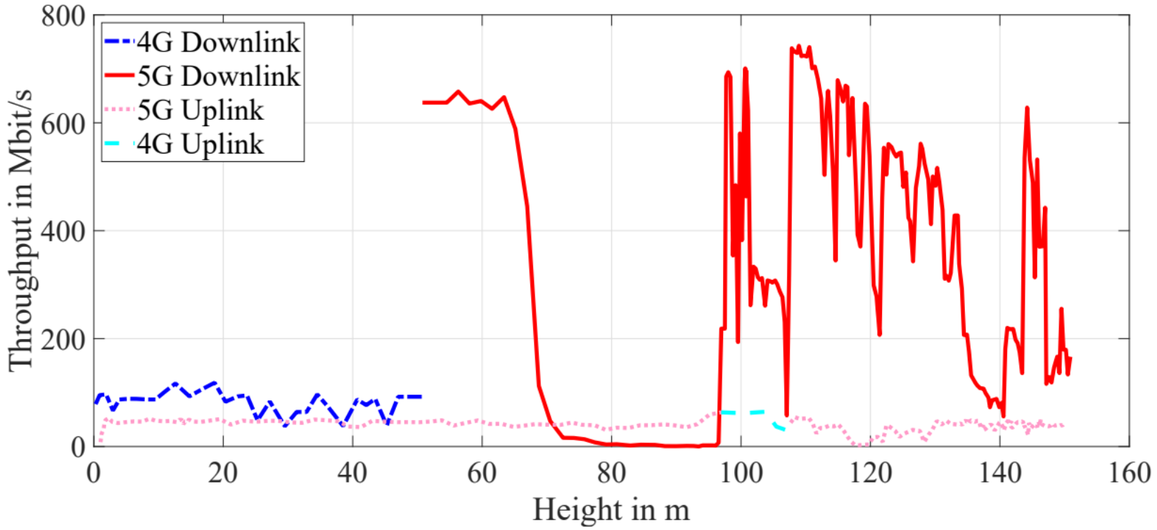
5G NSA Evaluation Setup

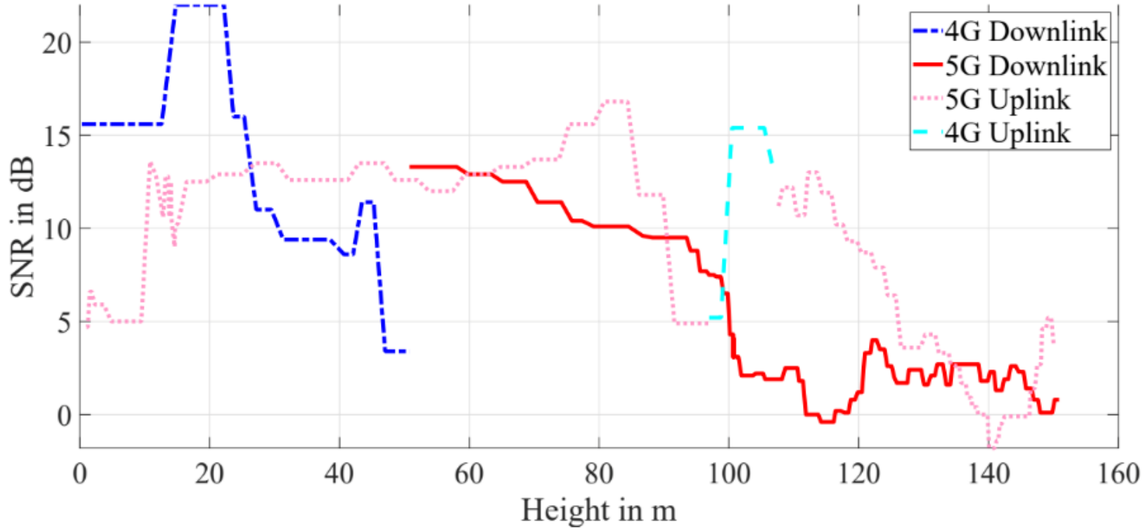


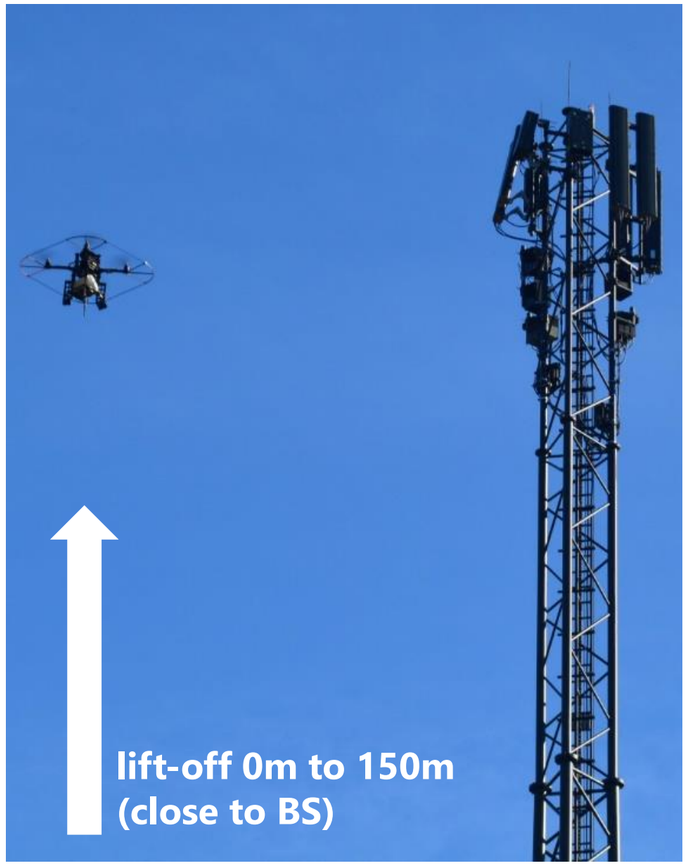


Cellular-connected drones

Real-world evaluation (5G NSA)



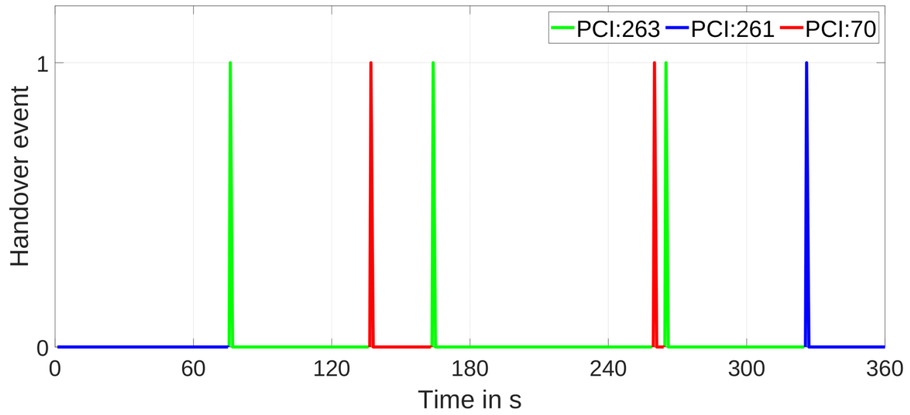




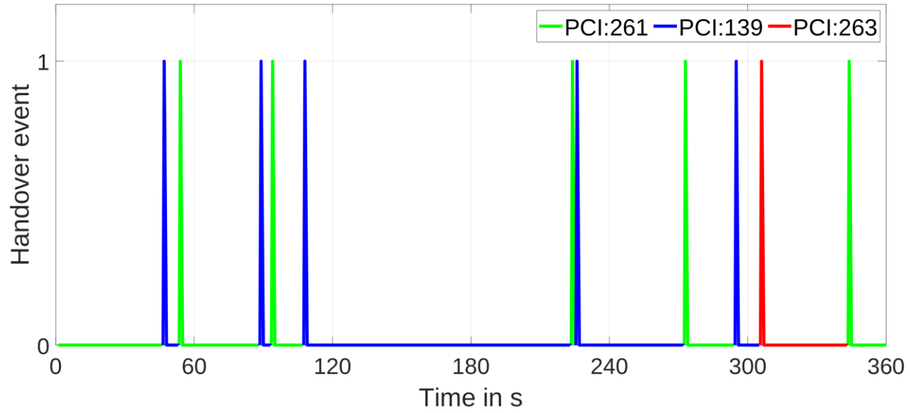
5G NSA Results

Experiment	Link	Throughput				Time in 5G	Handovers
		maximum	mean	stddev	5G mean		
Liftoff	DL	742 Mbit/s	345 Mbit/s	244 Mbit/s	387 Mbit/s	67 %	1
	UL	64 Mbit/s	44 Mbit/s	8 Mbit/s	39 Mbit/s	93 %	2
Horizontal flight at 30 m	DL	713 Mbit/s	388 Mbit/s	273 Mbit/s	618 Mbit/s	57 %	2
	UL	51 Mbit/s	46 Mbit/s	2 Mbit/s	46 Mbit/s	100 %	0
Horizontal flight at 100 m	DL	707 Mbit/s	354 Mbit/s	306 Mbit/s	644 Mbit/s	53 %	3
	UL	67 Mbit/s	47 Mbit/s	8 Mbit/s	42 Mbit/s	66 %	5

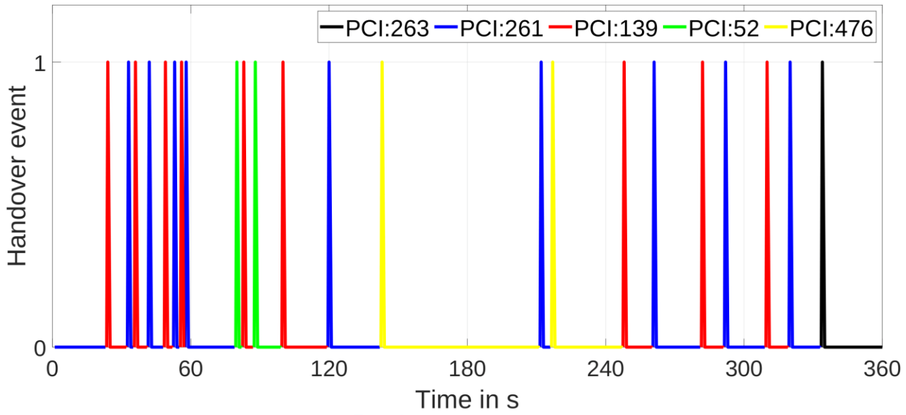
LTE Advanced Results: Handover



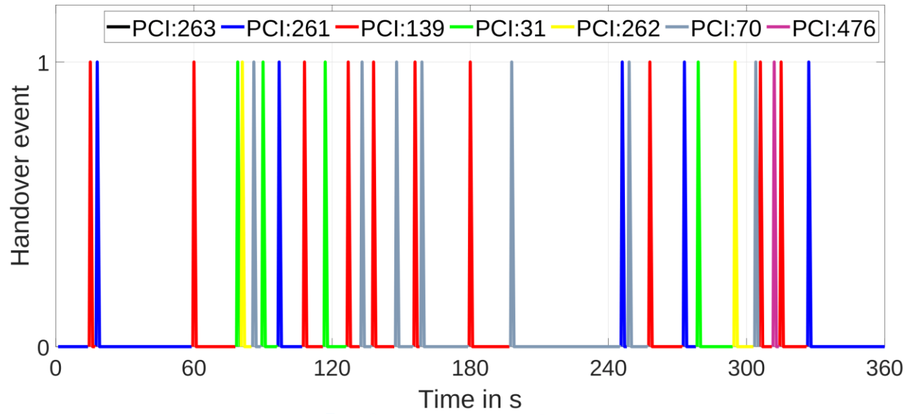
1. Ground scenario



2. Flying at 50 m

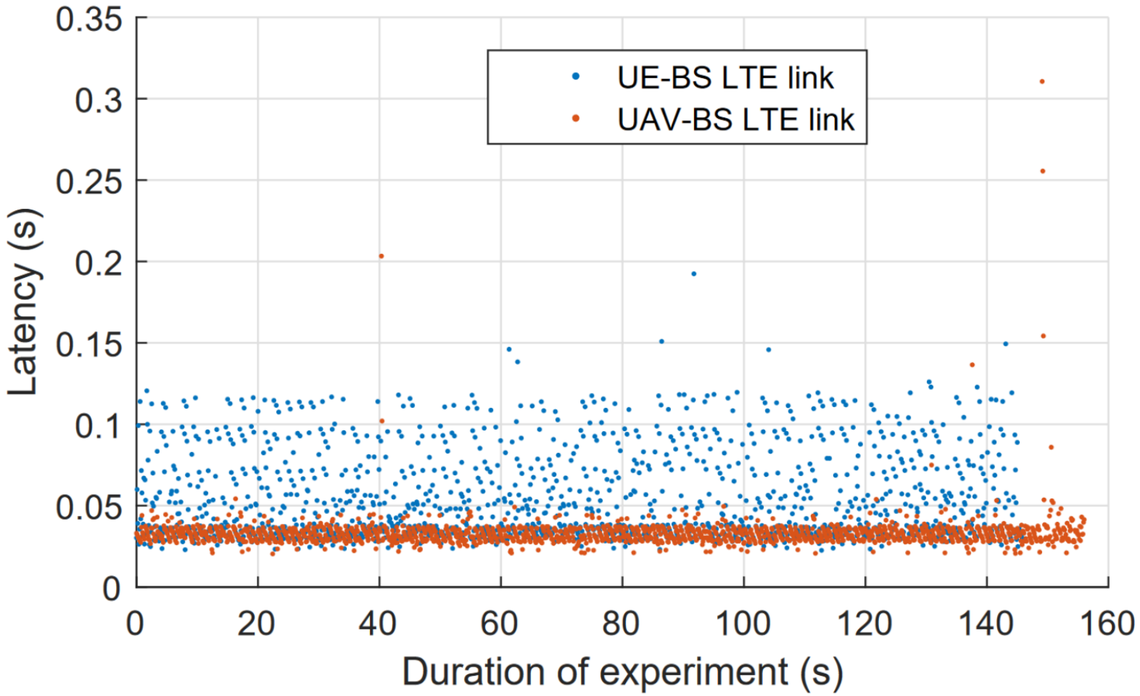


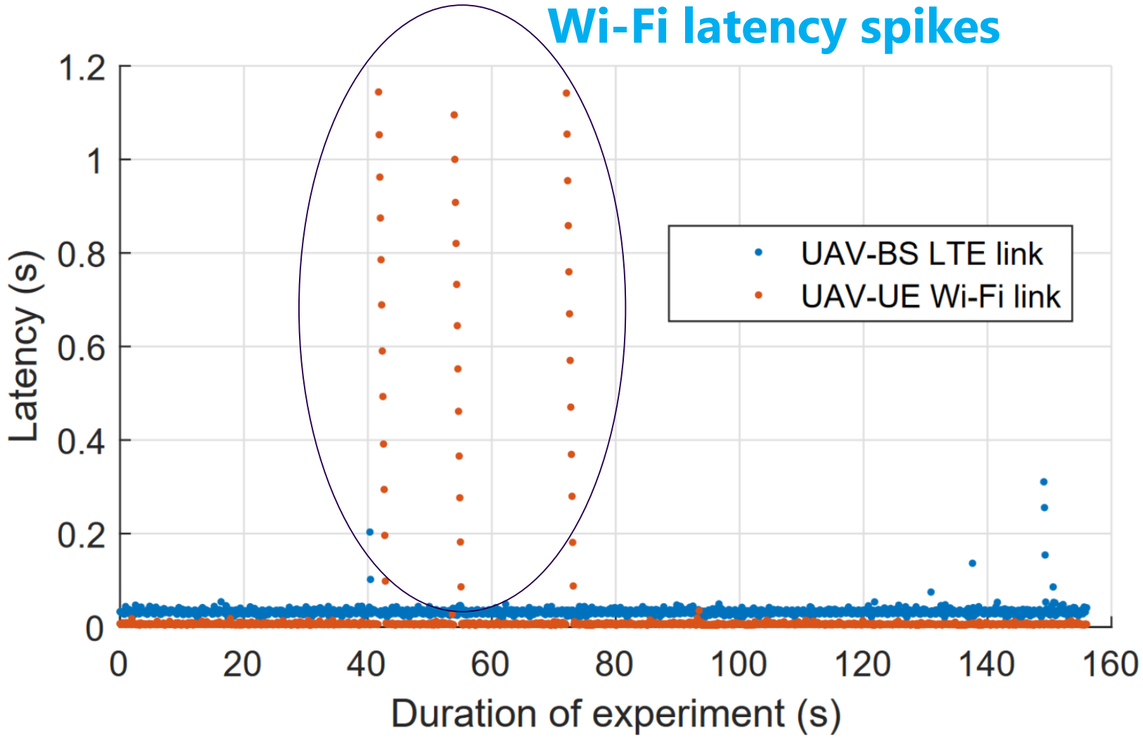
3. Flying at 100 m



4. Flying at 150 m

DSC Latency Results





average latency:
54ms (LTE-direct) vs 53.7ms (DSC)

Avemoy

True Autonomy

Upgrade Your Drone for Big Outdoor Data Collection

Avemoy

Current limits to drone applications are…

…**GPS loss**, prone to **hackers** when high precision is needed

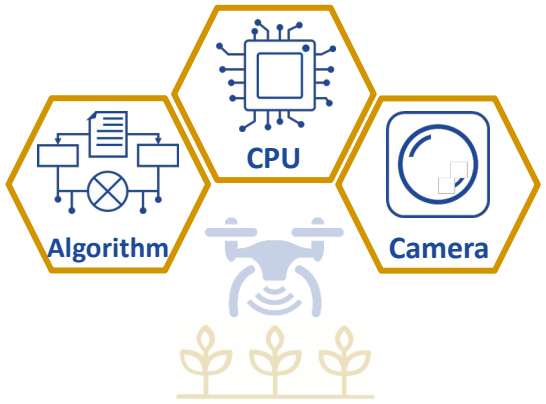
…**Unknown & uneven** terrain for applications close to ground

…**Indoors** & confined spaces

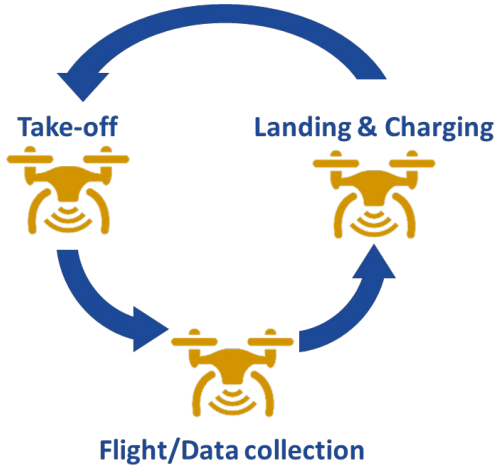
Avemoy

Our goals…

…to provide **reliable supported flight** and **autonomy**



A **plug-in** upgrade package to automate **any drone** from…

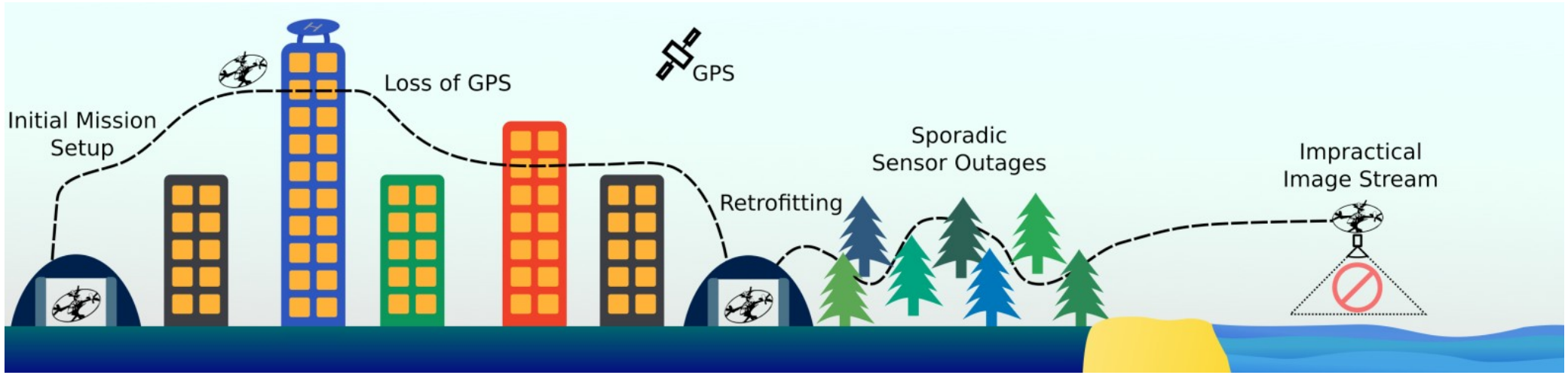


…**take-off**, to **flight** to **landing, GPS-free** without any manual operation, …

…saving **operation costs, resources** and **increasing revenue**.

The main component – Sensor Fusion

The key to autonomy - **reliable** and **robust knowledge** of the own **state**
…to provide **reliable supported flight** and **autonomy**



Self-initialization
Self-calibration

Modular

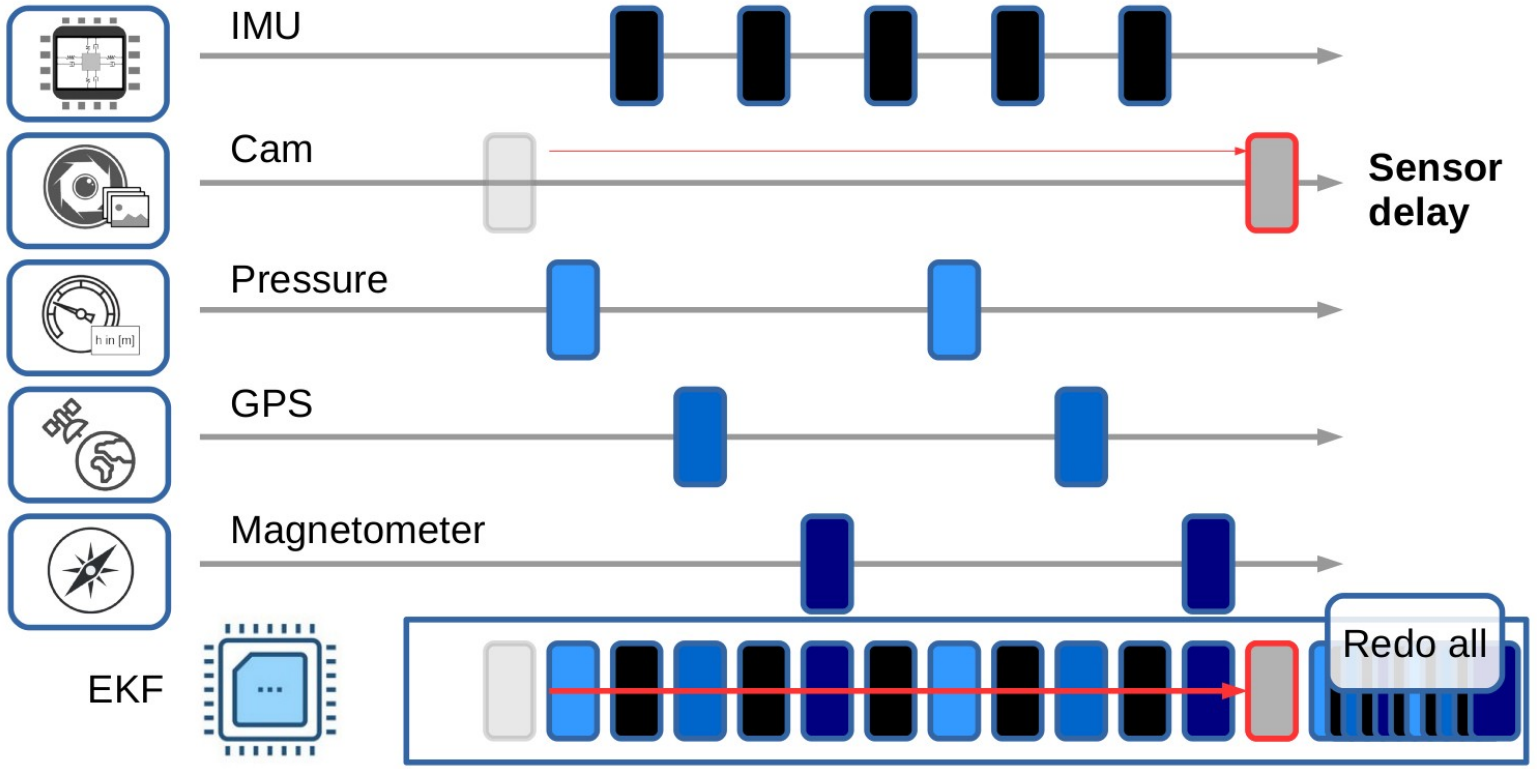
Self-analysis
Self-healing

Brommer, C., Jung, R., Steinbrener, J. & Weiss, S. (2021) MaRS: A Modular and Robust Sensor-Fusion Framework, *IEEE Robotics and Automation Letters,* Volume 6 (patent pending)
Ladinig, P., Rinner, B., Weiss, S. (2021): Time and Energy Optimized Trajectory Generation for Multi-Agent Constellation Changes. *Proceedings of the IEEE International Conference on Robotics and Automation (ICRA)*

Avemoy

Modular Multi-Sensor Fusion

Fast and **statistically robust** handling of out-of-order-updates



Delays require re-computations of previous measurements

Re-computation of uncertainties leads to computation spike

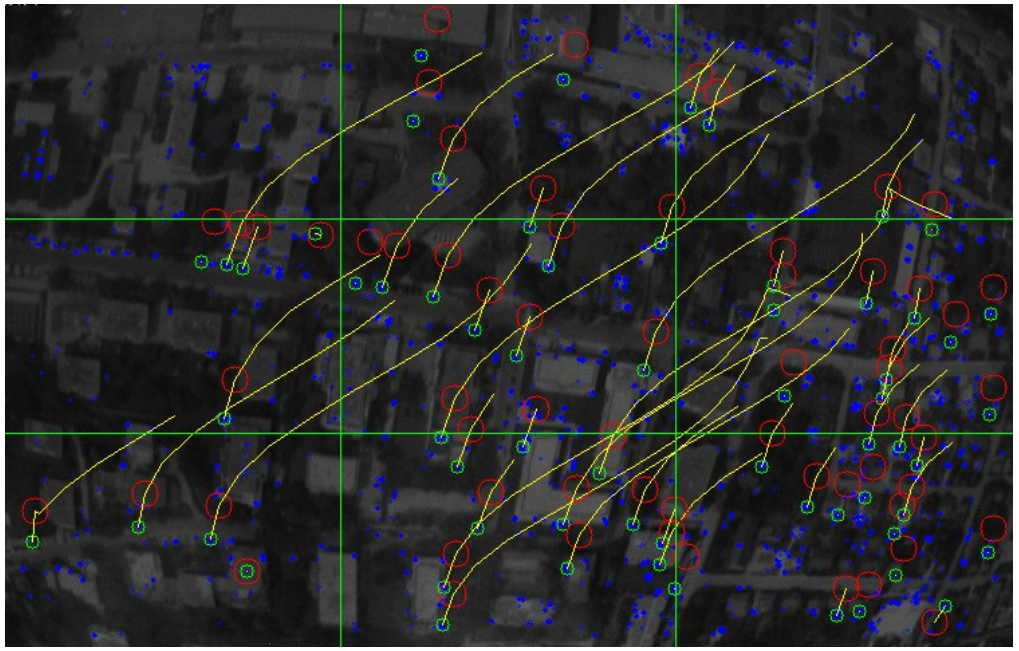
Potential Benefit of 5G: offload expensive calculations

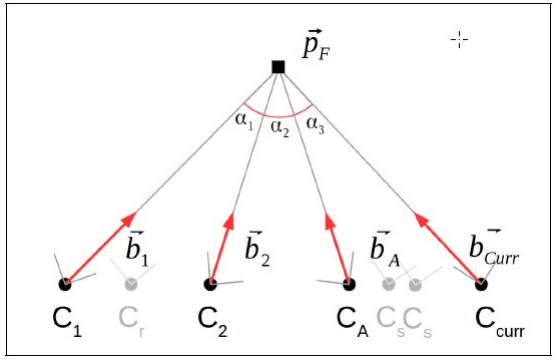
Control of Networked Systems

Allak et al. “Covariance Pre-Integration for Delayed Measurements in Multi Sensor Fusion”, IROS19.
Allak et al. “Consistent Covariance Pre-Integration for Invariant Filters with Delayed Measurements”, IROS20

Robust Vision Frontend - Features

Pose estimation based on **features**: new strategies for feature selection





Select feature trails with
large cumulative parallax
and even distribution of parallax

- No persistent features required
- Works inherently for zero and fast motion without motion case handling
- Real-time capable

Potential Benefit of 5G: offload expensive calculations

Allak, Hardt-Stremayr & Weiss, Key-Frame Strategy During Fast Image-Scale Changes and Zero Motion in VIO Without Persistent Features, IROS 2018

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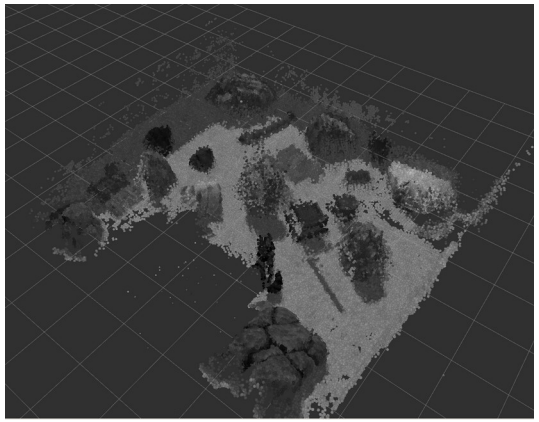
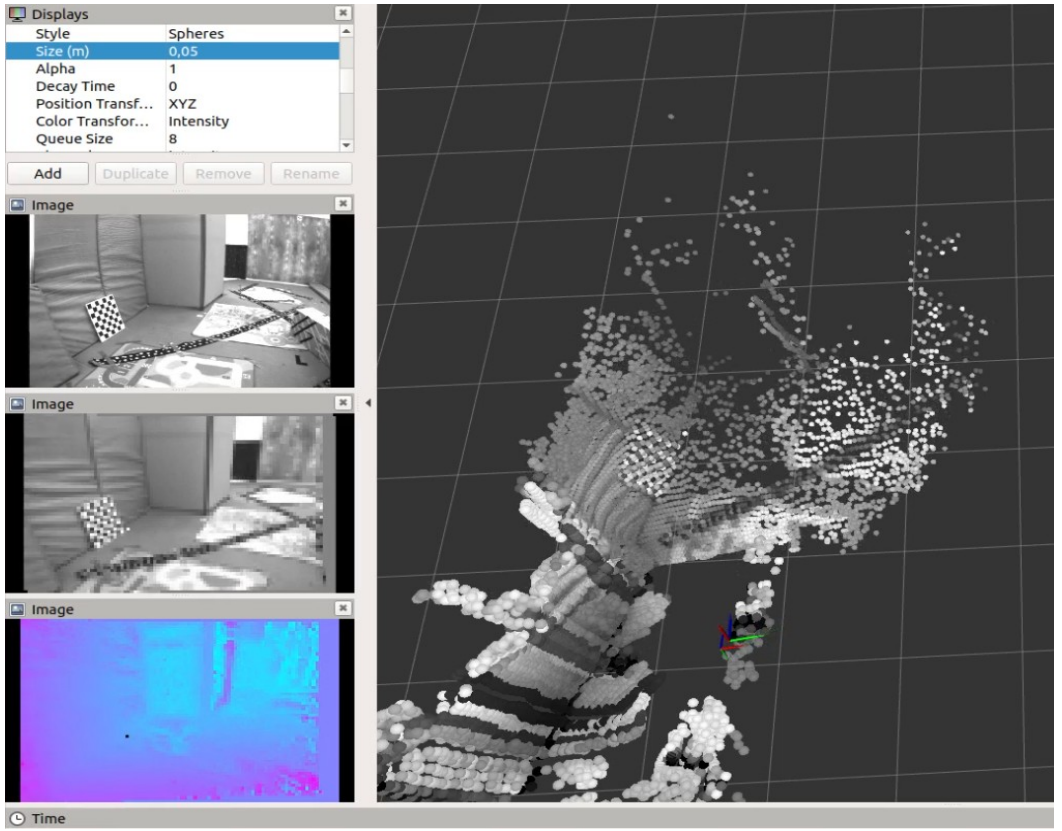
Robust Vision Frontend - Dense

Pose estimation based on pixel intensities





Fully Dense Direct Filter for Low-Textured Environments with Smooth Gradients

- Takes all pixels into account
- Predicts both state and depth for each pixel
- Works in low-textured environment with smooth gradients

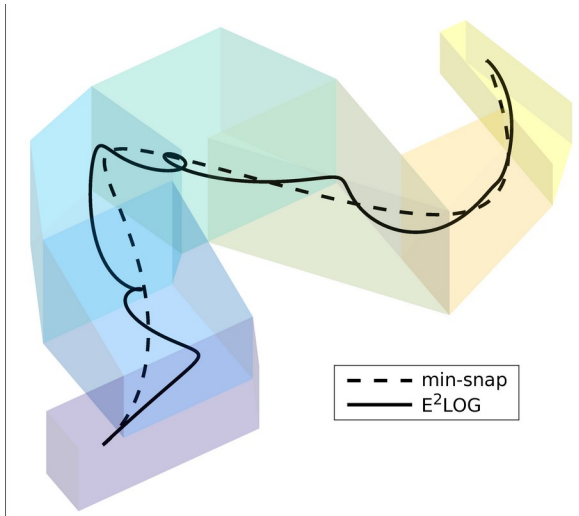
Potential Benefit of 5G: offload expensive calculations

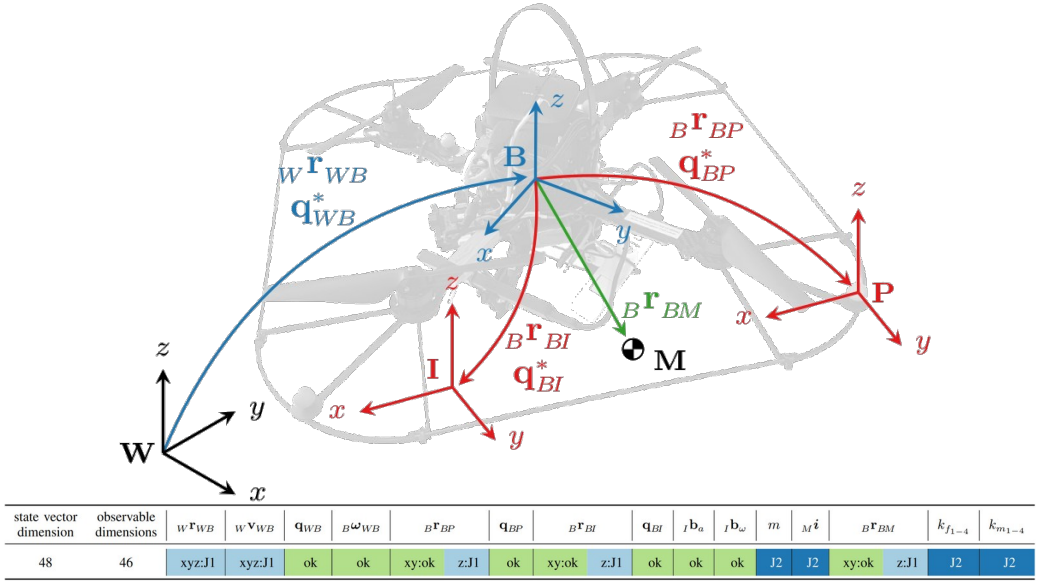
Control of Networked Systems

Hardt-Stremayr, A. and Weiss, S. “Monocular Visual-Inertial Odometry in Low-Textured Environments with Smooth Gradients, ICRA 2020

Geometric and Inertial Self-Calibration

Discovery of on **mass distribution** and **optimal trajectory** calculation





state vector dimension	observable dimensions	${}^W\mathbf{r}_{WB}$	${}^W\mathbf{v}_{WB}$	$\mathbf{q}_{WB}$	${}^B\boldsymbol{\omega}_{WB}$	${}^B\mathbf{r}_{BP}$	$\mathbf{q}_{BP}$	${}^B\mathbf{r}_{BI}$	$\mathbf{q}_{BI}$	${}_I\mathbf{b}_a$	${}_I\mathbf{b}_\omega$	m	${}_M\boldsymbol{i}$	${}^B\mathbf{r}_{BM}$	$k_{f_{1-4}}$	$k_{m_{1-4}}$
48	46	xyz:J1	xyz:J1	ok	ok	xy:ok	z:J1	xy:ok	z:J1	ok	ok	ok	J2	J2	xy:ok	z:J1	J2	J2

Extension of the set of self-calibration states with geometric and inertial properties of the mobile robot

- Mass and center of mass
- Moment of inertia
- Extrinsic misalignment between system body frame and sensors

With observability aware trajectory optimization

Potential Benefit of 5G:
offload expensive calculations

Preiss, Hausman, Sukhatme, and Weiss, Trajectory Optimization for Self-Calibration and Navigation, RSS 2017
Böhm, Brommer, Hardt-Stremayr, and Weiss, Combined System Identification and State Estimation for a Quadrotor UAV, ICRA2021

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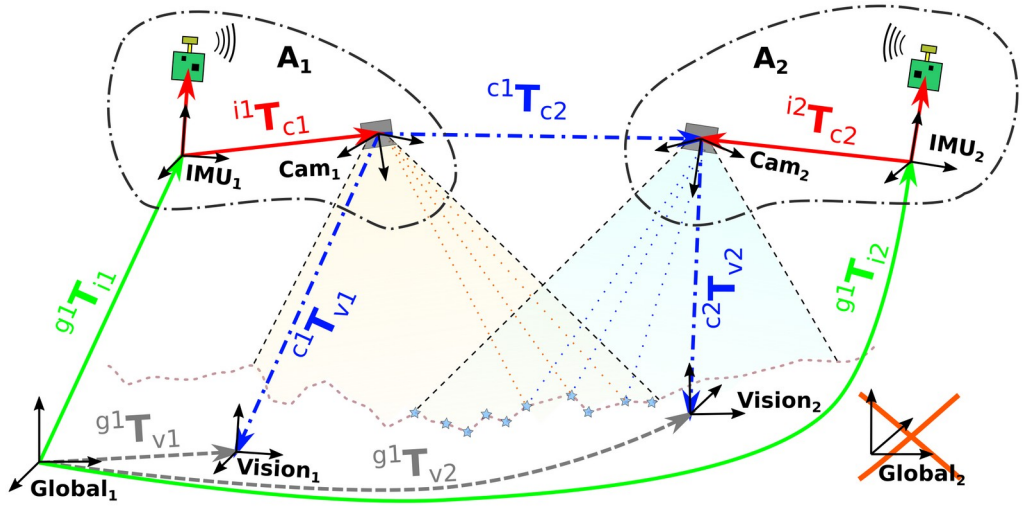
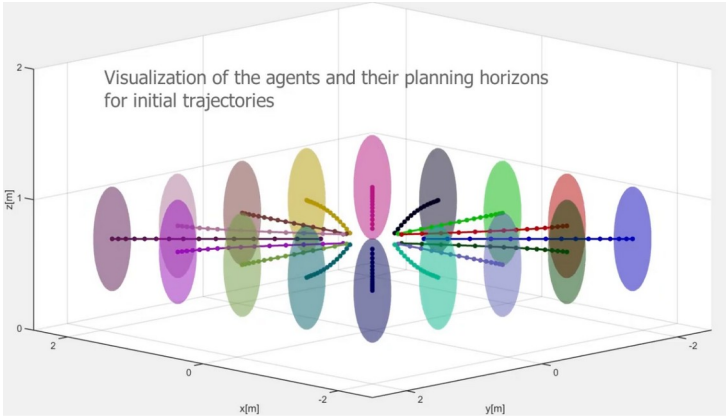
Collaborative State Estimation

Concurrent **state estimation** of **multiple** Drones





Multi-Agent Planning

Extend multi-sensor fusion framework for collaborative state estimation

- Decentraled implementation
- Inertial and camera/GNSS sensor
- Overlap detection

Potential Benefits of 5G: offload expensive calculations
fast communication between drones
centralized planning

Control of Networked Systems

Jung, Böhm & Weiss, Decentralized Collaborative State Estimation for Aided Inertial Navigation, ICRA 2020
Ladinig, Rinner,Weiss, Time and Energy Optimized Trajectory Generation for Multi-Agent Constellation Changes, ICRA 2021

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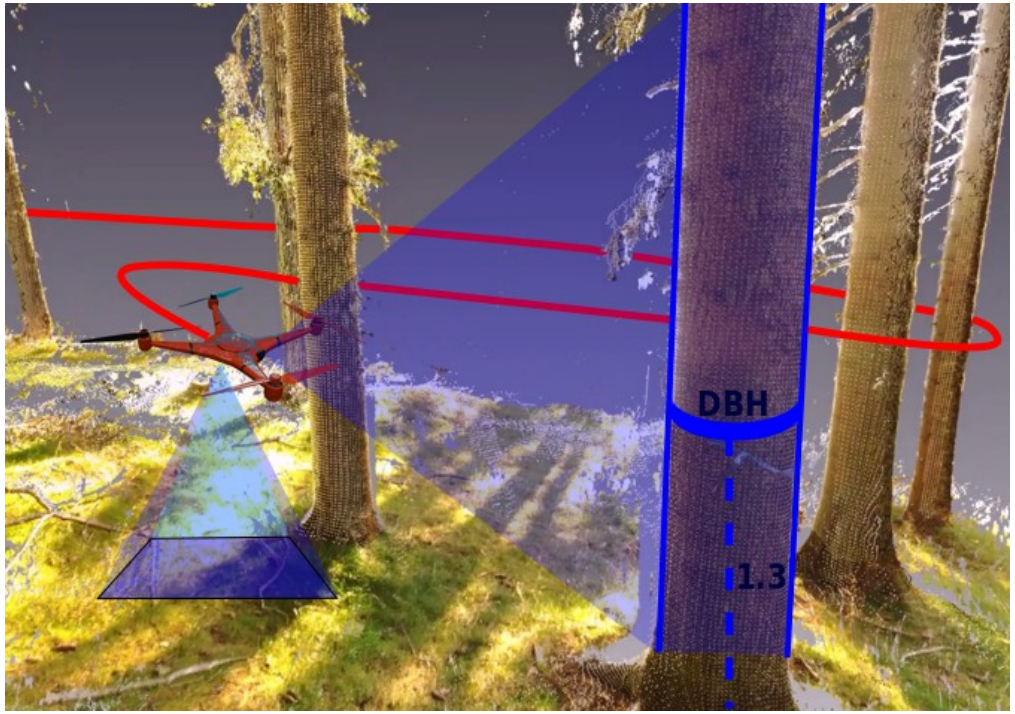
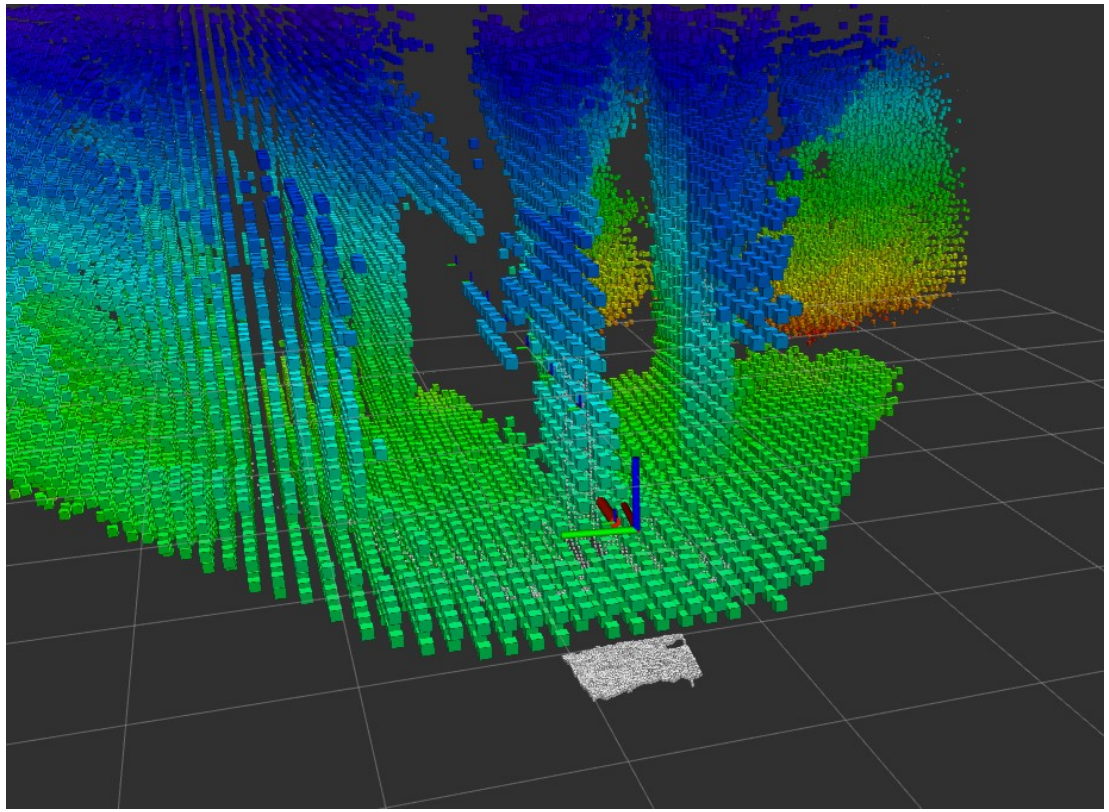
Use Case – Forest iMate

Autonomous flight and data collection **between trees**



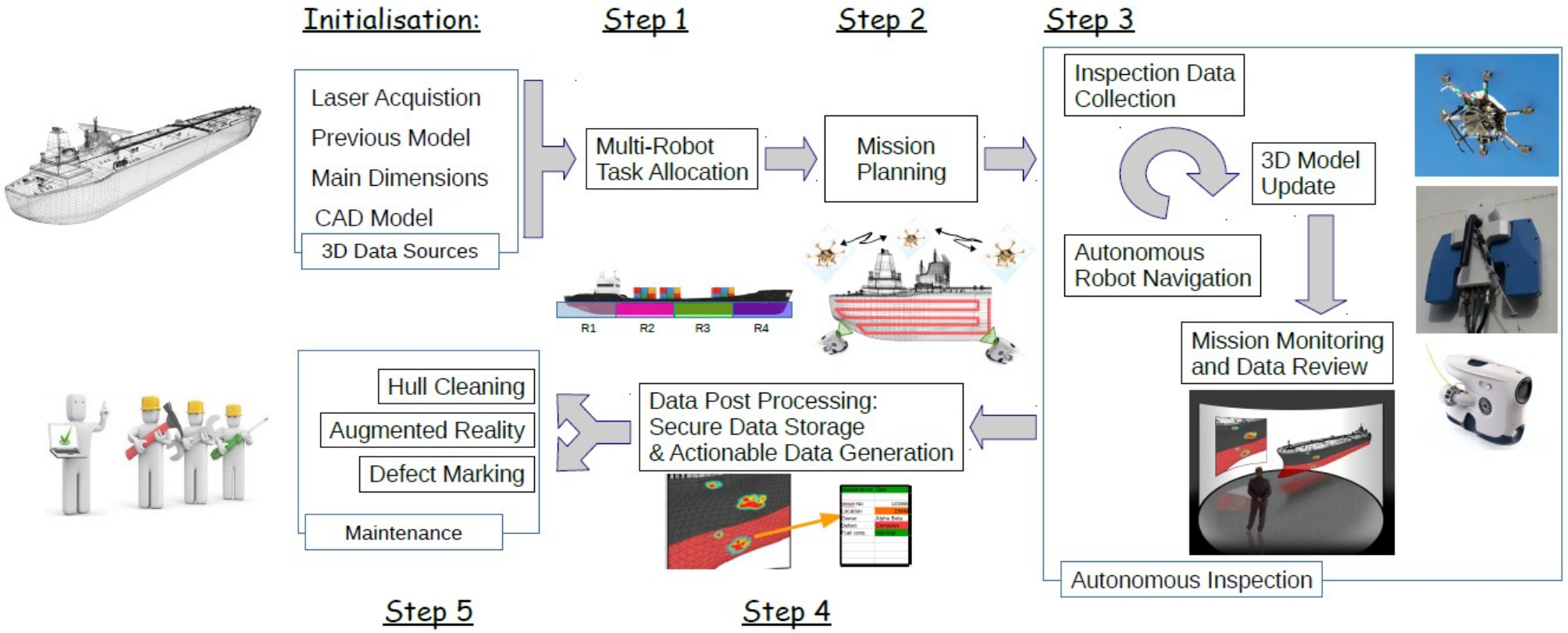
AAU-CNS: Vision-based, autonomous navigation
Incl. obstacle avoidance (sub-canopy)



Potential Benefit of 5G: fast data upload

Use Case – Bugwright 2

Autonomous robotic inspection of **ship hulls**



AAU-CNS: collaborative state estimation

Potential Benefits of 5G: fast data upload
remote drone control

Control of Networked Systems
Horizon 2020
https://www.bugwright2.eu/

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From Research to Industry

"Good enough" for research is not "good enough" for **industrial applications**

Current status: software **robustification**

Next step: **Pilot project**

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True Autonomy – Big Physical Data

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