5-GENIUS

5G Enhanced Navigation

Integrity for UAV Systems

ESA – NAVISP Element 2

CGI, esa, UK SPACE AGENCY, NATS, ublox, US UNIVERSITY OF SUSSEX

Agenda

- Why 5-GENIUS?
- Project Outcomes
- CGI Growth
- Benefits of working with ESA/NAVISP

Why 5-GENIUS?

Why 5-GENIUS?

- ADS in the UK, along with leading business analysts, estimate the advanced air mobility market to grow into a multi-Billion Dollar business throughout the 2020s
- This requires overcoming key challenges of urban airspace operations
- A key element of this is the operations beyond the visual line of sight (BVLoS)
- To sustainably leverage this market potential, aviation levels of operational safety need to be achieved

- Street mapping a city with optical and acoustic sensors
- Transporting parcels from a distribution centre to a customer
- Long-distance aerial surveys of a construction project
- Persistent surveillance at the scene of an incident, operated from a control centre
- Inter-hospital transport of medical supplies and materials
- Long-range heavy goods transport
- Air Taxi
- Agricultural spraying

Why 5-GENIUS?

Three technological enablers are needed for safe flight BVLoS:

Assured Positioning

GNSS alone does not meet aviation safety standards in urban airspace (interference and obscured satellite view)

Detect & Avoid Capability

Signal UAV's presence to other airspace users

Remote Pilot Takeover

Reliable (resilient and high rate) Data Comms

Why 5-GENIUS?

Multiple bands

5G is delivered over multiple diverse frequency bands, providing resilience to jamming

5G is strong

5G signals are significantly stronger than GNSS, so harder to jam and spoof

5G has clocks

5G base station clocks provide inter-cell synchronization – but how synchronized and stable are they?

Can 5G possibly be part of an assured positioning solution?

Multiple operators

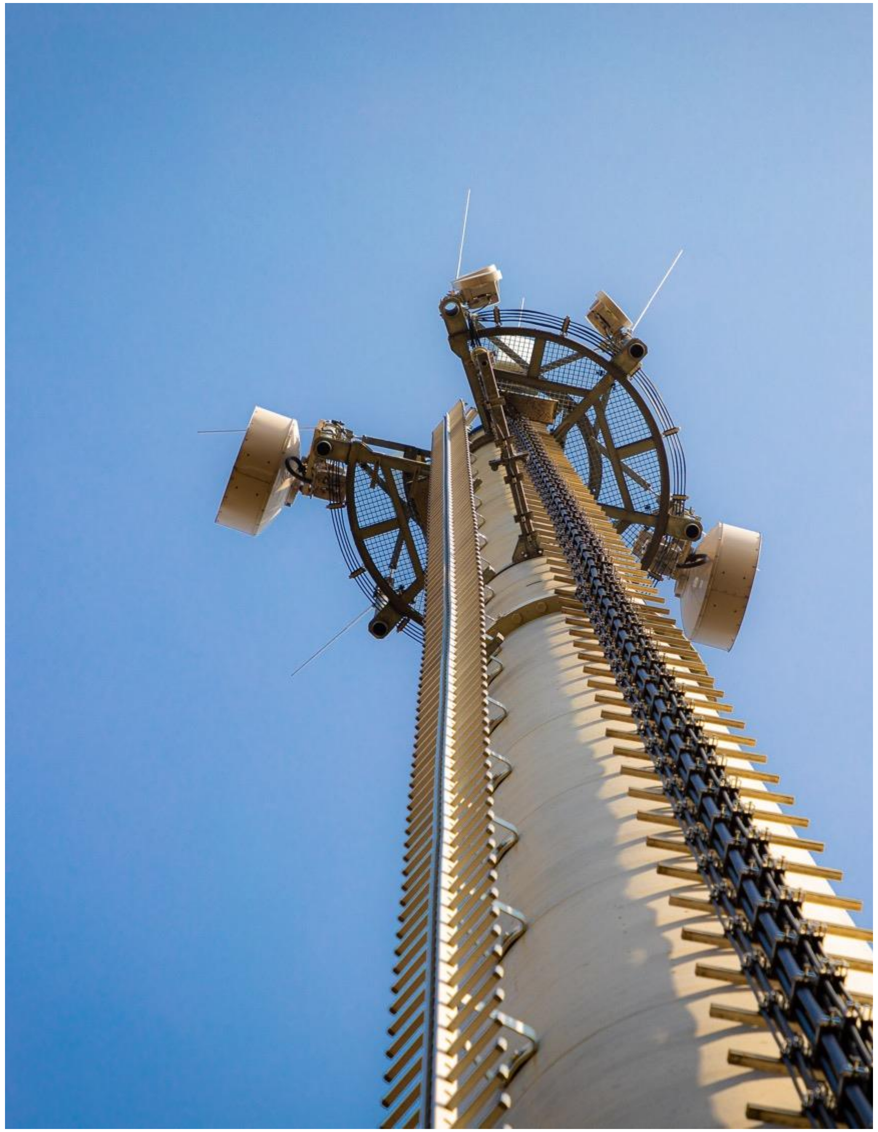
5G is delivered by multiple, independent mobile network operators, providing cyber resilience

5G is deploying

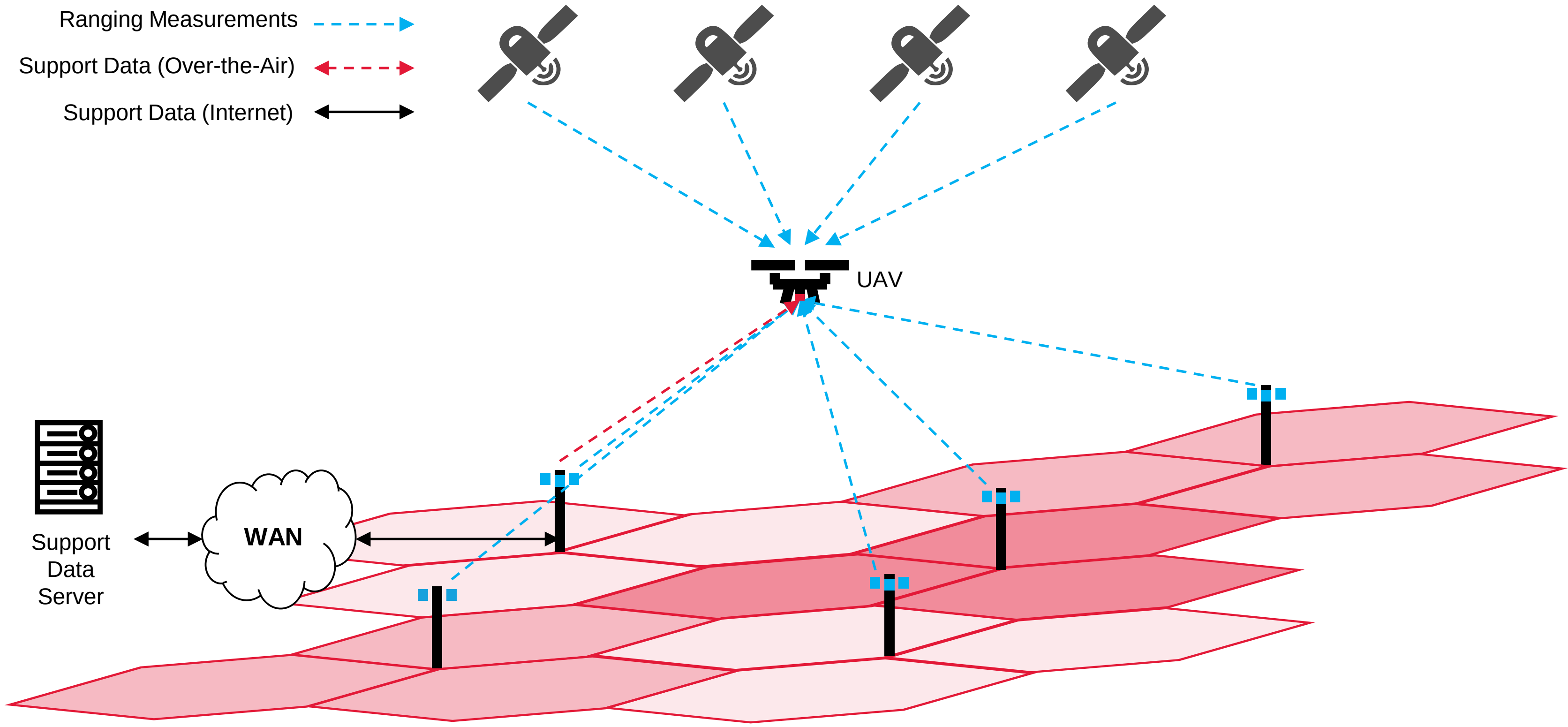
Focus is urban, where GNSS has the most issues – does this infrastructure deployment provide an opportunity?

5G for ground users

5G currently deployed to serve ground users – but what is the coverage for airborne users and does the geometry suit positioning?



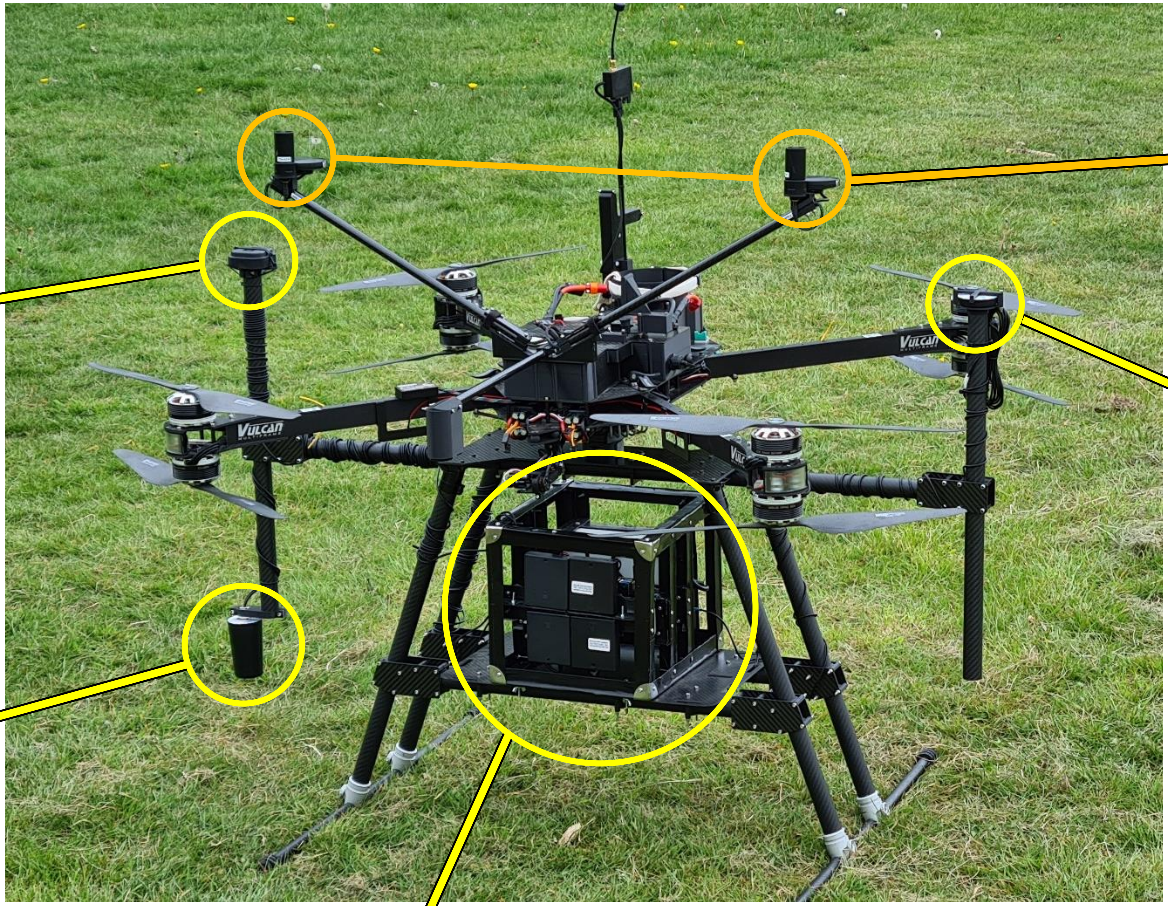
Project Overview



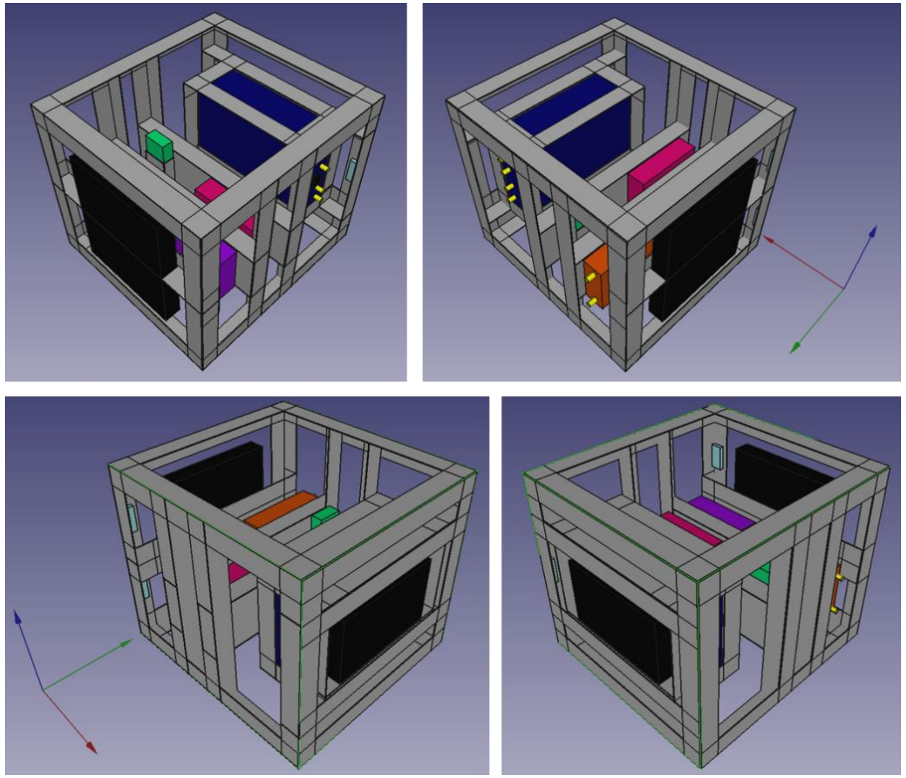
- ✓ Scalable with increasing UAV numbers
- ✓ Passive so no RF licence needed
- ✓ Uses 5G signals from all MNOs, providing resilience and transmitter diversity
- ✓ Compatible with 5G Release 15+
- ✓ Extensible to 4G/LTE and 5G PRS

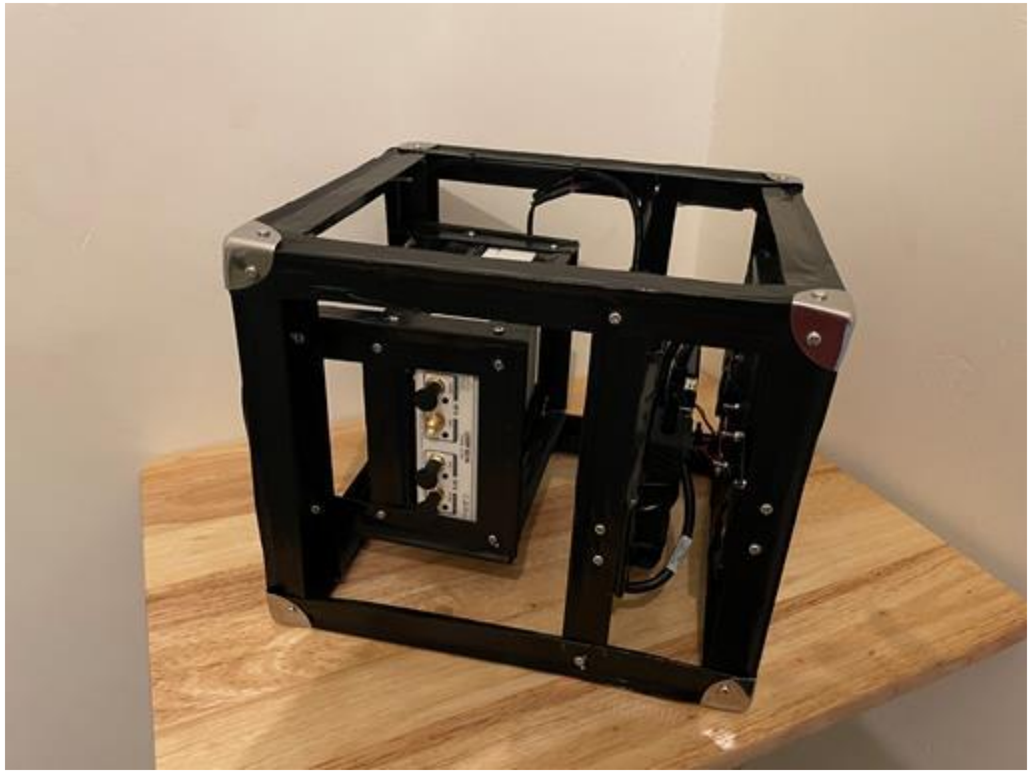
Project Outcomes

Drone Payload



Drone Payload

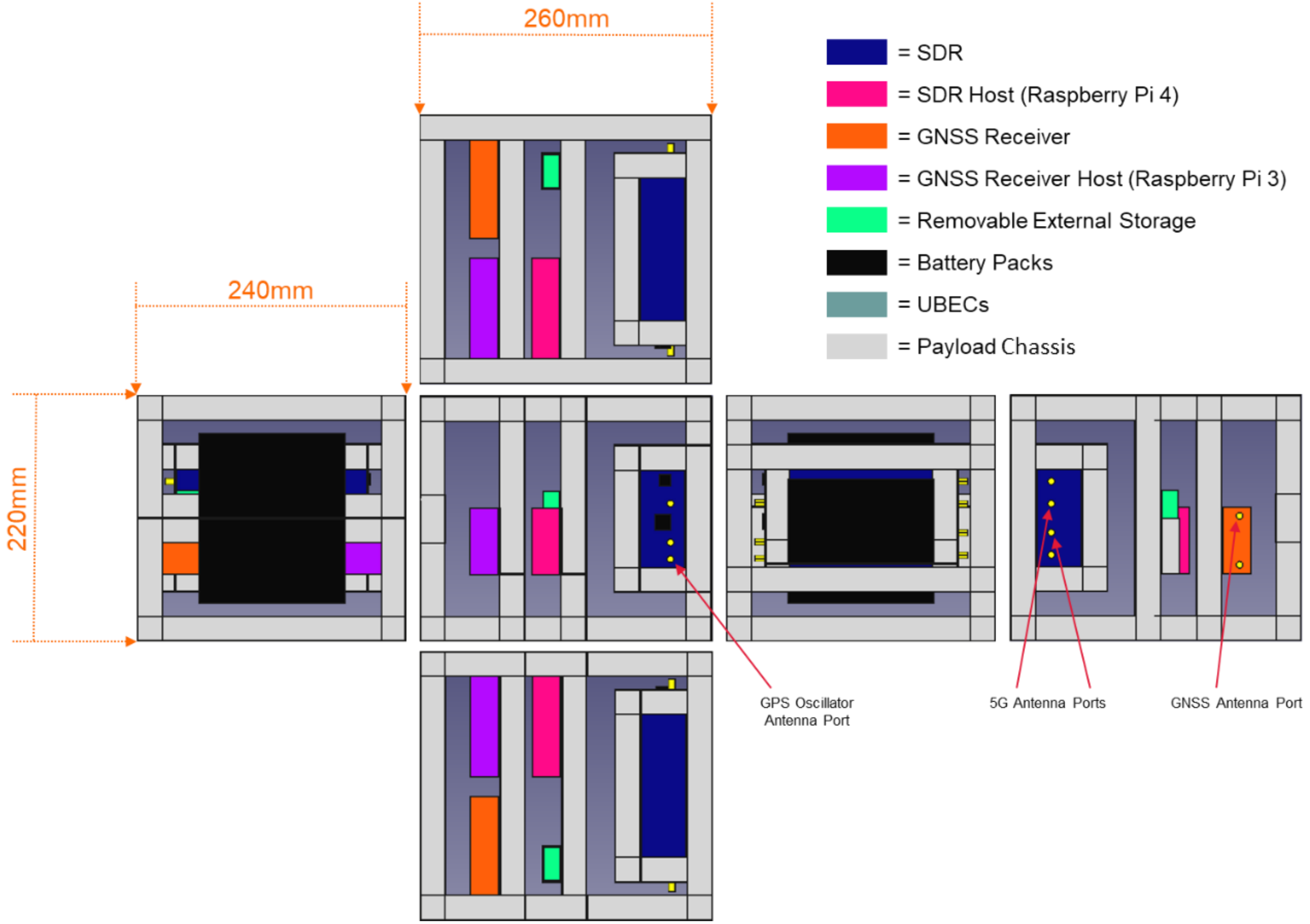




Drone Payload

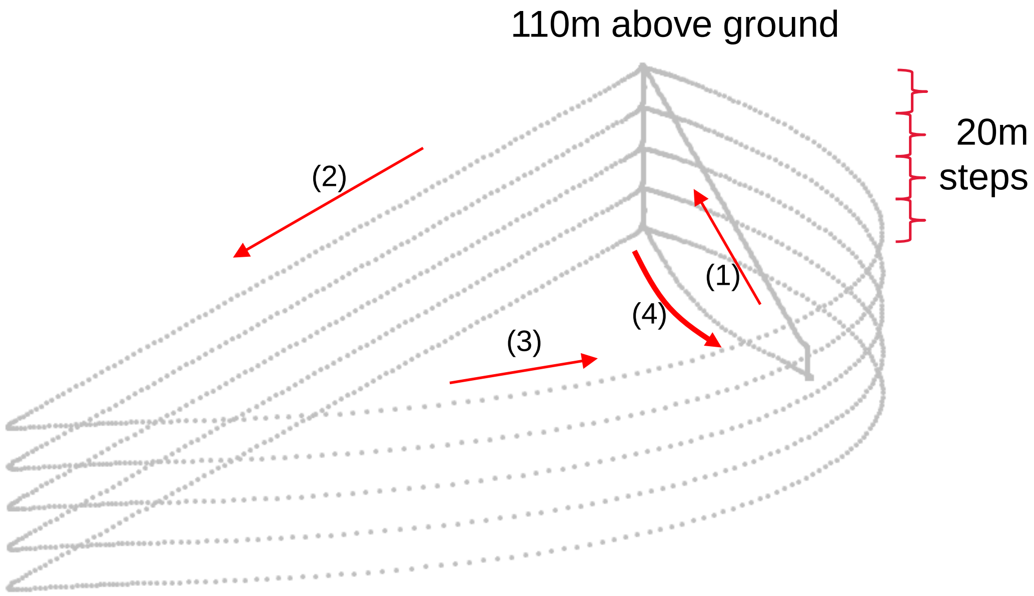
- SDR: Ettus USRP B210
- GNSS receiver: u-blox C099-F9P
- Controllers: 2 x Raspberry Pi
- Storage: 1TB USB 3.2 SSD
- Power: alkaline battery packs
- Form factor: approx. 25x25x25cm

Raw RF data and GNSS observations captured for offline processing.



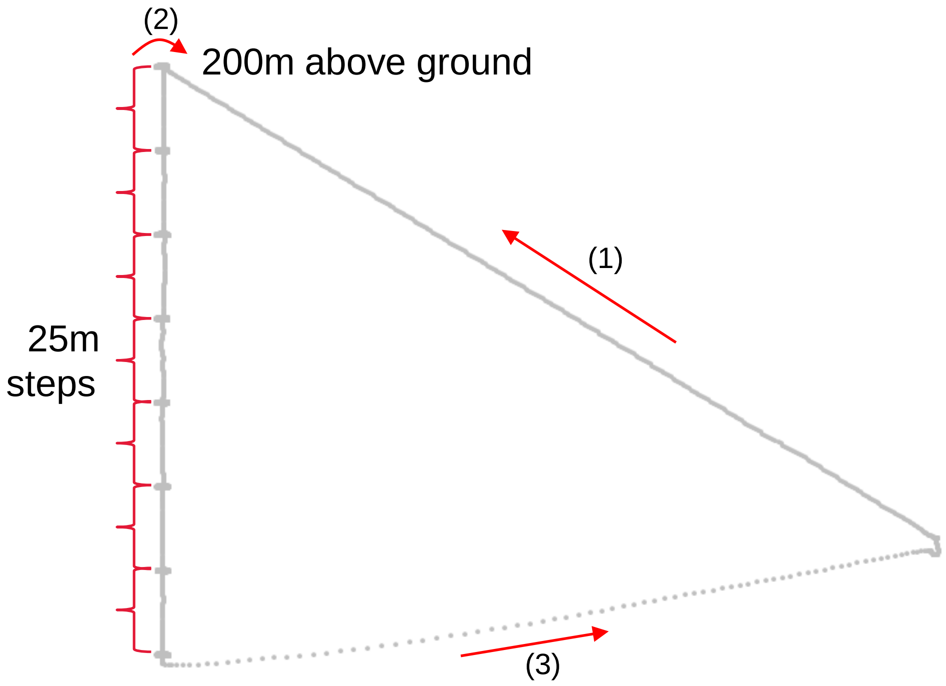
Flight Paths

D-Flights



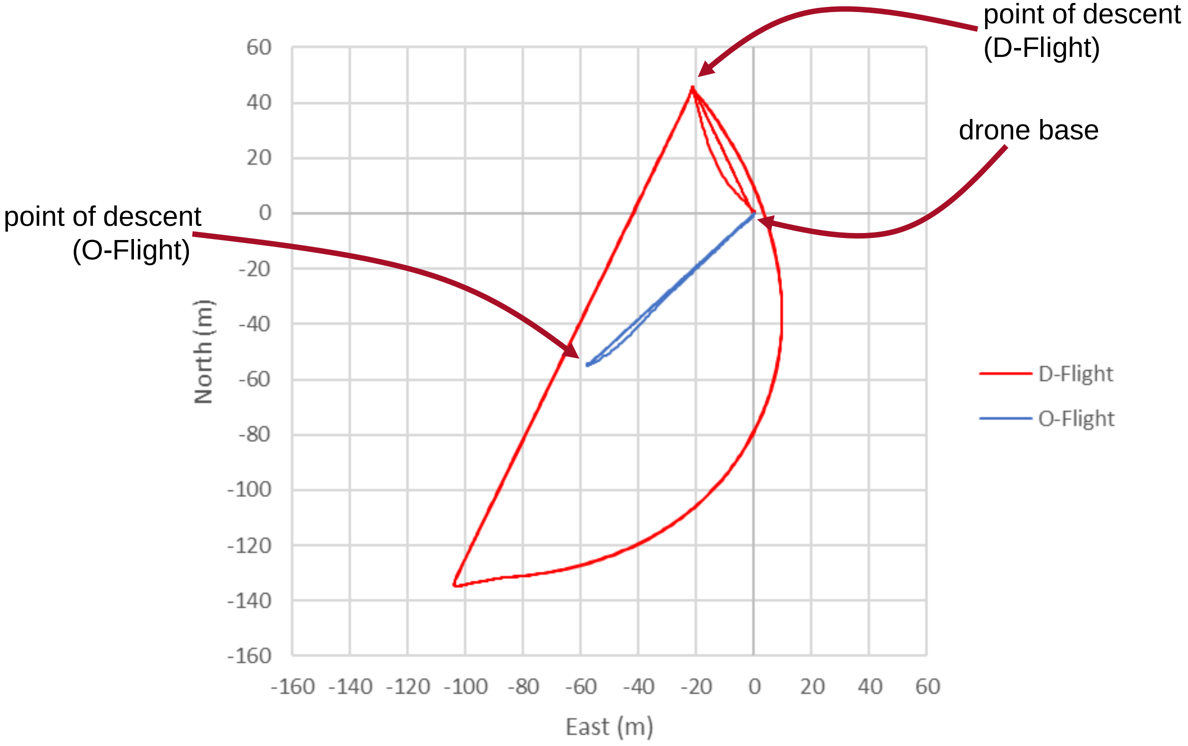
A series of "D" shapes at varying altitudes up to 110m above ground

O-Flights



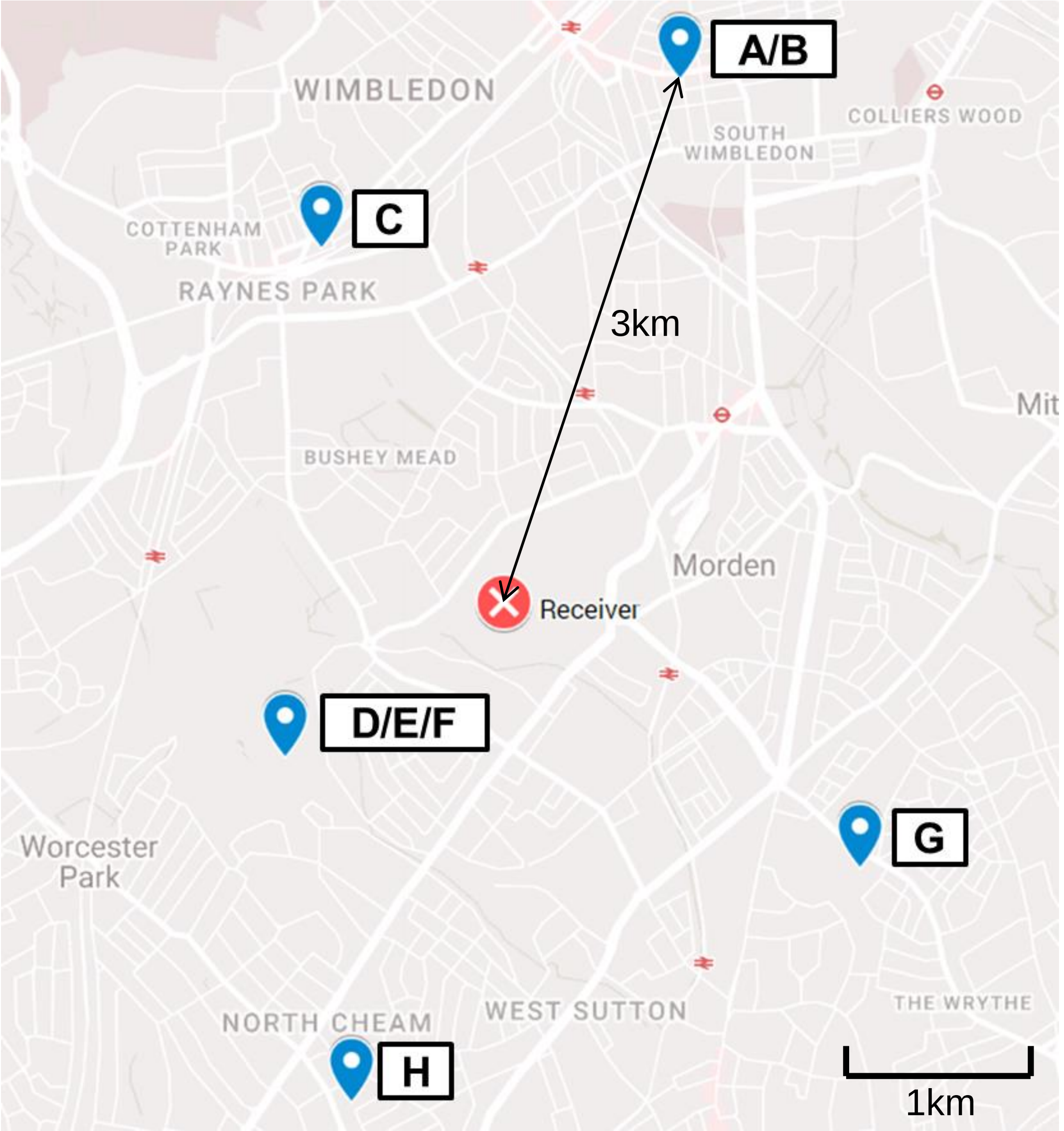
A series of drone rotations at varying altitudes up to 200m above ground

Flight Paths



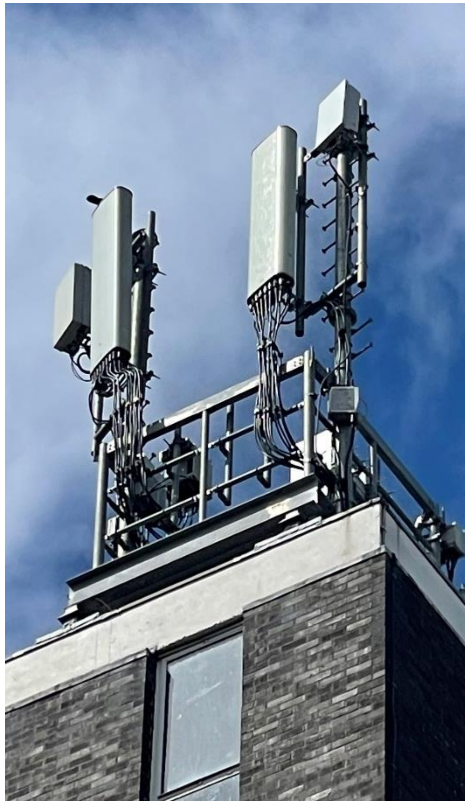
Transmitter Visibility

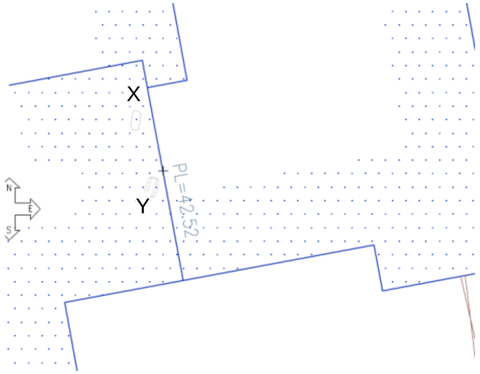
- Four frequencies explored across six flights:
  - ~3.5 GHz
  - ~2.16 GHz
  - ~2.14 GHz
  - ~780 MHz
- **32** unique transmitters observed over all flights
- Approximate locations of the known transmitters that were seen most often are shown on the map
- Good signals from transmitters up to 3km away



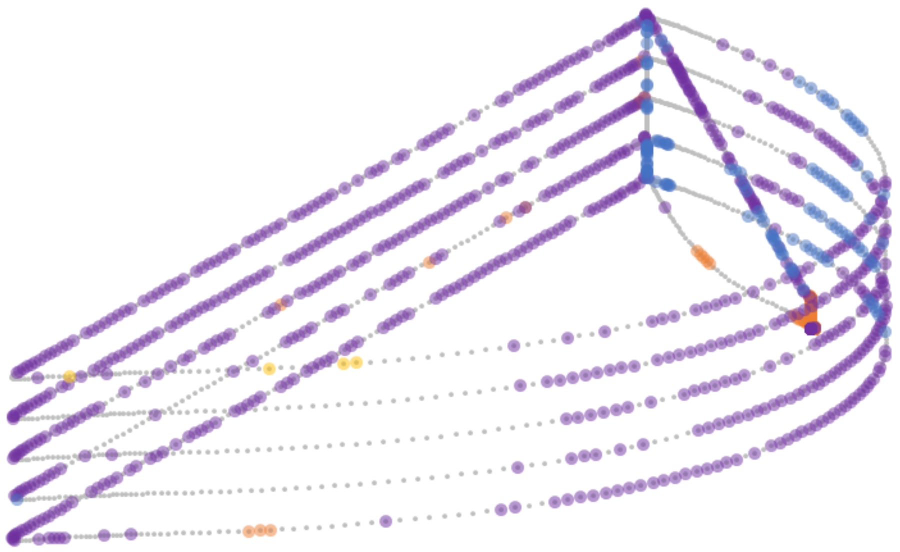
The Almanac Problem

- For positioning purposes, precise transmitter locations must be known
- MNOs have approximate location data only
- CGI commissioned surveys to obtain accurate transmitter locations for cells identified during trial runs
- 5G positioning systems will need to solve the “almanac problem” by collating and maintaining accurate transmitter data covering locations, frequencies and cell IDs

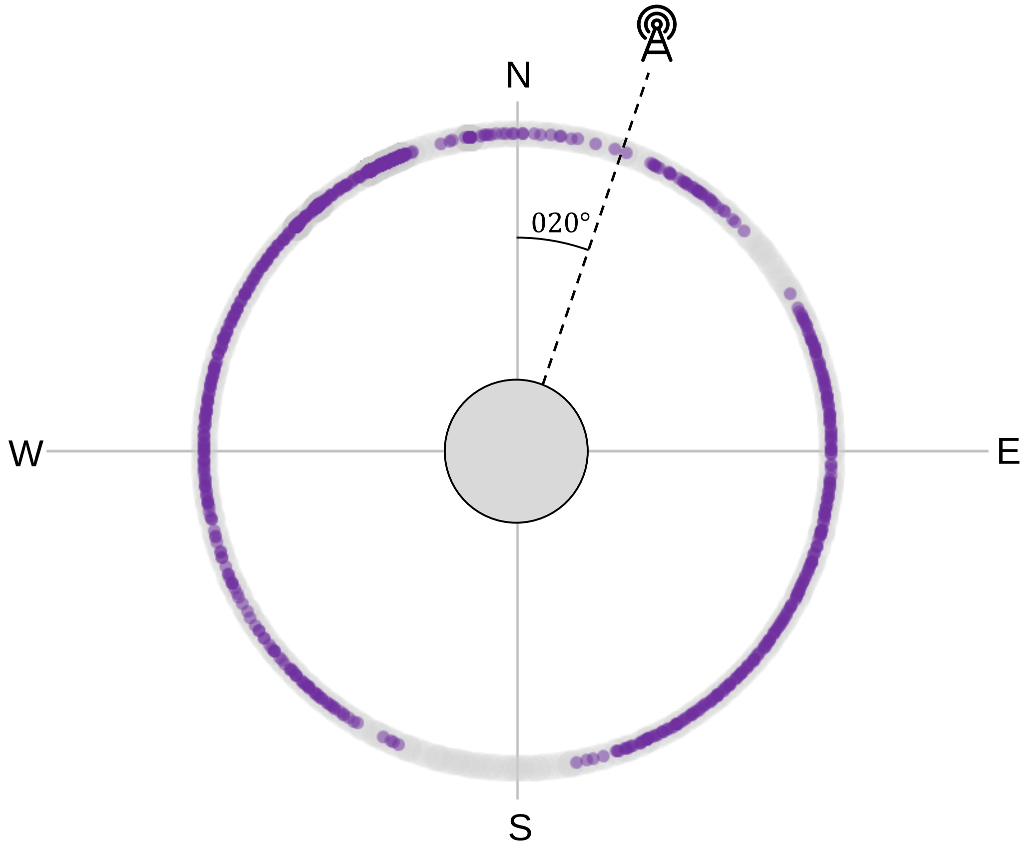




Transmitter Visibility



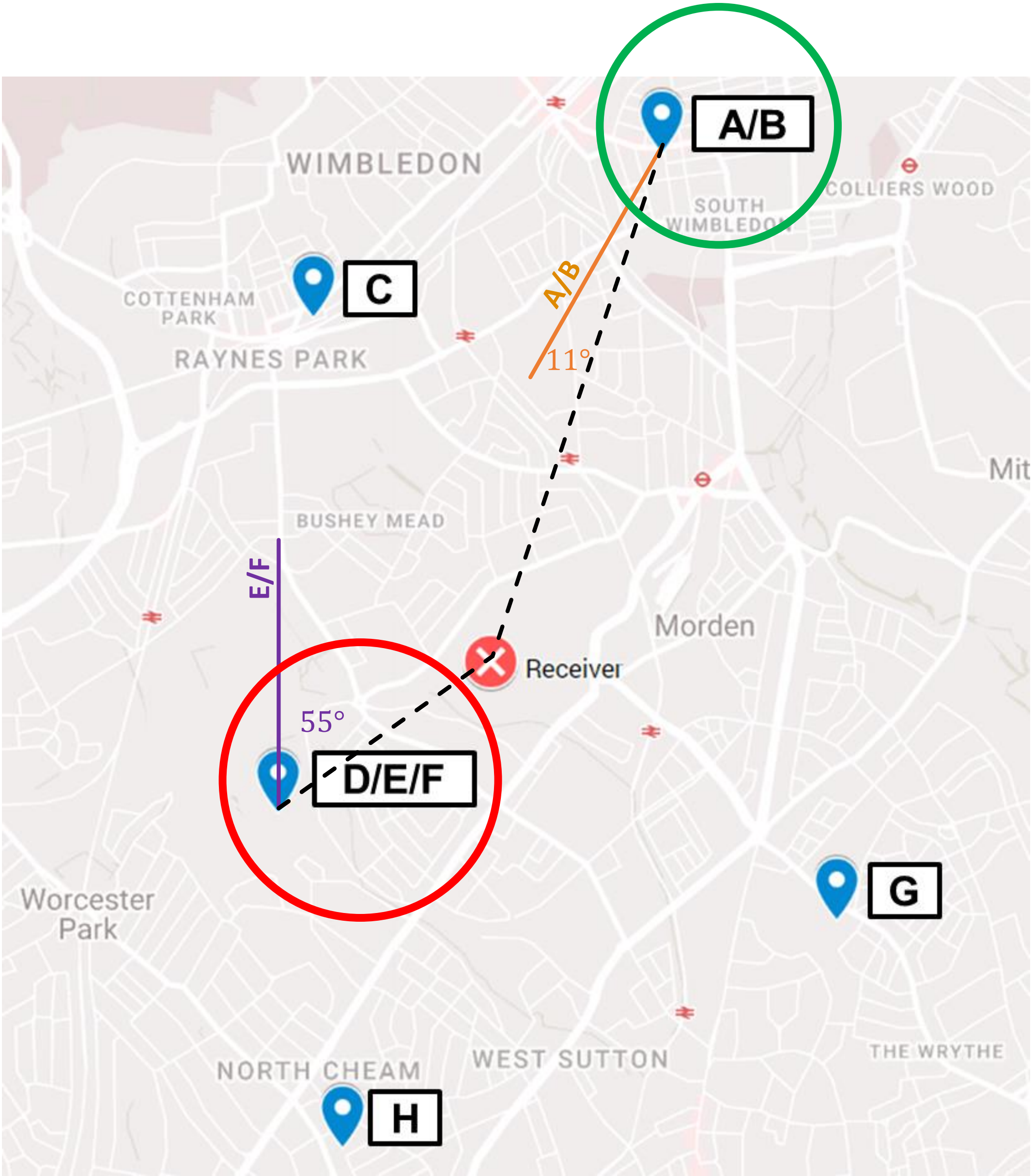
- Plot shows points during flight at which transmitters were visible
- Each colour represents a different transmitter
- One transmitter dominates at all altitudes
- Noticeable coverage gap



- Consolidated data from O-Flight shows gap due to drone body occlusion when the antenna is behind the drone body
- Also suggests reflective interference when the antenna is in front of the drone body

Transmitter Visibility at Altitude

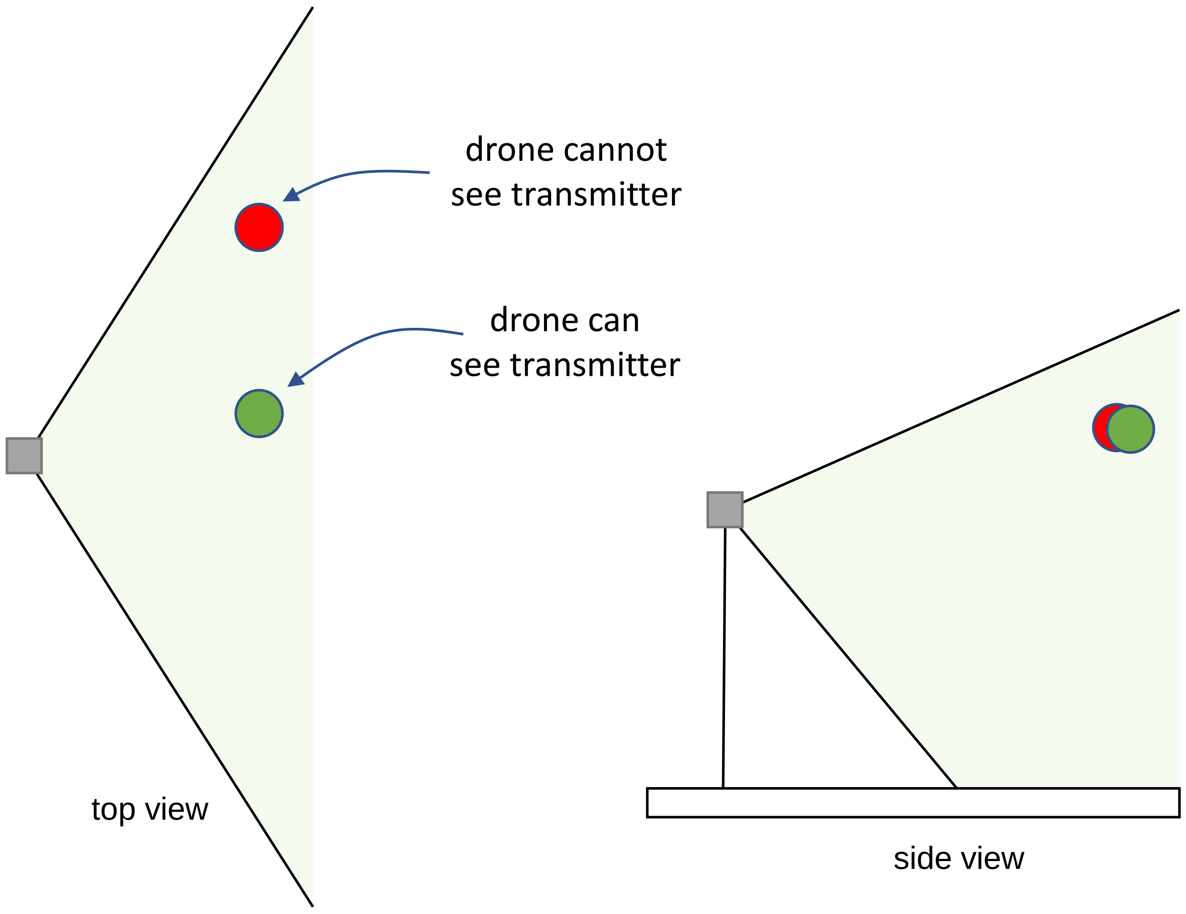
- Mixed results at altitude – for example, excellent visibility of transmitters A/B; poor visibility of E/F.
- E/F closer than A/B
- Transmitter heights and elevation angles to receiver similar (a few degrees)
- Possible answer presents itself when looking at azimuth from boresight



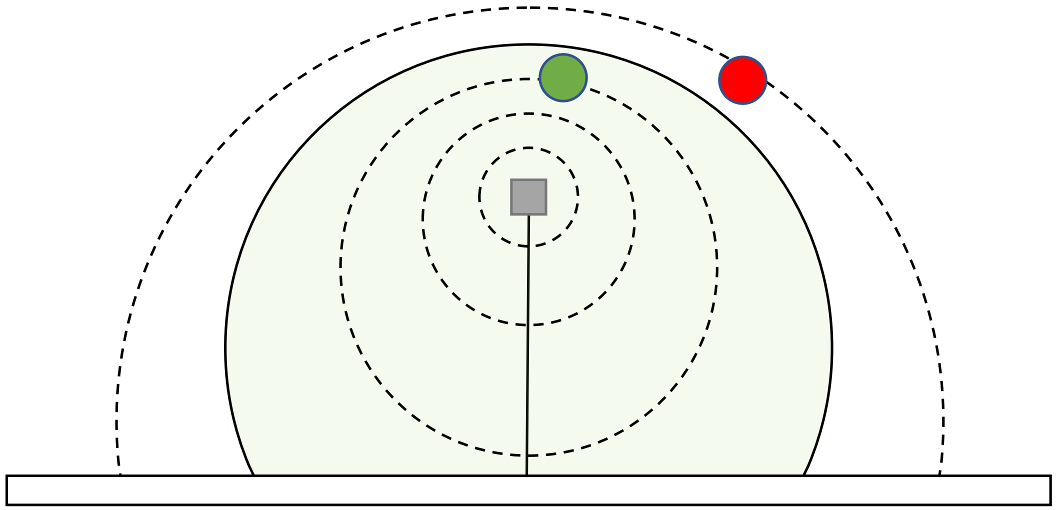
Azimuth Impact on Visibility

- Transmitter network designed for ground coverage

- Likely to be gaps at altitude due to conical spread

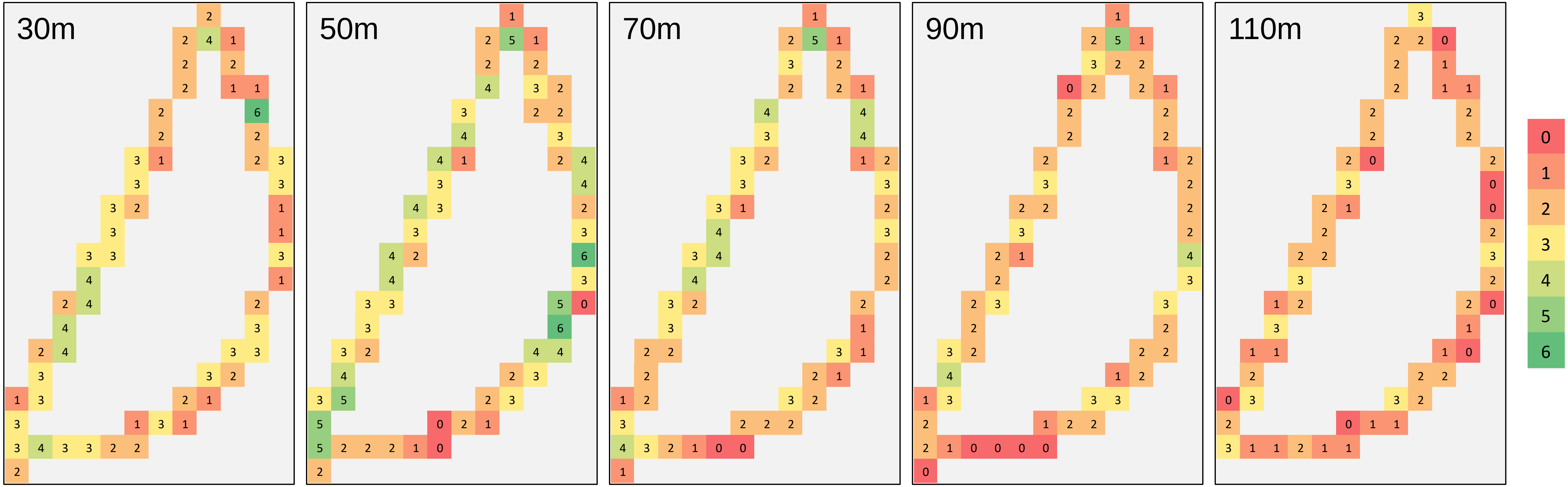


side view



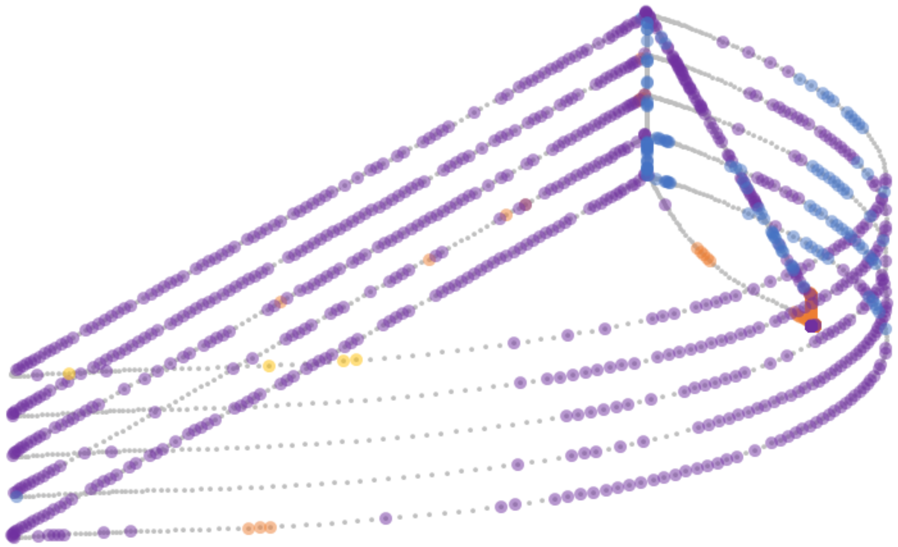
view down the boresight

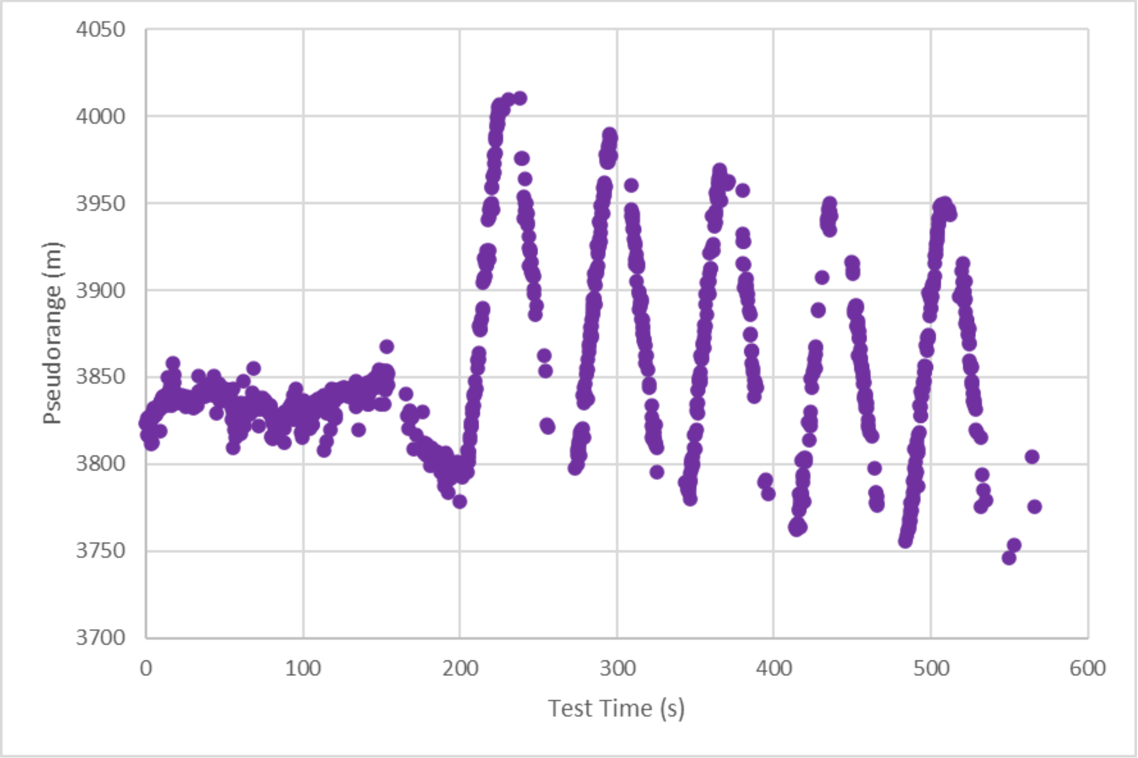
Transmitter Visibility



- Consolidated results across all four frequencies.
- At least some transmitters visible at all altitudes.
- Best results seen here below around 50m.
- Enough transmitters available to supplement GNSS observations, or for standalone positioning.

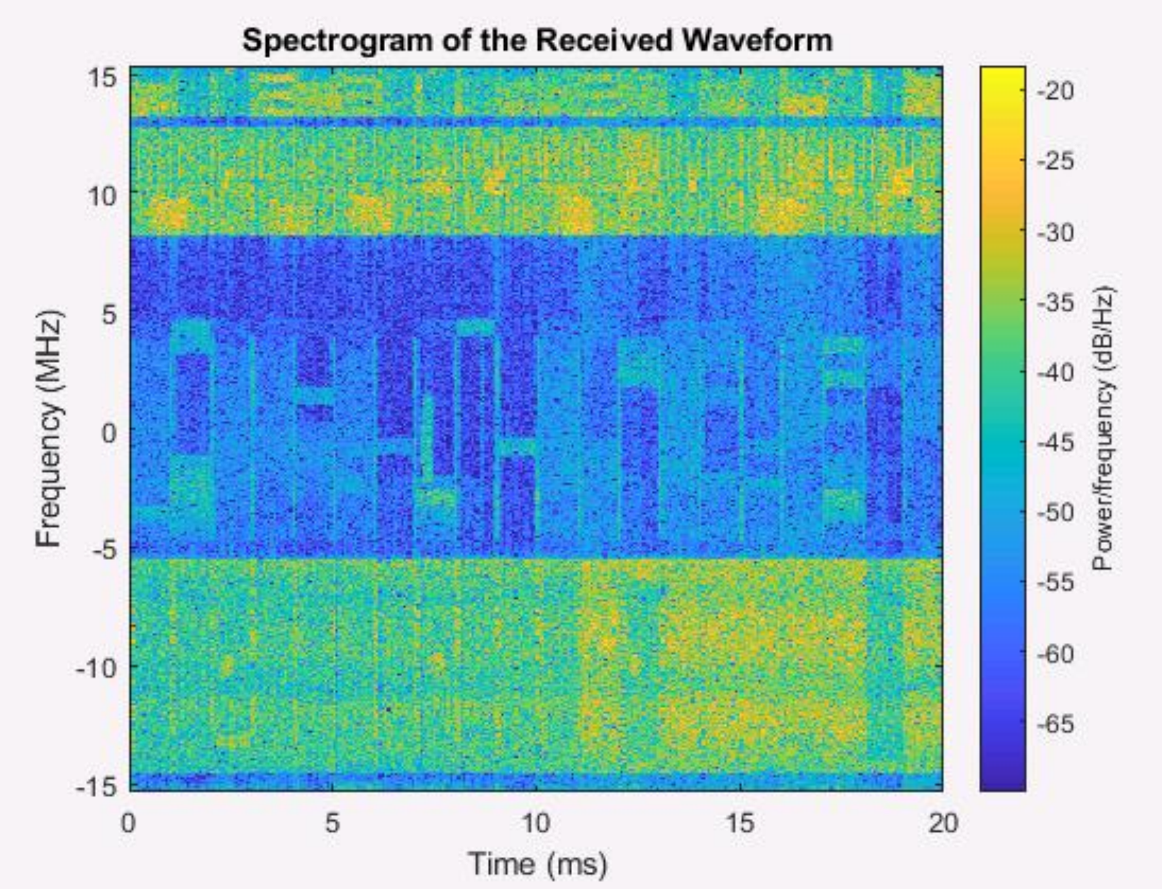
Pseudorange Extraction

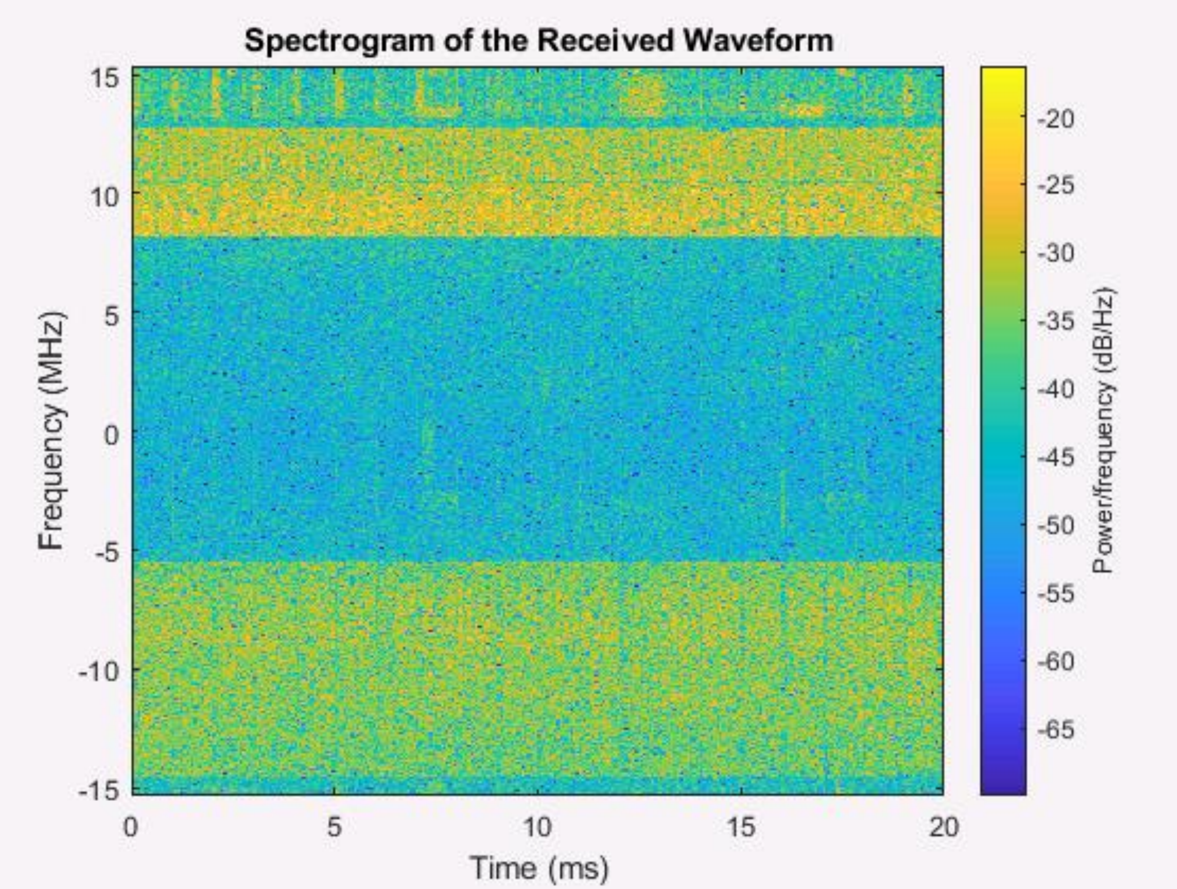




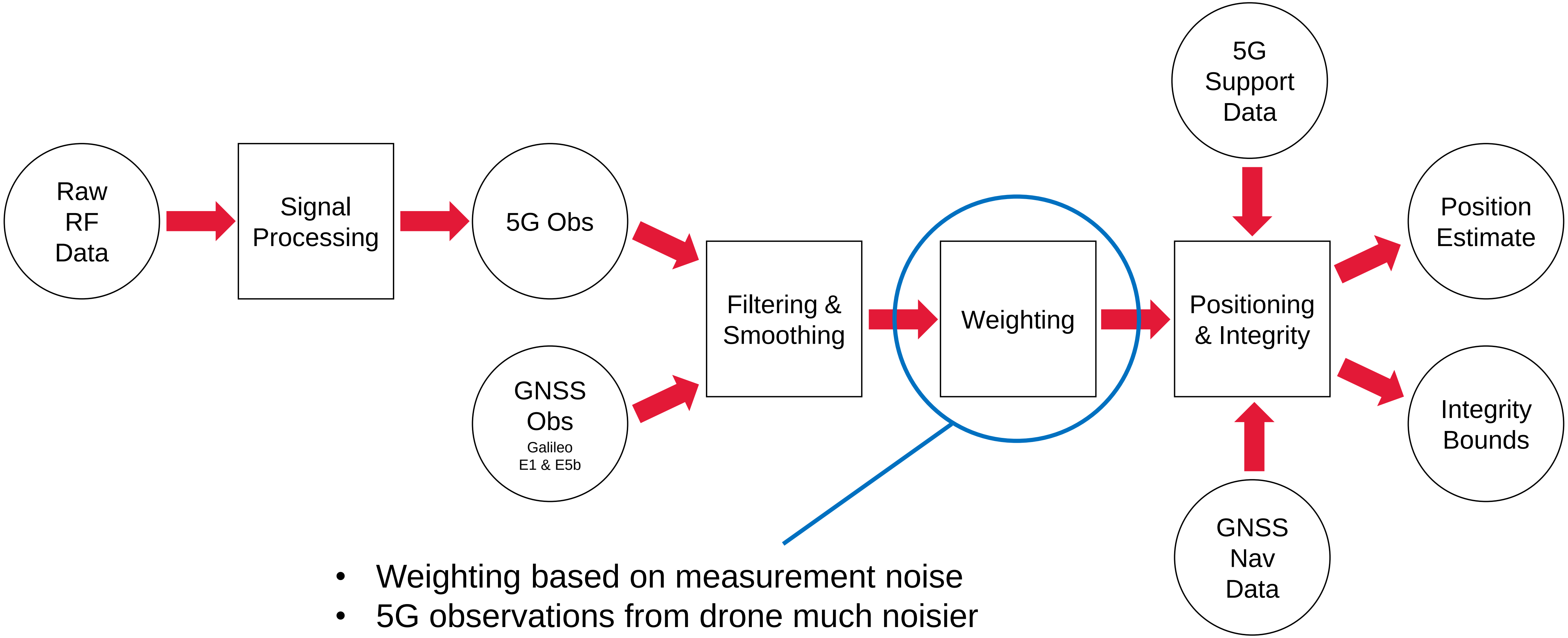
- Raw RF data processed to generated pseudorange observations
- Significant noise levels observed.

Noise – Before and After Drone Start





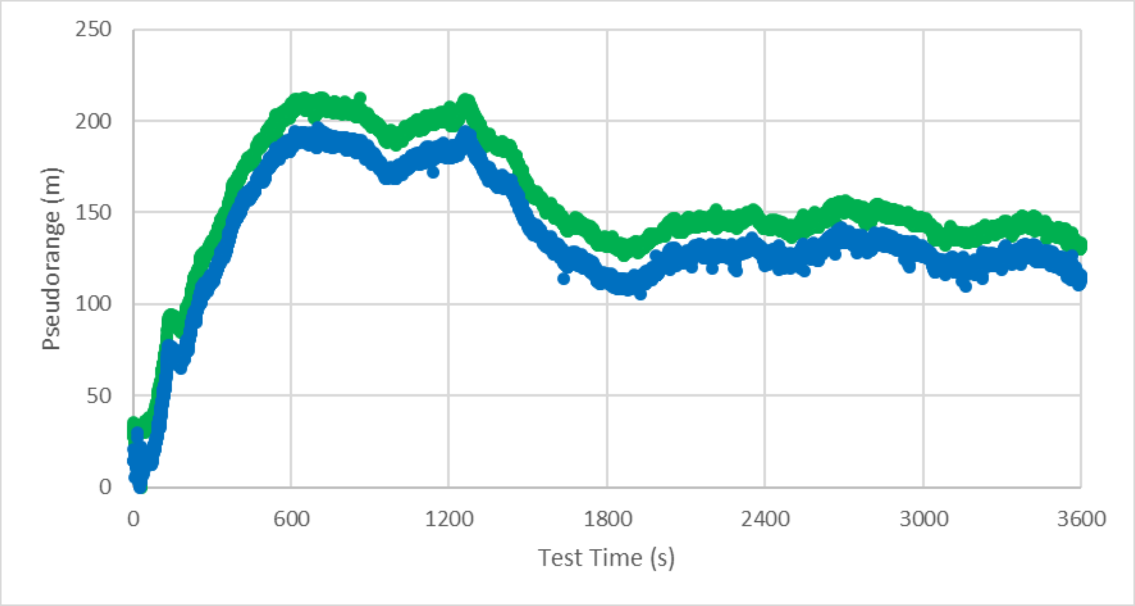
Processing



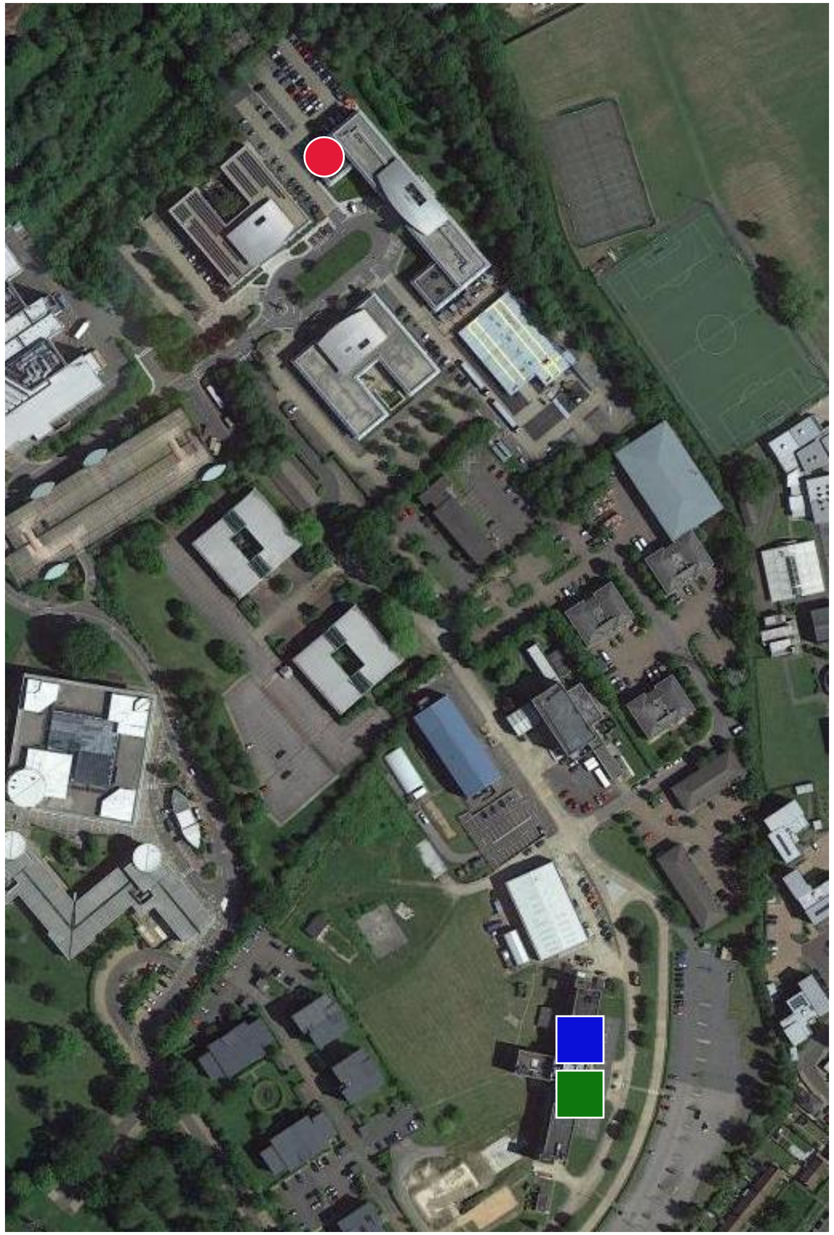
- Weighting based on measurement noise
- 5G observations from drone much noisier than GNSS observations
- 5G observations significantly down-weighted

Ground Capture

- From office location, perform a stationary capture of 5G signals from two local 5G transmitters.

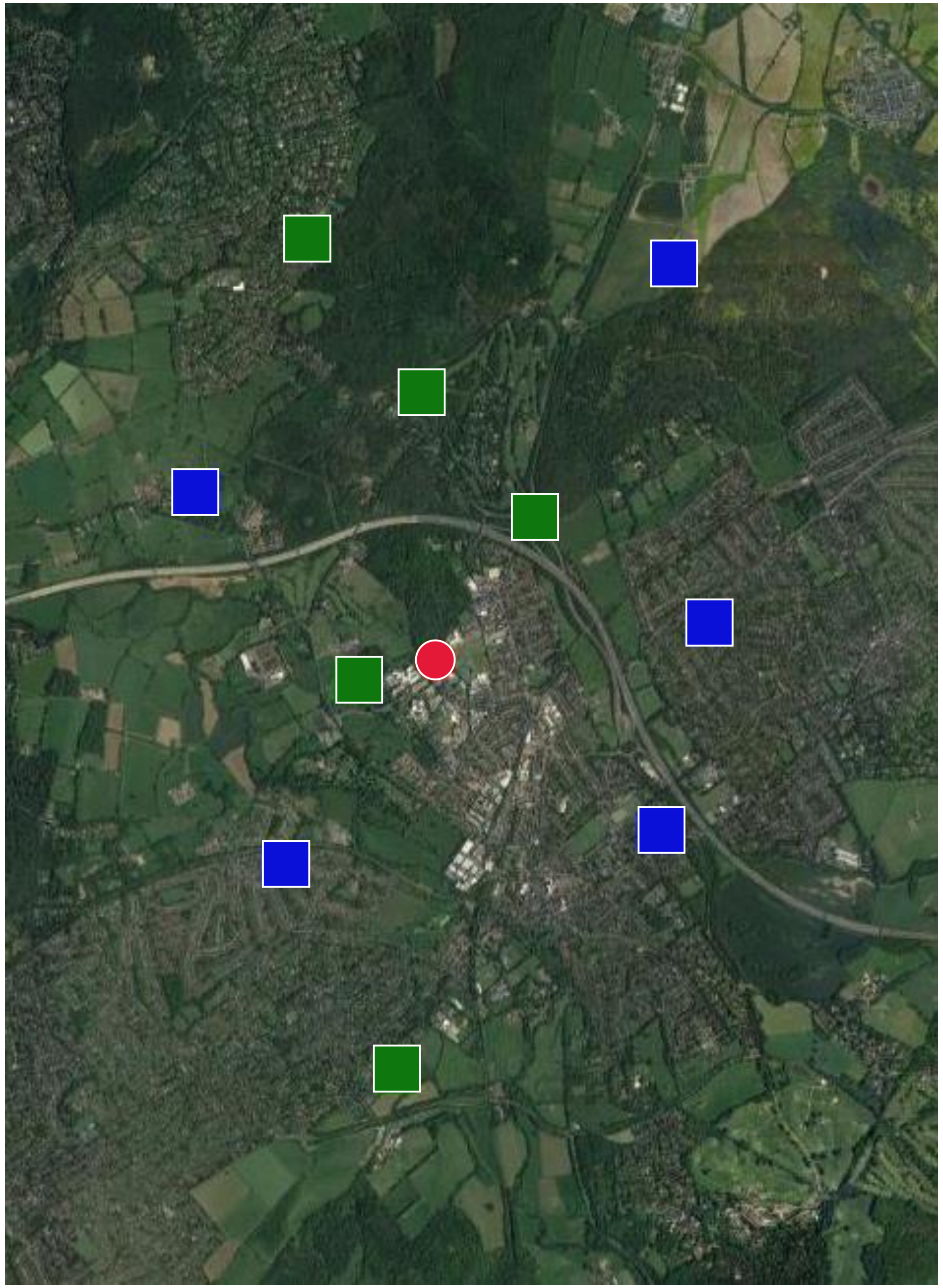


- Noise at ~1.6m standard deviation – comparable to GNSS observations.

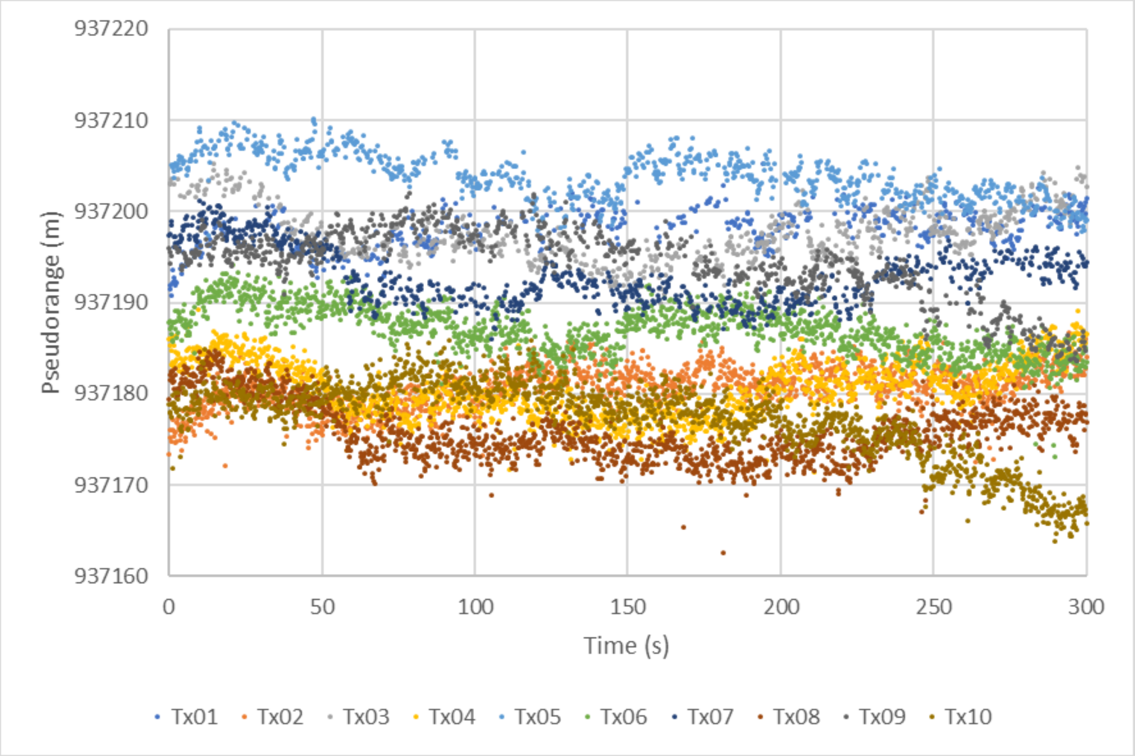


Test Setup

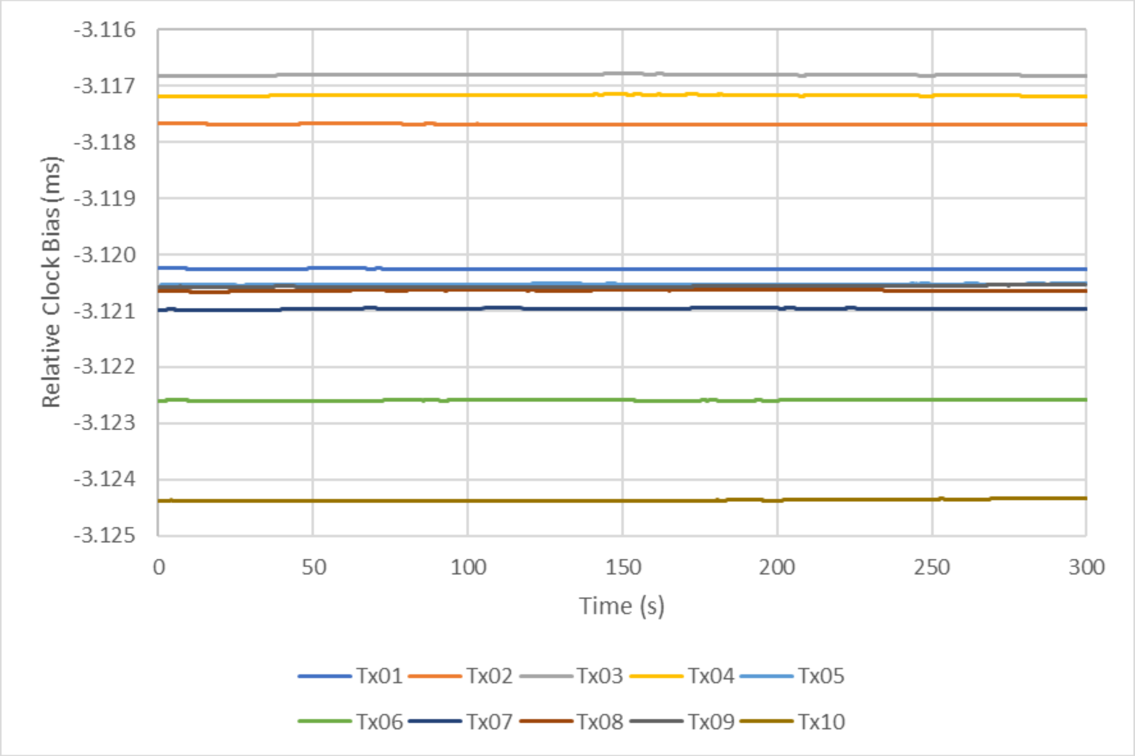
- Define random locations for a network of 5G transmitters, and use extracts from the two real observation sets for each synthetic transmitter.
- Determine clock models for each transmitter.
- Transmitter *location* is artificial, but observation data is *real*.
- Combine with real GNSS observation data for hybrid positioning.



Test Data



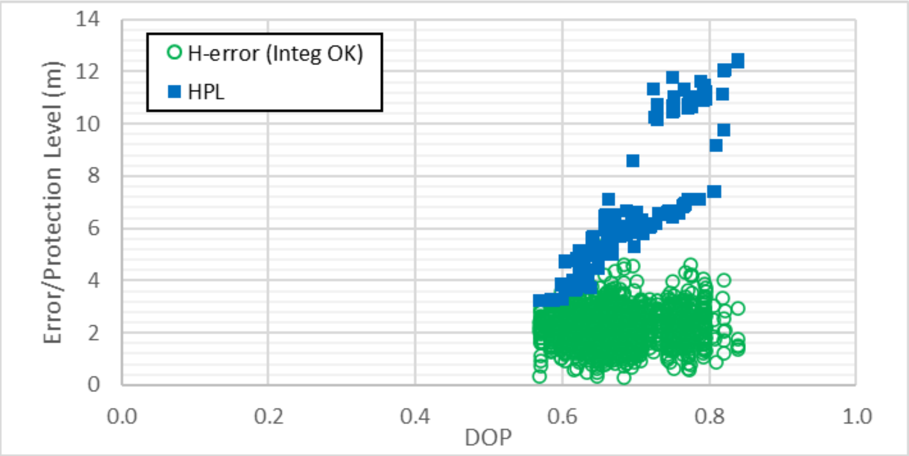
5G Pseudoranges

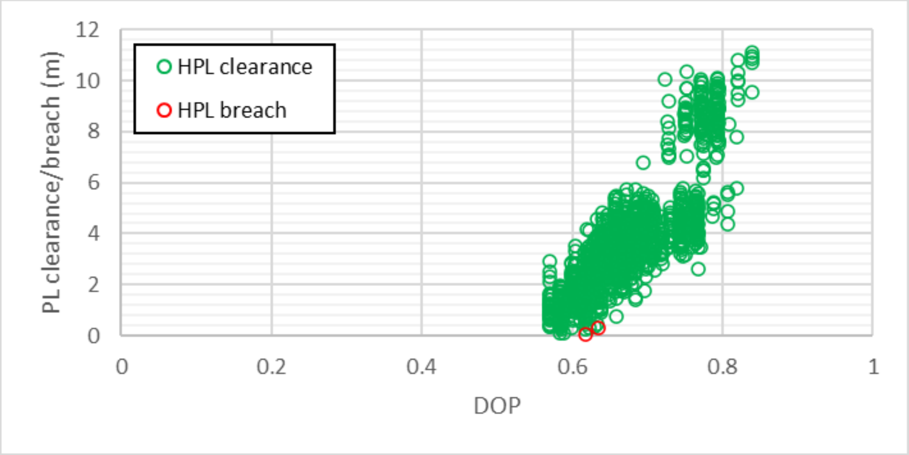


5G Clock Models

- derived using KF
- prediction accuracy over 10s approximately 4ns (1.3m)

Positioning & Integrity





- *real* data – but *artificial* geometry
- HDOP in the range 0.6-0.8
- protection levels at ~3-4m for best DOP cases

Outcomes

- Built and tested a PoC hybrid positioning system, fusing GNSS and 5G observations.
- Explored 5G transmitter geometry, and visibility at various altitudes.
- Extracted 5G observation data from raw RF capture.
- Derived clock models for transmitters wrt. receiver clock, confirming viability of support data concept.
- Demonstrated a system that:
  - is able to work with R15
    - not reliant on positioning extensions in R16 and later
  - is MNO-agnostic
    - can use signals from multiple MNOs and does not require connection to any MNO service
  - relies on passive ranging only
    - benefits for scalability and privacy
  - provides positioning with integrity measures
    - integrity crucial for BVLOS flight

Future Technical Considerations

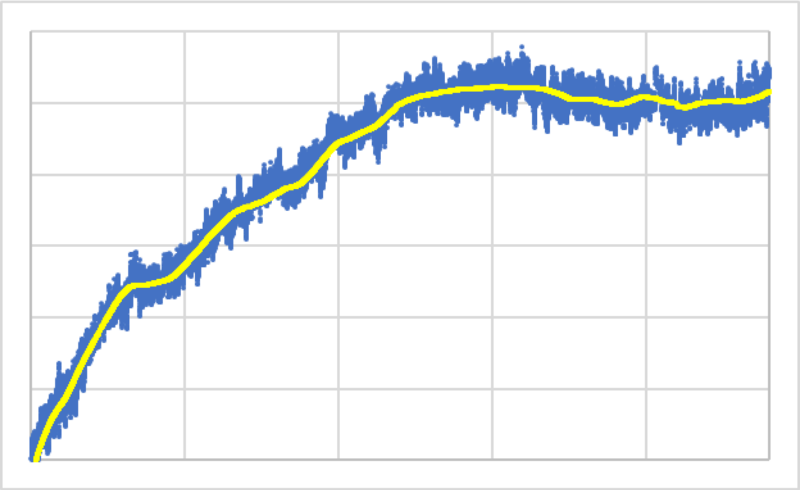
Physical steps to reduce drone interference

- Copper foil to provide shielding for equipment and 5G antenna

- 5G antenna moved below payload

Future Technical Considerations

Capability Extensions



- Generate and use carrier phase measurements – inherently less noisy than pseudorange, and less prone to multipath effects

- Generate and use Doppler measurements:
  - clock modelling (clock drift)
  - receiver velocity

- Incorporate other signal sources:
  - multi-GNSS
  - 4G/LTE

- Incorporate dedicated 5G positioning signals, as they become available

- Explore other use cases:
  - private networks
  - ground vehicles
  - indoor

CGI Growth

Benefits from eventual service/product – External impact

Enablement of BVLoS use cases

To leverage the market potential for advanced air mobility (AAM)

Autonomous Vehicles & Marine applications

To enable next-level autonomous vehicles (e.g., SAE Level 4 autonomous vehicles)

5G adoption within Drone market

Leveraging existing infrastructure in developed areas to enable advanced services

5G Private networks

To enable seamless transition from outdoor to indoor navigation, e.g., patients entering hospitals, drones entering buildings

Benefits to CGI

Hybrid Navigation focus

Forms a key capability in CGI's UAV strategy, which includes secure and assured communications, resiliency against denial-of-service threats, and UTM integration

Knowledge Growth

Adds to our experience in spectrum monitoring, signal of opportunity ranging and hybrid navigation and communications solutions

Stakeholder Engagement

Consortium-based work enabled rich stakeholder engagement, strengthening project deliverables

ESA/UKSA Contribution

Funding enabled CGI to develop the proof of concept

Technical feedback provided during the project offered valuable insights

CGI thank ESA and the UKSA for their Support via the NAVISP Element 2 programme

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