

A New Era for Aerospace Business



NAVHAPS – ESA 9323 Tender – Final Presentation

Ref. : ESA AO/I-9323/I8/NL/MP

January 16th

Agenda

- **Introduction**
- **First Part – Presentation of the Study Cases, Selection Process and Service Definition for Retained Study Case**
 - **HAPS Added Value**
 - **Study Cases Description**
 - **User Requirements and KPIs**
 - **Study Cases Scenarios Comparison Analysis & Selection**
 - **Service Definition: Sample Deployment Plan**
 - **System Definition & Risk Assessment: Aerial Vector, Ground Vector, Payload**
- **Second Part – Presentation of the Tests & Results and Roadmap**
 - **Tests Descriptions**
 - **Tests Results**
 - **Tests Conclusions: KPIs Compliance**
 - **Technological Roadmap**
 - **Next Steps towards Service Demonstration: Service Definition, System Definition**

Agenda

- **Introduction**
- **First Part – Presentation of the Study Cases, Selection Process and Service Definition for Retained Study Case**
 - HAPS Added Value
 - Study Cases Description
 - User Requirements and KPIs
 - Study Cases Scenarios Comparison Analysis & Selection
 - Service Definition: Sample Deployment Plan
 - System Definition & Risk Assessment: Aerial Vector, Ground Vector, Payload
- **Second Part – Presentation of the Tests & Results and Roadmap**
 - Tests Descriptions
 - Tests Results
 - Tests Conclusions: KPIs Compliance
 - Technological Roadmap
 - Next Steps towards Service Demonstration: Service Definition, System Definition

What HAPS Solution Offers

Stratospheric flight above commercial airspaces and bad weather

Performing high volume data treatment

Autonomous control allowing versatile flight plan

Providing (near) real-time service

Suited for civil and military applications

Enhanced efficiency for service permanency



A Roadmap Based on Existing Solutions

2018

EXISTING AIRPLANE

1

Legal Mitigation

End-to-end solutions

Markets looking for alternatives
(Current solutions are not always effective)

2021

MALE UAV

2

Technical Mitigation

Long endurance services

Markets characterized by needs to increase the duration of missions
(Current solutions are heavy and/or complex)

2021

HIGH ALTITUDE UAV DEMONSTRATOR

3

Technological Mitigation

Stratospheric Flying Lab

Markets interested in in situ flight testing in relevant condition to evaluate new services and application

2024

HAPS

4

Satellite look-like services

Markets characterized by real time requirement or large amounts of data to be generated
(Time or space coverage is a problem)

ESA's Interest for HAPS Product & Services

- **ESA is investigating HAPS technology as a complementary solution to satellite applications**
 - For telecommunications, Earth observation, remote sensing, meteorology, astronomy, navigation/positioning and defense
- **In this context ESA has recently initiated a number of activities on this subject in view of preparing a new ESA program on HAPS for the next Council Ministerial in 2019**
- **This meeting is held in the framework of tender for HAPS FOR PNT**
Ref. : ESA AO/1-9323/18/NL/MP



ESA 9323 Tender – Objectives

➤ The objectives of this technical Feasibility Study are:

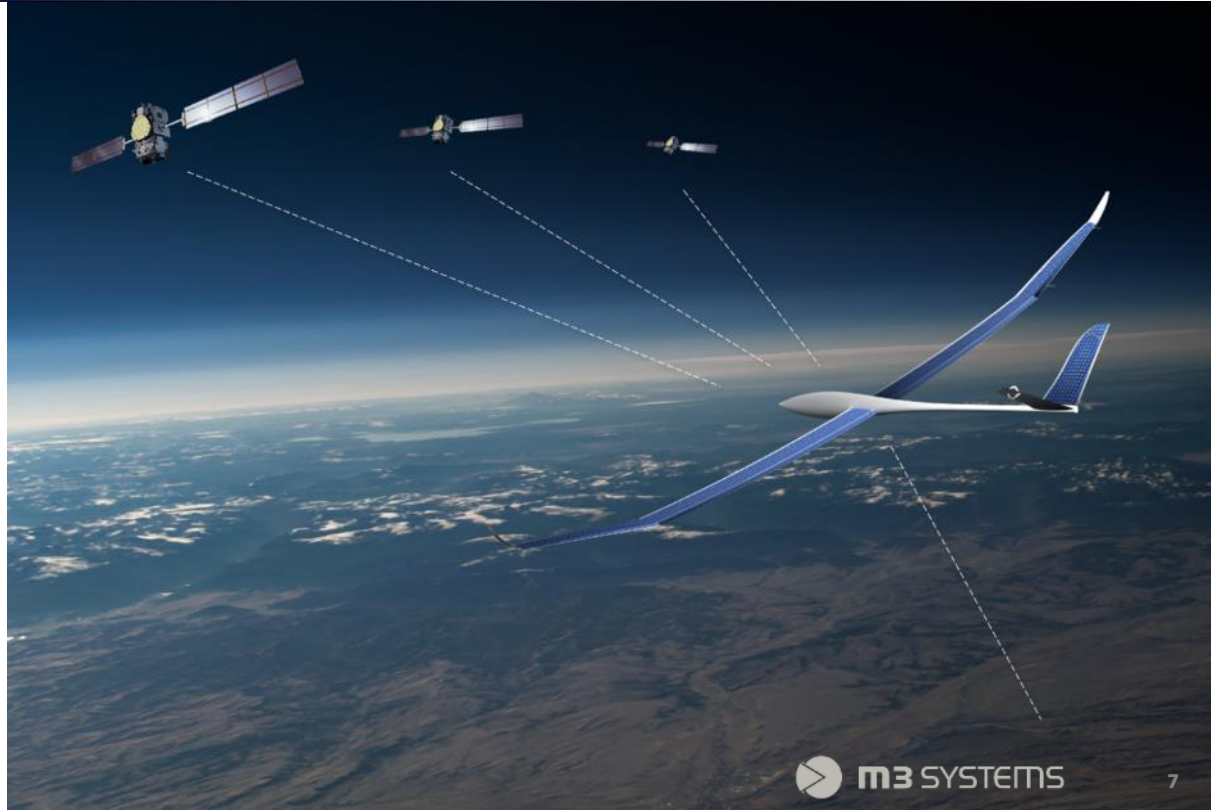
- To **study the benefits** of HAPS for GNSS augmentation in difficult environments, interference monitoring/location and alternative and complementary PNT
- to study the **different candidate** architectures and downlink signal plans of HAPS for PNT objectives, possibly in combination with communication services/systems, assessing **end-to-end system** performances
- To perform a HAPS PNT **payload technology trade-off**
- To perform a HAPS platform **suitability assessment** and high-level requirements
- To assess potential **future demonstrations**

→ We proposed to address following applications :

- **Radio-Navigation**
- **Constrained Environments**
- **Interference detection**
- **5G PPP Correction Broadcasting**

Why HAPS for PNT & GNSS ?

- ESA is deploying satellite solutions to support positioning, navigation (GNSS) and timing applications and systems
- Current GNSS solutions suffer some limitations, such as : weak signals from space, signal interference and blocking, masking & multi-path effects
- **HAPS is considered as a promising complementary solution to the existing GNSS systems as it could support and improve the current GNSS performances**

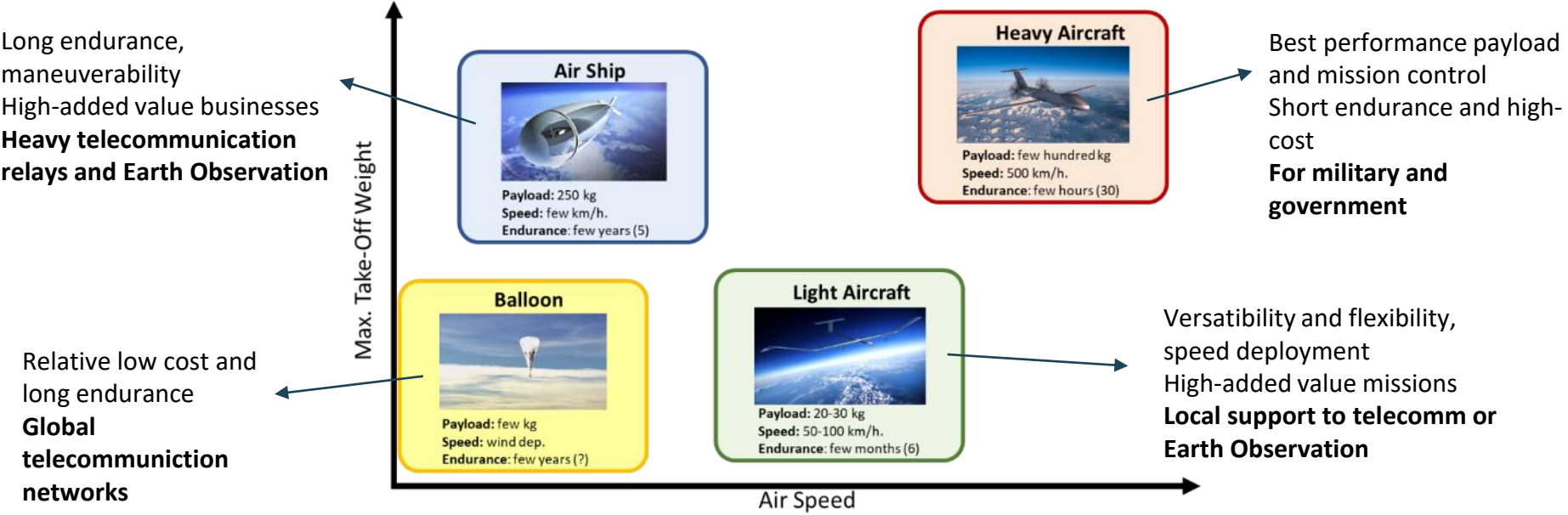


Agenda

- Introduction
- **First Part – Presentation of the Study Cases, Selection Process and Service Definition for Retained Study Case**
 - HAPS Added Value
 - Study Cases Description
 - User Requirements and KPIs
 - Study Cases Scenarios Comparison Analysis & Selection
 - Service Definition: Sample Deployment Plan
 - System Definition & Risk Assessment: Aerial Vector, Ground Vector, Payload
- **Second Part – Presentation of the Tests & Results and Roadmap**
 - Tests Descriptions
 - Tests Results
 - Tests Conclusions: KPIs Compliance
 - Technological Roadmap
 - Next Steps towards Service Demonstration: Service Definition, System Definition

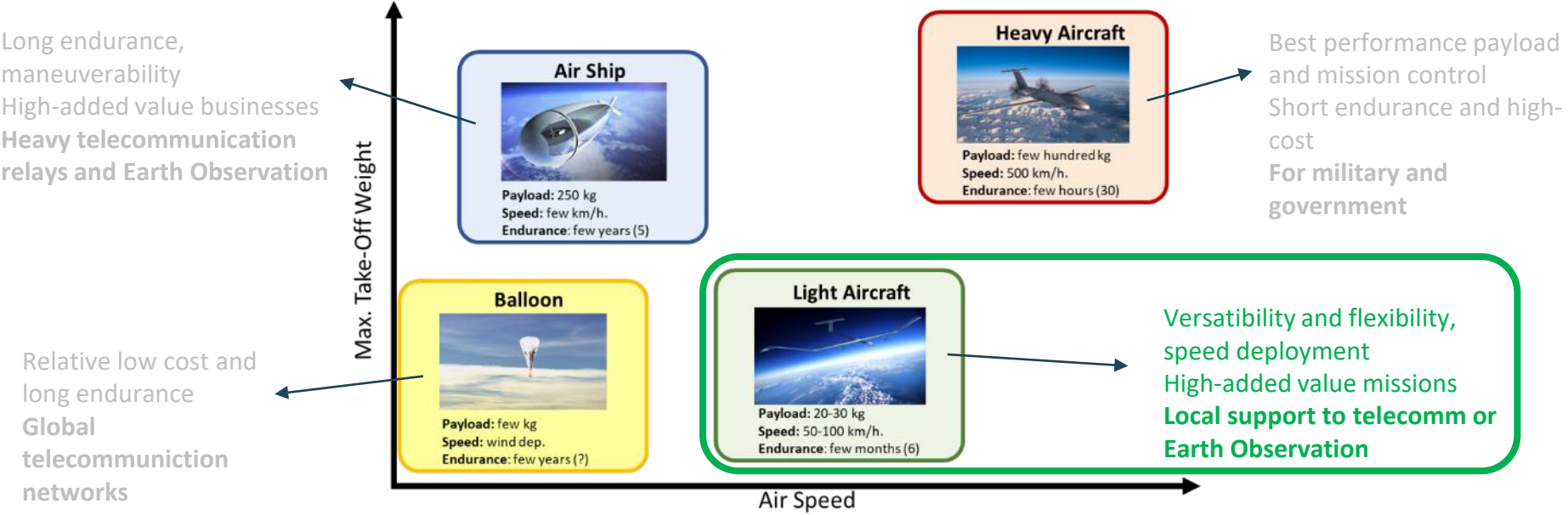
HAPS Added Value

- Stratospheric platform flying at high altitude (between 20km and 30km)
- To perform continuous and permanent missions
- Quasi-Static (few km/h) or mobile (50-100-500km/h)

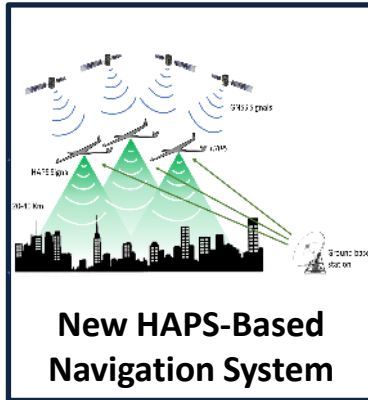


HAPS Added Value

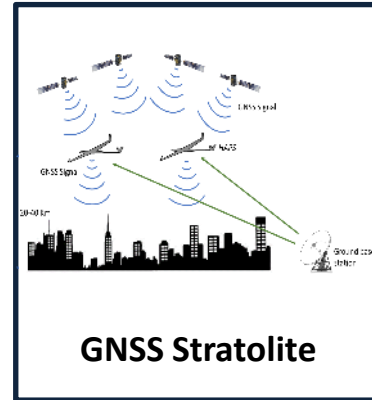
- Stratospheric platform flying at high altitude (between 20km and 30km)
- To perform continuous and permanent missions
- Quasi-Static (few km/h) or mobile (50-100-500km/h)



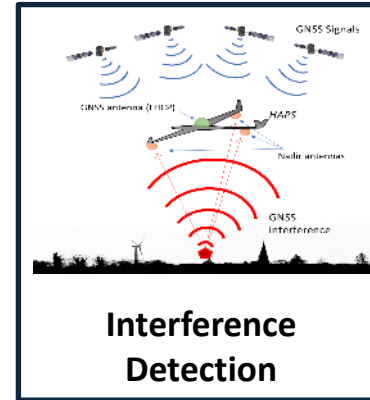
Study Cases Description



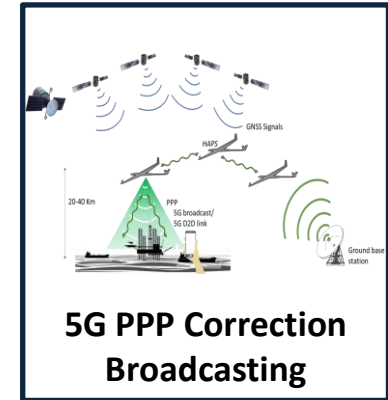
- **New signal** for PNT to overcome GNSS limitations
- **In-door** and **dense-building urban** environment



- Use HAPS to **increase # of visible satellites** of existing constellation
- Enable PNT at urban canyons **environment** (out-door only)



- Use HAPS to **detect & localize** ground-based source(s) of **GNSS interference**

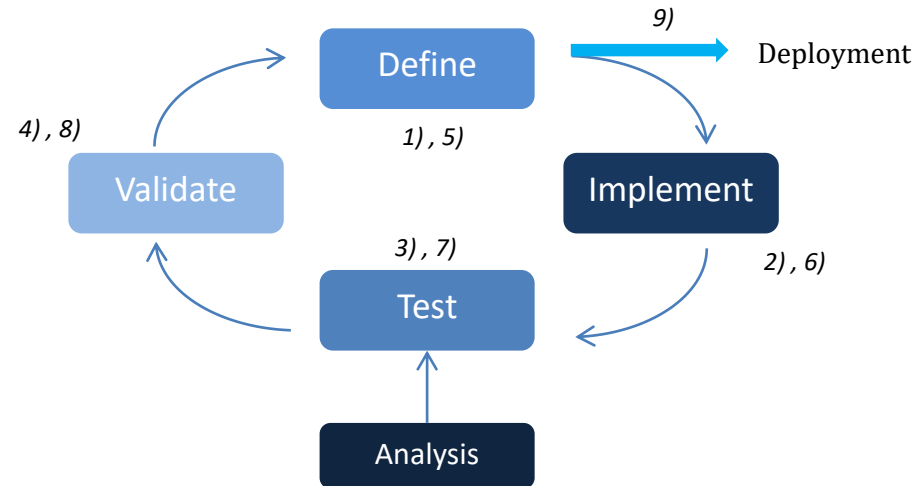


- Broadcasting of **PPP corrections** using **5G** to handsets/receivers for **< 1 m accuracy** for high precision uses (e.g. autonomous veh.)

4 different services = 4 different study cases (and several scenarios per study case)

User Requirements & KPIs

Study Case Requirements & KPIs Definition Process



- 1) Preliminary use case characterization (performances, feasibility & cost criteria)
- 2) Technical analysis of each use case (payload features, signal design, coverage area, ...)
- 3) Qualitative assessment & ranking of each use case based on a common analysis grid to ensure cross-comparison
- 4) First trade-off evaluation & key challenges
- 5) Scenarios definition per each use case for preliminary requirements & KPIs identification
- 6) Requirements classification and prioritization (MoSCoW)
- 7) Performance assessment per scenario based on KPI + risk assessment
- 8) Second trade-off analysis & use cases comparison
- 9) Selection of the most promising use case

Study Case 1 – New HAPS-Based Navigation System

KEY CHARACTERISTICS

- **Lower frequency** carrier for better in-door penetration and lower free space losses
- **Higher signal power** for in-door positioning and less interference sensitivity
- Not requires ionospheric delay removal, **only tropospheric error** correction
- Continuous **in & out-door positioning**

POSSIBLE APPLICATIONS

- **PNT to emergency services**
- **Autonomous vehicles**

CHALLENGES

- Avoid **near far effect** from closest transmitters
 - Require reconfigurable antenna gain pattern
- **Synchronization**
 - Use GNSS as time reference for clock synchronisation
 - 1 ns clock error (<30 cm HAPS PNT) → 1 m accuracy at receiver
- **Infrastructure**
 - Similar to current GNSS but for **local coverage**
 - **New navigation message** (HAPS pos., clock error, etc.)
 - **New receiver** (assuring GNSS compatibility)
- **Fleet of HAPS**
 - **High number of HAPS** are required for large coverage
 - Fleet control and formation flight
- **Added value compared to 5G ?**

Study Case 2 – GNSS Stratolite

KEY CHARACTERISTICS

- **New PRNs** must be allocated to HAPS
- **Navigation message** must be **modified** to **account for HAPS trajectories**
- Ionospheric delay corrections not applied to HAPS PRN
- **Minor upgrade** of current **GNSS receivers**
- Signal can have **higher power** for better penetration and multipath compensation (limited to avoid receiver saturation)
- Usually less than 4 satellites visible in deep-urban env.
→ accuracy is increased to 1-2 m by adding 2 HAPS

POSSIBLE APPLICATIONS

- **Autonomous vehicles**

CHALLENGES

- **Synchronization**
 - Use GNSS as time reference for clock synchronisation
 - 1 ns clock error (<30 cm HAPS PNT) → 1 m accuracy at receiver
 - Needs **extremely robust** solution with excellent synchronization to **minimize interferences with other GNSS signals**, and avoid blocking of PNT service
- **Infrastructure**
 - Similar to current GNSS but for **local coverage**
 - **New navigation message** to account for non-keplerian satellite trajectory (polynomial)
 - Require maintenance of navigation message for HAPS
- **Fleet of HAPS**
 - Number & formation **depend on city characteristics** (privileged orientation, urban canyon concentration, etc.)
- **Added value compared to 5G ?**

Study Case 3 – Interference Detection

KEY CHARACTERISTICS

- **Single** HAPS to detect & localize interference threat
- Use of **several detection techniques** (ToA, TDoA, FoA, FDoA, RSSD, AoA)
- **Continuous monitoring** over an area
- **On-demand deployment** when threat has been identified (for localization)
- Ability to **fusion data** from several HAPS (optimization)
- Benefits from **two separated RF paths: GNSS and interference source**

POSSIBLE APPLICATIONS

- **Malicious jamming / spoofing source localisation**

CHALLENGES

- **Operational detection and localization on moving platform**
 - Development of all-in-one embarked detection and localization system
 - High computational requirements for real-time operation
- **Accuracy uncertainty dependance on type of interference**
- Ability to detect (weak) interferences **from 20 km altitude**
 - Minimum power of interference threat

Study Case 4 – 5G PPP Correction Broadcasting

KEY CHARACTERISTICS

- **5G comm. already proved** from stratospheric platform
- Reference station not needed (as for real-time kinematic)
- Can provide **accuracy <1m** (30 s conv. time) or better
- **Dual-frequency multi-constellation chipset** already available for SoA smart devices
- **Ionospheric corrections** can be provided by **SBAS**
- Use of **<2GHz** 5G band
- Allows **Open or on-demand** service

POSSIBLE APPLICATIONS

- **Maritime / off-shore mining**
- **Autonomous vehicles**

CHALLENGES

- Choice of **5G broadcasting method**
- **Reduction of PPP convergence time**
 - PPP with zero-difference ambiguity resolution method (<10 s) and small bandwidth (<500 bits/sec)
 - NAVCAST from Spaceopal
- Availability of **PPP applications** (e.g. PPP Wizlite)
- Access to raw GNSS data from chipset
- Accessibility of **5G devices**
 - Market penetration of 5G
 - Base stations and terminal
 - Coverage

Study Cases Comparison Analysis & Selection

Performance Assessment based on KPIs

| KPI Performance Assessment | KPI Description |
|----------------------------|---|
| Continuity | Service ensured to be continuous 24/7 for several weeks over AoI |
| Easy Operation | Low complexity of the fleet & system to be deployed and managed |
| Timeliness | Processing / alog. convergence / service ready under 30 seconds |
| Controllability | Monitoring & updating position, trajectory, payload sensors at all time |
| Large Coverage | From several tens of km ² up to several thousands km ² given Use Case |
| Precise Positioning | Achieve sub-meter precision, despite urban canyoning effects |
| Deployment time | Deployment of the service shall be achieved under a target value |
| Remote Operation | Several hundreds kilometres away from GS (e.g. use of SATCOM) |

Study Cases Comparison Analysis & Selection

Performance Assessment based on KPIs

| KPI Performance Assessment | Use Case 1 | Use Case 2 | Use Case 3 | Use Case 4 |
|----------------------------|------------|------------|------------|------------|
| Continuity | + | + | ++ | - |
| Easy Operation | -- | -- | + | ++ |
| Timeliness | + | + | + | + |
| Controllability | + | + | + | + |
| Large Coverage | -- | - | + | N/A |
| Precise Positioning | -- | - | N/A | - |
| Deployment time | - | + | N/A | N/A |
| Remote Operation | N/A | N/A | + | + |

- 4 HAPS required per spot
- implementation of a whole new system from scratch
- large development costs for new signals and hardware

- 2 HAPS required per spot
- minor software modification
- new GNSS signal to develop
- flight oper. on case-by-case
- rely on existing satellites positions and coverage

- covered by a single HAPS
- lot of unknowns on TRL on techno.; complex payload
- uncertainty on efficiency to detect medium and smaller interferences from HAPS

- covered by a single HAPS
 - lot of potential applications
 - offers quick time-to-market & high commercial interest
- **most promising UC**

Study Cases Comparison Analysis & Selection

Study Cases Comparison



New HAPS-Based Navigation System

- **4 HAPS** to be visible **per spot at all time**
- Implementation of **new signals & HW** (e.g. new transmitters)



GNSS Stratolite

- **2 HAPS** to be visible **per spot at all time**
- **New GNSS signal** and **minor SW adaptation**
- **Case-by-case** op. plan



Interference Detection

- **1 HAPS** per site
- **Uncertain efficiency** to detect medium & small interferences
- **Complex** payload dev.

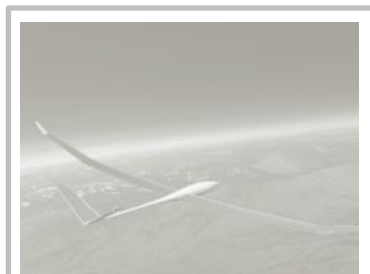


5G PPP Correction Broadcasting

- **1 HAPS** per site
- **Lots of opportunities** & business application
- 5G yet to be defined
- **Obsolescence risk?**

Study Cases Comparison Analysis & Selection

Study Cases Selection



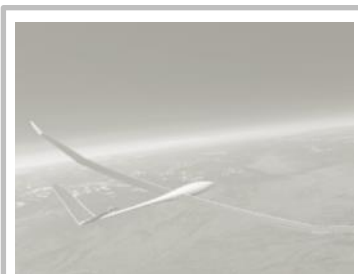
New HAPS-Based Navigation System

- **4 HAPS** to be visible **per spot at all time**
- Implementation of **new signals & HW** (e.g. new transmitters)



GNSS Stratolite

- **2 HAPS** to be visible **per spot at all time**
- **New GNSS signal** and **minor SW adaptation**
- **Case-by-case op. plan**



Interference Detection

- **1 HAPS** per site
- **Uncertain efficiency** to detect medium & small interferences
- **Complex** payload dev.



5G PPP Correction Broadcasting

- **1 HAPS** per site
- **Lots of opportunities** & business application
- 5G yet to be defined
- **Obsolescence risk?**

Selected study case = 5G PPP Correction Broadcasting



A Study Case example

5G PPP Corrections for Offshore Drilling Operations

Continuous and **uninterrupted** service in the Mediterranean Sea basin over the Vega Oil Field (South Italy, 20 km offshore)

5G PPP correction messages broadcasting for offshore platforms or ships for **sub-meter positioning accuracy**

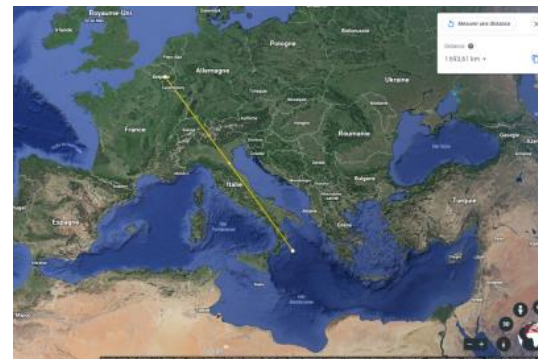
PPP correction messages allow for **real-time** and precise corrections against tides and sea current during drilling operations

Yearly coverage, all-weather operational capacity, day & night operation

Service Definition

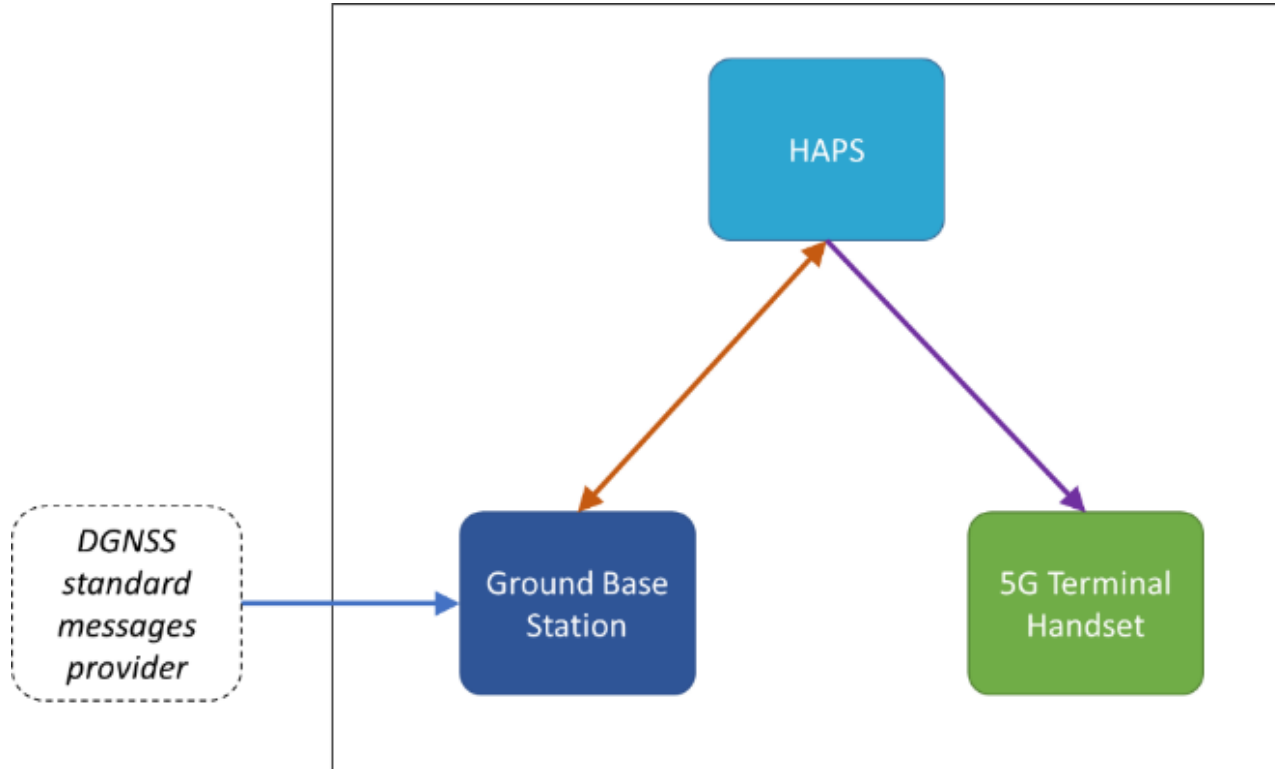
SAMPLE DEPLOYMENT PLAN

- Drilling location is on the Southern shore of Italy, at the Vega Oil Field, 1600 km away from Temploux, Belgium
- HAPS ground speed is 120 km/h, taking into account wind effects at stratospheric altitudes
- As such, reaching Aol location takes about 15 h, including flight preparation and climbing time
- Mission tasking up to 24 h before beginning of the mission
- A single HAPS needs to be tasked for this mission, with coverage capacity up to 500 km²
- Once on target, the HAPS performs a constant circular flight around the drilling area, with a radius of 4 km (compliant with the maximum turn angle of 2.7 km)



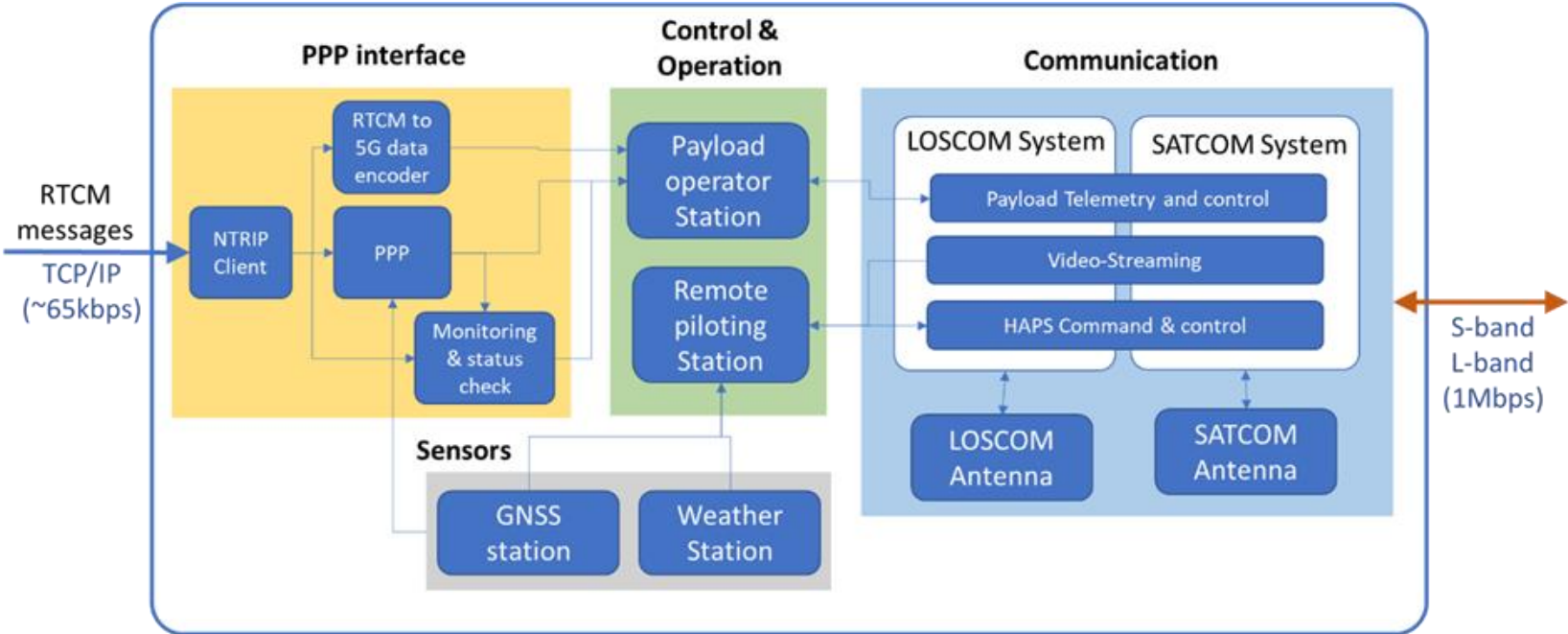
System Definition & Risk Assessment

High-Level System Architecture



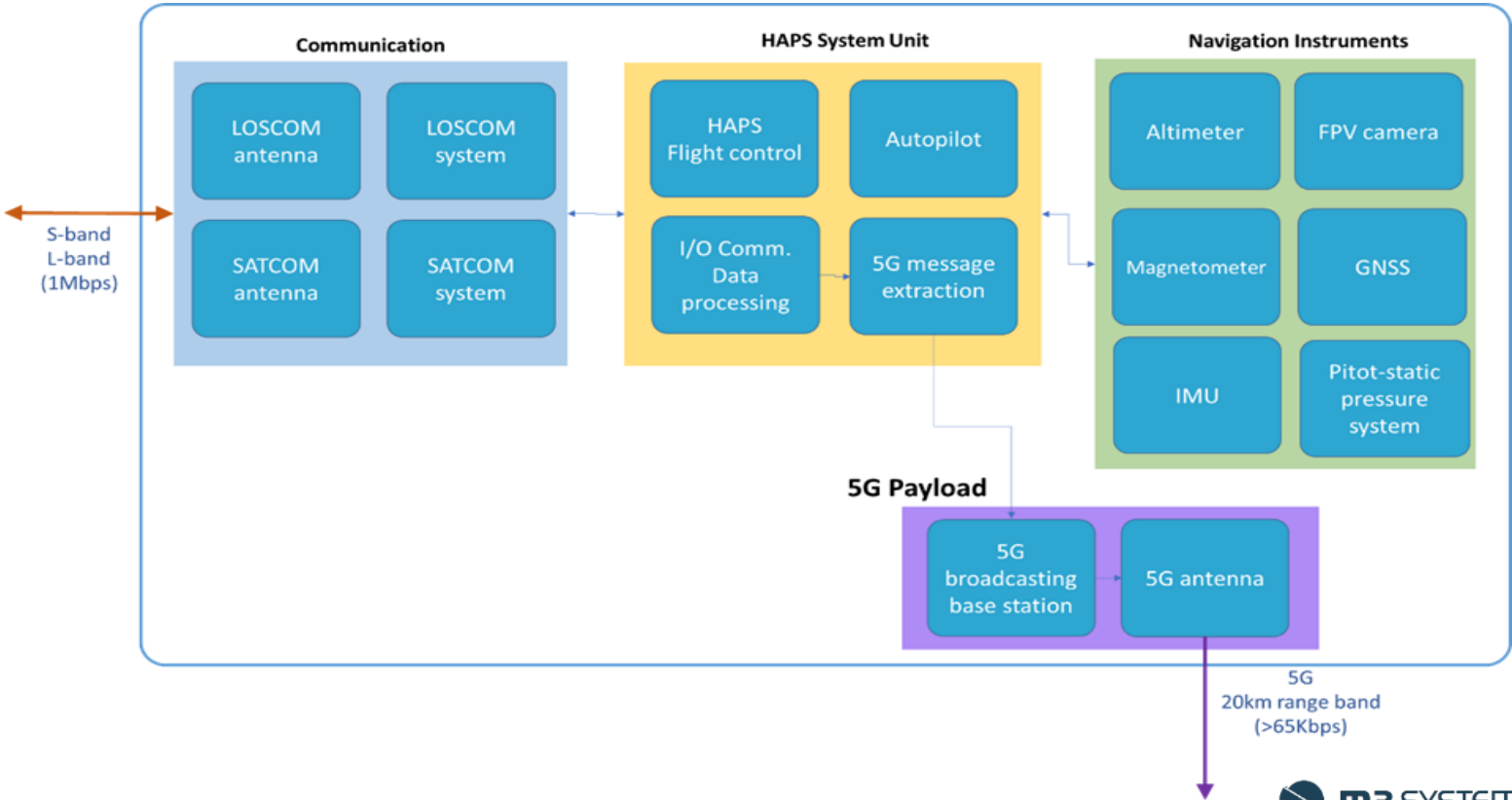
System Definition & Risk Assessment

Ground Base Station



System Definition & Risk Assessment

HAPS – Aerial Vector



HAPS – 5G Payload

5G Base Station

- ✓ Control from ground base station through comm. link
- ✓ Broadcasting of PPP corrections (using standardized 5G 3GPP):
 - Public: To all terminal connected to network (idle connection)
 - Private: - on-demand “GNSS Assistance Data Request Elements” (encrypted)
 - SIM-secured (through network connection)
- ✓ 5G communication capability not required
- ✓ 5G macro cell
 - Targeting > 20 km range: Total coverage > 500km²
 - 600/700¹ MHz band w/ 15 kHz SCS and 40 MHz BW
(eventually 2GHz² band w/ 30 kHz SCS and 100 MHz BW could be used)
 - Large number of “idle” connections (>10 000)

5G Antenna

- ✓ Multiple Passive MIMO antennas at 700 MHz (or 2GHz) freq. band
- ✓ Large beam width (e.g. 70°)

Risk Assessment Summary

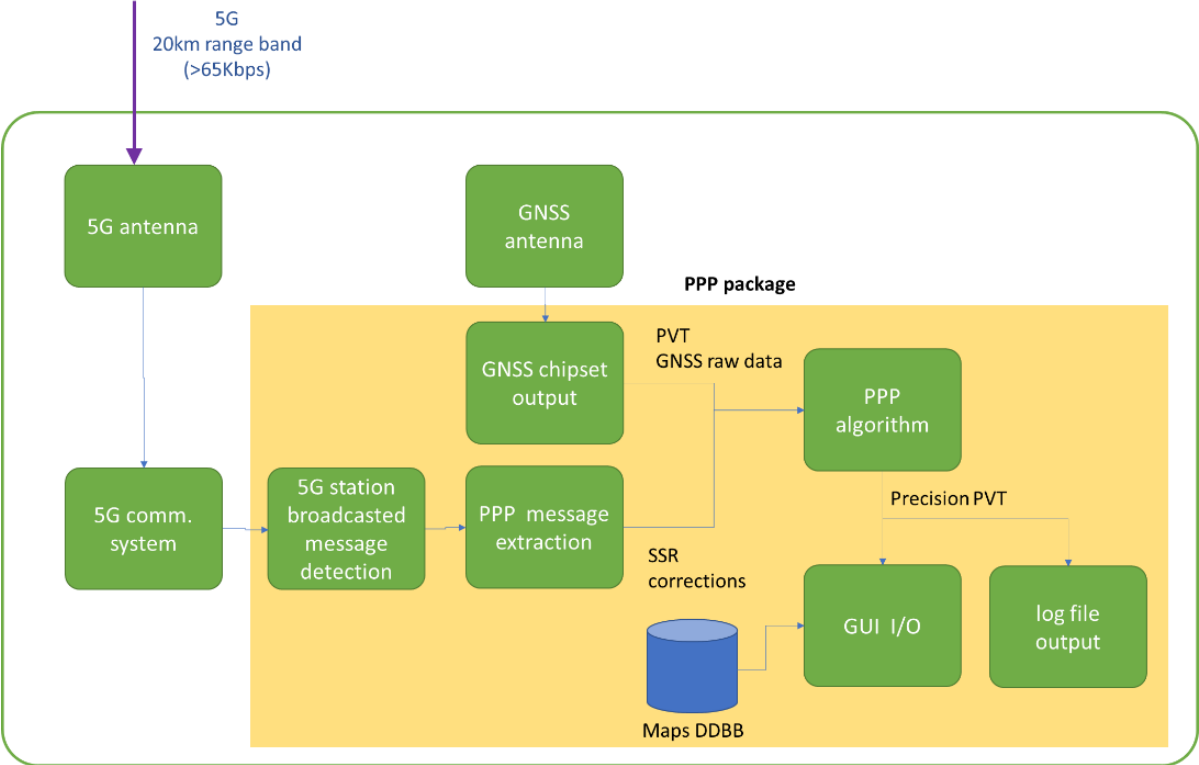
- Total payload mass and size
- Payload power consumption
- 5G payload temperature of operation
- Certification of 5G equipment
- Antenna integration (Fuselage, on-board)

¹ EU <1GHz assigned band (end 2019). Currently for terrestrial application only.

² 2GHz band is currently used for 5G stratospheric communication.

System Definition & Risk Assessment

5G Terminal Handset



5G Terminal Handset

- ✓ 5G communication standard
- ✓ Dual SIM card (For 5G comm. And for 5G HAPS PPP broadcasting)
- ✓ Able to access 5G PPP broadcasted message (5G 3GPP standard)
- ✓ GNSS chipset
 - ✓ Dual frequency (at least)
 - ✓ Multi-constellation (at least 2)
 - ✓ GNSS raw measurements (P-R, clock, Nav msg, etc)
- ✓ Shall include PPP algorithm (native or via dedicated app.)
- ✓ High computing and memory capabilities
- ✓ GUI I/O for PVT before and after PPP correction



Risk Assessment Summary

- Availability of 5G terminal handset 5G IoT sensor with GNSS chipset and computational capabilities

¹ EU <1GHz assigned band (end 2019). Currently for terrestrial application only.

² 2GHz band is currently used for 5G stratospheric communication.

Agenda

- Introduction
- First Part – Presentation of the Study Cases, Selection Process and Service Definition for Retained Study Case
 - HAPS Added Value
 - Study Cases Description
 - User Requirements and KPIs
 - Study Cases Scenarios Comparison Analysis & Selection
 - Service Definition: Sample Deployment Plan
 - System Definition & Risk Assessment: Aerial Vector, Ground Vector, Payload
- **Second Part – Presentation of the Tests & Results and Roadmap**
 - **Tests Descriptions**
 - **Tests Results**
 - **Tests Conclusions:** KPIs Compliance
 - **Technological Roadmap**
 - **Next Steps towards Service Demonstration:** Service Definition, System Definition

A series of performance tests have been evaluated on the proposed system

- Tests related to the DGNSS Standard Message Provider sub-system (MSS-*nnn*)
- Tests related to the Ground Base Station sub-system (GBS-*nnn*)
- Tests related to the HAPS sub-system (HAPS-*nnn*)
- Tests related to the 5G Terminal sub-system or alternative solution (5GT-*nnn*)
- Tests related to the whole system (SYS-*nnn*)

DISCLAIMER: These test were not done on a real prototype but to estimate the performance of a future prototype implementation

Tests Descriptions

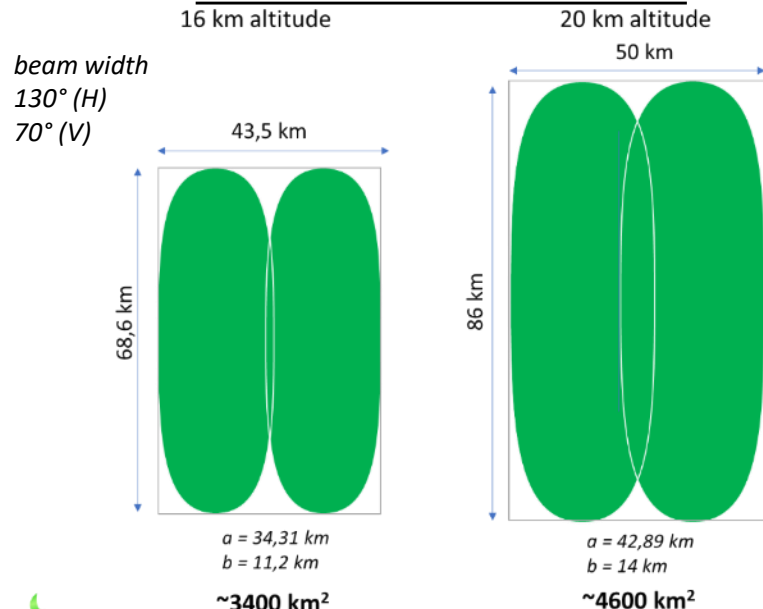
| Test ID | Test short description | Expected results |
|-----------------|---|----------------------|
| MSS-001 | Datarate of RTCM corrections | <65kbps |
| MSS-002 | Check consistency of RTCM message | OK |
| MSS-003 | Continuity of RTCM streaming | Continuity over 3h |
| GBS-001 | Delay due to RTCM to 5G comm protocol conversion | <50ms |
| GBS-002 | Delay due to transmission to HAPS from GBS | <200ms |
| GBS-003 | Check fulfilment of 5G protocol | OK |
| HAPS-001 | Delay due to processing of PPP corrections at HAPS | <250ms |
| HAPS-002 | Coverage area of the 5G communication @ 16 km ALT and 20 km ALT | >500 km ² |
| HAPS-003 | Transmission delay from HAPS to end user | <250ms |
| HAPS-004 | Number of simultaneous 5G connections established by the HAPS | 10 000 |
| HAPS-005 | Maximum power consumption of 5G payload | <500W |

| Test ID | Test short description | Expected results |
|-----------------|--|---|
| HAPS-006 | Sensitivity to possible deviations in roll & pitch of the platform due to HAPS stability | Evaluate need of gyro-stabilized mount |
| HAPS-007 | Evaluation of the dynamicity of the coverage area, taking into account wind effects at stratospheric altitudes | Evaluate need of additional stabilization |
| HAPS-008 | Structural impact of the installation of the antenna | Demonstration of non-detrimental to structure |
| 5GT-001 | Convergence time of PPP algorithm | 30s and 60s for 1m and 30cm horizontal accuracy |
| SYS-001 | Total delay of transmission corrections to end user | <1s |
| SYS-002 | Impact of 10 sec delay on corrections | Impact <100ms additional convergence |

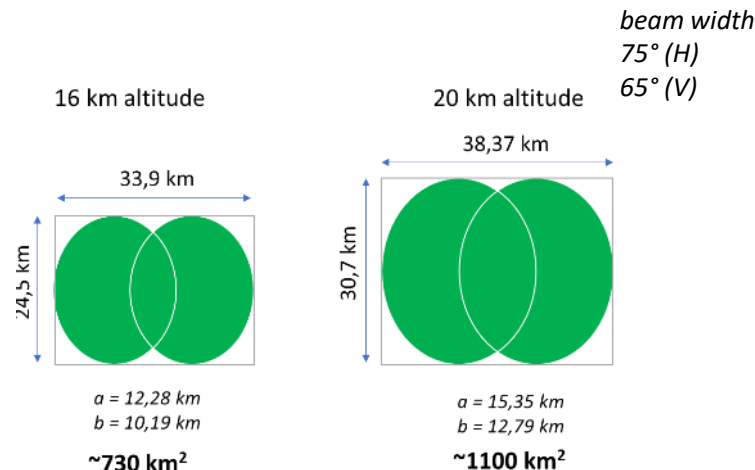
HAPS-002: Coverage area of the 5G communication @ 16 and 20 km altitude

- Need to assure -80 dBm power level at the user for good/excellent connectivity (four bars)
- Output power from HAPS = 45 dBm (40dBw + 5dBi)
- Max propagation attenuation 130 dB (45-130 = -85) → **55 km range at 700 MHz, 37 km at 2 GHz**

Illuminated area at 700 MHz

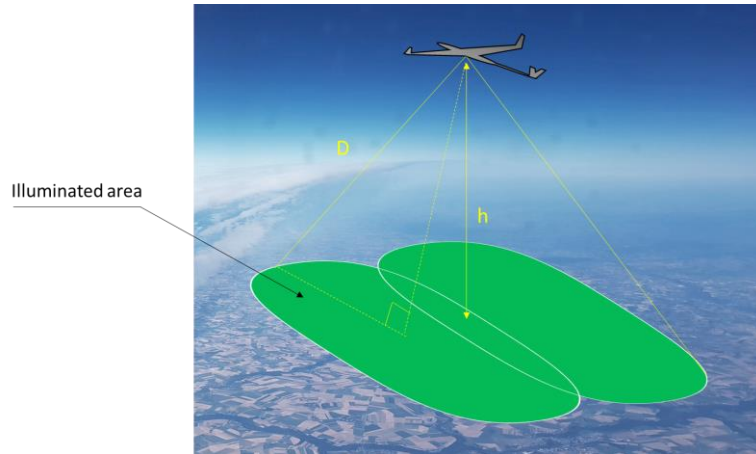


Illuminated area at 2000 MHz



HAPS-002: Coverage area of the 5G communication @ 16 and 20 km altitude

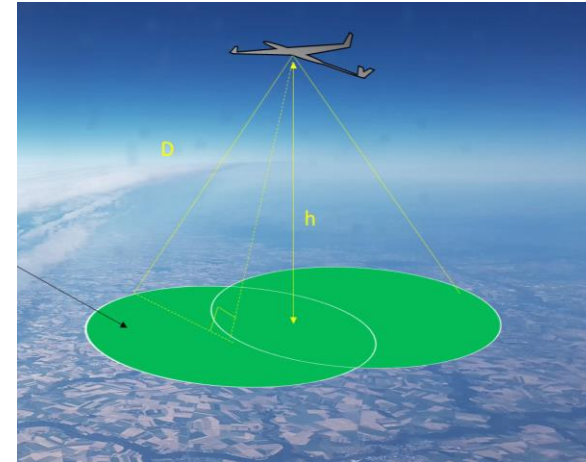
700 MHz



| h | D [km] | Att @700 MHz | 5W (37dB) | 10W (40dB) |
|------|--------|--------------|-----------|------------|
| 16km | 37,86 | 120,9 | -78,9* | -70,9* |
| 20km | 47,32 | 122,8 | -80,8* | -72,8* |

* Including 5dBi antenna gain

2000 MHz



| h | D [km] | Att @2GHz | 5W (37dB) | 10W (40dB) |
|------|--------|-----------|-----------|------------|
| 16km | 20,17 | 120,9 | -81,1* | -78,1* |
| 20km | 25,21 | 122,8 | -83,0* | -80,0* |

* Including 6,5dBi antenna gain

5GT-001: Convergence time of PPP algorithm

- Study of the convergence time of PPP algorithm (PPP-Wizard)
- Several constellation/modes configurations were considered:
 - GPS only – Mode: Ambiguity Resolution (AR)
 - GPS and GLONASS – Mode: Ambiguity Resolution (AR)
 - GPS and GLONASS – Mode: Dual Frequency (DF)
 - GPS, GLONASS, GALILEO and BEIDOU – Mode: Ambiguity Resolution (AR)
 - GPS, GLONASS, GALILEO and BEIDOU – Mode: Dual Frequency (DF)
- The convergence time can be estimated using the covariance on the three axes X, Y and Z (from the output result)
- The horizontal, vertical and 3D covariances are given by:

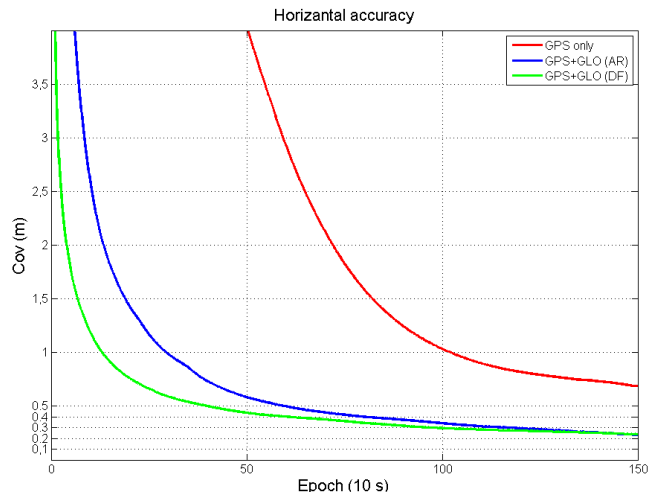
$$Cov_h = \sqrt{Cov_X^2 + Cov_Y^2}$$

$$Cov_v = Cov_Z$$

$$Cov_{3D} = \sqrt{Cov_X^2 + Cov_Y^2 + Cov_Z^2}$$

5GT-001: Convergence time of PPP algorithm

- Septentrio Polarx5 GNSS receiver at M3S Lab premises



- Only two constellation (GPS & GLO) available due to format incompatibility of receiver output with PPP-Wizard
- Difference could be due to the location of our antenna, that in our case could suffer from multipath and other effects that seem to reduce the PPP algorithm performance

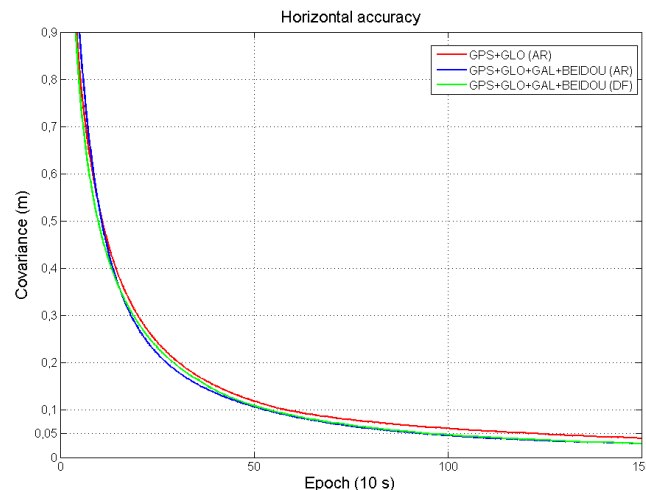
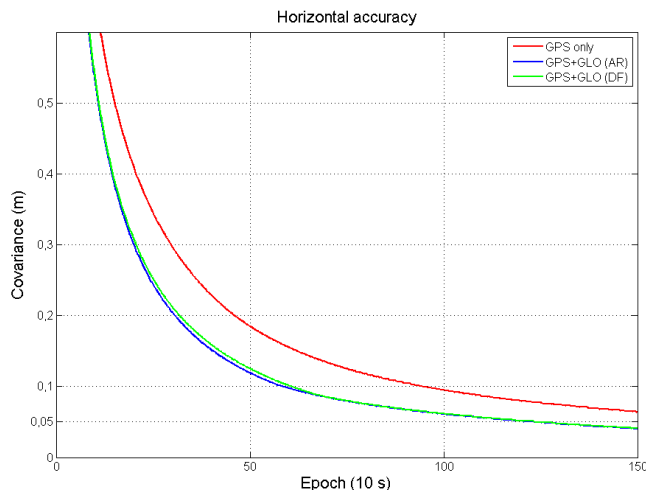
| Horiz. accuracy | 1 m | 60 cm | 30 cm | 10 cm |
|-----------------|--------|-------|--------|--------|
| GPS only | 1020 s | - | - | - |
| GPS + GLO (AR) | 295 s | 485 s | 1170 s | 2500 s |
| GPS + GLO (DF) | 130 s | 290 s | 974 s | 3578 s |
| GPS + GLO [1] | - | - | - | 1200 s |

More than twice the time than reference

[1] D. Laurichesse, A. Privat, 'An Open-source PPP Client Implementation for the CNES PPP-WIZARD Demonstrator', ION GNSS 2015, September 15-18, 2015 - Tampa, FL

5GT-001: Convergence time of PPP algorithm

- Best case scenario:** GNSS receiver located at CNES (raw data is recovered via RTCM message)



| Horiz. accuracy | 1 m | 60 cm | 30 cm | 10 cm |
|----------------------------|------|-------|-------|-------|
| GPS only | 47 s | 114 s | 246 s | 945 s |
| GPS + GLO (AR) | 35 s | 84 s | 200 s | 586 s |
| GPS + GLO (DF) | 41 s | 85 s | 206 s | 606 s |
| GPS + GLO + BDS + GAL (AR) | 41 s | 86 s | 183 s | 532 s |
| GPS + GLO + BDS + GAL (DF) | 33 s | 74 s | 188 s | 540 s |

SYS-001: Total delay of transmission corrections to end user

- Total delay is sum of single delays at different blocks and subsystems

- ❑ GBS-001: Delay between the reception of the PPP corrections and the transmission of the 5G message including PPP corrections to the Payload Control } ✓ 30ms
- ❑ GBS-002: transmission delay between the ground base station, once it has been received at the Payload Control Unit, and the HAPS } ✓ 200 ms (LOSCOM)
- ❑ HAPS-001: delay between the reception of the PPP corrections at the HAPS, and the transmission from the HAPS to the 5G Terminal } ✓ 30ms
- ❑ HAPS-003: transmission delay of broadcasted 5G PPP corrections, between the HAPS and the 5G terminal } ✓ 0.2 ms

TOTAL: 260 ms

KPIs Compliance

| Test ID | Test short description | Type | Expected results | Obtained result | Status |
|----------|--|----------|---|--|--------|
| MSS-001 | Data rate of RTCM corrections | Unitary | <65kbps | 15kbps | PASS |
| MSS-002 | Check consistency of RTCM message | Unitary | OK | OK | PASS |
| MSS-003 | Continuity of RTCM streaming | Unitary | Continuity over 3h | 1 faulty message every 10000 It can be considered negligible | PASS |
| GBS-001 | Delay due to RTCM to 5G comm protocol conversion | Unitary | <50ms | 30ms | PASS |
| GBS-002 | Delay due to transmission to HAPS from GBS | Unitary | <200ms | 200ms | PASS |
| GBS-003 | Check fulfilment of 5G protocol | Unitary | OK | OK | PASS |
| HAPS-001 | Delay due to processing of PPP corrections at HAPS | Unitary | <250ms | 30ms | PASS |
| HAPS-002 | Coverage area of the 5G communication @ 16 km ALT and 20 km ALT | Unitary | >500 km ² | 3400 km ² to 4500 km ² | PASS |
| HAPS-003 | Transmission delay from HAPS to end user | Unitary | <250ms | 0.2ms | PASS |
| HAPS-004 | Number of simultaneous 5G connections established by the HAPS | Unitary | 10000 | 10600 | PASS |
| HAPS-005 | Maximum power consumption of 5G payload | Unitary | <500W | 232W | PASS |
| HAPS-006 | Sensitivity to possible deviations in roll & pitch of the platform due to HAPS stability | Analytic | Evaluate need of gyro-stabilized mount | No required compensation for 2° angular deviation | PASS |
| HAPS-007 | Evaluation of the dynamicity of the coverage area, considering wind effects at stratospheric altitudes | Analytic | Evaluate need of additional stabilization | No required additional stabilization | PASS |
| HAPS-008 | Structural impact of the installation of the antenna | Analytic | Demonstration of non-detrimental to structure | Payload located under the wings: impact on structure is managed because the chosen solution is identical as the proved one developed for the ES15, an existing aircraft based on the S12 | PASS |
| 5GT-001 | Convergence time of PPP algorithm | Unitary | 30s and 60s for 1m and 30cm horizontal accuracy | 41s for 1m and 180s for 30cm | FAIL |
| SYS-001 | Total delay of transmission corrections to end user | System | <1 | 260ms | PASS |
| SYS-002 | Impact of 10sec delay on corrections | System | Impact <100ms additional convergence | No impact | PASS |

Technological Roadmap

Specific Payload Development

- Specific 5G modules for high-altitude broadcasting of PPP corrections of GNSS signal still to be developed
→ standards definition, low operating temperatures ability, weight constraints, antenna design & integration, qualif. & certif.

Telecom

- SATCOM challenges = power usage ; weight ; high cost of the system (i.e. heavy penalty for commercial competitiveness)
- Possible solution = deployment of LOSCOM tracker antennas (mobile/fixed) in appropriate locations for corrections broadcasting

Batteries & Solar Panels

- Batteries & solar panels efficiency not mature yet for HAPS applications ; further development needed on these technologies
- Solution for short to mid-term operations = envisage other types of propulsion (e.g. hybrid)

Ground Application

- Integration of PPP correction messages at the ground level yet to be practically designed & implemented
- Interface with payload control + RTCM to 5G message conversion also has to be designed & implemented

PPP Algorithm

- Convergence time required for 30 cm exceeded 60 seconds → further analysis & development of new PPP algorithms needed

Operational Procedures

- Regulations not yet fully defined for upper airspace operation → monitoring activity of regulations is performed
- Mission planning aspects, flight plan locking (by analogy with satellite orbits), etc. will strongly affect global operation of HAPS
- Detailed business case analysis and comparison with competitors required on a case-by-case basis to assess operational viability

Stratospheric Service Demonstration

- First flight test in Belgium, with support of DGTA, planned in mid-2021. Stratospheric demonstrator characteristics are given here below:

| Stratospheric Demonstrator Specifications | |
|---|--|
| TAS | 100 km/h |
| Altitude | 16 km |
| Endurance | 5 h (up to 2 h in the stratosphere) |
| Operation | OPV and UAV |
| Purpose | High-altitude service demonstration & validation |



- Service demonstration flights under IAP program for Earth Observation expected between mid-2021 and mid-2022. Stratospheric operating conditions will be representative of those that will be endured by a full-scale / long-endurance HAPS system.
- Possibility to propose an IAP demonstration project for PNT if business opportunities which might result from this demonstration are clear
→ business model should be outlined ahead of any IAP project proposition

Thank you!

Any questions?

Contacts

Partners

STRATOS : CREPIN Jean-Philippe → jp.crepin@stratos-solution.com
STRATOS : SIMONIS Alexandre → a.simonis@stratos-solution.com
SONACA : EBOLI Alessio → alessio.eboli@sonaca.com
M3SYSTEMS : RODA NEVE César → cesar.rodaneve@m3systems.eu
M3SYSTEMS : DESENFANS Olivier → olivier.desenfans@m3systems.eu