Cost Effective Fit-for-Purpose Positioning for the 21st Century

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Chair FIG Working Group 5.4 on GNSS

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OUTLINE OF PRESENTATION

- Part 1 – Overview of FIG Commission 5
- Part 2 – GNSS Positioning Fundamentals
- Part 3 – Cost Effective Positioning – Hardware
- Part 4 – Cost Effective Positioning – Services
- Part 5 – Mobile Phone Positioning
- Part 6 – Looking into the Future – LEO PNT

PART 1 – FIG Commission 5 Overview

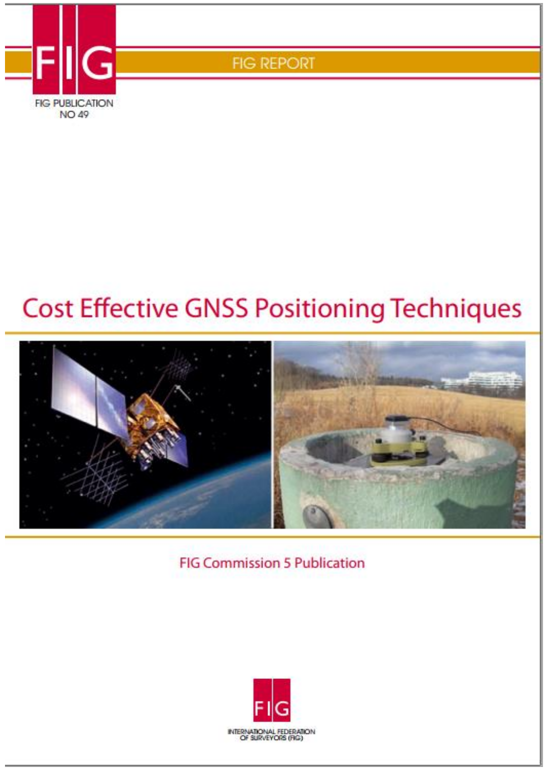


FIG Commission 5
Positioning and Measurement

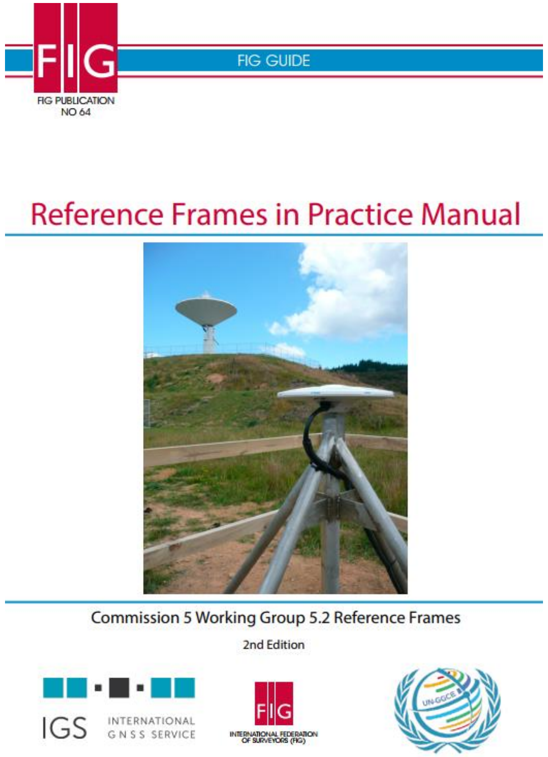


FIG Commission 5
Positioning and Measurement

2023-2026

Chair: ***Ryan Keenan***, Australia

Vice-Chair of Administration: ***Kevin Ahlgren***, USA

Working Group	Chair	Co-Chair
WG 5.1: Standards, Quality Assurance and Calibration	David Martin, France	
WG 5.2: 3D Reference Frames	Nic Donnelly, New Zealand	Chris Pearson, New Zealand
WG 5.3: Vertical Reference Frames	David Avalos, Mexico	
WG 5.4: GNSS	Eldar Rubinov, Australia	Safoora Zaminpardaz, Australia
WG 5.5: Multi-Sensor Systems (Joint w/ IAG / Com. 6)	Amir Khodabandeh, Australia	
WG 5.6: Cost Effective Positioning	Li Zhang, Germany	David Mulindwa, Uganda
WG 5.7: Emerging Technologies for PNT	Allison Kealy, Australia	Jelena Gabela, Austria

FIG Commission 5
Positioning and Measurement

FIG Commission 5 - Positioning and Measurement Contributions to UN SDGs (Sustainable Development Goals) Activity Report: 2023-2024

SDGs Task Force led by Paula Dijkstra (Comm5 representative Allison Kealy)

- Objective of the Task Force is to ensure that ‘in 2026 the understanding of the 2030 Agenda and the relevance of the SDGs for our profession are embedded within FIG’.
- Pilot Project initiated to link FIG abstracts (for the last 5 years) to SDG themes - Commission 5 as Pilot
  - Pilot idea is to go over all the papers that were submitted to Comm5 during FIG 2023 Conference and see which SDGs are relevant.
- <u>Aim:</u> To develop a formal approach to connecting all Commissions’ work to the SDGs (directly or indirectly), with

Commission 5 Sessions 2024
Pre-event: RFIP Workshop 18/19 May 2024

ICG International Committee on Global Navigation Satellite Systems

Trimble®

FIG
FIG Commission 5
Positioning and Measurement

TS07F - Land Administration Success with GNSS CORS – Insights for Senior Decision Makers

Tuesday,
21 May
14:30–16:00
Kundum, La Palm

TS07F: Accelerating Land Administration Success with GNSS CORS Networks: Insights for Senior Decision Makers

Commission: 5, 7, ARN, IAG, IGS, UN-GGIM-Africa, UN-GGCE
Chair: Dr. **Ryan Keenan**, Chair, FIG Commission 5, Australia
Rapporteur: Dr. **Kevin Ahlgren**, United States

GNSS Reference Stations (aka CORS) are now commonplace in in nearly every nation on Earth – either as standalone stations or part of a networked solution, and contribute to both scientific and civil applications. They can support multiple purposes, ranging from real-time surveying and positioning on land, from the air, and on water.

The ambitious vision for extending land administration across Africa is highly dependent on nations establishing their own national reference frame as well as regional reference frames the establishment and sustained management of GNSS CORS infrastructure.

This session, is the first of two sessions, and will introduce the subject: GNSS CORS Reference Stations in the context of geodetic infrastructure to support and sustain land administration. The second session will be more focussed on technical presentations followed by a panel discussing sustainable CORS infrastructure and practices.

Presentations:

- Setting the Scene:

Panel discussion:

- Ms. **Izuegbu Ogochukwu UJU**, Office of the Surveyor-General, (Nigeria)
- Ms. **Rachael UMAZI**, Land Administration & FIG Commission 7 (Kenya)
- Mr. **Aslam PARKER**, TRIGNET (South Africa)
- Mr. **Nicholas BROWN**, Head, UN-GGCE (Germany)

Further Reading:

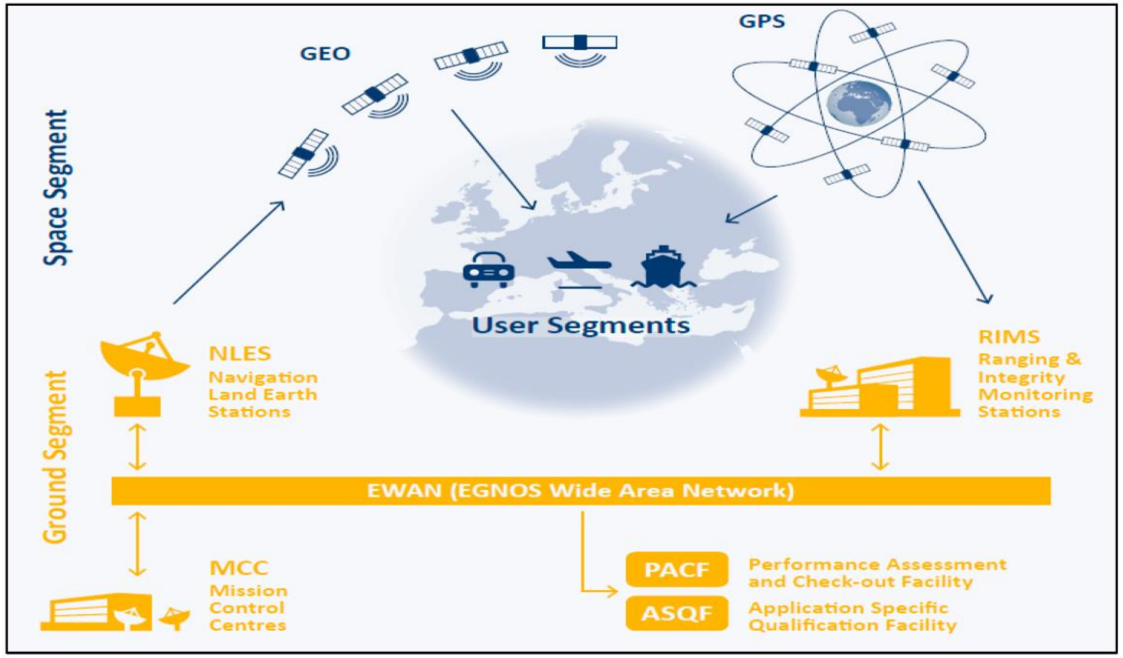
Izuegbu Ogochukwu UJU (Nigeria):
GNSS CORS and Land Administration
[handouts]

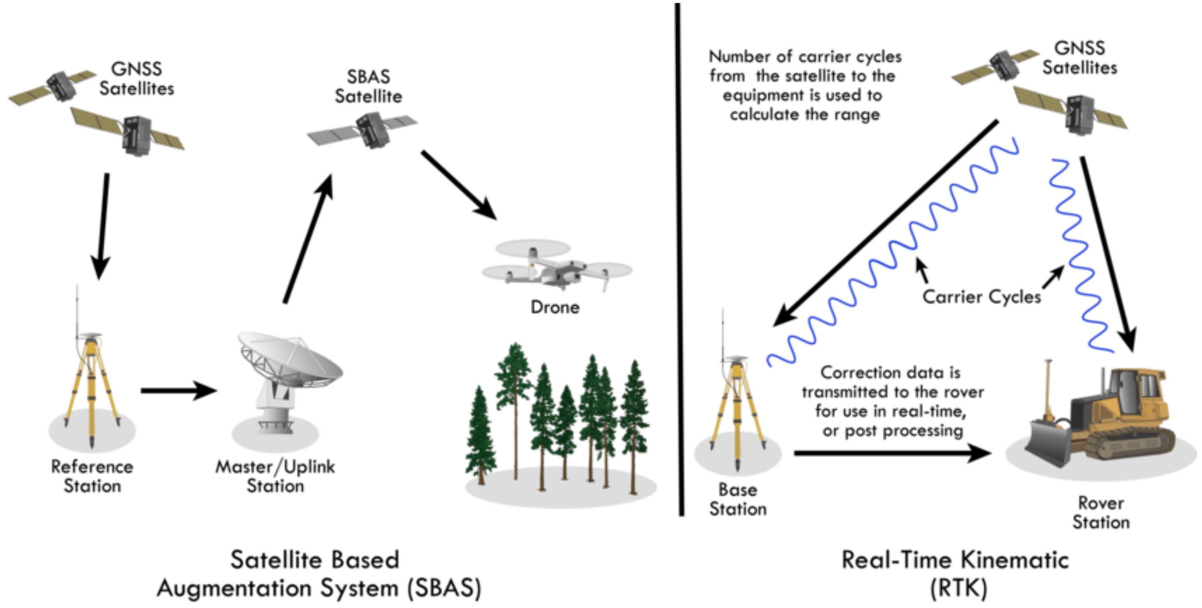
Rachael UMAZI(Kenya): GNSS CORS for Land Administration and Reform
[handouts]

Diogoye Diouf (Senegal):
ITRF and Geodetic Reference Frames in Africa (12365)
ITRF et Référentiels géodésiques en Afrique
[abstract] [paper] [handouts] [video]

Markus Bradke (Germany), **Ryan Ruddick** (Australia), **Allison B. Craddock** (USA) and **Ryan Keenan** (Australia):
Exploring the IGS Network: Engaging with the Global GNSS Community (12715)
[abstract] [paper] [handouts] [video]

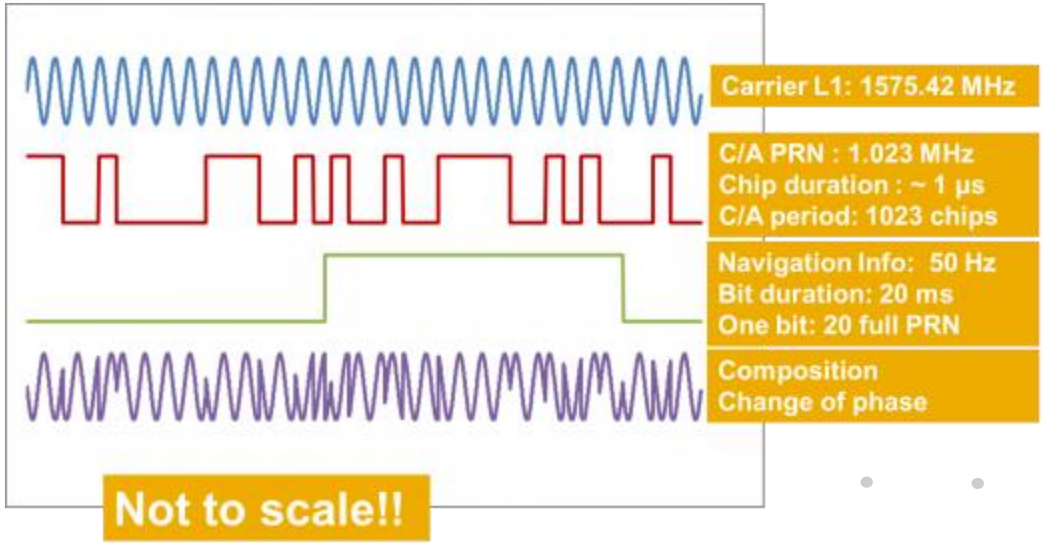
PART 2 – GNSS Positioning Fundamentals





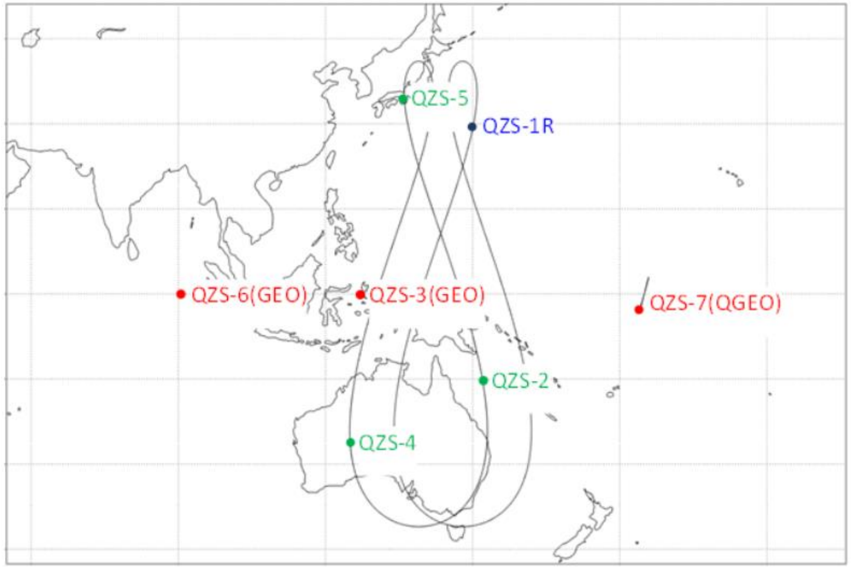
Satellite Positioning – Current State

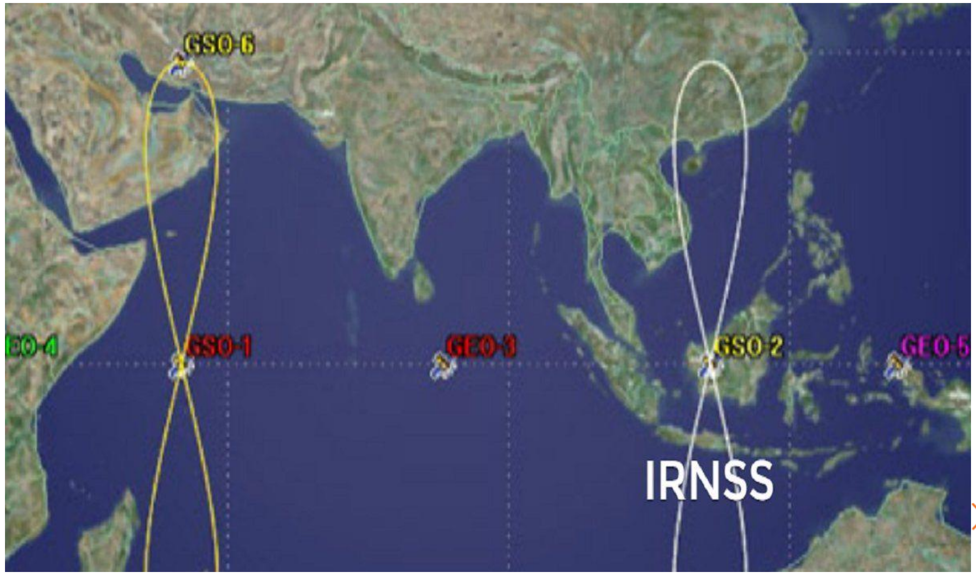
- GNSS – GPS (USA), GLONASS (Russia), Galileo (EU), Beidou (China)
- Each constellation has around 30 satellites in the Medium Earth Orbit (MEO), ~20,000km
- Each constellation provides code and carrier phase signals in L-Band



Satellite Positioning – Current State

- Additionally, there are two Regional Navigational Satellite Systems (RNSS)
- QZSS (Japan) and NAVIC (India) providing regional services in their selected regions
- Mix of geostationary (GEO) and inclined geosynchronous (GSO) orbits





Standalone GNSS Positioning

- **Standalone GNSS** will commonly experience **3-5m** of positional error
- Uses code signals
- No corrections applied
- Requires at least 4 common satellites in view to solve for 3D position and time
- 5m accuracy can locate an individual car, but not necessarily the lane in which it's driving

Standalone GNSS 3-5m

GNSS Augmentation (SBAS)

- We can use **GNSS Augmentation** to improve GNSS accuracy to sub-meter levels using Satellite Based Augmentation System (SBAS)
- Satellite broadcast transmits corrections to orbits and clocks
- **<1m accuracy** allows us to differentiate the bonnet, windscreen, or roof of the car

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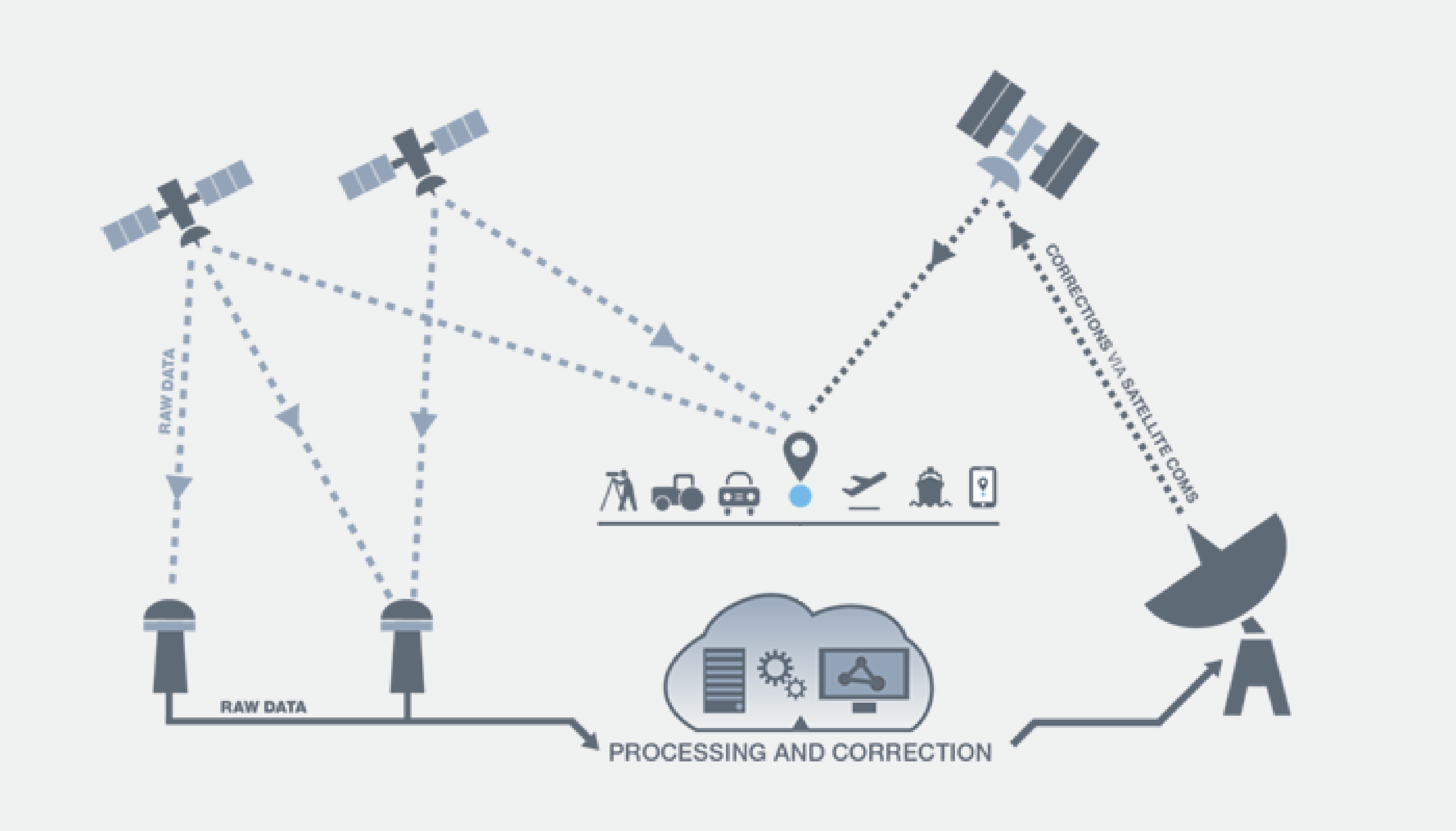
HOW DOES SBAS WORK



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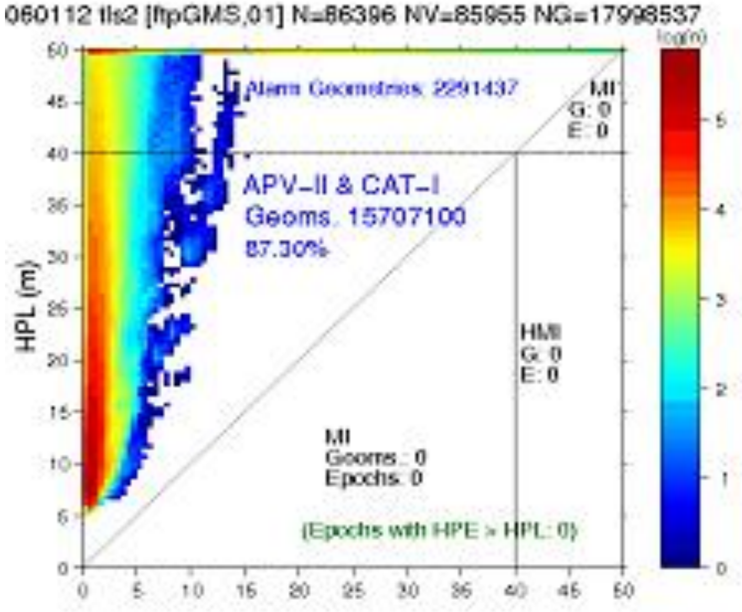
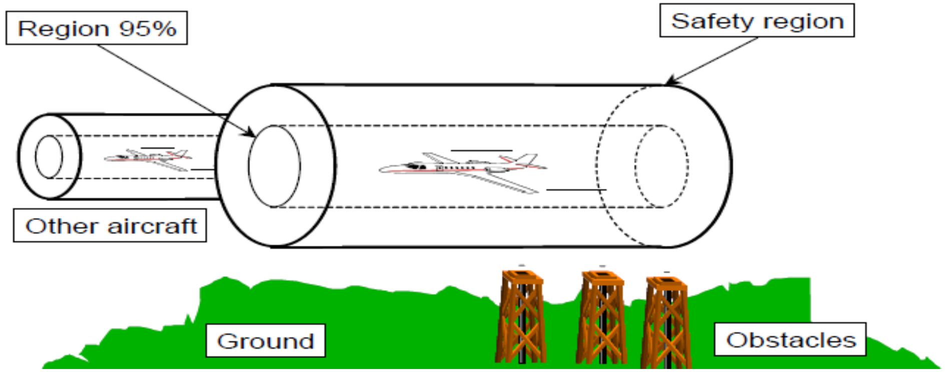
WHAT IS SBAS

- Originally designed for aviation to improve vertical guidance for safer landings
- Has been used in many other non-aviation fields
- Includes integrity component





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GNSS Augmentation - SBAS

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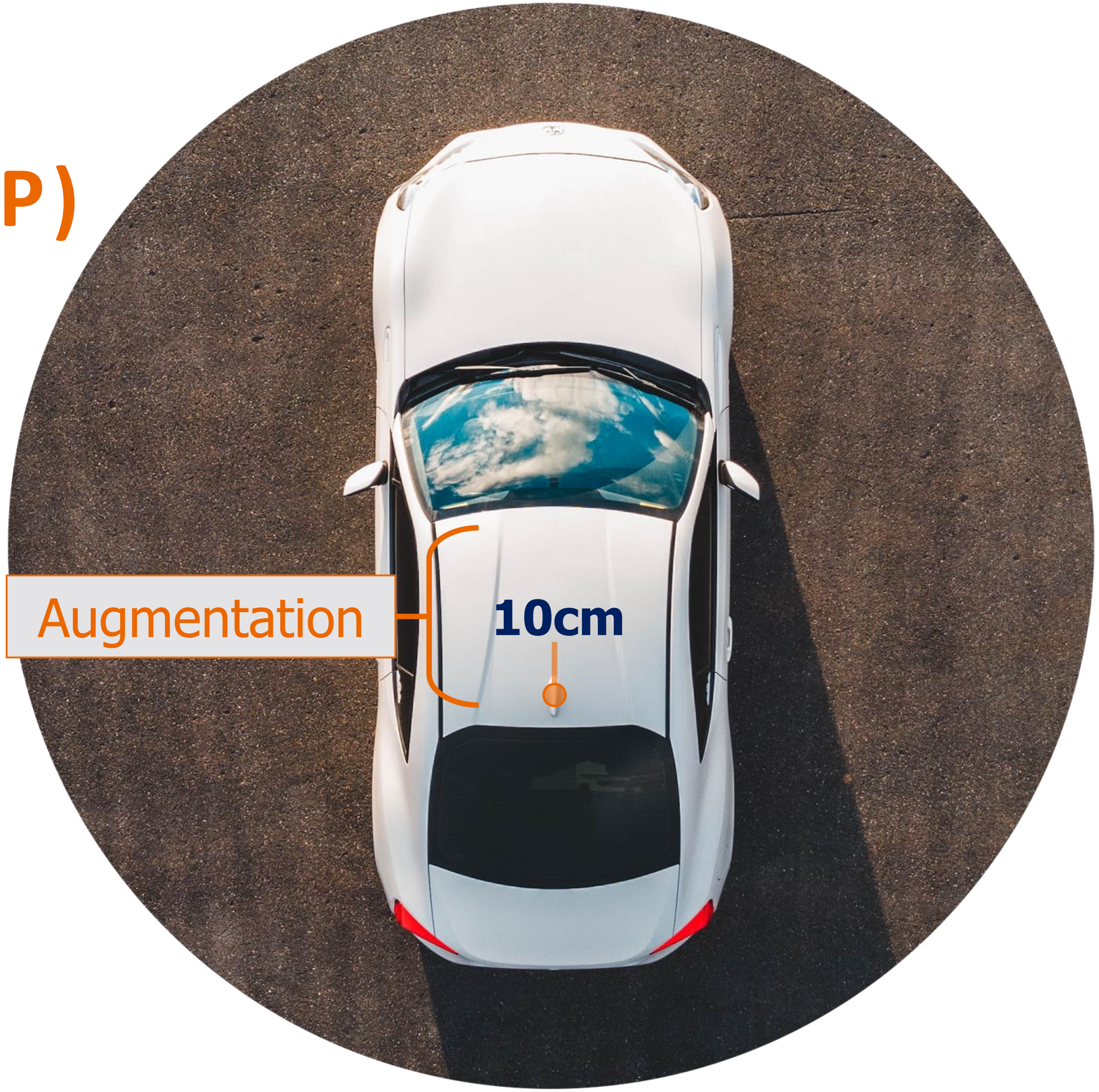
GNSS Augmentation (PPP)

- Precise Point Positioning (PPP) can achieve even higher accuracy, at the **decimetre level**
- Has a convergence period from several minutes to tens of minutes
- **10cm accuracy** can locate objects as small as a deck of cards



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WHAT IS PPP

- PPP stands for Precise Point Positioning
- Single receiver positioning technique
- Also applies corrections to satellite orbits and clocks, but unlike SBAS uses carrier phase observations
- Since carrier observations are ambiguous, requires a convergence period of tens of minutes to achieve decimetre-level accuracy
- Regional ionospheric models can be used to achieve fast convergence
- Typically global solution, but can also be regional
- Orbit and clock errors are computed from a global network of reference stations

GNSS Augmentation (RTK)

- Highest accuracy positioning can be achieved using Real-Time Kinematic (RTK) method 3-5cm
- Works by applying a correction from a nearby reference station or a network of stations
- Uses carrier phase signals
- **5cm accuracy** can locate a single AA battery
- **3cm accuracy** can locate a single grape

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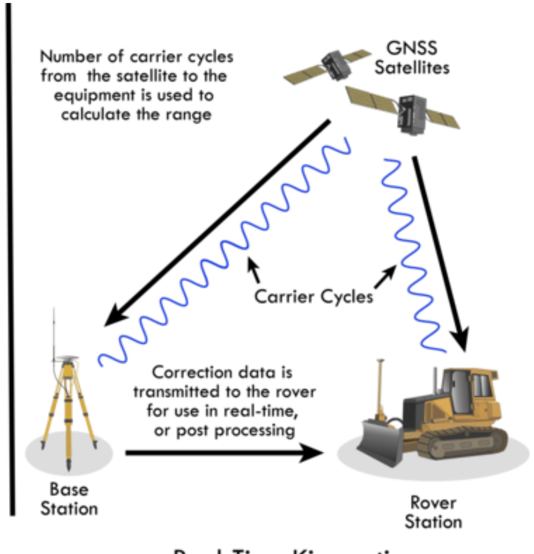
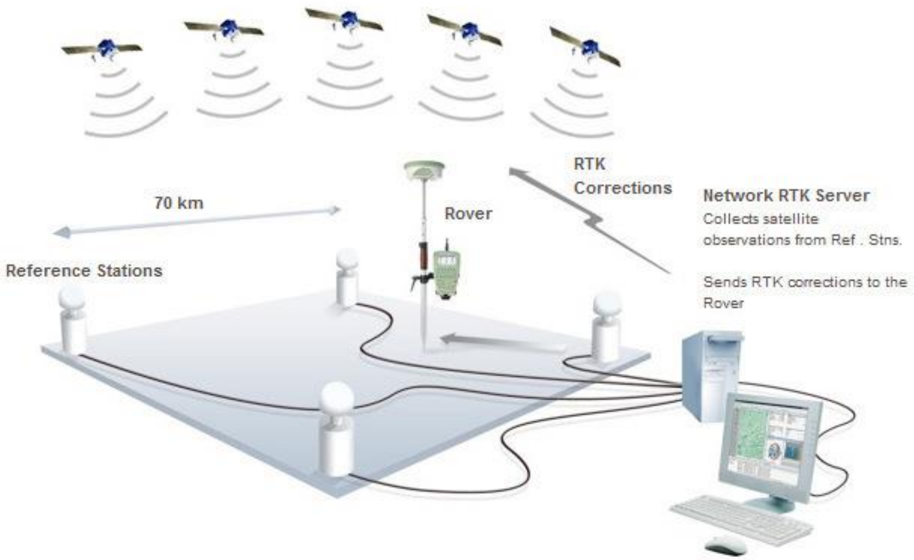
WHAT IS RTK

- RTK stands for Real-Time Kinematic
- Most accurate real-time GNSS positioning mode, capable of achieving centimetre-level accuracy (millimetre-level is possible in post-processed mode)
- Requires two or more receivers
- Works by applying corrections from a local reference station or a network of stations to the rover receiver



Real-Time Kinematic (RTK)



PART 3 – Cost Effective Positioning - Hardware

High Precision Positioning is Expensive!

- High precision RTK positioning is typically aimed at professional users in sectors such as surveying, construction, agriculture, etc.
- It normally requires expensive equipment and a commercial subscriptions
- Fit-for-purpose for professional users requiring high-accuracy, availability, maintenance, technical support, etc.
- Not fit-for-purpose for many users in different industry sectors due to price, scale, technical skill level, etc.

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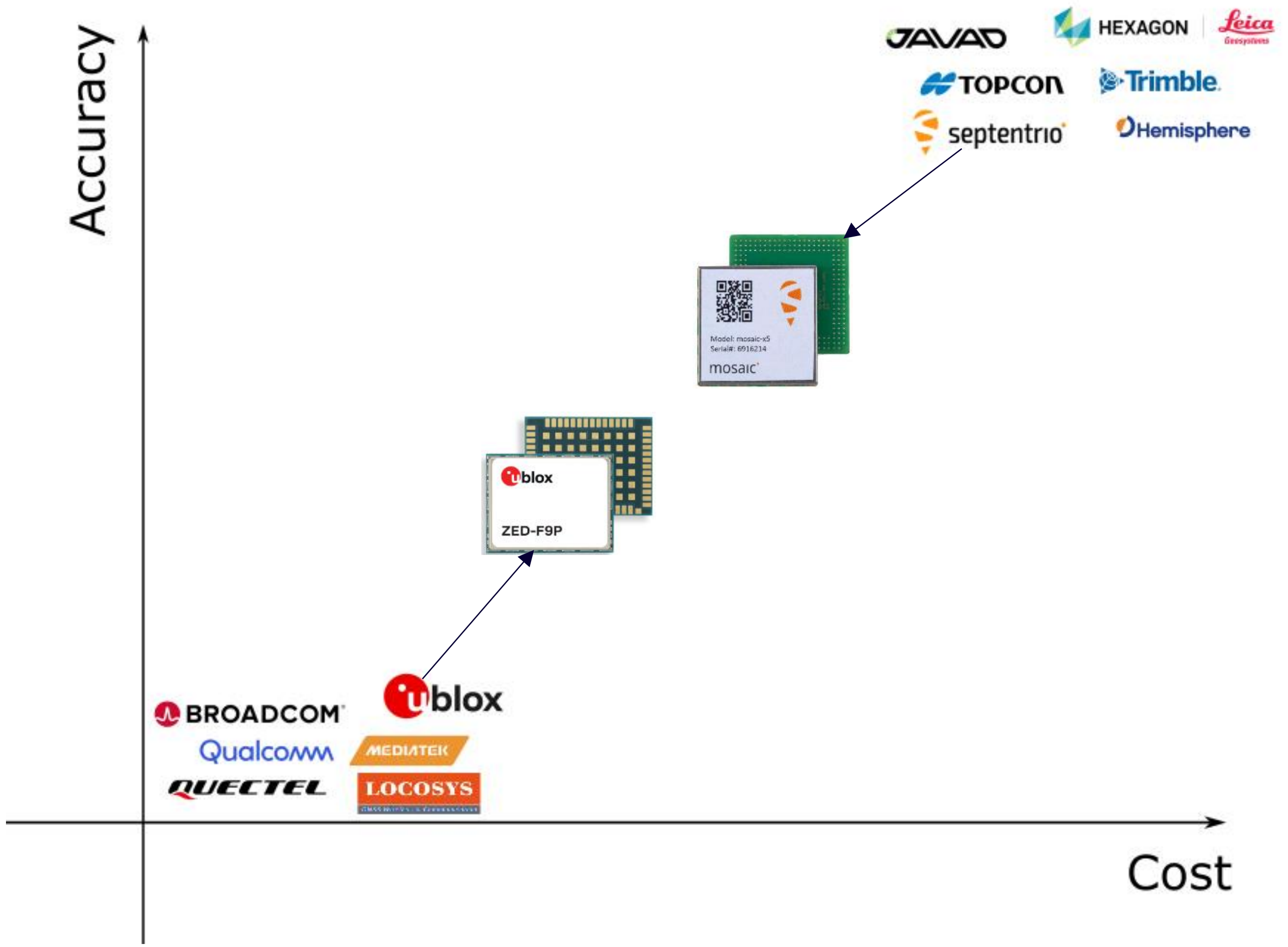
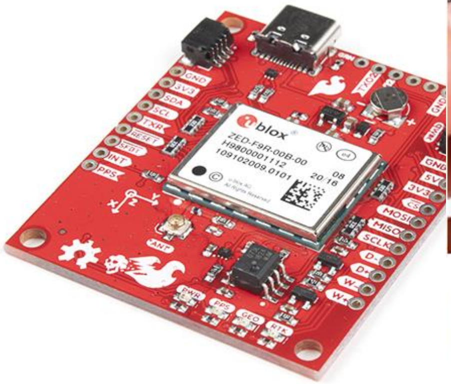
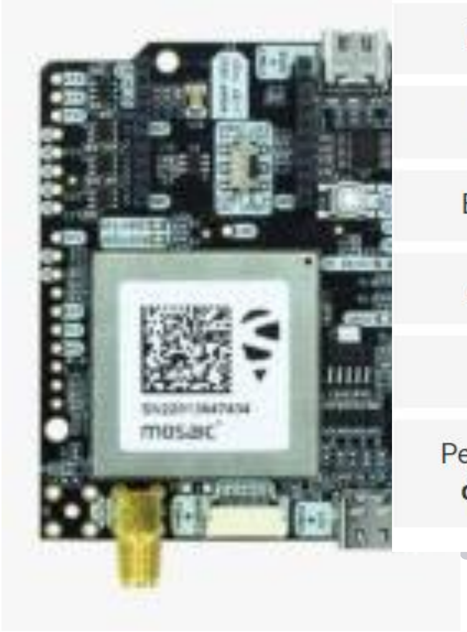
Precise Positioning is Changing!

Evolution of Precise Positioning



Low Cost RTK – Plethora of receiver options





simpleRTK3B Series

From USD $654.35

Explore Series

Millimeter level GPS/GNSS RTK receivers

Up to 100Hz position and 50Hz heading

Based on Septentrio **Mosaic-X5, Mosaic-H**

Advanced **Antijamming** and **Antispoofing**

Supporting L1/L2/L5 and more

Perfect for **future-proof systems, base station deployments, high-speed moving systems**

simpleRTK2B Series

From USD $197.80

Explore Series

Centimeter level GPS/GNSS RTK receivers

Up to 10Hz position and heading

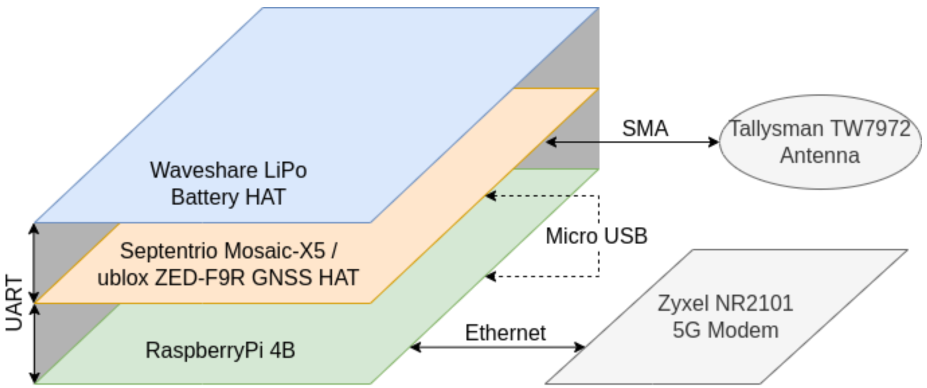
Based on u-blox **ZED-F9P, F9R, F9T**

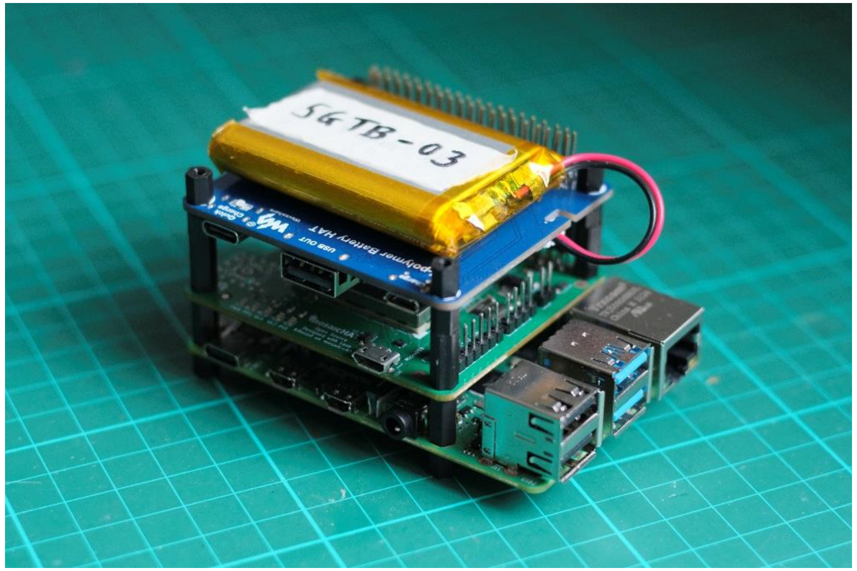
Lightweight, **low power** and low cost

Supporting L1/L2/E5b and more

Perfect for **mass market applications: precision farming, DYI drones, ground and maritime robots**

Why don't make your own GNSS receiver?





PART 4 – Cost Effective Positioning - Services

SouthPAN

Free Correction Services

- Various alternatives to commercial NRTK are available
- Positioning method depends on may factors such as application, industry sector, accuracy requirements, equipment budget, receiver SWaP, availability of correction services, etc.
- In South-East Asia there are several options for free-to-air correction services that are available including:
  - SBAS – SouthPAN, MSAS, GAGAN, BDSBAS
  - PPP – SouthPAN PPP, Galileo HAS, Beidou B2BPPP, QZSS Madoca

SouthPAN Coverage

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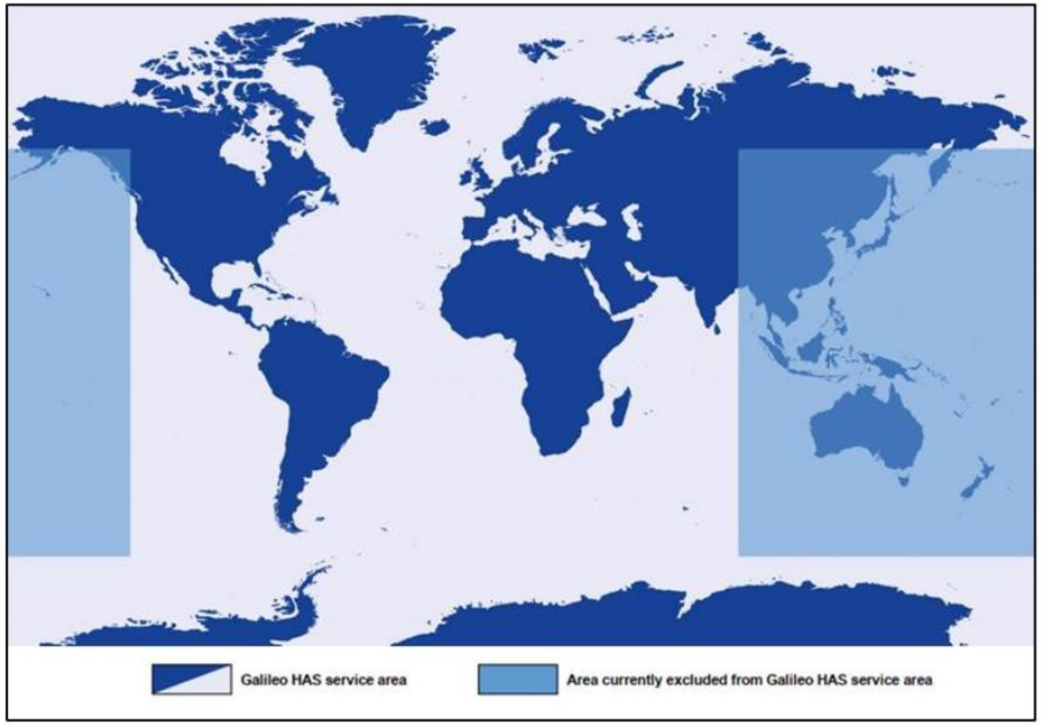
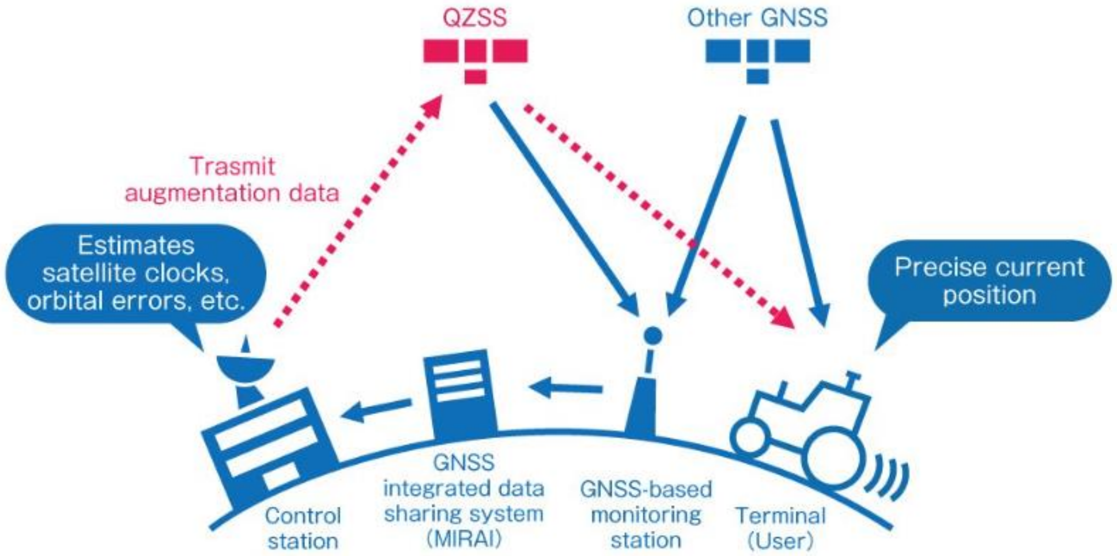
Galileo High Accuracy Service (HAS)

- Galileo HAS is a global PPP service that is provided by Galileo
- It is aimed to provide 20cm positioning worldwide after a convergence period at no charge to the user
- Currently has a gap in service in the Australasian region due to lack of reference stations, however the service still works
- Delivered on the E6 channel, which poses a problem, as many consumer-grade receivers do not support that channel



QZSS MADOCA

- MADOCA is a free-to-air PPP service that is provided by QZSS
- It is available in Australia and SE-Asian region at no charge to the user
- However, it is currently not being used in Australia due to the lack of receivers on the market
- The only MADOCA receivers are manufactured by Japanese manufacturers for Japanese market

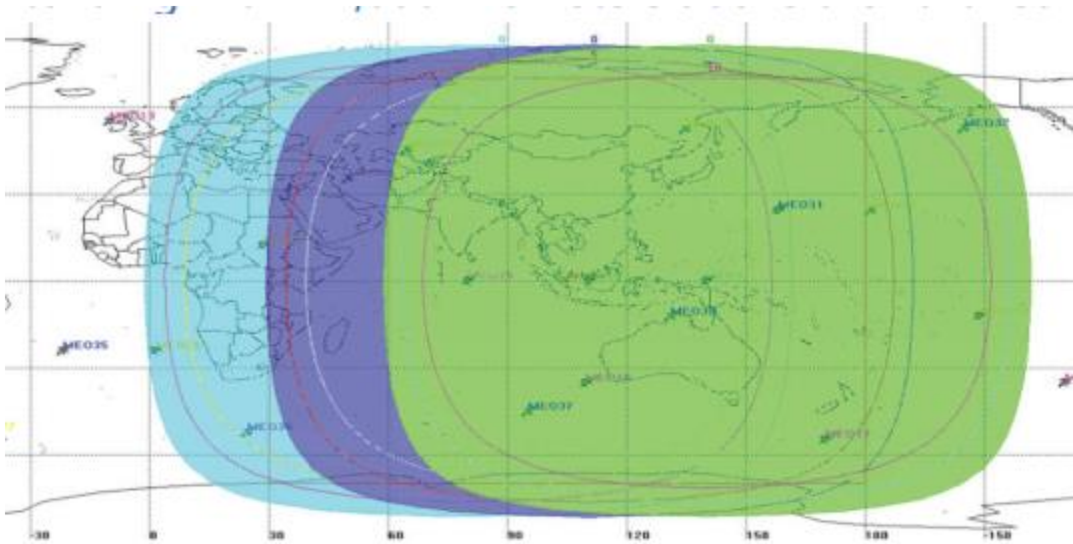


Beidou – BDSBAS, B2BPPP

- Beidou has both an SBAS service (BDSBAS) and a PPP service (B2BPPP)
- Both services are spanning the SE-Asian and Australasian regions

Characteristics		Performance Standard
Time System		BDT
Coordinate System		BDCS
BDS	Horizontal Positioning Accuracy(95%)	≤0.3m
	Vertical Positioning Accuracy(95%)	≤0.6m
	Convergence Time	≤30min
BDS+GPS	Horizontal Positioning Accuracy(95%)	≤0.2m
	Vertical Positioning Accuracy(95%)	≤0.4m
	Convergence Time	≤20min

(Nie, 2022)

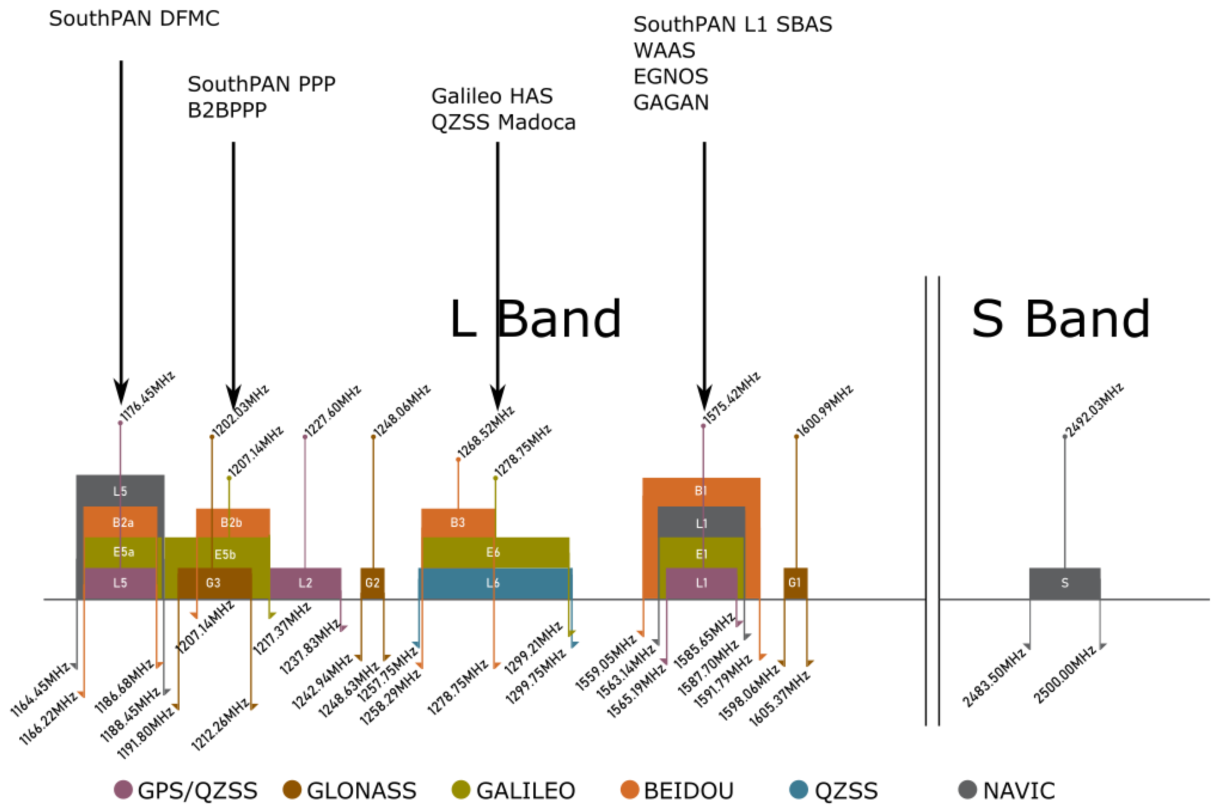


GNSS Frequencies and Signals

- Various free-to-air correction services are transmitted on different frequencies
- The most important consideration when purchasing a new receiver is knowing which frequencies it is capable of tracking

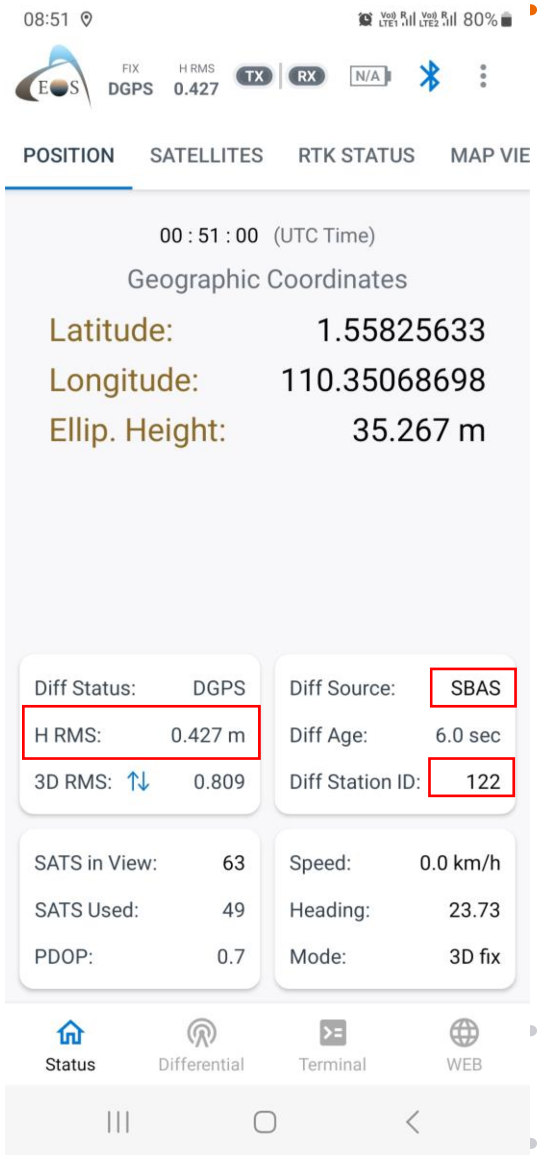
Signals tracked simultaneously	GPS: L1C, L1C/A, L2C, L2E, L5
	GLONASS: L1C/A, L1P, L2C/A, L2P, L3
	SBAS (WAAS, EGNOS, GAGAN, MSAS): L1C/A, L5
	Galileo: E1, E5A, E5B, E5 AltBOC, E6[2]
	BeiDou: B1, B1C, B2, B2A, B3
	QZSS: L1C/A, L1S, L1C, L2C, L5, L6
	NavIC (IRNSS): L5

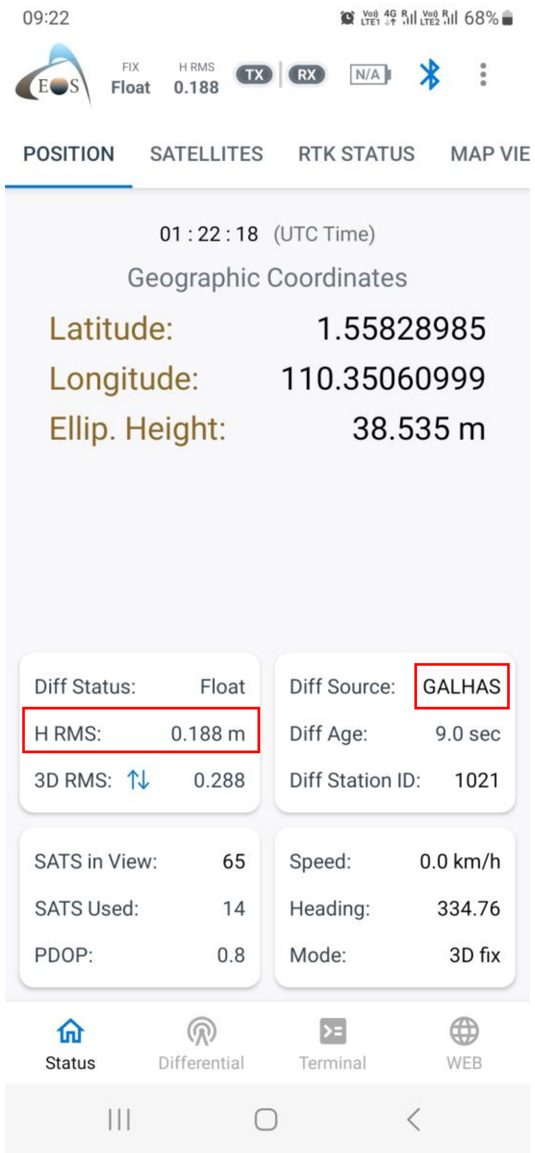
Frequency	GPS, GALILEO, QZSS: L1 1575.42MHz, C/A code
	GLONASS: L1 1598.0625MHz ~ 1605.375MHz, C/A code



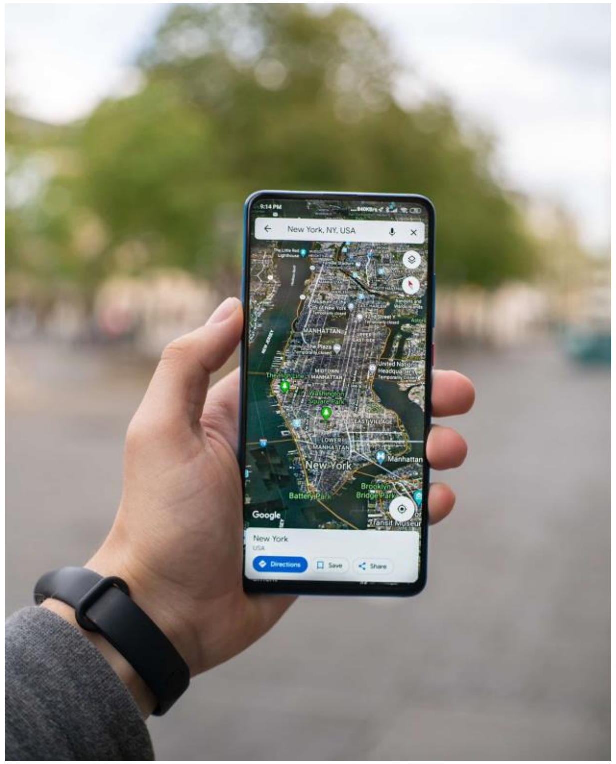
Test Results in Kuching

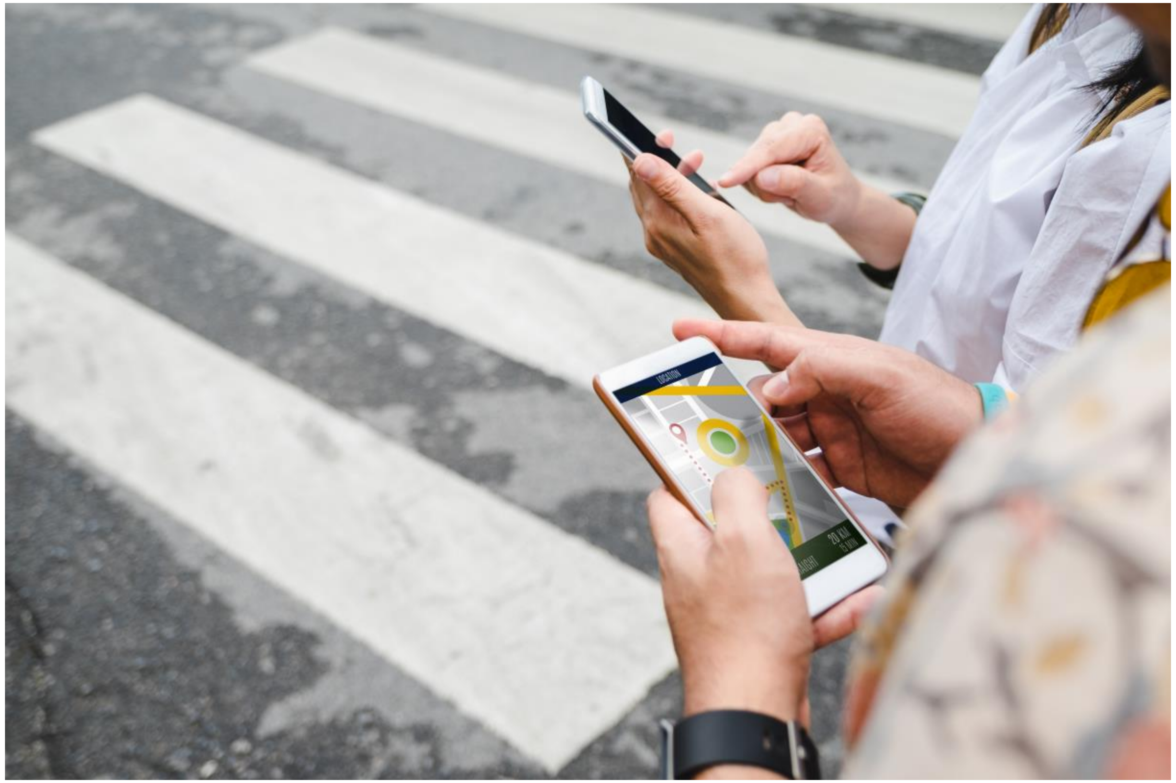
Test Results in Kuching





PART 5 – Mobile Phone Positioning





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Mobile Phone Positioning

- Mobile phones present the most challenging use for high precision positioning, mainly due to the fact that the antenna in the phone is the size of a paper clip
- Typical accuracy achievable on a mobile phone is between 3-10m depending on the environment
- However, a number of factors have happened in recent years, which can improve the positioning performance on the phone
  - Mobile phone chipset manufacturers have introduced dual frequency chipsets allowing for greater accuracy and different positioning methods
  - Google has released access to the raw carrier phase measurements on the Android platform
  - Availability of free-to-air RTK and PPP services available via the internet (e.g. SouthPAN PPP, Galileo HAS, GDGPS, etc.)

Mobile Phone Positioning

- In 2024, FrontierSI together with the Google Positioning team has carried out testing of SouthPAN PPP on a mobile phone

Android phone, with raw GNSS measurements (code and carrier)

Ground truth from survey-grade receiver

(Van Diggelen, 2024)

Test setup and data collection by Eldar Rubinov and Chris Marshall; Frontiers SI, Australia.
https://frontiersi.com.au/southern-positioning-augmentation-network-southpan/

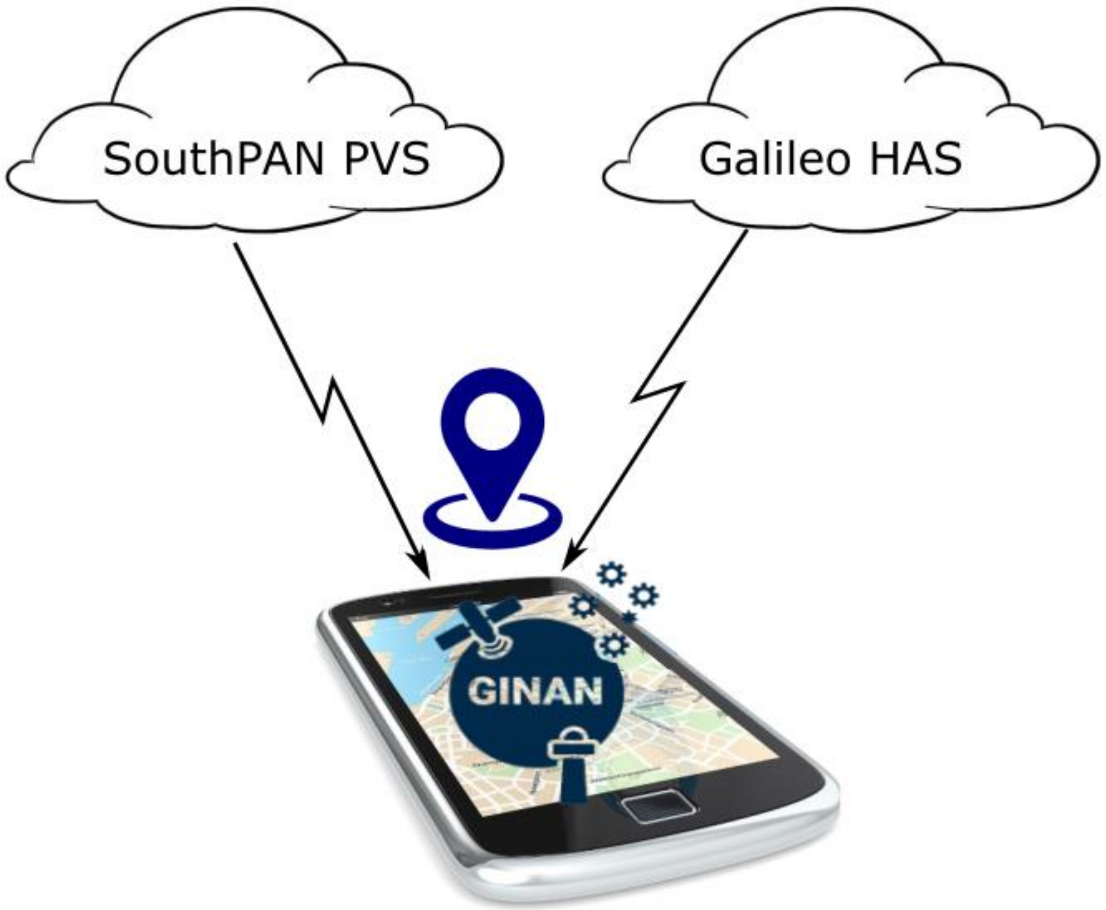
Mobile Phone Positioning

- It was shown that a substantial improvement was achieved
- Similar results were reported by Google using Galileo HAS in the USA (Van Diggelen, 2023)

	Standalone	SouthPAN PPP
Mean	1.800 m	0.927 m
50%	1.863 m	0.897 m
95%	2.189 m	1.521 m

Mobile Phone Positioning

- Currently, mobile phone testing results are computed offline by post-processing the data
- In order to do it in real-time, a positioning engine is needed that can run on the mobile phone
- FrontierSI is currently working on developing a positioning engine to run on the Android platform in order to enable high-precision positioning on mobile devices
- Ginan open-source PPP software will be the most likely option



PART 6 – Looking into the Future – LEO PNT

Looking into the Future – LEO PNT

- A new era in high precision positioning is starting
- Several PNT constellations are being developed in the Low Earth Orbit
- A number of key differences to GNSS
  - Orbit altitude of 1,000km instead of 20,000km
  - Constellations of ~300 satellites instead of 20
  - Smaller and cheaper satellites, easier to launch
  - More powerful signals, harder to jam and spoof
  - Constellations are launched by private companies, as well as governments

Why LEO PNT, if we have GNSS?

- GNSS has served and continues to serve humanity well for decades, however it has some limitations
  - GNSS is vulnerable, the signals are unprotected
  - GNSS does not perform well in obstructed environments, such as urban canyons
  - GNSS is run by governments, and in some cases by military (e.g. GPS), but most of the users are civilian
- LEO PNT is aimed fixing these shortcomings of GNSS
- There are at least 6 (possibly more) LEO PNT constellations that are being developed at the moment in the USA, Europe, China and Japan
- Exciting space to watch!

Questions

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