IPIN 2018

TUTORIAL

Using GNSS Raw Measurements on Android Devices

by

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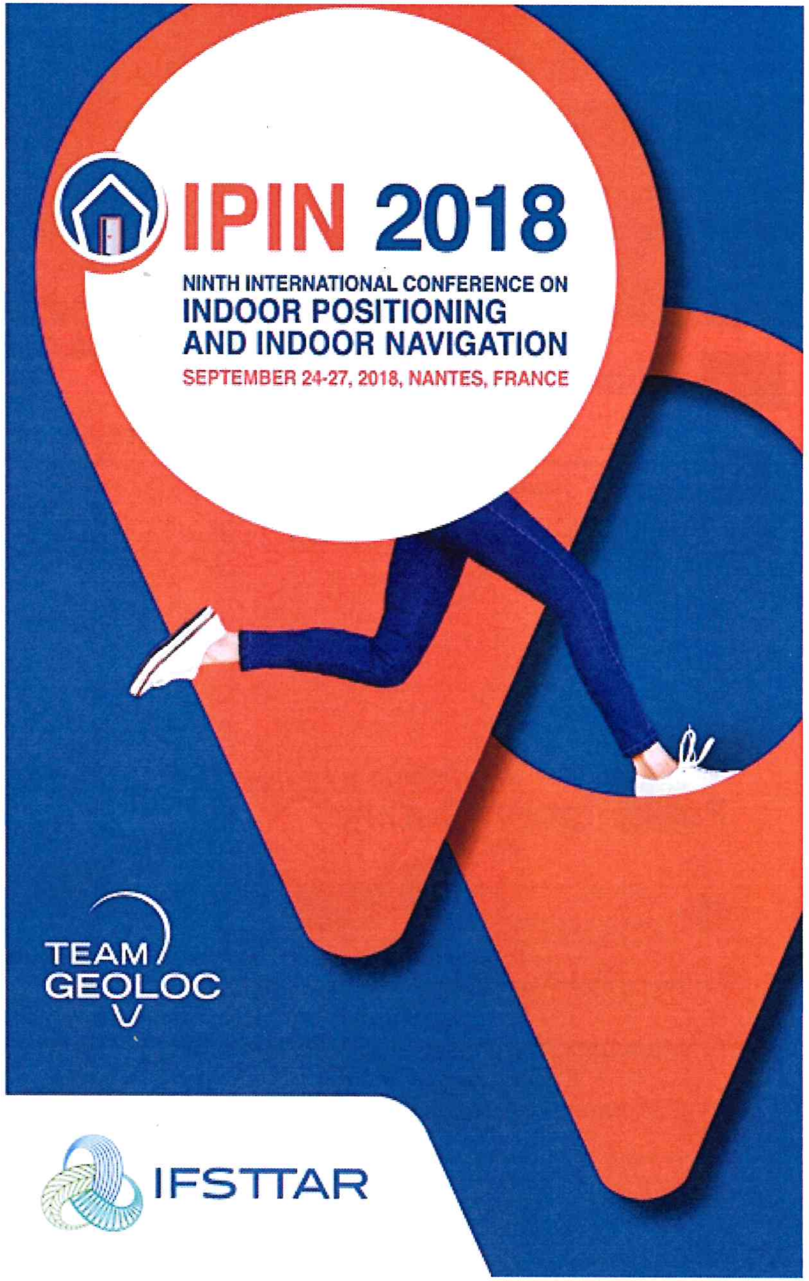
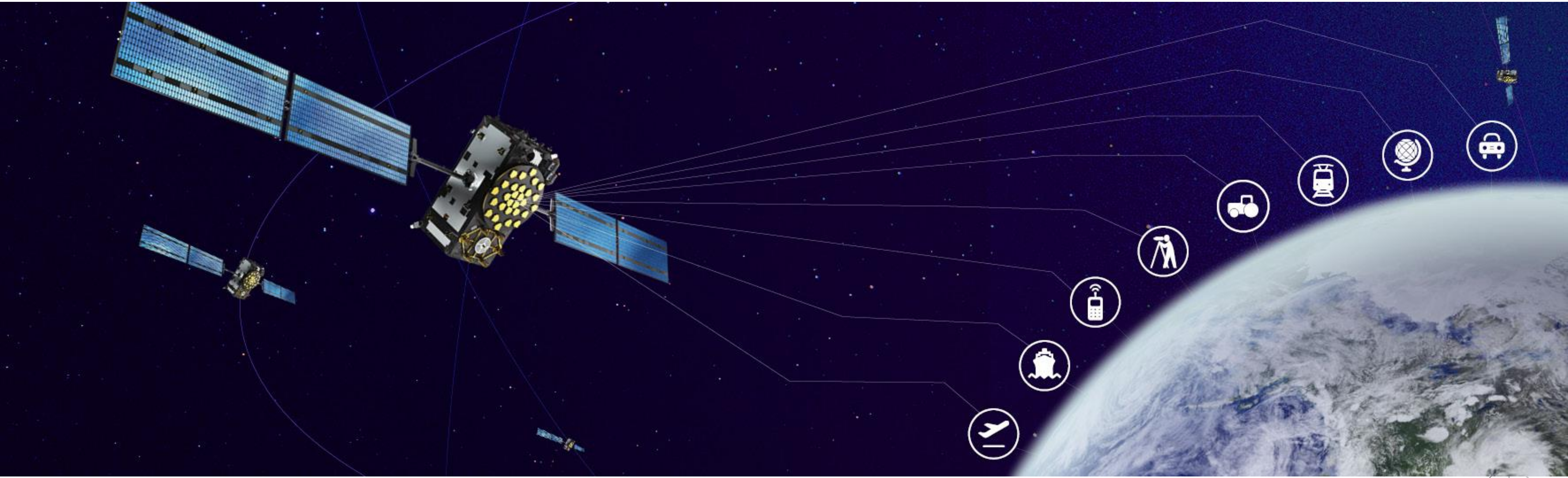




Using GNSS Raw Measurements on Android Devices – Tutorial part I

Towards better location performance in mass market applications

Martin Sunkevic, European GNSS Agency

24 September 2018

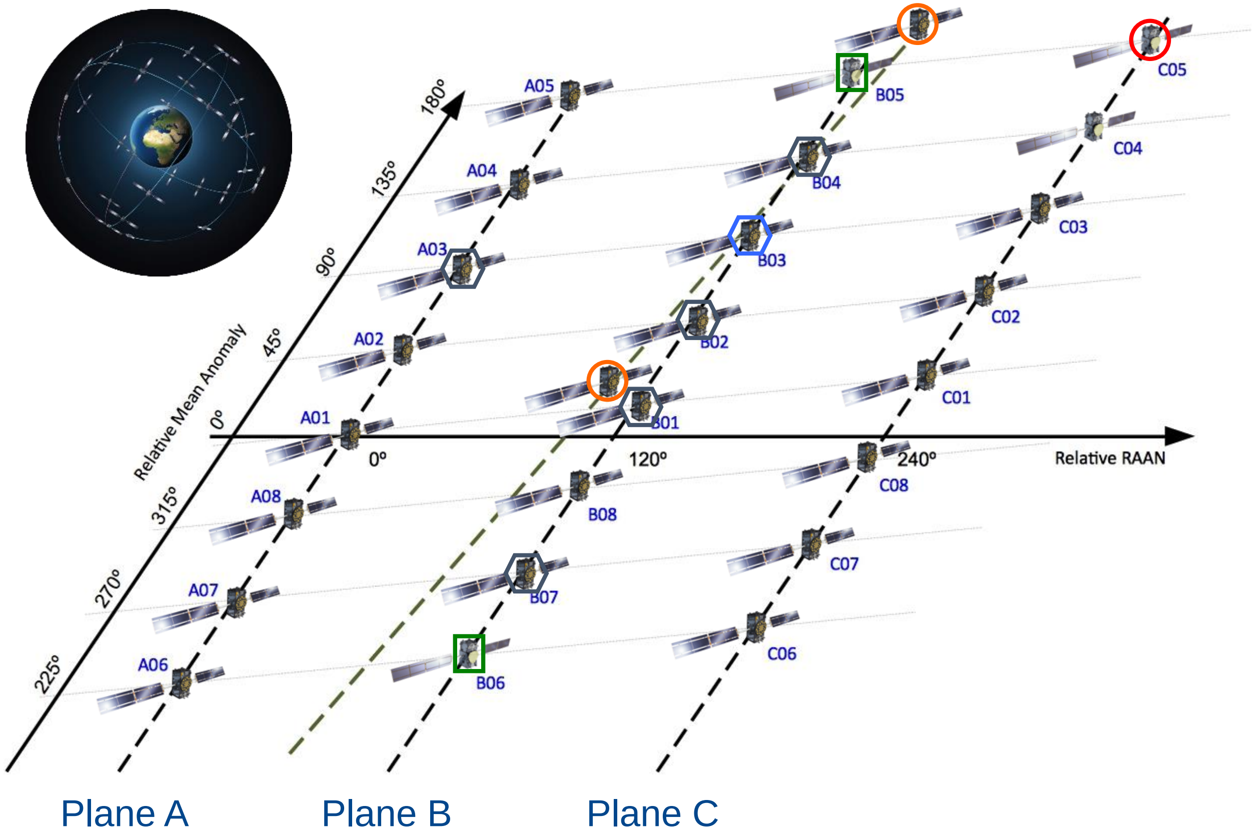
European Global Navigation Satellite Systems Agency

GALILEO EGNOS
NAVIGATION SOLUTIONS POWERED BY EUROPE

Presentation Outline

- Galileo system status
- What the “Raw Measurements” are
- Main benefits/uses of Raw measurements - “The four areas”
- GSA Raw Measurements Task Force and the White Paper

Galileo Constellation Status



Navigation Payload (17 Operational)

26 satellites in orbit

5 under commissioning

2 in testing

1 spare

1 unavailable

Search and Rescue Payload (18 Operational)

2 out of 26 satellites with no SAR Transponder (by design)

5 under commissioning

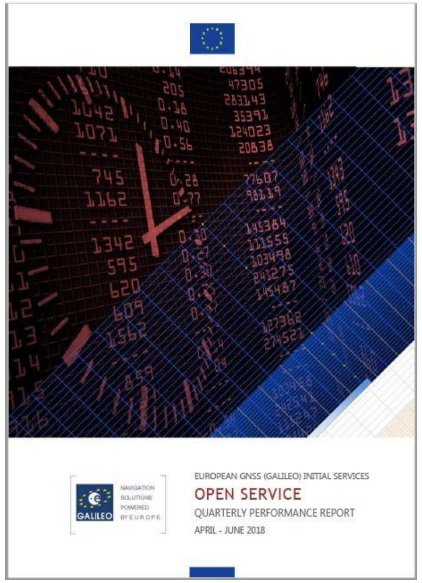
1 spare

0 unoccupied reference slots

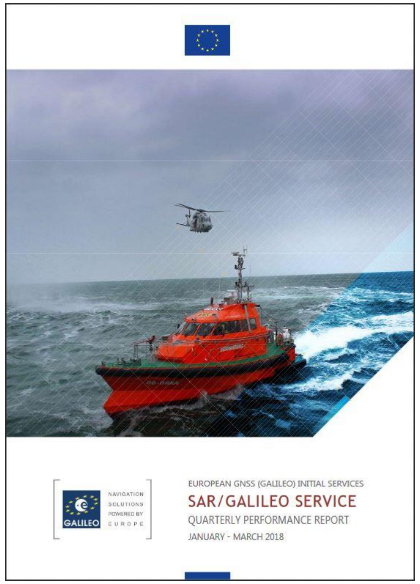
Quarterly Performance Reports

Following the declaration of Initial Services in December 2016, the Galileo Initial Open Service (OS) and the Galileo Search and Rescue (SAR) Service Public Performance Reports are published quarterly, to provide the public with information about the Galileo OS and the Galileo SAR Service measured performance statistics

OS Performance Report - Q2 2018



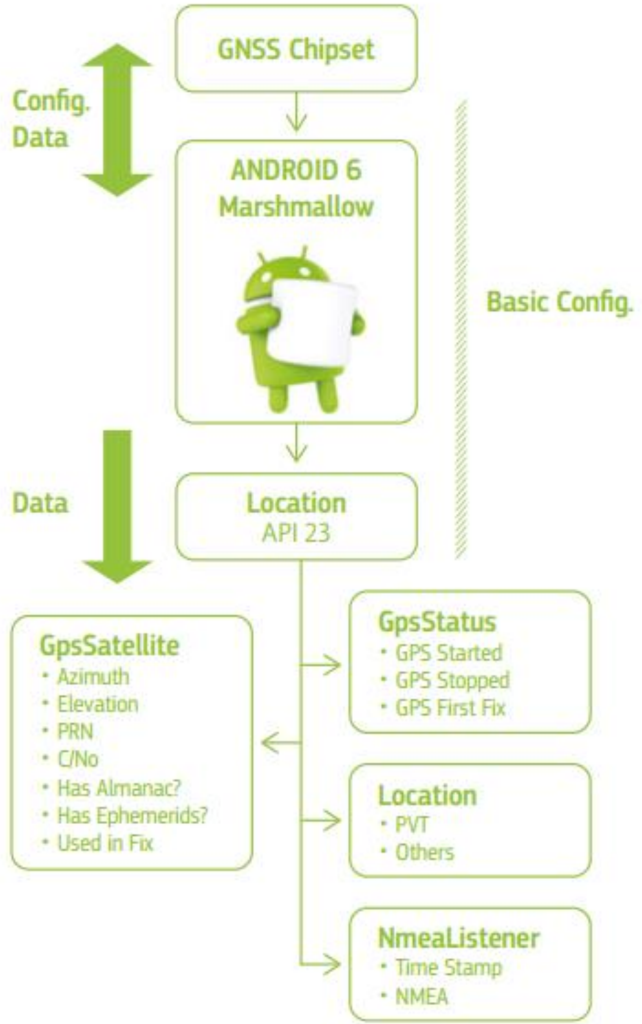
SAR Service Performance Report - Q1 2018



Android GNSS Raw Measurements (1)

- Google made available GNSS Android Raw Measurements in August 2016 with the release of Android 7 (Nougat)

- Before that, developers had access (with API 23) to the following Android classes
  - **GPS Satellite**, containing such basic satellite information as azimuth, elevation, PRN and C/No. It also flags if the satellite is used in the PVT solution and the availability of almanac and ephemerides.
  - **GPS Status** provides information about the status and solution of the GNSS chipset.
  - **Location**, indicating if a positional and time solution is provided.
  - **NMEA Listener**, providing basic NMEA sentences.



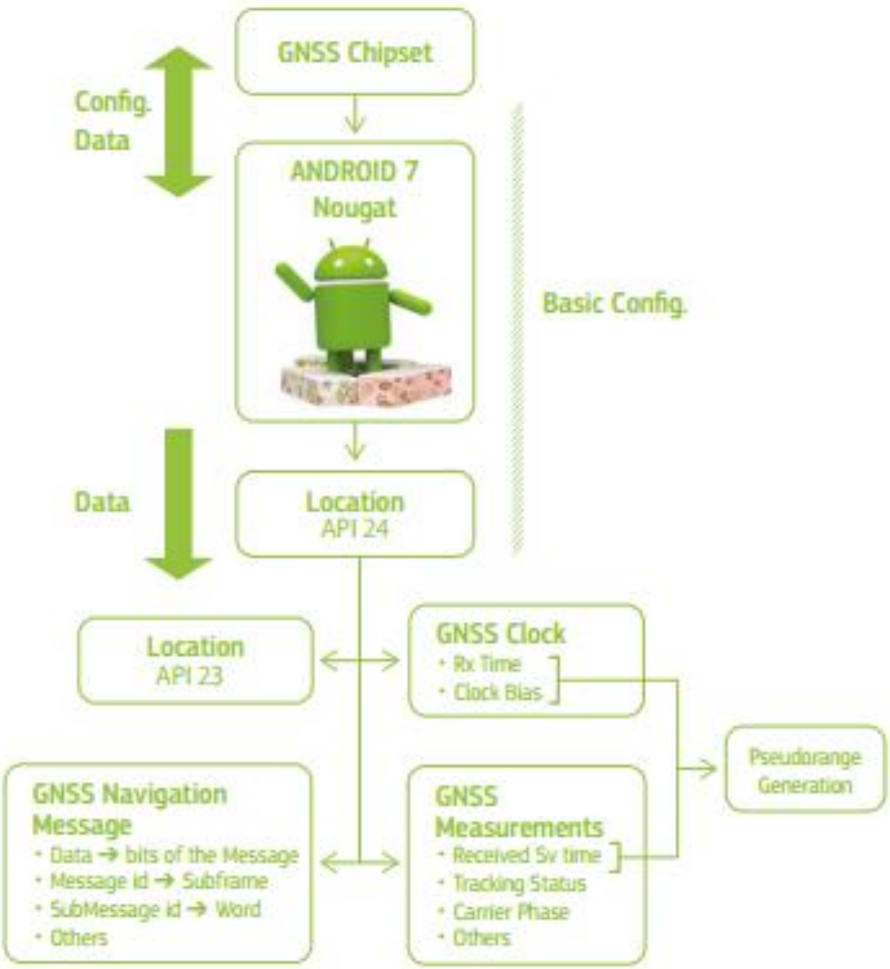
Android GNSS Raw Measurements (2)

From API 24 (Android 7), developers have access to (API 23 and) the following GNSS raw and computed information via Android classes:

- *GNSS Clock*, that contains:
  - Receiver time (used to compute the **pseudorange**);
  - Clock bias.

- *GNSS Navigation Message* that contains:
  - Navigation Message bits (all the constellations);
  - Navigation message status.

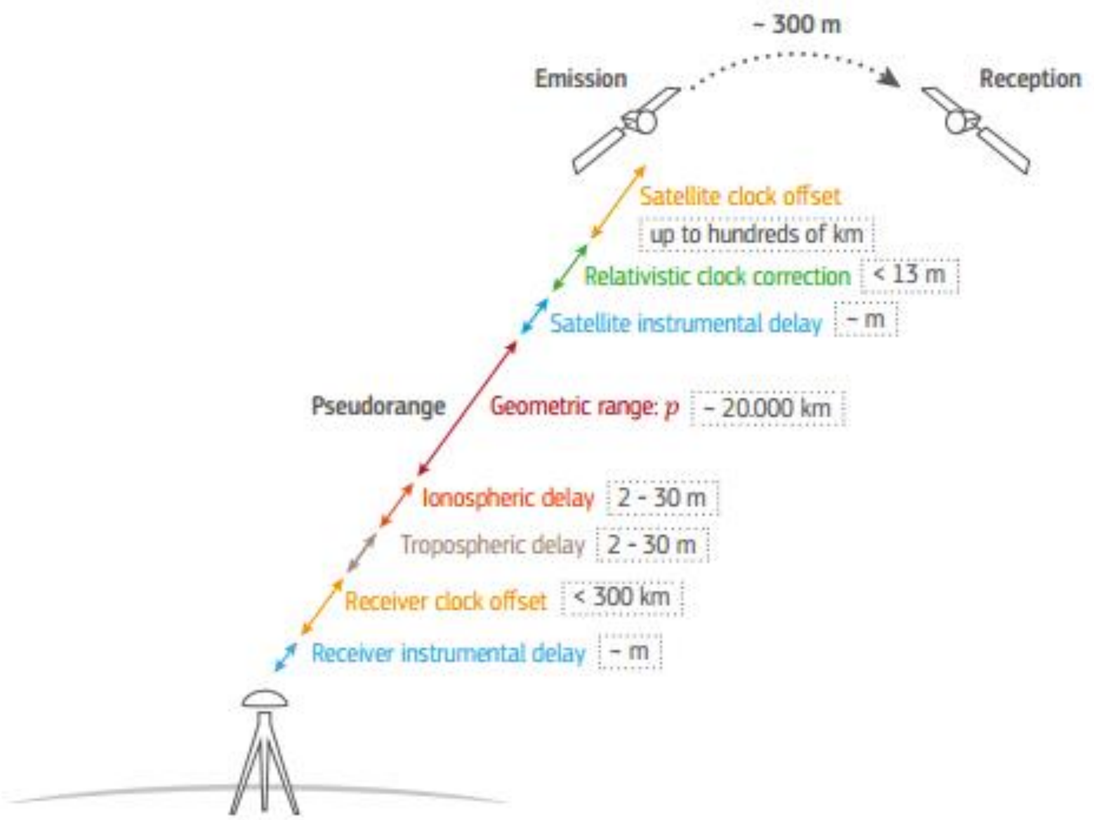
- *GNSS Measurement* that contains:
  - Received Satellite Time (used to compute the pseudorange);
  - Code;
  - Carrier phase.



Android GNSS Raw Measurements (3)

- What is so “cool” about it?

➡ you can use android devices to calculate pseudoranges and PVT on your own while using additional data from other sensors and sources



Sources of GNSS pseudorange measurement errors

What are the benefits/ main uses of GNSS raw measurements?

Four main areas of use are enabled by GNSS raw measurements

Scientific use and R&D

- As the observations are provided in a much more coarse form they can be used for **testing hardware and software solutions and for new post processing algorithms** e.g. for modelling **ionosphere or troposphere**.

Increased accuracy

1

- **Subject to hardware limitations**, access to raw measurements means a developer can employ **advanced positioning techniques** (RTK, PPP) and create a solution currently only available in professional receivers.
- It results in a technological push to develop new applications.

Integrity/Robustness

2

- Access to raw measurements will offer new ways to detect **RF interferences** and to locate the interference source by combining the measurements from multiple devices (crowdsourcing), or **verify the source** (OS-NMA).
- **SBAS corrections** can be incorporated without the need for additional equipment.

Testing, performance monitoring and education

3

- Raw measurements can be used for **monitoring performance** (data, accuracy, Rx clock), testing and to compare solution from single constellations, eliminate specific satellites or test for worst scenario performance.
- **Education use** for understanding GNSS, Signal processing or orbits in smartphone is not negligible too.

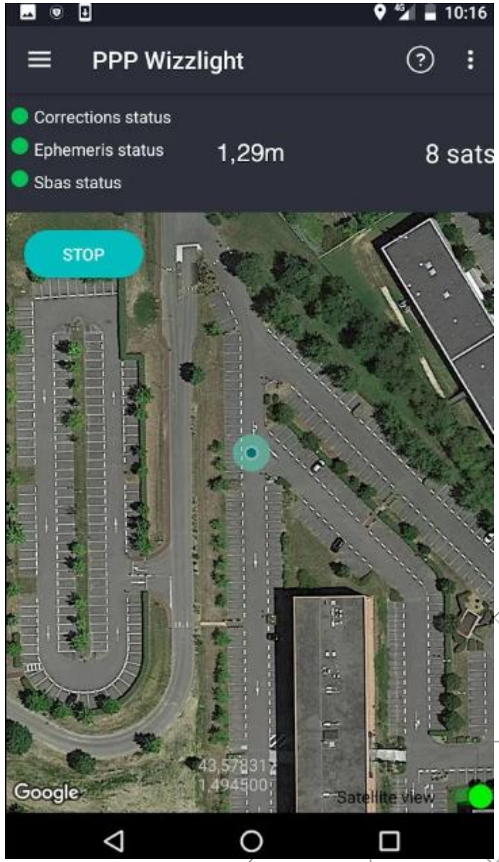
High accuracy apps

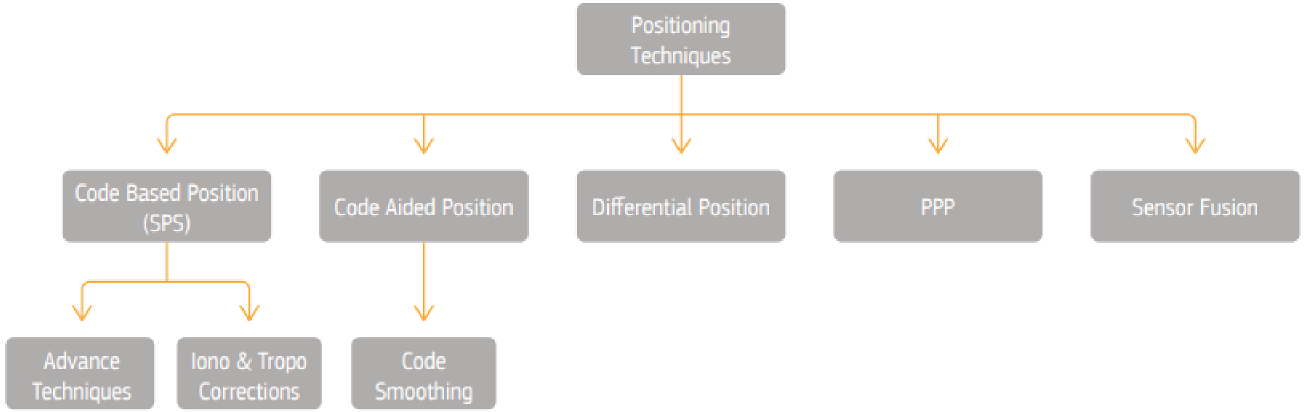
Example of app providing high accuracy: **PPP WizzLite**

- based on raw GNSS measurements, the app combines RTK library and very high level algorithms developed by the French Space Agency (CNES PPP-Wizard)

- Accuracies of 1-2 meters can be reached in kinematic mode and sub-meter in static mode

- To do so, users need to pull external RTCM streams **for orbits/clocks corrections and broadcasts**, such as ones available from the International GNSS Service Real-Time Service (IGS RTS)





2

Integrity/robustness: Galileo OS Navigation Message Authentication

"Navigation Message Authentication" is the ability of the system to guarantee to the users that they are utilising navigation data that has not been modified and comes from the Galileo satellites and not from any other source.

Ref. ***Galileo Navigation Message Authentication Specification for Signal-In-Space Testing – v1.0*** *(to be updated)*

- Clear **differentiator w.r.t. other GNSS** available to the civil community
- Fully **backward compatible**
- Disseminated on the first Galileo frequency (**E1B**)
- Contributes to **mitigate GNSS vulnerabilities**
- No need to store secret keys in the Rx, just public key
- Follows crypto standards and recommendations to be secure over the next decades

Can be used by apps in near future thanks to access to raw measurement navigation message

10

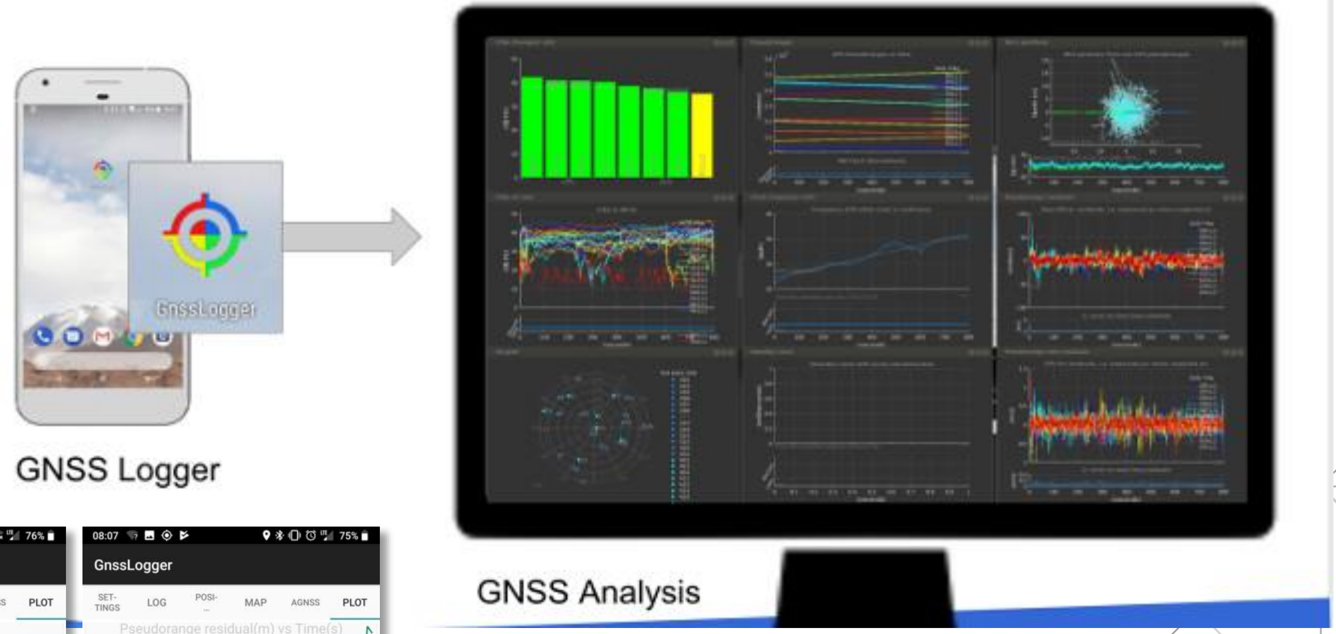
Education/Testing: Logging and monitoring apps (1)

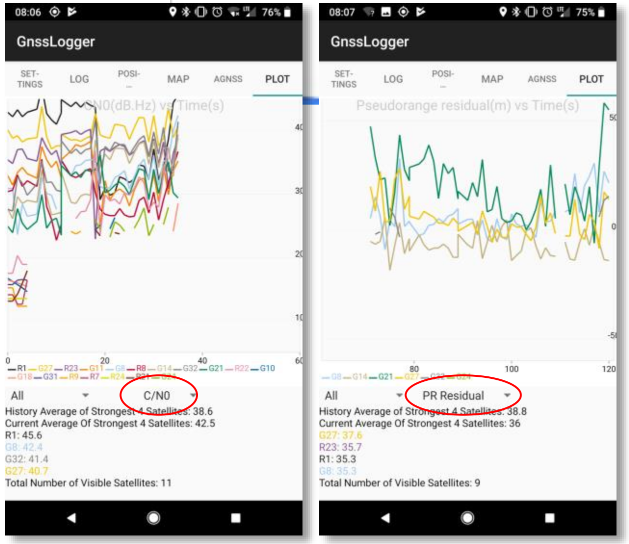
3

GNSSLogger:

- The **GNSS Analysis** reads the GPS/GNSS raw measurements collected by the **GNSS Logger app** and uses them to analyze the GNSS receiver behaviour

- The GNSS Analysis app is built on [MATLAB](), but you don't need to have MATLAB to run it. The app is compiled into an executable that installs a copy of the MATLAB Runtime





New in 2018:

- **duty cycling** control
- Analysis on the phone

Education/Testing: Logging and monitoring apps (2)

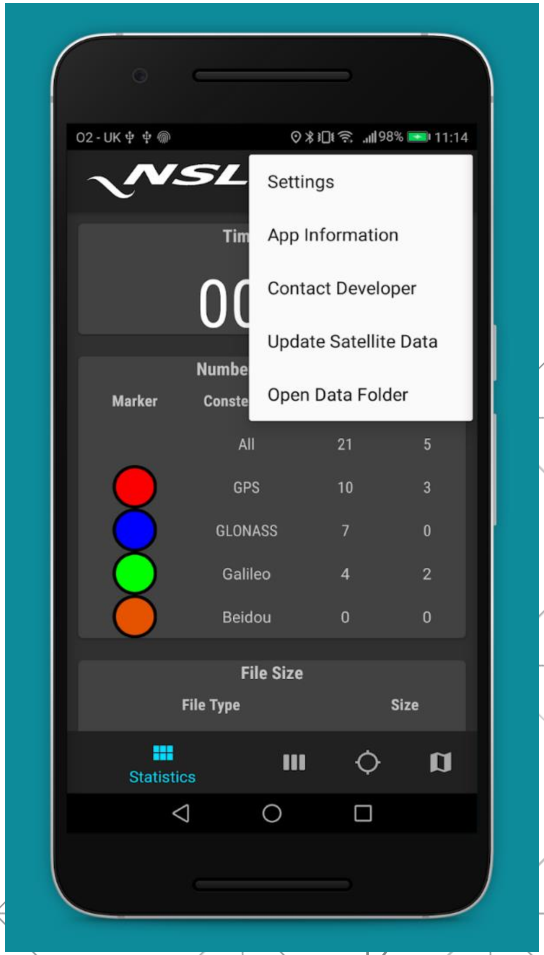
3

HORIZON 2020

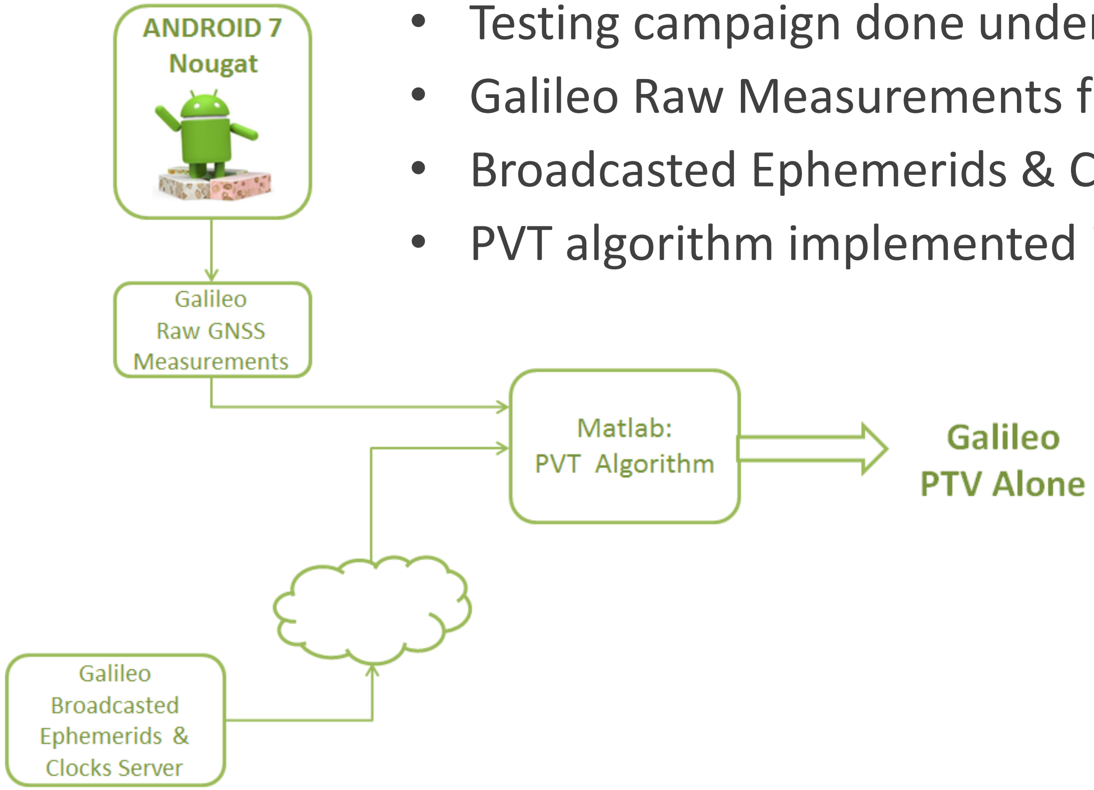
RINEX ON

Written by NSL as part of the H2020 FLAMINGO project

- An ongoing development as the project progresses
- Includes:
  - RINEX Observation and Navigation Message File writer. Can choose constellations
  - GNSS skyplot and satellite planner in 24-hour timescale
  - Signal-to-noise (signal strength) graphic
  - Satellites tracked and measured monitor
  - File size monitor



Education/Testing: Outcome of GSA smartphone testing campaign (1)

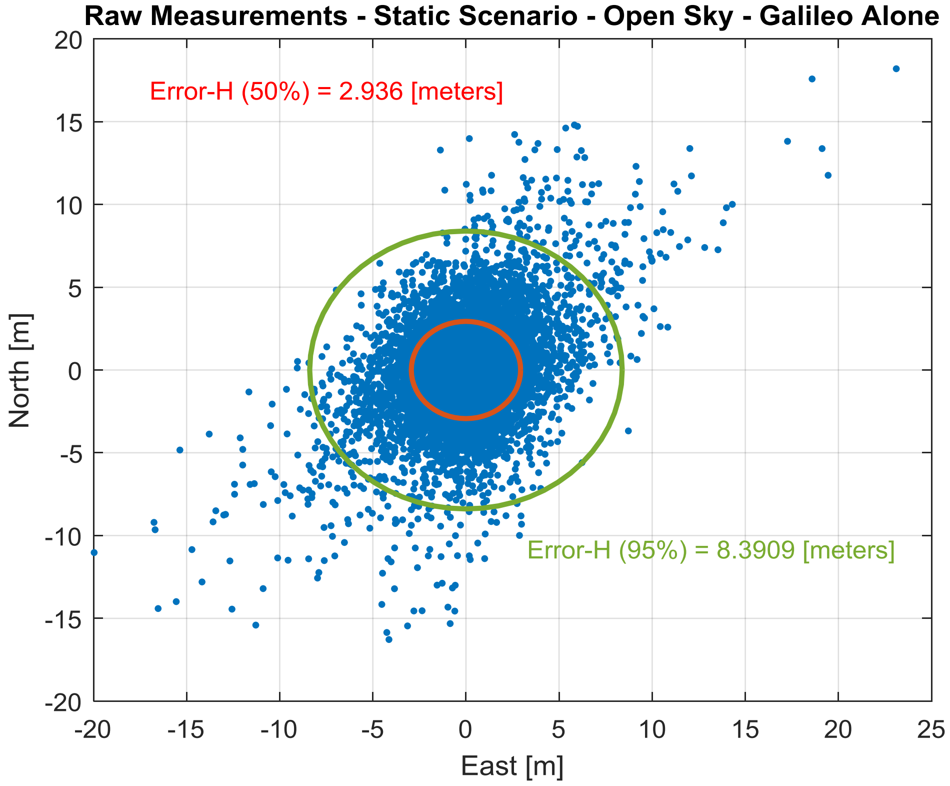


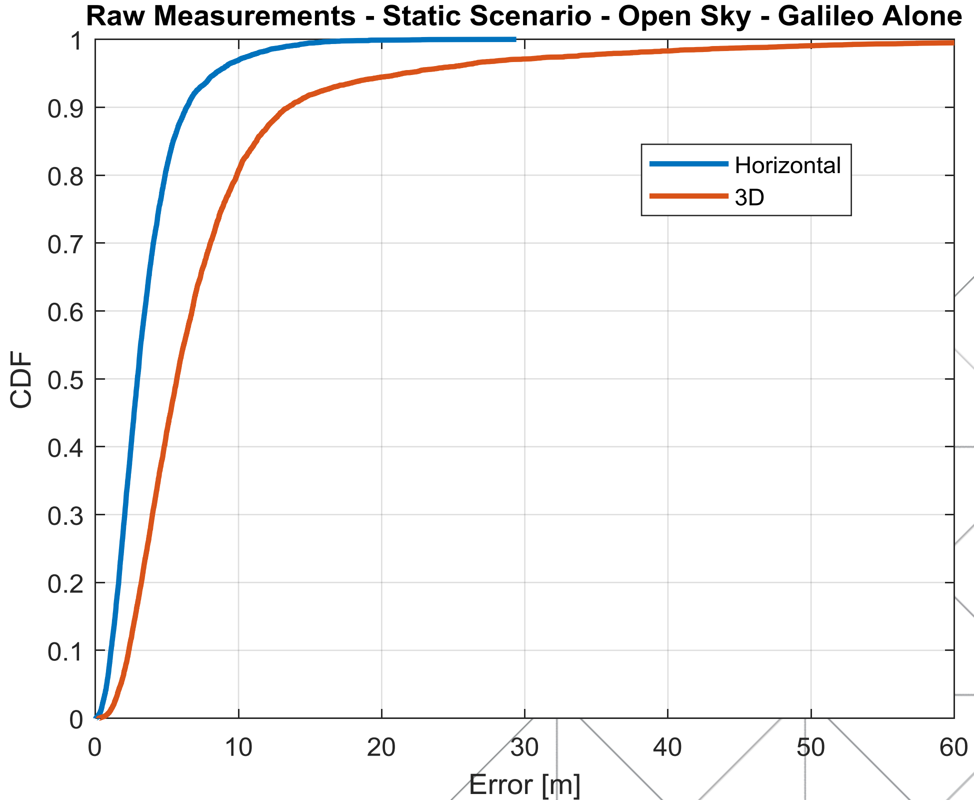
- Testing campaign done under contract with Airbus D&S
- Galileo Raw Measurements from Samsung S8
- Broadcasted Ephemerids & Clocks from Server (IGS)
- PVT algorithm implemented in Matlab

3 Education/Testing: Outcome of GSA smartphone testing campaign (2)

Galileo-only PVT – Open Sky, Static

- 5 Galileo Satellites used for the PVT solution
- 2.9 meters accuracy (50%)
- 8.4 meters accuracy (95%)

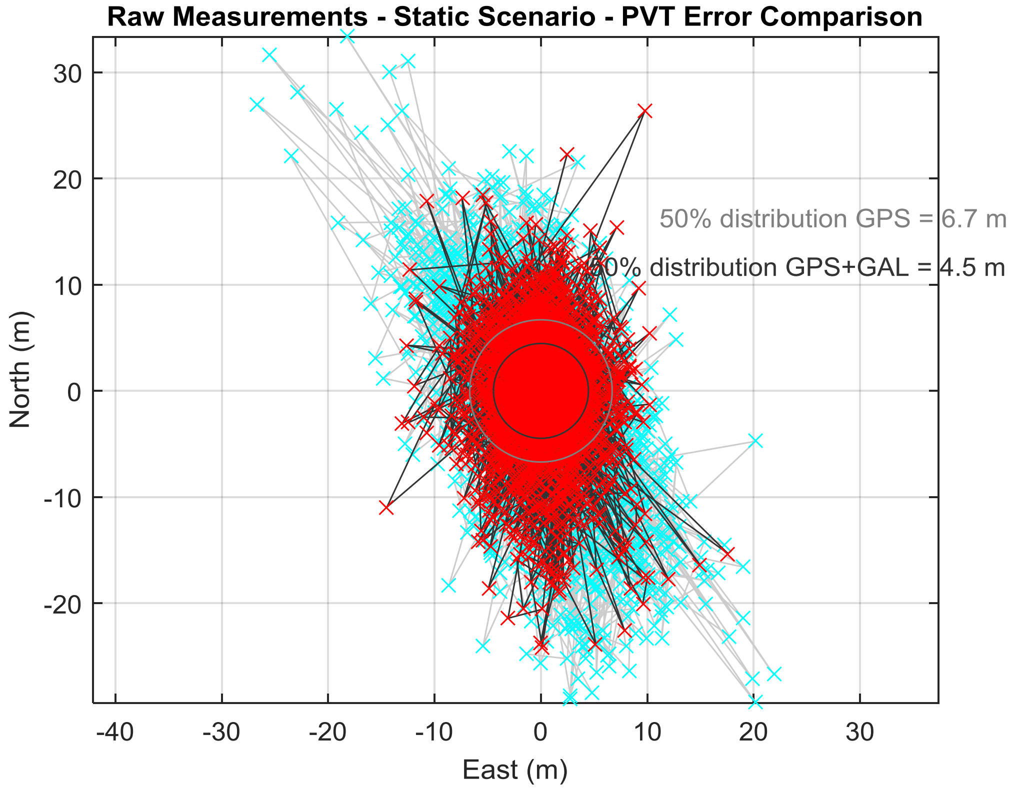


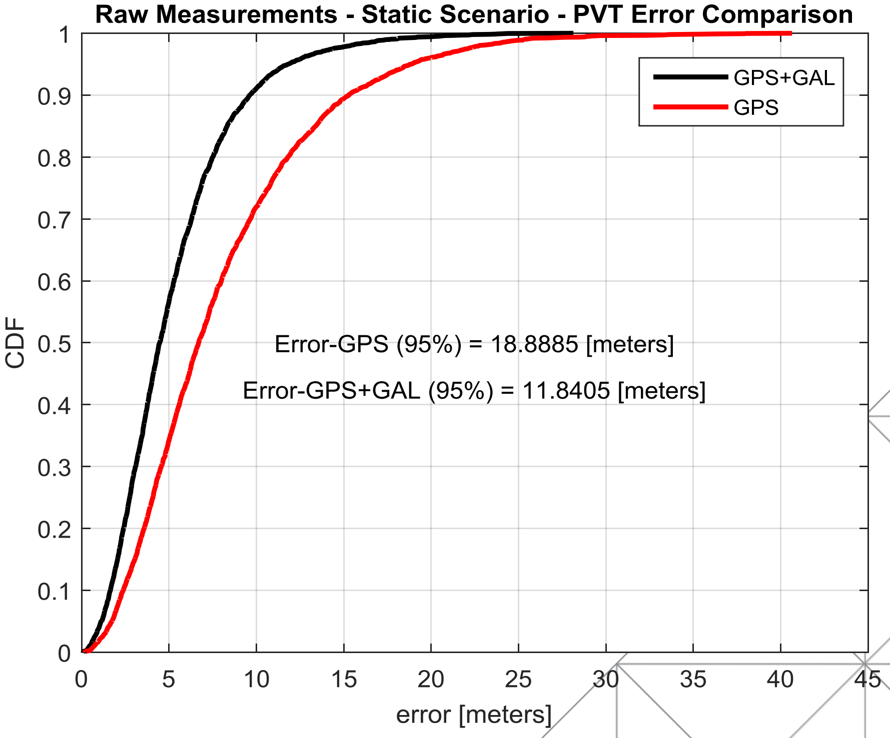


3 Education/Testing: Outcome of GSA smartphone testing campaign (3)

GPS vs GPS + Galileo PVT - Open Sky, Static

- 5 Galileo Satellites used for the PVT solution
  - GPS alone 6.7 meters error
  - **Galileo increases the accuracy up to 4.5 meters**





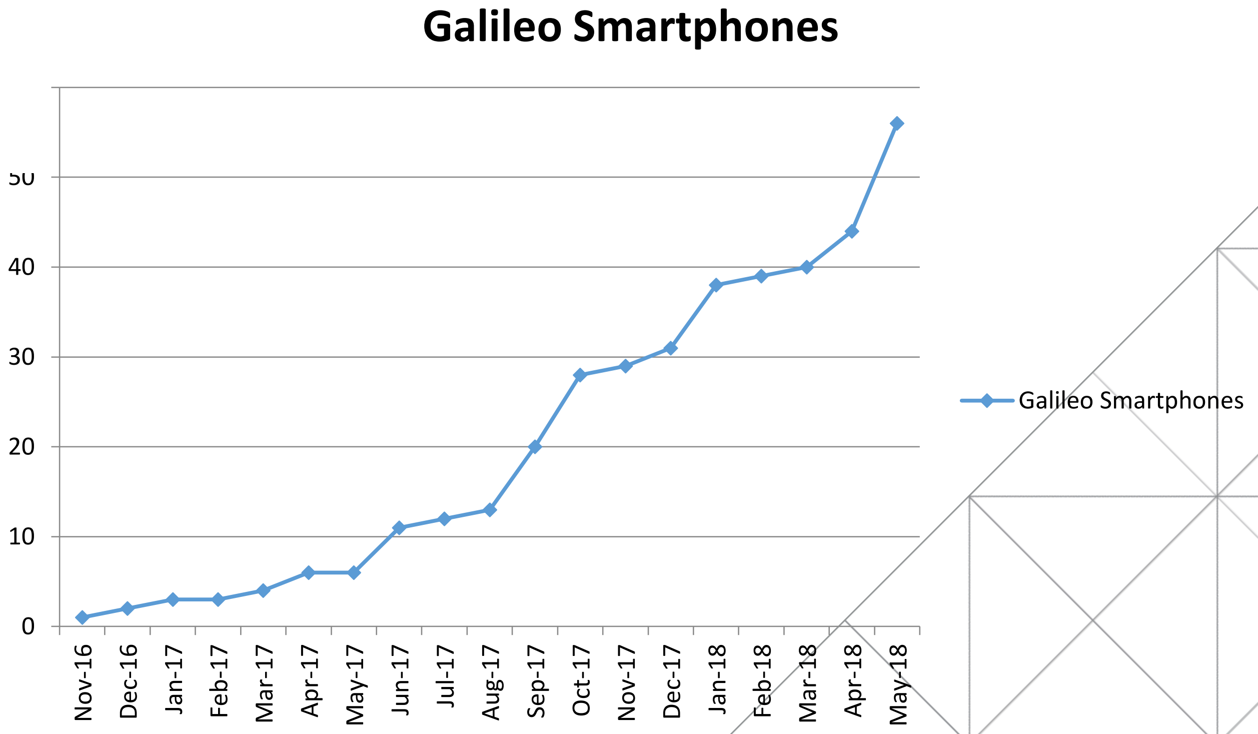
Which are smartphones using Galileo?

- Almost 60 Smartphone models include Galileo
- Leading smartphone manufactures use Galileo

SAMSUNG

HUAWEI

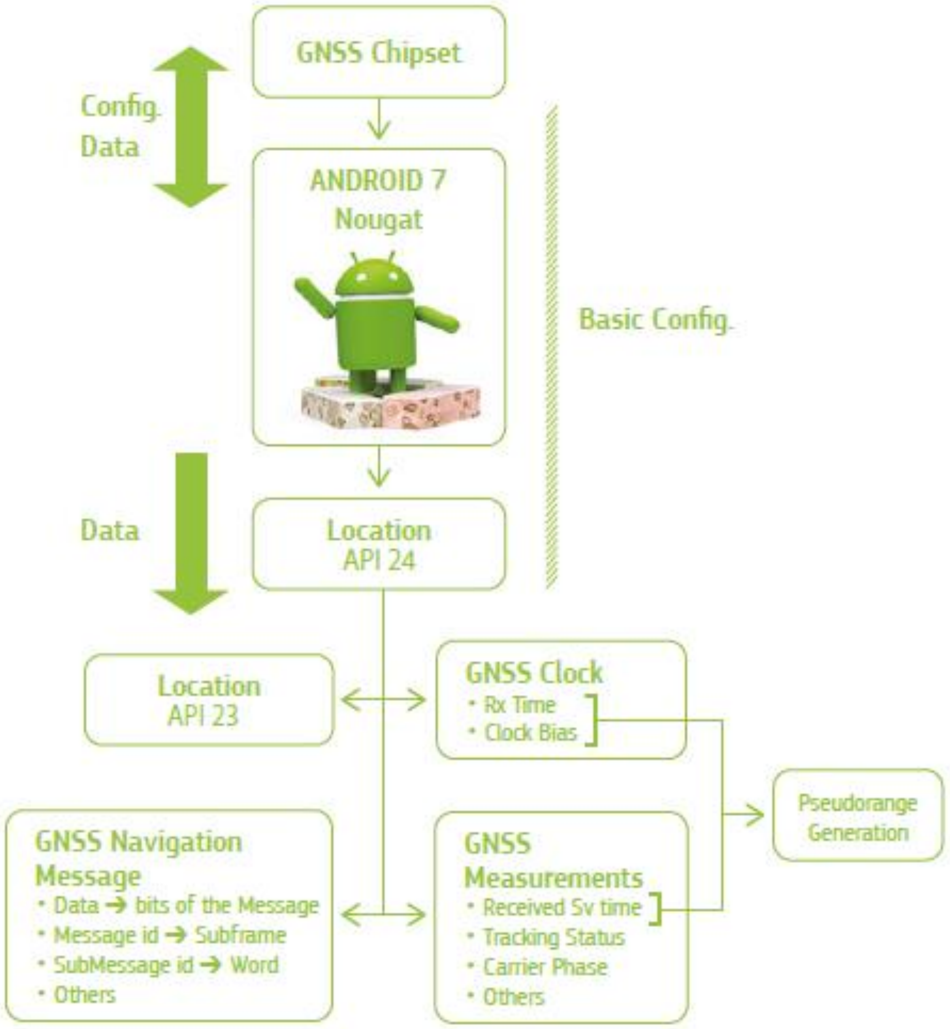
bq



Do you want to know if your smartphone is using Galileo?

http://usegalileo.eu/

3 Education/Testing: Outcome of GSA smartphone testing campaign (4)



Which satellites have been used in the PVT by phone?

Google Location class:

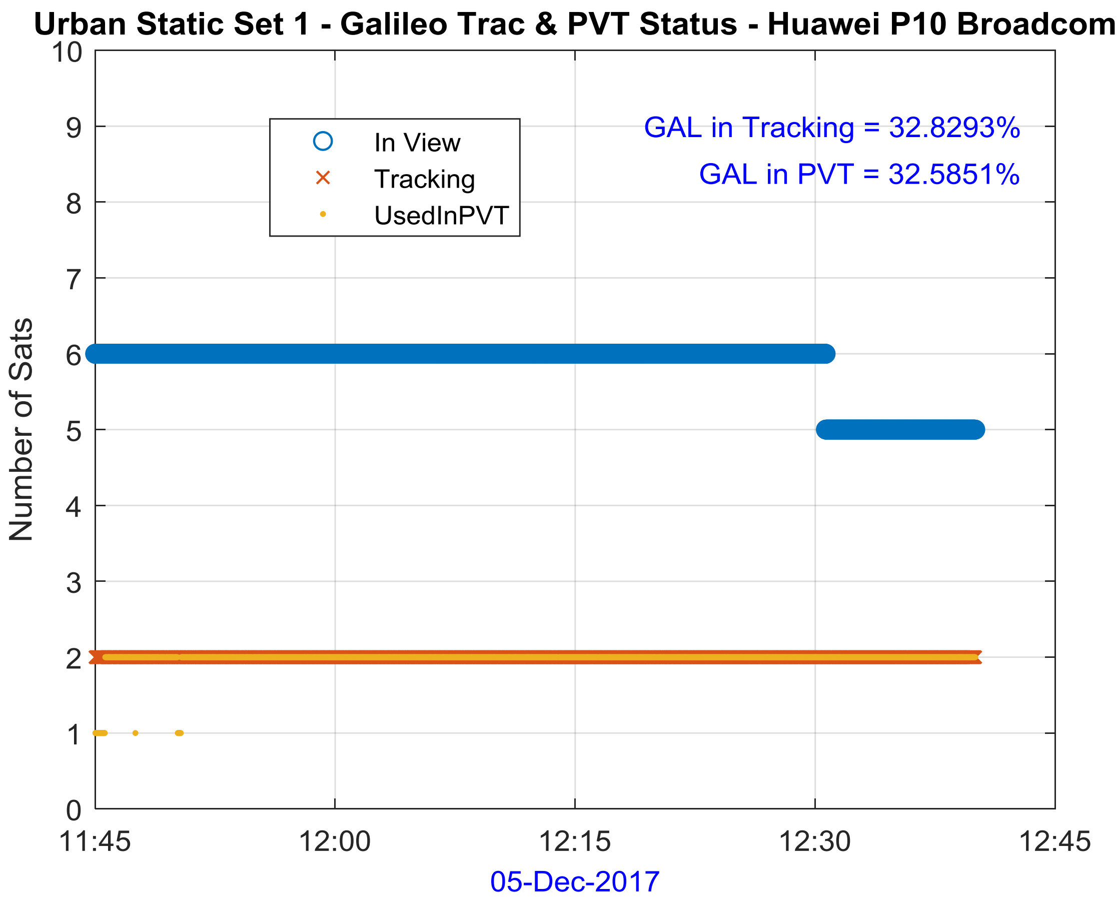
- Satellites used for PVT
- Ephemerids and almanac available

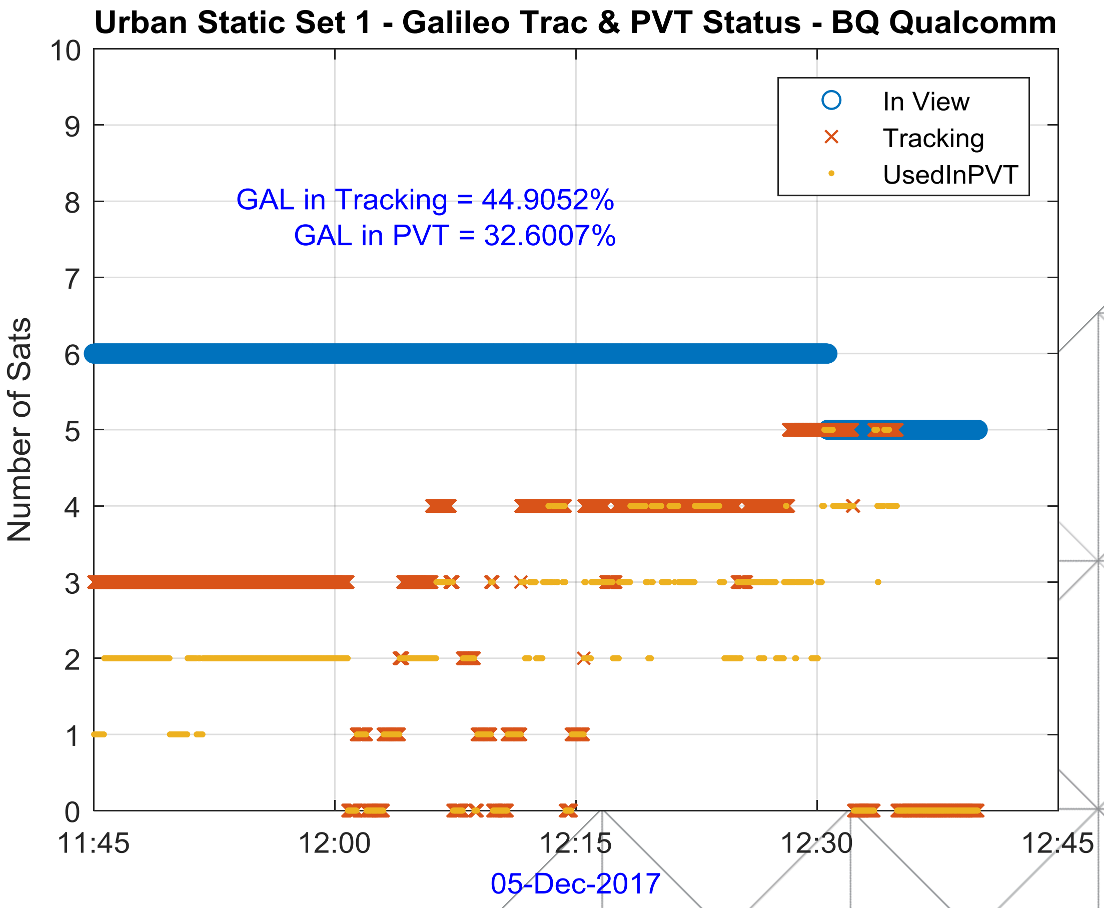
Analysis of Galileo usage by phone in PVT can be done

3 Education/Testing: Outcome of GSA smartphone testing campaign (5)

PVT & Tracking: **Percentage over the in-view healthy Galileo Satellites**

- Same scenario for both phones





Education/Testing: Outcome of GSA smartphone testing campaign (5)

PVT & Tracking: **Percentage over the in-view healthy Galileo Satellites**

Huawei P10:

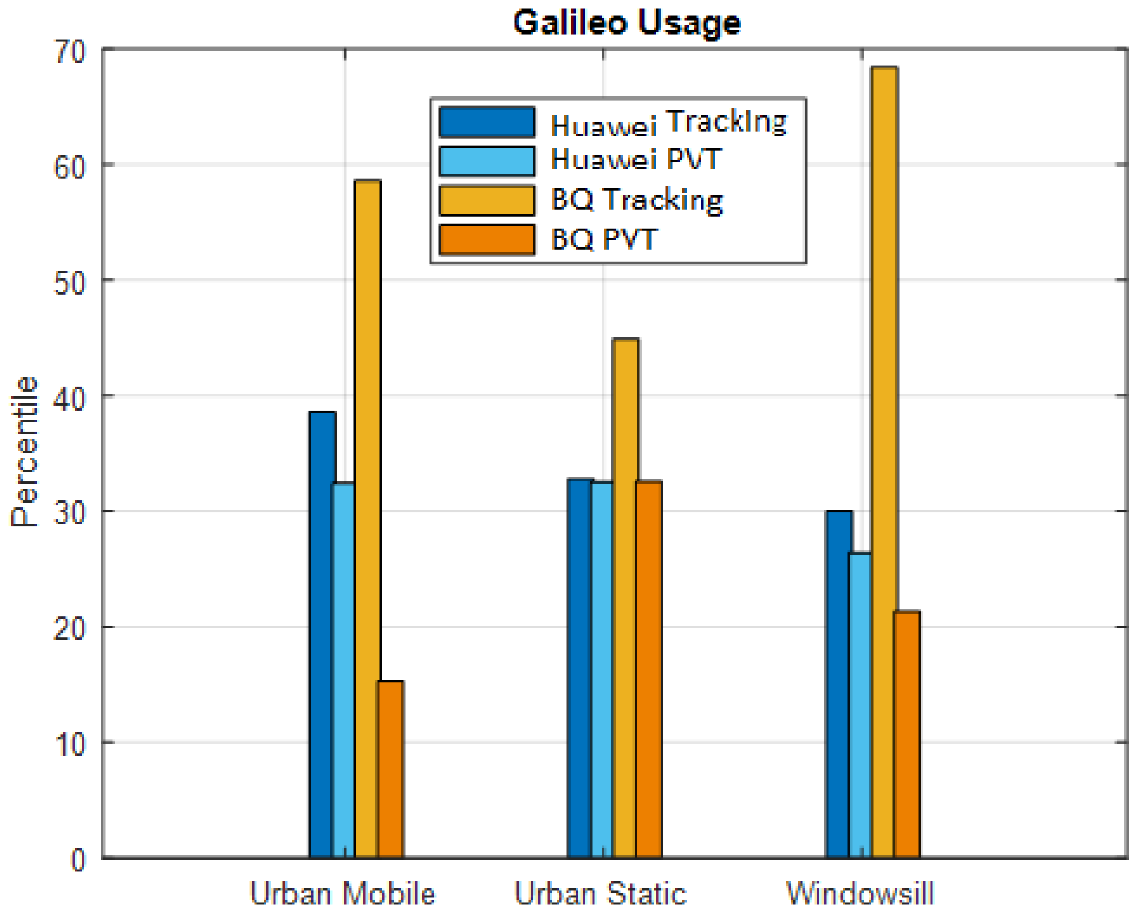
- Almost all the measurements are used in the PVT solution.
- Less than 40% of the measurements are tracked

BQ:

- More than 45% of the measurements are tracked in all the scenarios.
- Up to 70% of the measurements are tracked in the windowsill scenario
- The measurements used in PVT reduced

Comparison:

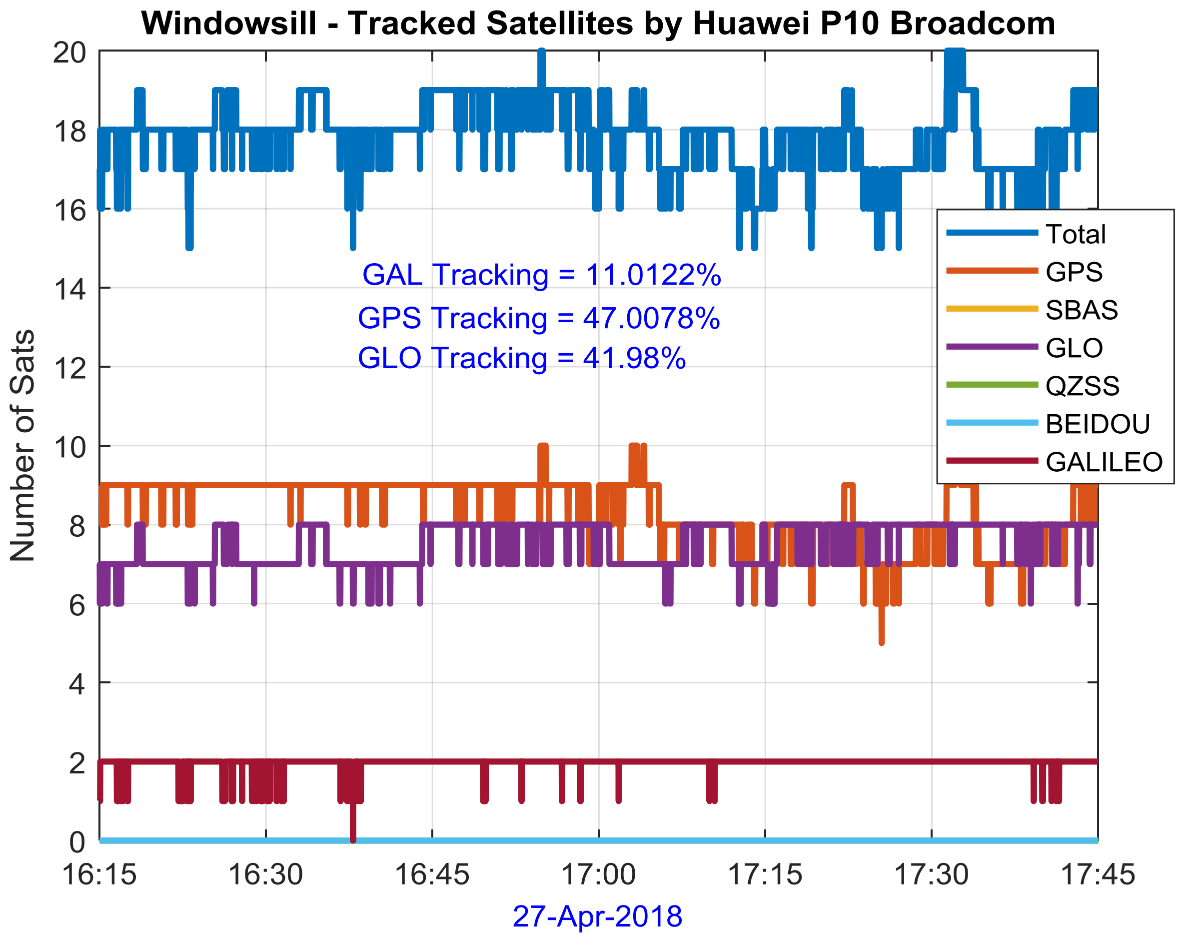
- Huawei uses a bit more of the Galileo measurements for the PVT solution
- BQ tracks almost 2 times more the Galileo satellites compared to Huawei

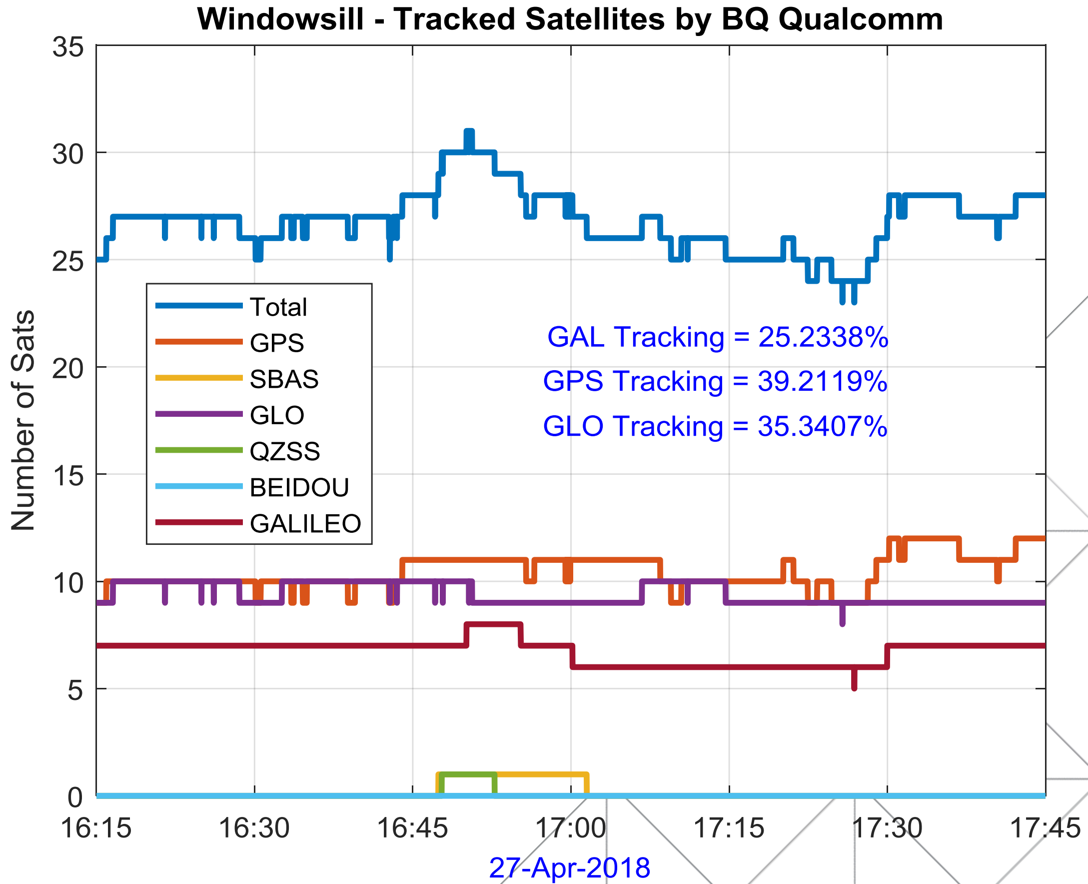


Education/Testing: Outcome of GSA smartphone testing campaign (6)

Tracking per Constellation : Channel allocation per constellation

- Same Scenario for both phones





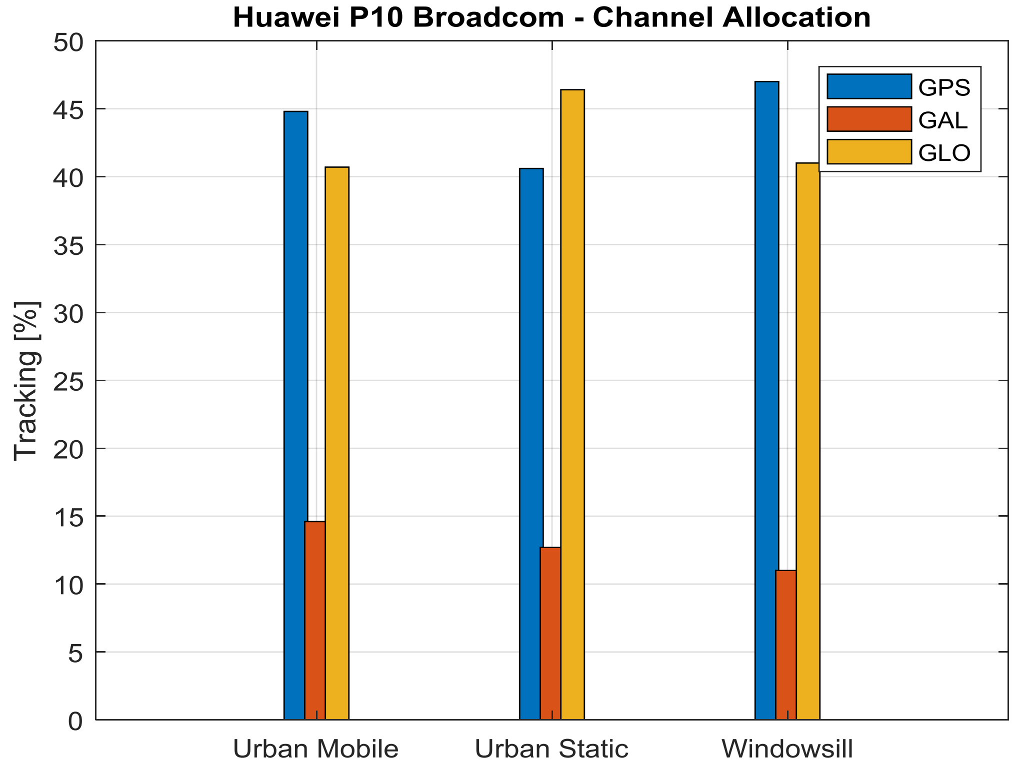
Education/Testing: Outcome of GSA smartphone testing campaign (7)

Tracking per Constellation : Channel allocation per constellation

- Same Scenario for both phones

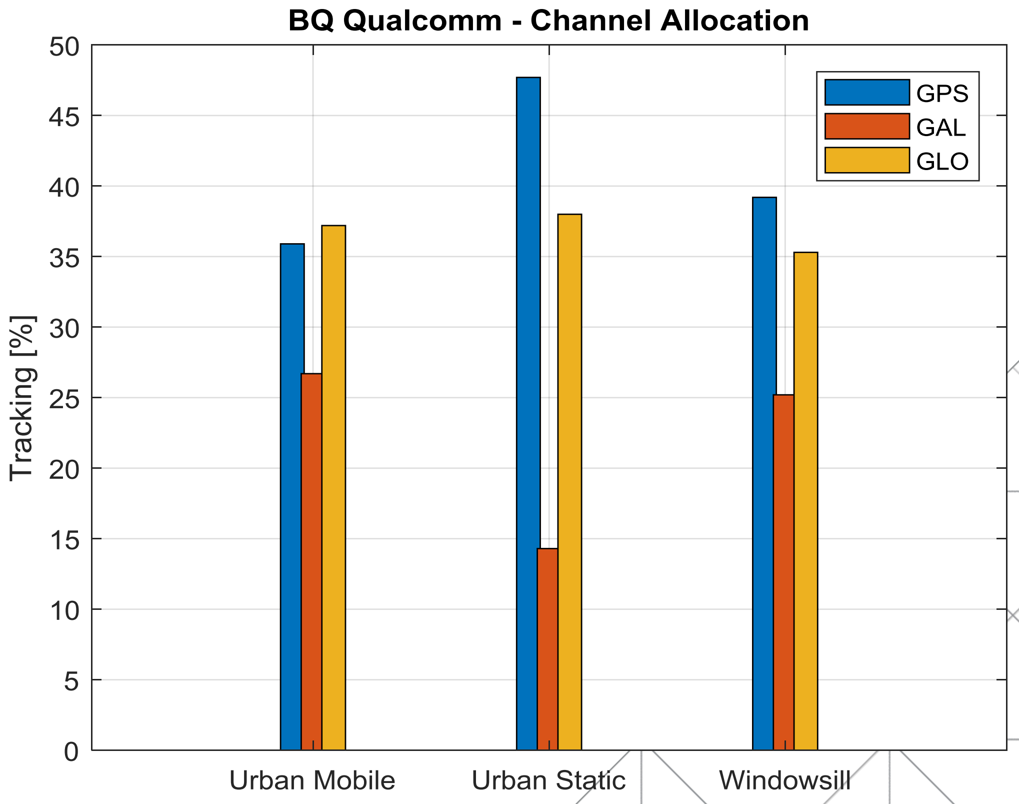
Huawei P10:

- **15%** of the channels track Galileo satellites



BQ:

- **28%** of the channels track Galileo satellites



Android devices that support raw GNSS Measurements

Model	Android version	Automatic Gain Control	Navigation messages	Accumulated delta range	HW clock	Global systems
HTC U11 Plus	8.0	no	no	no	yes	GPS GLONASS
HTC U11 Life	8.0	no	no	no	yes	GPS GLONASS
Huawei Mate 10	8.0	no	yes	yes	yes	GPS GLONASS
Huawei Mate 10 Pro	8.0	no	yes	yes	yes	GPS GLONASS QZSS
Google Pixel 2 XL	8.0	yes	no	no	yes	GPS GLONASS GALILEO BeiDou QZSS
Google Pixel 2	8.0	yes	no	no	yes	GPS GLONASS GALILEO BeiDou QZSS
Sony Xperia XZ1	8.0	no	no	no	yes	GPS GLONASS
Samsung Note 8 (Exynos)	7.1	no	yes	yes	yes	GPS GLONASS GALILEO BeiDou
Samsung Note 8 (QCOM)	7.1	no	no	no	yes	GPS GLONASS GALILEO BeiDou
LG V30	7.1.2	no	no	no	yes	GPS GLONASS
Moto X4 2017	7.1	no	no	no	yes	GPS GLONASS
Essential PH-1	7.1	no	no	no	yes	GPS GLONASS
Moto Z2	7.1	no	no	no	yes	GPS GLONASS
HTC U11	7.1	no	no	no	yes	GPS GLONASS
OPPO R11	7.1	no	no	no	yes	GPS GLONASS GALILEO BeiDou
Huawei Honor 9	7.0	no	yes	yes	yes	GPS GLONASS
Samsung S8 (Exynos)[1]	7.0	no	yes	yes	yes	GPS GLONASS GALILEO BeiDou QZSS
Samsung S8 (QCOM)[2]	7.0	no	no	no	yes	GPS
Huawei P10	7.0	no	yes	yes	yes	GPS GLONASS GALILEO BeiDou QZSS
Huawei P10 Lite	7.0	no	no	no	yes	GPS
Huawei Honor 8	7.0	no	yes	yes	yes	GPS GLONASS BeiDou
Huawei Mate 9	7.0	no	yes	yes	yes	GPS GLONASS BeiDou
Huawei P9	7.0	no	yes	yes	yes	GPS GLONASS BeiDou
Google Pixel XL	7.0	no	no	no	yes	GPS
Google Pixel	7.0	no	no	no	yes	GPS
Nexus 6P[3]	7.0	no	no	no	no	GPS
Nexus 5X[3]	7.0	no	no	no	no	GPS
Nexus 9 (non cellular version)[4]	7.1	no	yes	yes	yes	GPS GLONASS

https://developer.android.com/guide/topics/sensors/gnss

Recently announced first dual-frequency phone

- Xiaomi`s world's first dual-frequency GNSS smartphone Mi8
- Fitted with a Broadcom BCM47755 chip
- launched on May 31
- the world's first smartphone providing below meter accuracy for location-based services and vehicle navigation
- Raw measurements can help to provide even higher accuracy
- Use L1/E1 and L5/E5 frequencies

GSA Task Force: created shortly after Google`s announcement

- **The GSA GNSS Raw Measurements Task Force** was established following the announcement of Google in 2016 to make the Android Raw Measurements available from Android 7.0

  - Continuously open call for participation (write to market@gsa.europa.eu)
  - No fee for membership

- **Objective(s):**

  -"to share knowledge and expertise on Android raw measurements and its wider use, including its potential for high accuracy positioning techniques"

  - "valorise the Galileo differentiators"

GSA Task Force: Short history

Task force had almost 60 members before today`s workshop

- The Task Force includes GNSS experts, scientists and GNSS market players

- First workshop took place in July 2017 (over 30 participants)
  - Meeting served as a **brainstorming event** for what later became the White Paper

- Testing results of some members were presented during ION 2017 conference in Portland, USA

GNSS raw measurements in consumer devices

A playground for scientists or a real market opportunity?

Join the session for an interactive discussion with **Frank van Diggelen** (Google), **Mark Dumville** (NSL), **Moises Navarro** (Astrium) and **Lukasz Bonenberg** (University of Nottingham) and preview the GSA Raw Measurements Task Force White Paper.

Thursday, September 28, 2017 | **2:00 p.m. - 2:45 p.m.** | **Room C120-122**

With a smartphone featuring Android 7.0 (i.e., Nougat), users now have access to raw GNSS measurements. This feature opens the door to higher-accuracy and the development of algorithms once restricted to more advanced GNSS receivers. This new capability will allow users to fully benefit from the special features offered by Galileo, and to combine it with other constellations in the most efficient way.

Although Nougat makes accessing raw data easier, using it remains a challenge. In fact, its use remains largely limited to research centres, universities and GNSS experts – which raises the question: is there real market opportunity in GNSS raw measurements or is it simply a playground for scientists and experts?

To answer this question, the European GNSS Agency (GSA) launched the Raw Measurements Task Force. Comprised of GNSS experts, scientists and market players, the Task Force aims to foster a wider use of these raw measurements. Their White Paper, set to be published soon, will provide application developers with a range of tools, including practical tips and innovative ideas on how to take full advantage of GNSS raw measurements.

To discover smartphones and other devices that are already Galileo-enabled go to: www.useGalileo.eu

A sneak peek at ION

This exclusive session will include:

- First-hand tips and innovative ideas on using GNSS raw measurements
- Results from tests using raw measurements conducted by different experts
- Advice on how to ensure the use of Galileo in smart-phone applications
- Expert insights on the challenges and opportunities of GNSS raw measurements

The session will be moderated by Fiammetta Diani, Deputy Head of Market Development at the European GNSS Agency (GSA).

www.gsa.europa.eu

LINKING SPACE TO USER NEEDS

GSA Task Force: Galileo Raw measurements White Paper published in January 2018

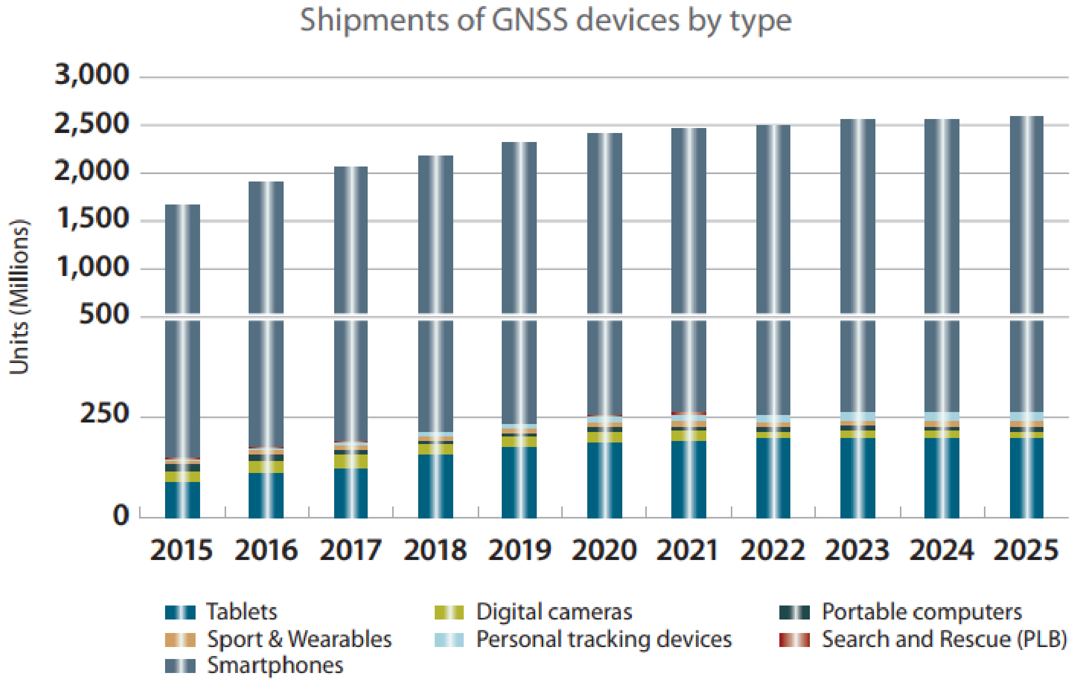
Part I: overview of the theoretical basics needed to reconstruct GNSS raw measurements using Android, including a basic overview of GNSS, GNSS time references, pseudoranges, navigation messages and position estimation

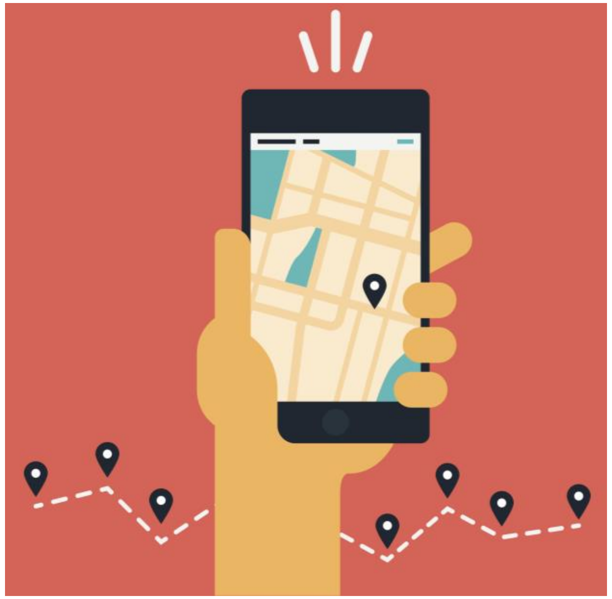
Part II: information on how to access and use raw measurements, including generating pseudoranges and Doppler

Part III: a look at the most promising techniques and discussion on the benefits and limitations of each technique

Part IV: use cases that may benefit from the increased accuracy and integrity obtained with the use of GNSS raw measurements

Smartphones will continue to be the most popular platform to access location-based services





GNSS Market report 2017

Get all the latest GNSS market updates, opportunities and trends on the LBS segment

Available for download on GSA website

The second issue of the GNSS User Technology Report, a publication on user technology

The 2nd edition of the GSA's GNSS User Technology Report is available free of charge

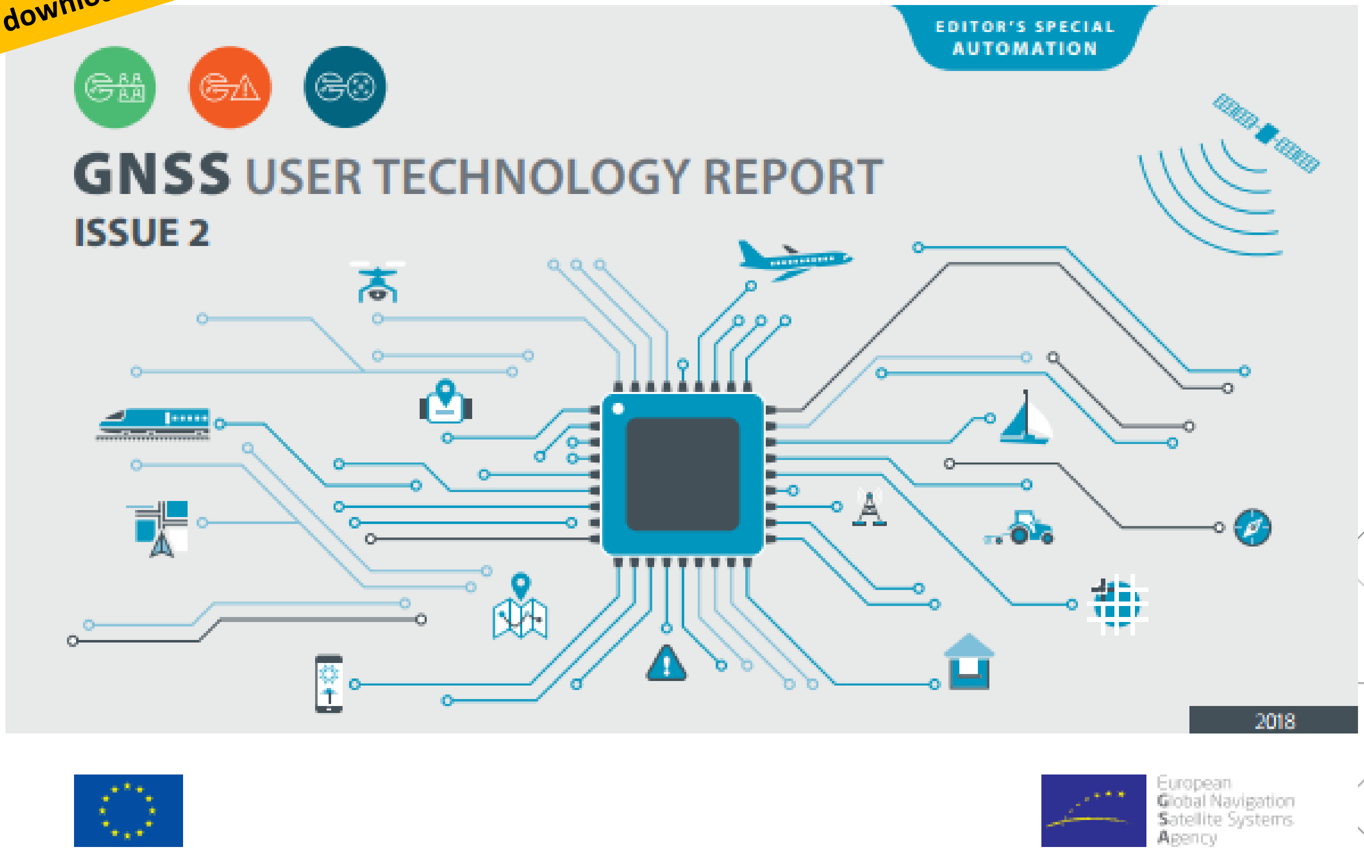
Including:

- General overview of the latest GNSS receiver technology common to all application areas

- An in-depth analysis of GNSS user technology as it pertains to three key macrosegments:
  - ✓ Mass market solutions
  - ✓ Transport safety and liability-critical solutions
  - ✓ High precision, timing and asset management solutions

- Editor's special on Automation and increasingly important role of GNSS

Available for download



Linking space to user needs

How to get in touch: www.GSA.europa.eu

EGNOS-portal.eu

GSC-europa.eu

UseGalileo.eu

Using GNSS Raw Measurements on Android Devices Part II

Towards better location performance in mass market applications

Moises Navarro-Gallardo

AIRBUS

Agenda

- Introduction to GNSS Systems
- PVT Needs
- What are the Raw Measurements?
- GNSS Measurements Generation From Raw Measurements
  - Pseudorange
  - Carrier Phase
  - Doppler
- Examples
  - Dual Frequency
  - Pseudorange generation in Matlab
  - RTK positioning

GNSS Systems: Introduction

DEFENCE AND SPACE

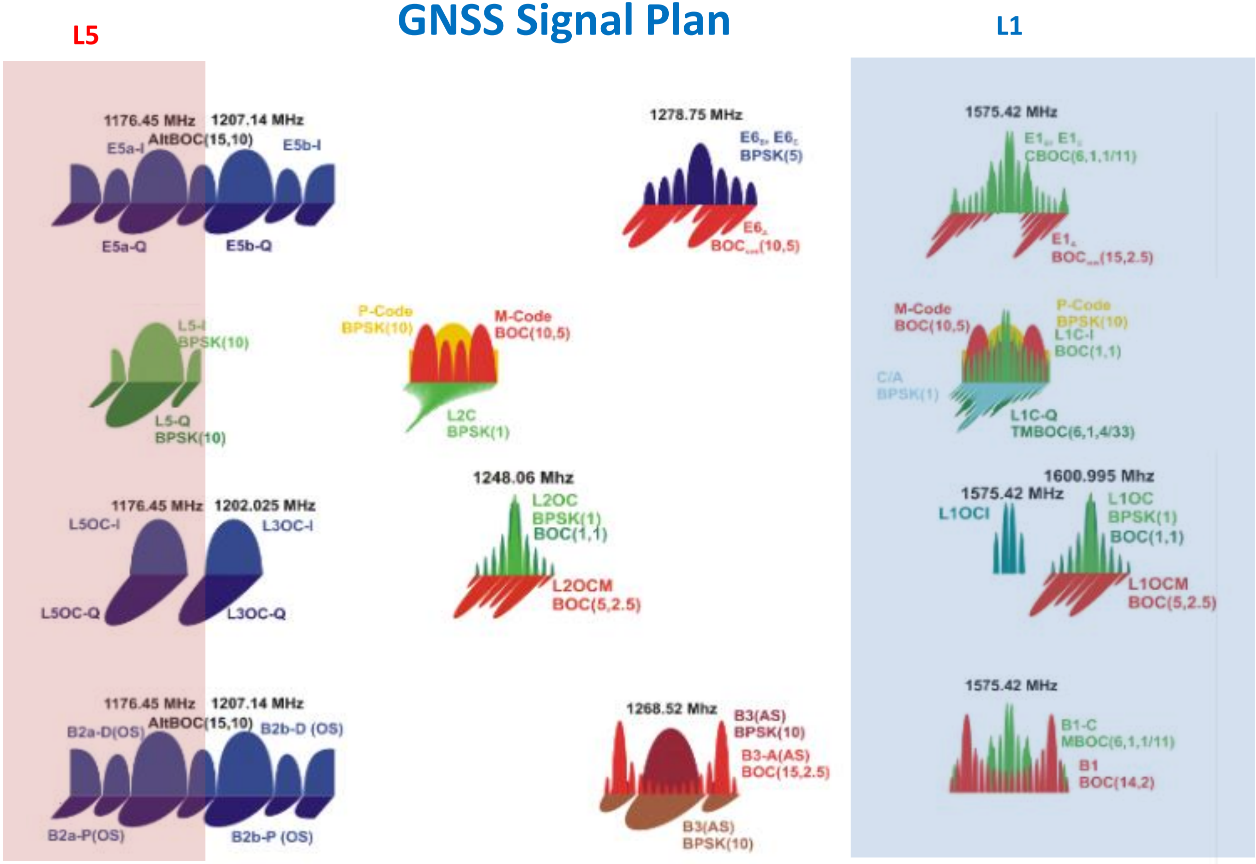
GNSS Signal Plan

Galileo

GPS

GLONASS

BeiDou



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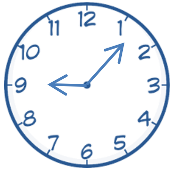
GNSS Systems: Time References I

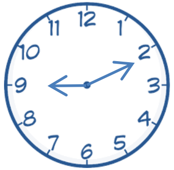
DEFENCE AND SPACE

Galileo System Time

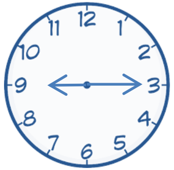


GPS Time

GLONASS Time



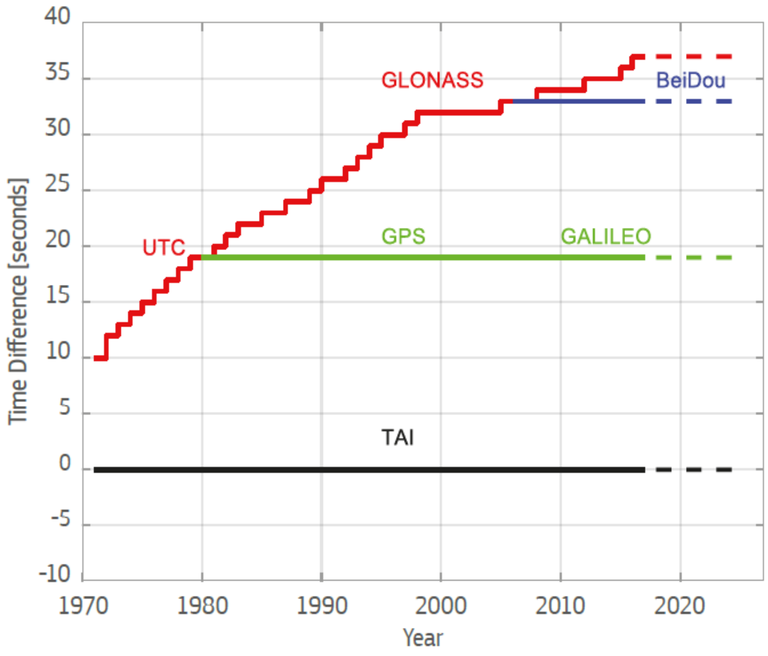
BeiDou Time



- GNSS reference times are really stable
- Each GNSS System has its own System Time
- Each System Time uses its own Reference time
- Biases between reference times are known

- The bias between all GNSS System Times and UTC can be computed

Multi-constellation Receivers only provide one time



These biases are needed for the generation of pseudorange using raw measurements

Time difference between reference times

- Receivers need to know the time differences between systems
- Small variations are computed by each system and broadcasted in the navigation message

Systems	Relationship
GPST - TAI	$TAI = GPST + 19s$
GST - TAI	$TAI = GST + 19s$
GLONASST - TAI	$TAI = GLONASST - 3h + leapsecond$
TAI *UTC-TAI*	$UTC = TAI - leapsecond$
UTC - TAI	$TAI = BDT + 3\ 3s$

Inputs for PVT Computation

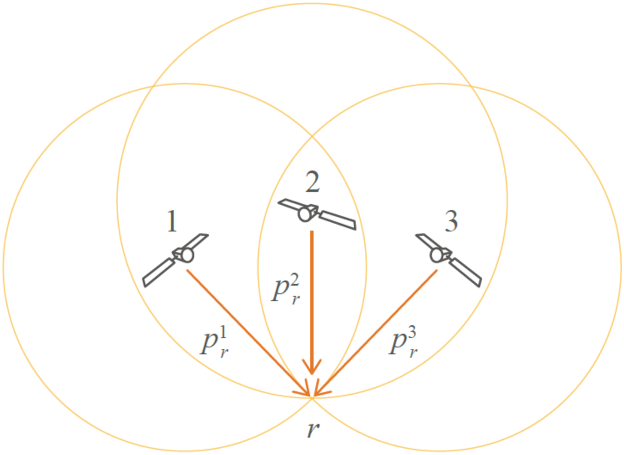
- **Pseudorange**: distance measurements between the user's receiver antenna and the satellite position and the clock bias.

- **Satellite Position**: computed by each GNSS system and broadcasted in the navigation message or obtained by third systems (assisted data).

PVT Computation

- **Clock Bias**: Bias between the receiver time and GNSS System Time. The same bias applies for the entire number of satellites of each constellation.

- At least four pseudorange are needed (x,y,z and the clock bias).
- The navigation solution shall be computed



$$R^j = \rho^j + c \cdot dt_r$$

$$\begin{bmatrix} R^1 - \rho_0^1 \\ \vdots \\ R^n - \rho_0^n \end{bmatrix} = \underbrace{\begin{pmatrix} \frac{x_0 - x^1}{\rho_0^1} & \frac{y_0 - y^1}{\rho_0^1} & \frac{z_0 - z^1}{\rho_0^1} & 1 \\ \vdots & \vdots & \vdots & \vdots \\ \frac{x_0 - x^n}{\rho_0^n} & \frac{y_0 - y^n}{\rho_0^n} & \frac{z_0 - z^n}{\rho_0^n} & 1 \end{pmatrix}}_{H} \begin{bmatrix} dx \\ dy \\ dz \\ c \cdot dt_r \end{bmatrix}$$

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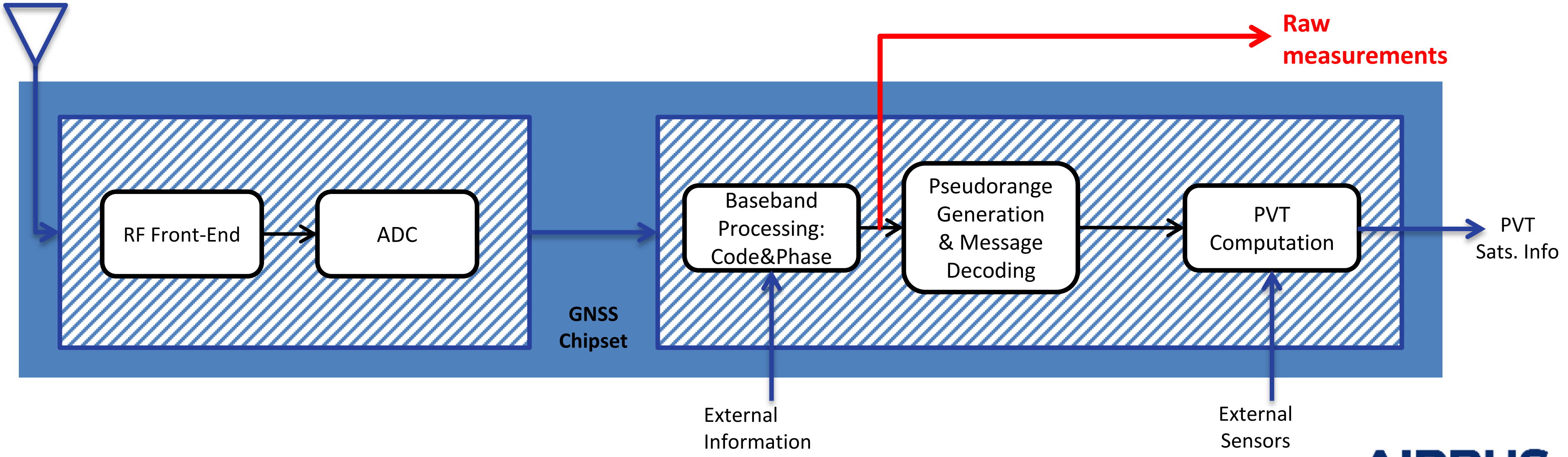
What are the Raw Measurements?

GNSS Chipset Structure

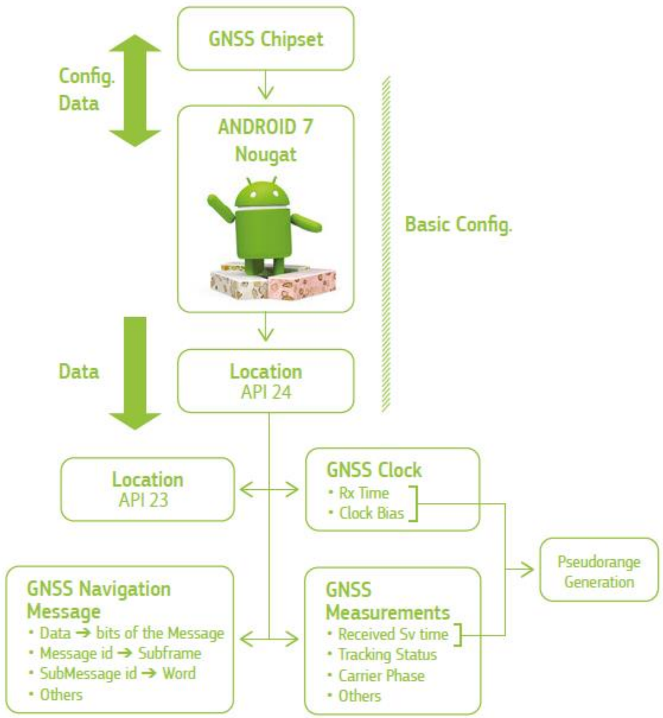
- RF Signal is downconverter to baseband or IF frequency
- The signal is digitalized by the ADC
- The Baseband module tracks the Code and the Carrier
- Pseudoranges and PVT is computed

Raw measurements take place before the pseudorange generation



DEFENCE AND SPACE

Android Raw Measurements



Relation between Raw and typical GNSS Measurements

- The *Accumulated Delta Range* is directly the Carrier Phase
- The *Revived Satellite Time* is needed to Compute the pseudorange
- *Rx Time* is needed to compute the pseudorange
- *Clock Bias* can be used to compute the pseudorange

GNSS Measurement	Raw Meas.	Criteria
Doppler	*PseuRangeRate*	needed
Carrier Phase	*Accumulated Delta Range*	needed
Pseudorange	*Received Satellite Time*	needed
	Rx Time	needed
	Clock Bias	optional

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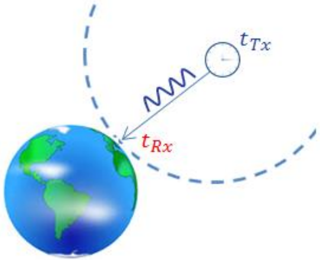
Pseudorange Generation

- The generation is a measurement of distance obtained through time measurements

$$\rho = (t_{Rx} - t_{Tx}) \cdot c$$



t_{Rx} is based on the receiver clock

- t_{Tx} Is the time when the signal was transmitted at the measurement time
  - It is the *Received Satellite time* measurement provided by android raw measurements
  - It is provided in GNSS time → Depends on the constellation
  - Depending on the tracking status it can be ambiguous (explained in the next slide)

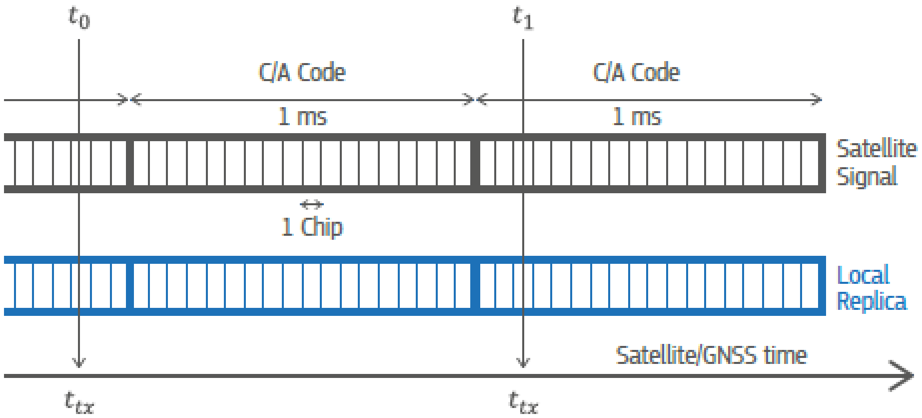
- t_{Rx} is the time when the signal arrived to the received or the measurement time
  - It must be in the same time reference as the T_{Tx}

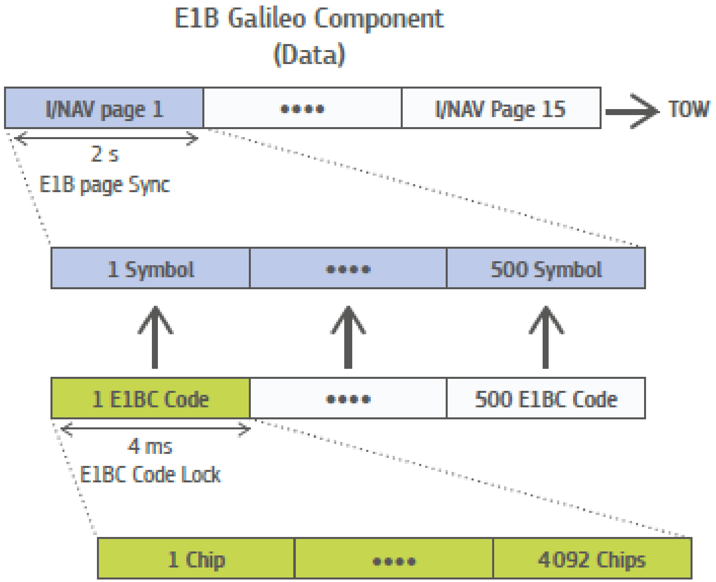
Pseudorange Generation

$$\rho = (t_{Rx} - t_{Tx}) \cdot c$$

- t_{Tx} is provided by Android (*ReceivedSvTimeNanos*).
- Their valid range changes depending on the tracking status.

$$t_0 = t_1$$





Pseudorange Generation

- Ranges bigger than the propagation time can be used for the pseudorange generation

ReceivedSvTimeNanos Range

GPS		GALILEO		GLONASS		BeiDou	
Sync	**Status Time**	**Sync**	**Status Time**	**Sync**	**Status Time**	**Sync**	**Status Time**
C/A code	1 ms	**E1BC code**	4 ms	**C/A code**	1 ms	**C/A code**	1 ms
Bit	20 ms	**E1C 2nd code**	**100 ms**	**Bit**	20 ms	**Bit**	20 ms
Subframe sync	**6 s**	**E1B page**	**2 s**	**String**	**2 s**	**Subframe sync**	**6 s**
TOW	**1 week**	**TOW**	**1 week**	**Time of Day**	**1 day**	**TOW**	**1 week**

$$\rho = (t_{Rx} - t_{Tx}) \cdot c$$

Values bigger than the propagation time can be used for unambiguous pseudorange computation

Pseudorange Generation

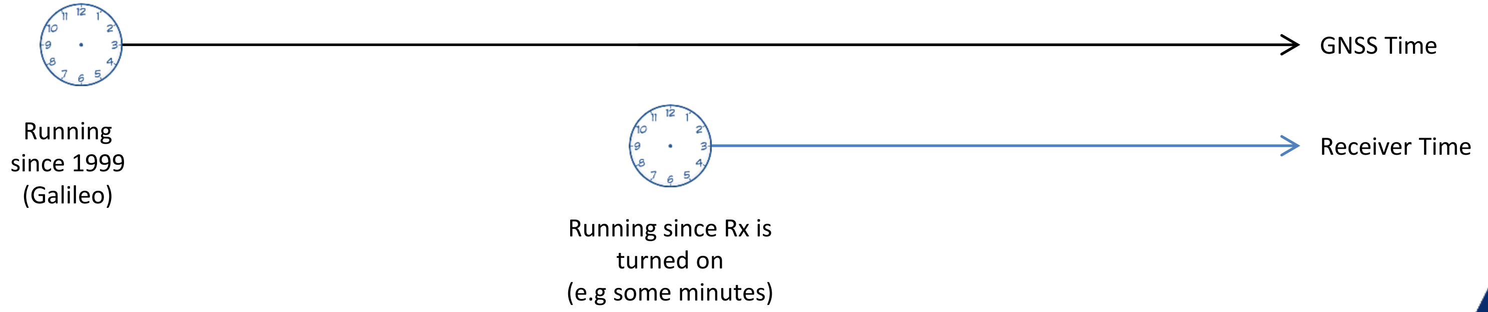
The main task is to compute t_{Rx}

$$\rho = (t_{Rx} - t_{Tx}) \cdot c$$

The receiver only has the internal hardware clock → *TimeNanos* in Android

- The clock is not synchronized with any GNSS system
- The initial time could be when the receiver is turned on

At the beginning there is no information about any GNSS time system



Pseudorange Generation

What is the time difference between the Receiver time and the GNSS time?

↓

<u>The Clock Bias</u>

(*FullBiasNanos* in Android)

Google Solution – Matlab Code (GPS)

```
%compute tRx using gnssRaw.FullBiasNanos(1), so that
% tRx includes rx clock drift since the first epoch:
tRx = gnssRaw.TimeNanos -gnssRaw.FullBiasNanos(1) - weekNumberNanos;
```

↑ **Receiver clock** Provided by Android

↑ First Sample of the **Clock Bias** Computed in PVT

↑ Needed since t_{Tx} is in TOW range

Pseudorange Generation

What is the time difference between the Receiver clock and the GNSS clock?

<u>The Clock Bias</u>

(*FullBiasNanos* in Android)

Google Solution – Matlab Code

```
%compute tRx using gnssRaw.FullBiasNanos(1), so that
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tRx = gnssRaw.TimeNanos -gnssRaw.FullBiasNanos(1) - weekNumberNanos;
```

↑ **Receiver clock** Provided by Android

↑ First Sample of the **Clock Bias** Computed in PVT

↑ Needed since t_{Tx} is in TOW range

Pseudoranges are needed for PVT but Clock bias (from PVT) is needed for pseudorange generation

Pseudorange Generation

A different Approach

Lets going to roughly Synchronize the *Receiver Clock* with a GNSS System Time

- We can assume a standard propagation delay between the GNSS satellites and a receiver in the earth.

$$PropagationTimeRef = 70\ ms$$

  - Standard values are between 65 and 85 milliseconds

- The Receiver clock is initialized based on the first measurement receiver plus a propagation delay

```
tRxNanos = TimeNanos - TimeNanos(1) + ReceivedSvTimeNanos(1) + PropagationTimeRef
```

`TimeNanos - TimeNanos(1)`: We initialize the receiver clock to 0

`TimeNanos - TimeNanos(1) + ReceivedSvTimeNanos(1) + PropagationTimeRef`: We sum the GNSS time of the first sample + a propagation delay

Pseudorange Generation

$$\rho = (t_{Rx} - t_{Tx}) \cdot c$$

GPS and Galileo TOW Pseudoranges

- Pseudorange can be computed as (nanoseconds)

```
pr = ( tRx - tTx )C
```

Galileo 2nd Code Lock

- Since the valid range is 100 milliseconds the pseudorange can be computed. The mod operator 100 milliseconds (nanoseconds) is needed

```
pr = ( mod(tRx,100Milli) - mod(ReceivedSvTime, 100Milli) )
```

GLONASS Pseudoranges

- The time difference can be applied using the mod operator 1 day (nanoseconds)
- The leap second and the UTC difference must be taken into account

```
pr = ( mod(tRx, DAYSEC) + 3h +LeapSecond - tTx )
```

Doppler Generation

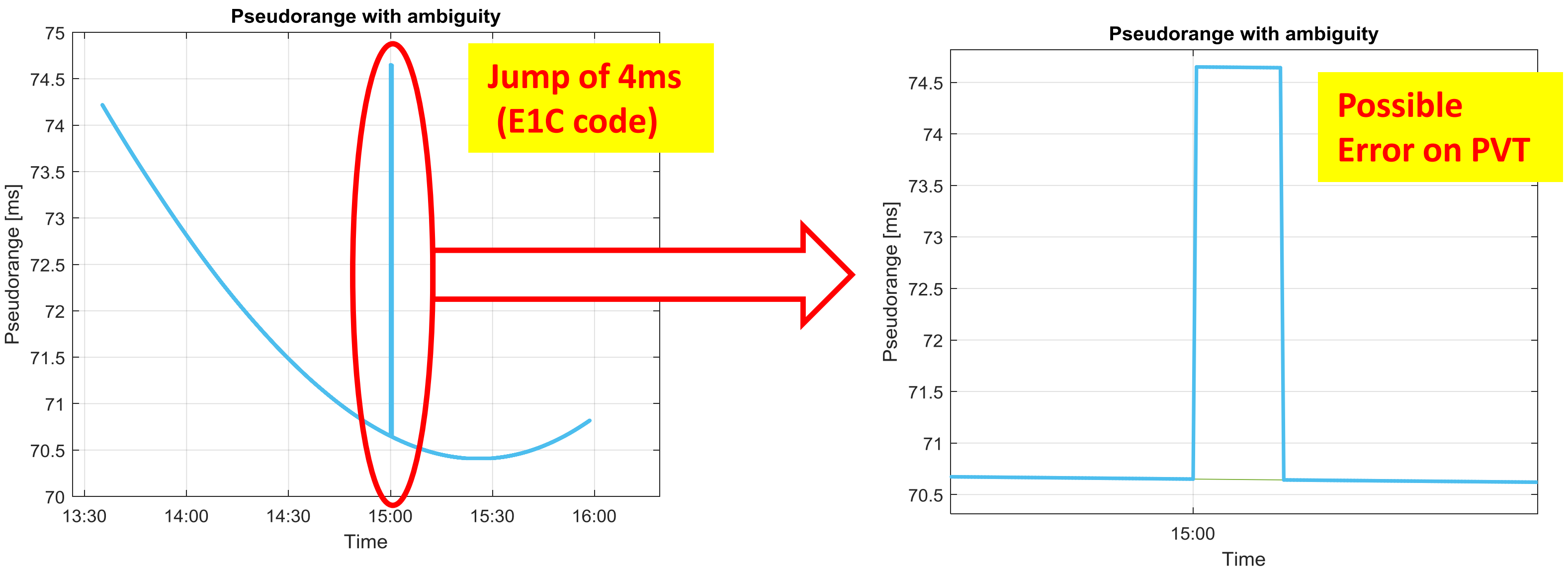
- The Doppler can be generated using the rate of the pseudorange (*PseudorangeRatemetersperSecond)*
  - It is provided directly by android
- The Doppler can be generated as

$$\mathrm{D} = -PseudorangeRatemetersperSecond * \frac{Frequency}{c} \; [Hz]$$

Frequency is the center frequency of the signal, e.g. L1 = 1.57542 GHz.

Pseudoranges ambiguous

- There is a jump of 4 ms (Galileo E1C code length)
- After some epochs the pseudoranges goes back to the right value
- During the "jump epochs" the measurements can affect the positioning accuracy



How to correct the pseudoranges?

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PVT Computation: Ambiguity Resolution II

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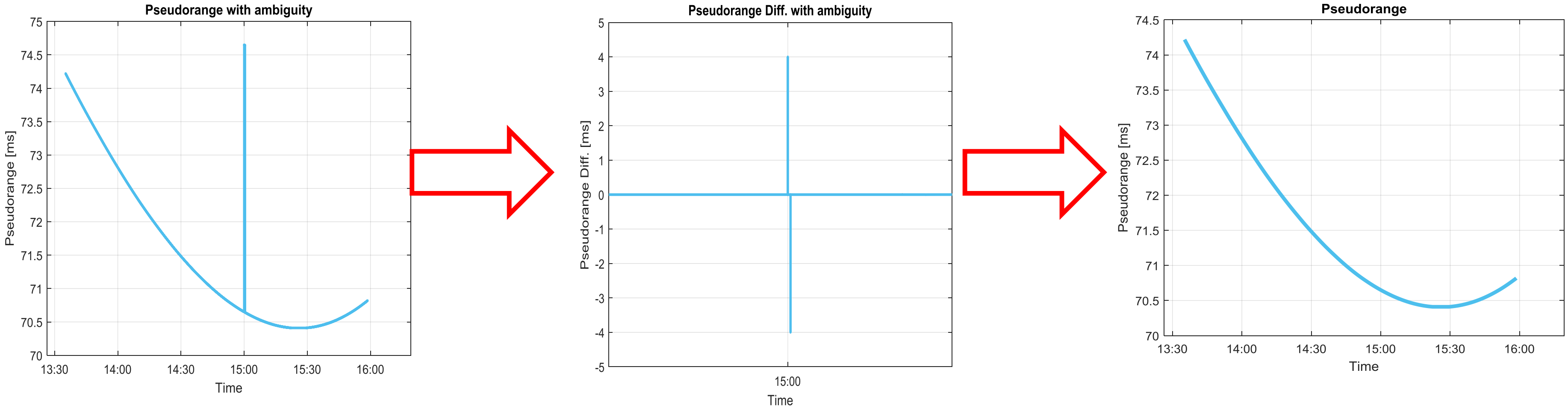
- The difference between 2 consecutive samples is applied to the pseudorange:

$$pr_{diff} = pr[n+1] - pr[n]$$

- A value around 4 (absolute value) indicates a jump in the pseudorange.
- From the detected epoch, all the measurements must be moved

$$pr[jump:end] = pr[jump:end] +/-4ms$$



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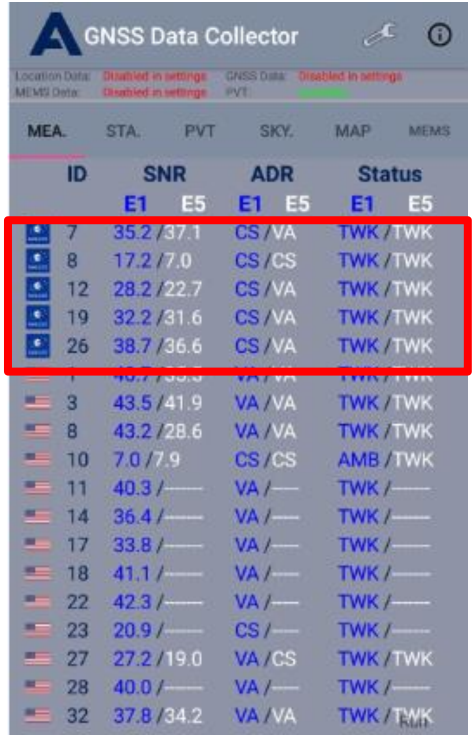
Dual Frequency Smartphone

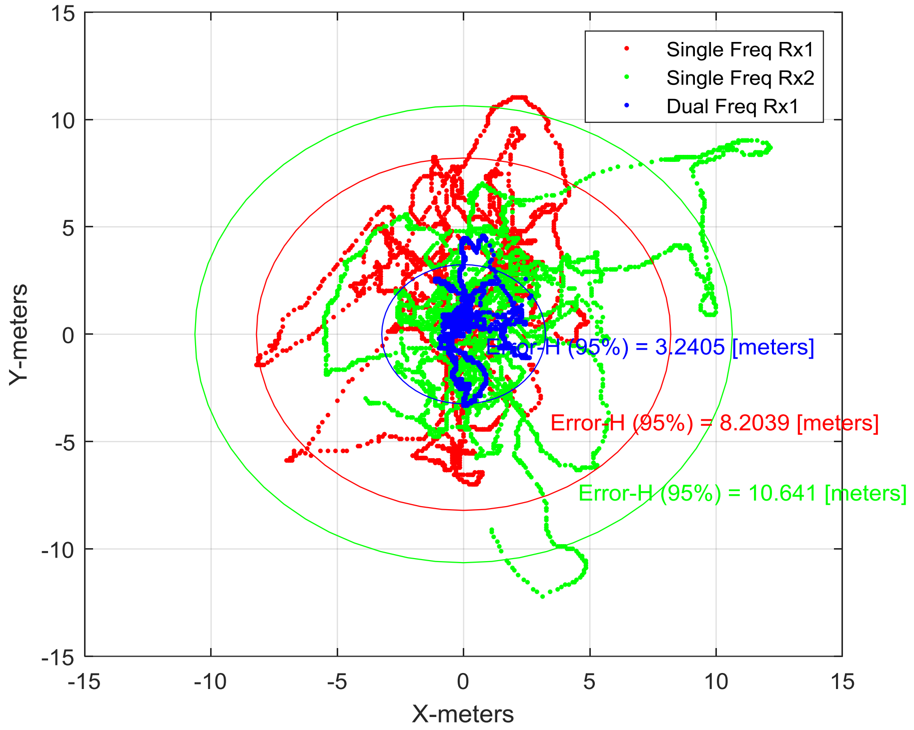
Airbus Roof


GNSS Data Collector

Location Data: Disabled in settings GNSS Data: Disabled in settings
MEMS Data: Disabled in settings PVT:

MEA. STA. PVT SKY. MAP MEMS

ID	SNR E1 / E5	ADR E1 / E5	Status E1 / E5
7	35.2 /37.1	CS /VA	TWK /TWK
8	17.2 /7.0	CS /CS	TWK /TWK
12	28.2 /22.7	CS /VA	TWK /TWK
19	32.2 /31.6	CS /VA	TWK /TWK
26	38.7 /36.6	CS /VA	TWK /TWK
1	[illegible]	VA /VA	TWK /TWK
3	43.5 /41.9	VA /VA	TWK /TWK
8	43.2 /28.6	VA /VA	TWK /TWK
10	7.0 /7.9	CS /CS	AMB /TWK
11	40.3 /——	VA /——	TWK /——
14	36.4 /——	VA /——	TWK /——
17	33.8 /——	VA /——	TWK /——
18	41.1 /——	VA /——	TWK /——
22	42.3 /——	VA /——	TWK /——
23	20.9 /——	CS /——	TWK /——
27	27.2 /19.0	VA /CS	TWK /TWK
28	40.0 /——	VA /——	TWK /——
32	37.8 /34.2	VA /VA	TWK /TWK



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Pseudorange Generation

What do we need?

- Raw measurement log file
- PC running Matlab

LET'S DO IT TOGETHER!

RTK Positioning Using Raw Measurements

What do we need?

- Raw measurements → Transform to a RINEX file
- Ephemerids & Observations → Download from Internet
- RTK tool → Lets use RTKLIB (public tool ☺)

LET'S DO IT TOGETHER!

Earth Observation, Navigation and Science

Using GNSS Raw Measurements on Android Devices Part II

Moises.navarro.gallardo@airbus.com

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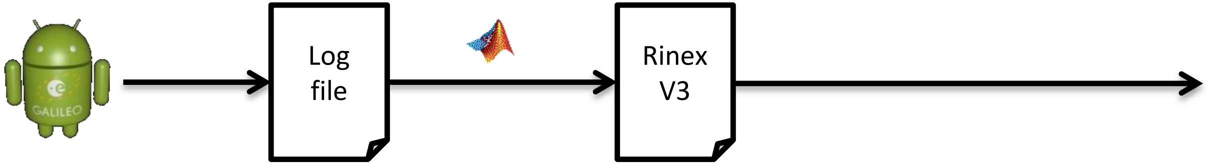
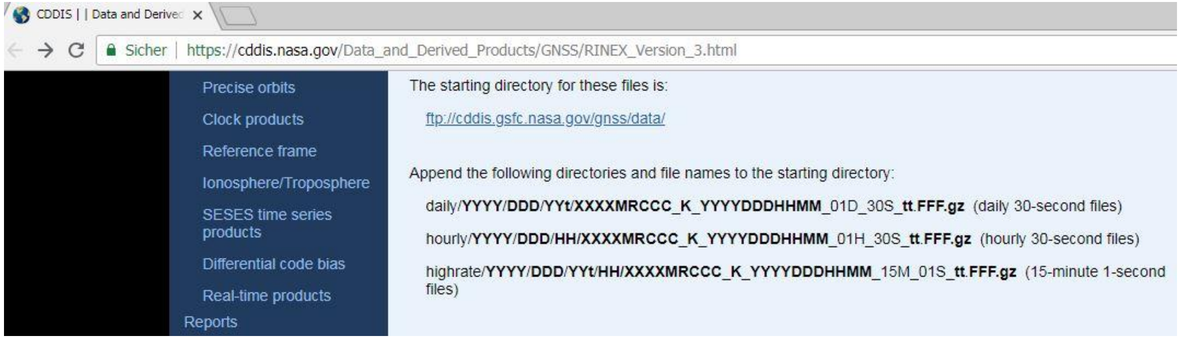
RTK Positioning Using Raw Measurements

- ➢ Raw measurements → Transform to a RINEX file




```
     3.03           Observation Data    M: Mixed            RINEX VERSION / TYPE
GNSS Data Collector AIRBUS              20180515 085205 UTC PGM / RUN BY / DATE
                                                            MARKER NAME
                                                            MARKER TYPE
SMSw                unknown                                 OBSERVER / AGENCY
unknown             Smartphone          Android 7           REC # / TYPE / VERS
n/a                 built-in                                ANT # / TYPE
        0.0000        0.0000        0.0000                  APPROX POSITION XYZ
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
G    4 C1C L1C D1C S1C                                      SYS / # / OBS TYPES
R    4 C1C L1C D1C S1C                                      SYS / # / OBS TYPES
E    4 C1X L1X D1X S1X                                      SYS / # / OBS TYPES
  2018    05    15    08    52   35.0000000     GPS         TIME OF FIRST OBS
                                                            GLONASS COD/PHS/BIS
                                                            END OF HEADER
> 2018 05 15 08 52 35.0000000  0 14
G10  23955980.020 5 118169990.271       -1350.136         43.955
G12  21531513.443 5 118139269.071        1719.489         49.427
G13  23051503.476 5 118206846.658       -4578.088         45.682
G15  21641474.619 5 118194717.660       -3475.211         48.353
G17  22196364.377 5 118173028.586       -1647.119         48.032
G19  21471384.969 5 118155029.817         142.804         47.064
G20  24524065.143 5 118193171.666       -3662.476         40.303
G24  20401769.249 5 118156056.786          41.622         49.186
G28  25159566.095 5 118197671.760       -4111.480         37.504
G32  25696543.253 5 118127857.492        2599.469         40.749
E02  28898377.669 0                     -2999.022         45.115
E07  24714382.989 5 118182491.772       -2600.903         47.159
E08  28783488.206 0                     -4163.898         39.337
E30  21557286.001 5 118165246.080        -875.969         47.303
> 2018 05 15 08 52 36.0000000  0 13
G10  23956234.244 5 118171340.596       -1350.461         43.812
```

- ➢ Ephemerids & Observations (RINEX)
  - ➢ Download from Internet
  - ➢ Local Base Stations



http://cddis.nasa.gov/Data_and_Derived_Products/GNSS/RINEX_Version_3.html

Examples: RTK

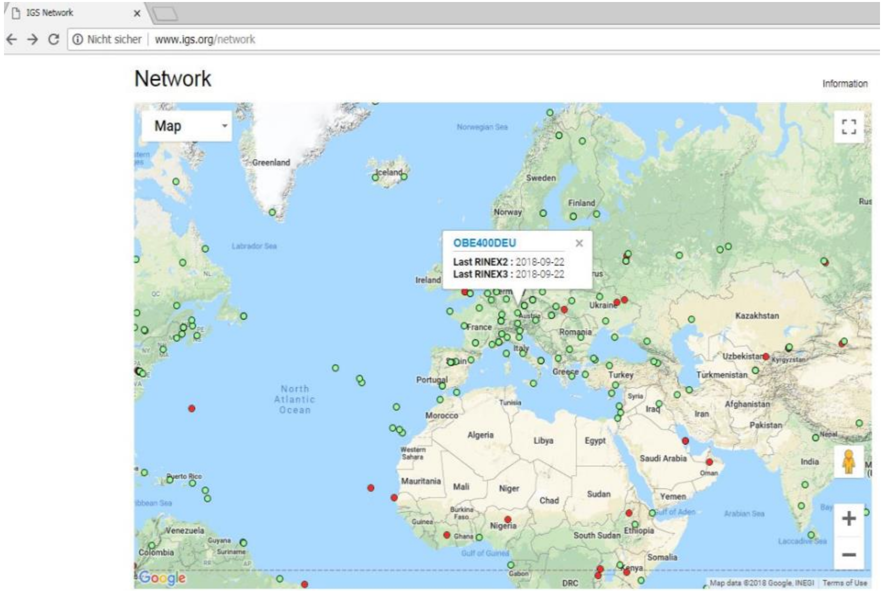
RTK Positioning Using Raw Measurements

- Ephemerids & Observations → Download from Internet

http://cddis.nasa.gov/Data_and_Derived_Products/GNSS/RINEX_Version_3.html

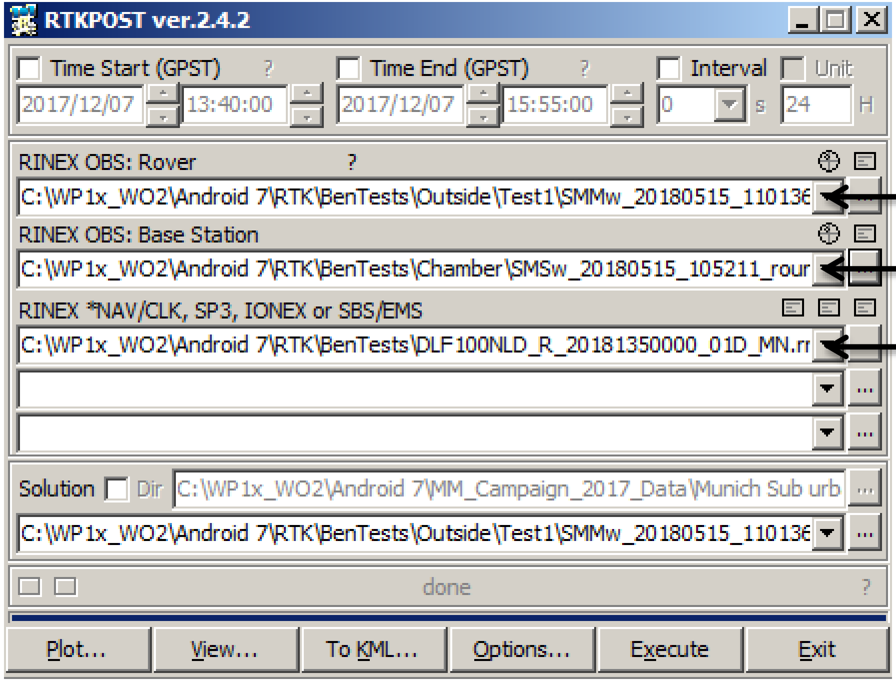
Code	Meaning
XXXX	4-character IGS station name
M	monument or marker number (0-9)
R	receiver number (0-9)
CCC	ISO country code
K	Data source: R = From Receiver data using vendor or other software S = From data Stream (RTCM or other) U = Unknown
YYYY	4-digit Gregorian year
DDD	3-digit day of year
YY	2-digit year
t	type of data: d = Hatanaka-compressed observation data f = Beidou navigation message data g = GLONASS navigation message data h = SBAS payload navigation message data l = GALILEO navigation message data m = meteorological data n = GPS navigation message data o = observation data p = mixed GNSS navigation message data q = QZSS navigation message data s = observation summary files (extracted from RINEX header)
HH	2-digit hour
MM	2-digit minute
tt	type of data: GO = GPS Obs. RO = GLONASS Obs. EO = Galileo Obs. JO = QZSS Obs. CO = BDS Obs. IO = IRNSS Obs. SO = SBAS Obs. MO = Mixed Obs. GN = Nav. GPS RN = GLONASS Nav. EN = Galileo Nav. JN = QZSS Nav. CN = BDS Nav. IN = IRNSS Nav. SN = SBAS Nav. MN = Nav. (All GNSS Constellations) MM = Meteorological Observation
FFF	File format: rnx = RINEX crx = Hatanaka Compressed RINEX
.gz	Compressed file

www.igs.org\network



RTK Positioning Using Raw Measurements

- RTKLIB



RINEX created from raw data

Observation RINEX (internet)

Navigation RINEX (internet)

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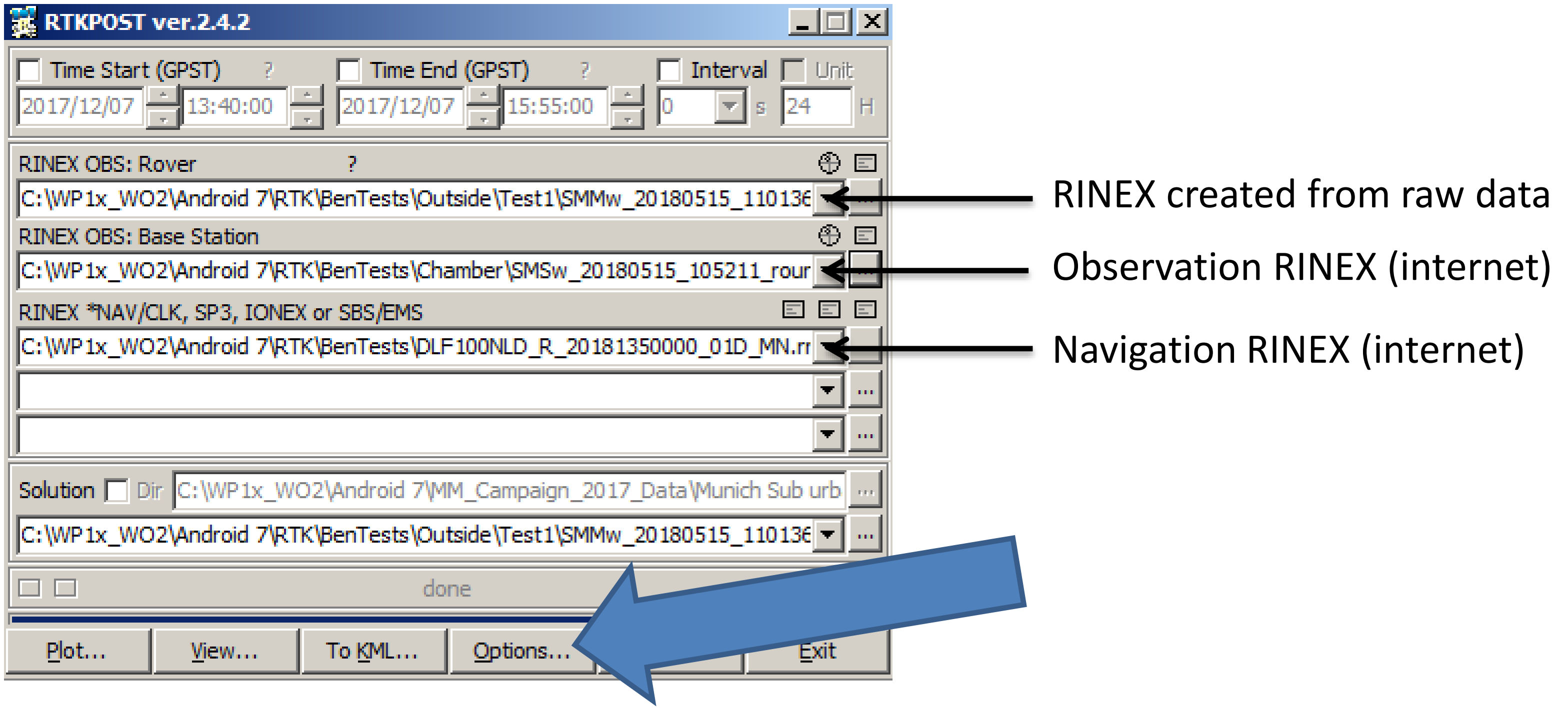
RTK Positioning Using Raw Measurements

- RTKLIB



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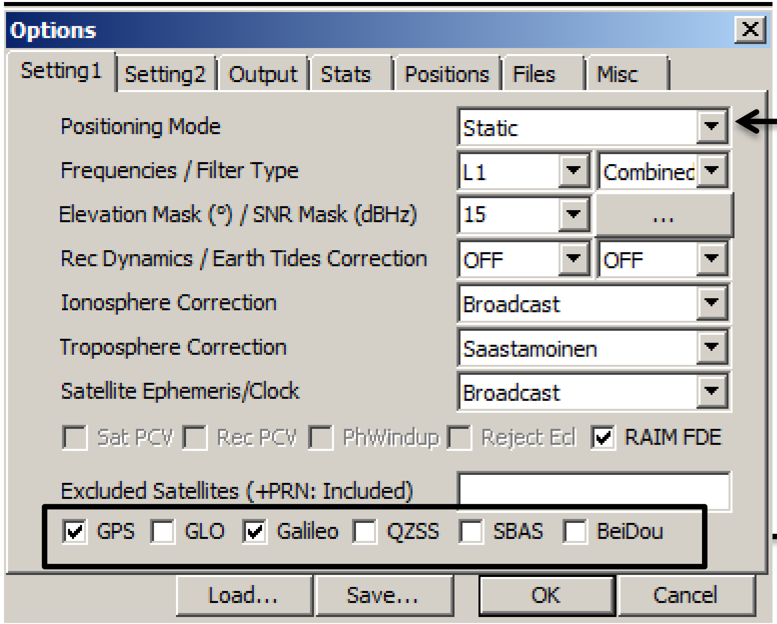
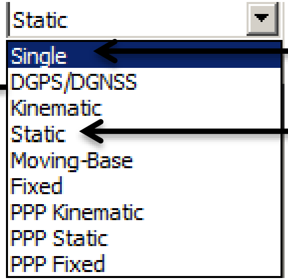
RTK Positioning Using Raw Measurements

- ➢ RTKLIB





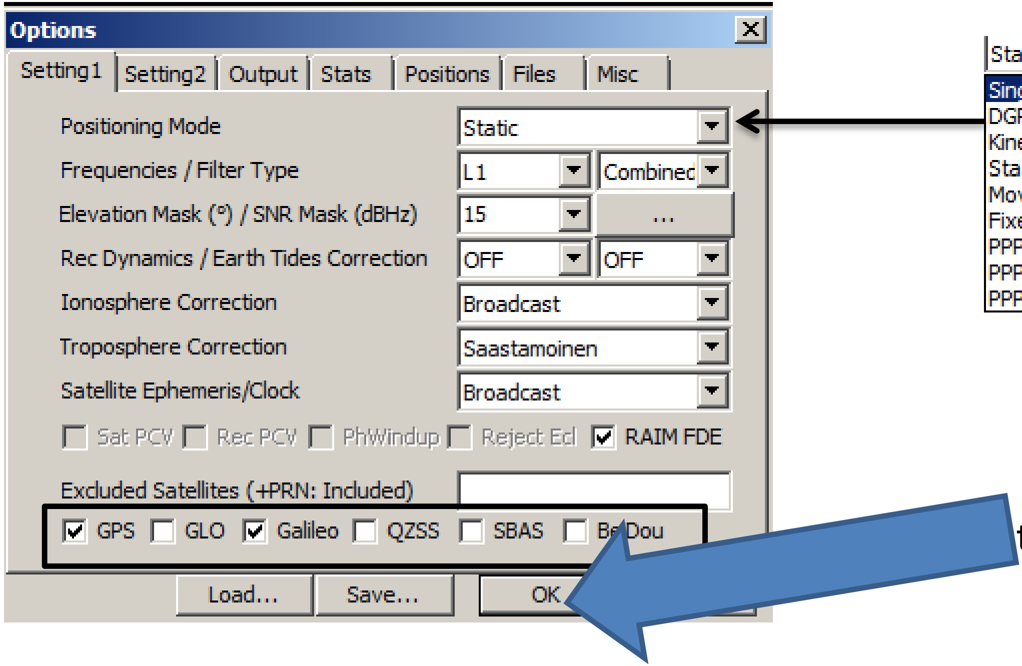
Standalone

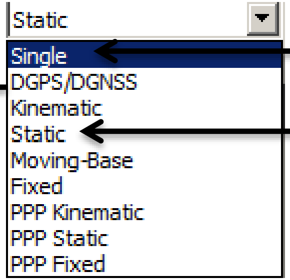
Smartphone Static RTK

Constellations to be used

RTK Positioning Using Raw Measurements

➢ RTKLIB





Standalone

Smartphone
Static RTK

tellations to be used

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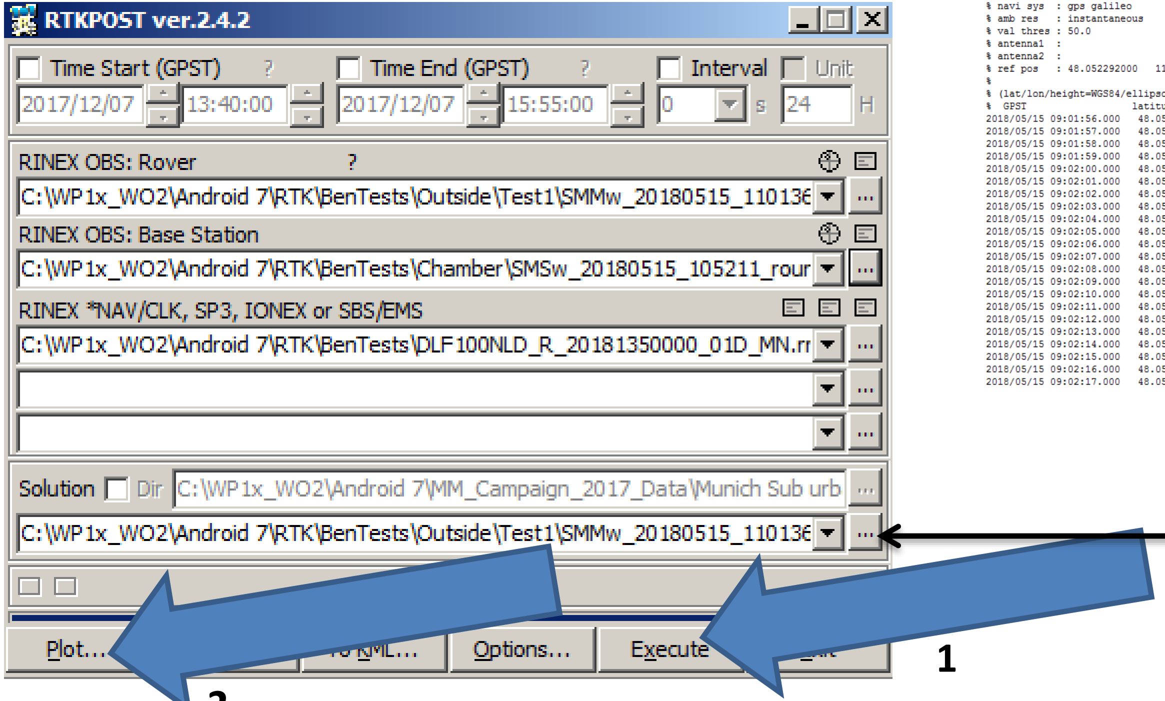
RTK Positioning Using Raw Measurements

- RTKLIB



1

2

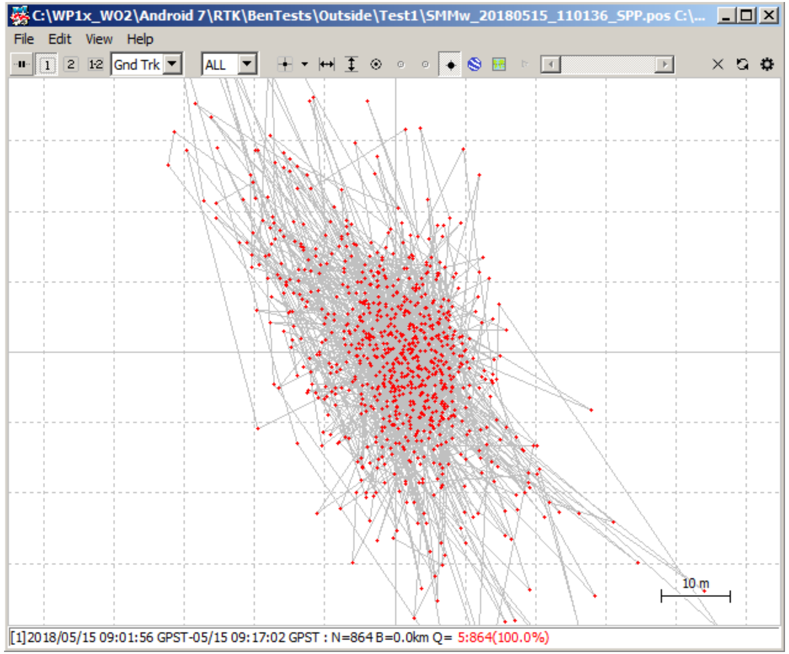
```
% ionos opt : broadcast
% tropo opt : saastamoinen
% ephemeris : broadcast
% navi sys  : gps galileo
% amb res   : instantaneous
% val thres : 50.0
% antenna1  :                       ( 0.0000  0.0000  0.0000)
% antenna2  :                       ( 0.0000  0.0000  0.0000)
% ref pos   : 48.052292000   11.653226000   631.5896
%
% (lat/lon/height=WGS84/ellipsoidal,Q=1:fix,2:float,3:sbas,4:dgps,5:single,6:ppp,ns=# of satellites)
%  GPST                    latitude(deg) longitude(deg)  height(m)   Q  ns   sdn(m)   sde(m)   sdu(m)  sdne(m)  sdeu(m)  sdun(m) age(s)  ratio
2018/05/15 09:01:56.000   48.051653015   11.655380650   611.8123   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.1
2018/05/15 09:01:57.000   48.051652845   11.655380783   611.8275   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.2
2018/05/15 09:01:58.000   48.051653071   11.655380639   611.8559   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.0
2018/05/15 09:01:59.000   48.051652771   11.655380887   611.8554   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.3
2018/05/15 09:02:00.000   48.051652968   11.655380757   611.8703   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.1
2018/05/15 09:02:01.000   48.051653060   11.655380639   611.8294   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.1
2018/05/15 09:02:02.000   48.051653193   11.655380597   611.8319   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.8
2018/05/15 09:02:03.000   48.051653061   11.655380808   611.8433   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.0
2018/05/15 09:02:04.000   48.051652961   11.655380650   611.8272   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.4
2018/05/15 09:02:05.000   48.051653189   11.655380520   611.8556   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.3
2018/05/15 09:02:06.000   48.051653104   11.655380532   611.8335   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.3
2018/05/15 09:02:07.000   48.051652982   11.655380735   611.8325   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.0
2018/05/15 09:02:08.000   48.051652984   11.655380605   611.8134   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.5
2018/05/15 09:02:09.000   48.051653193   11.655380614   611.8325   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.1
2018/05/15 09:02:10.000   48.051653038   11.655380496   611.8414   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    2.0
2018/05/15 09:02:11.000   48.051652831   11.655380719   611.8373   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    3.0
2018/05/15 09:02:12.000   48.051653028   11.655380826   611.8479   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.1
2018/05/15 09:02:13.000   48.051652951   11.655380686   611.8024   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.2
2018/05/15 09:02:14.000   48.051653052   11.655380636   611.8260   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.1
2018/05/15 09:02:15.000   48.051653005   11.655380705   611.8248   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.3
2018/05/15 09:02:16.000   48.051652861   11.655380926   611.8274   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    2.0
2018/05/15 09:02:17.000   48.051652868   11.655380676   611.8341   2   7   0.0312   0.0239   0.0685  -0.0181   0.0246  -0.0310   0.00    1.1
```

Name of the new file

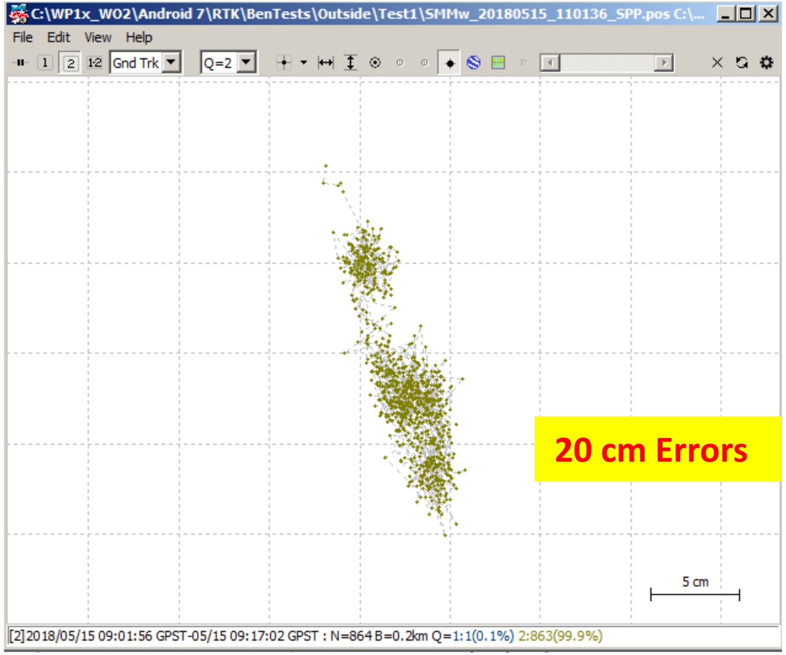
RTK Positioning Using Raw Measurements

- RTKLIB

Single Point Positioning



RTK



Earth Observation, Navigation and Science

Using GNSS Raw Measurements on Android Devices Part II

Moises.navarro.gallardo@airbus.com

AIRBUS

Using GNSS Raw Measurements on Android Devices – Part III

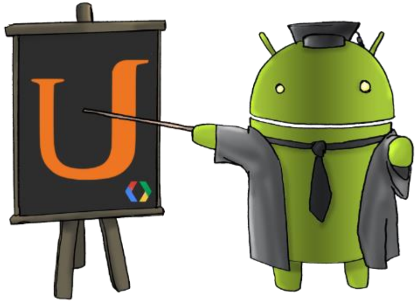
Towards better location performance in mass market applications

Dr. Gaetano Galluzzo
Galileo Service Performance Engineer
ESA-ESTEC

24/09/2018

Outline

1. Results from 1st Galileo App Competition
    - Teams and apps developed
    - GNSS Compare, winning app
    - In field app testing
2. Current smartphone positioning performance
    - From open-sky to urban and indoor
3. Towards sub-meter High Accuracy Apps
    - Dual Frequency
    - Carrier Phase
    - User algorithms
4. Expected Android P location enhancements
    - Wi-Fi RTT for indoors
5. Hands-on examples (MATLAB, RTKLIB)



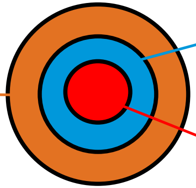
Galileo Android App Competition

The context of the challenge

→ Launch of the ESA internal competition: *October 2017*

→ Objectives of the competition

Form teams
(3 to 5 persons)



Design an Android application that processes GNSS Raw measurements

Galileo only, GPS only and Galileo+GPS PVT functionalities

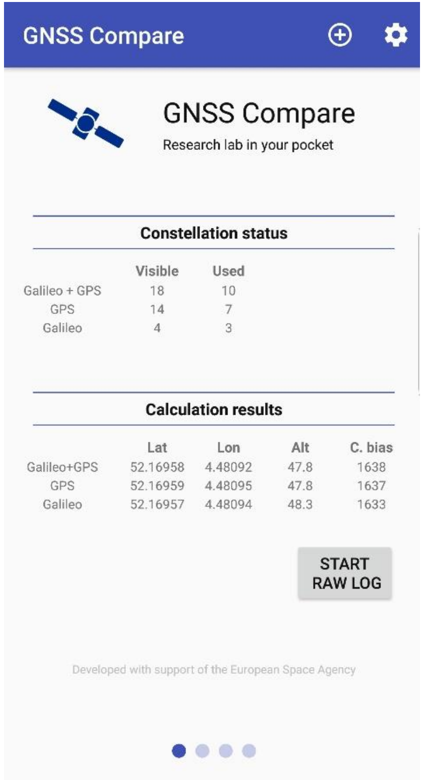
→ Three teams into the final:

Galocator
(Team 5G)

Calisto
(Chocolateam)

GNSS Compare
(The Galfins)

GNSS Compare – Winning App



Supported constellations:

- Galileo, GPS (separate or combined)

Implemented PVT estimators:

- Weighted Least Squares
- Extended Kalman Filter *(initialized with Android FINE location)*

Data logging formats:

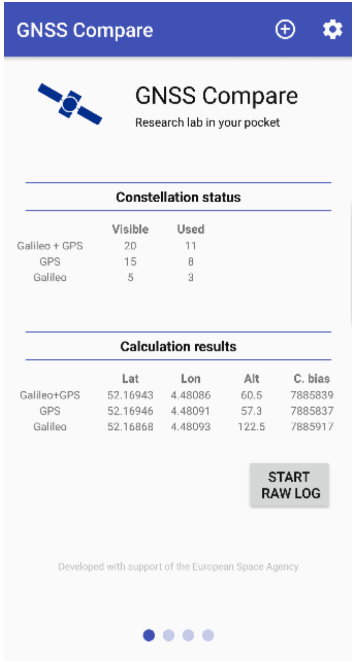
- Simple logger (UTC timestamp, X, Y ,Z)
- NMEA (UTC timestamp, lat, lon, alt, CN0)

Available on Google Play:

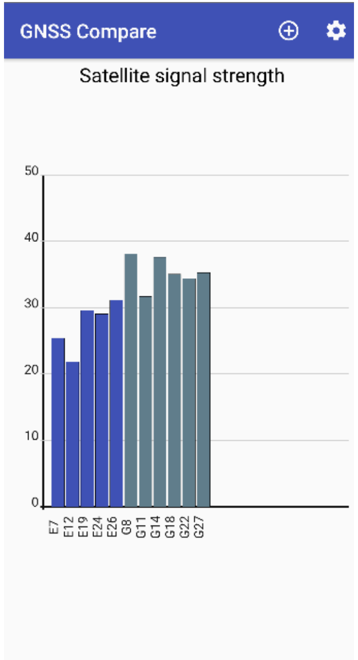
→ **Online documentation** https://gnss-compare.readthedocs.io

ESA YGT winning team, “The Galfins”: *Mareike Burba, Sebastian Ciuban, Dominika Perz, Mateusz Krainski*

GNSS Compare as an educational tool

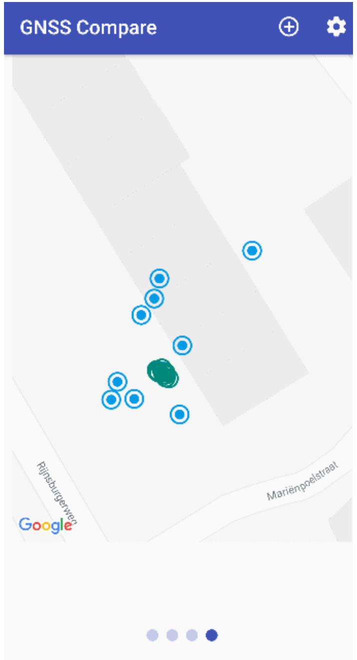


Real-time PVT estimations display



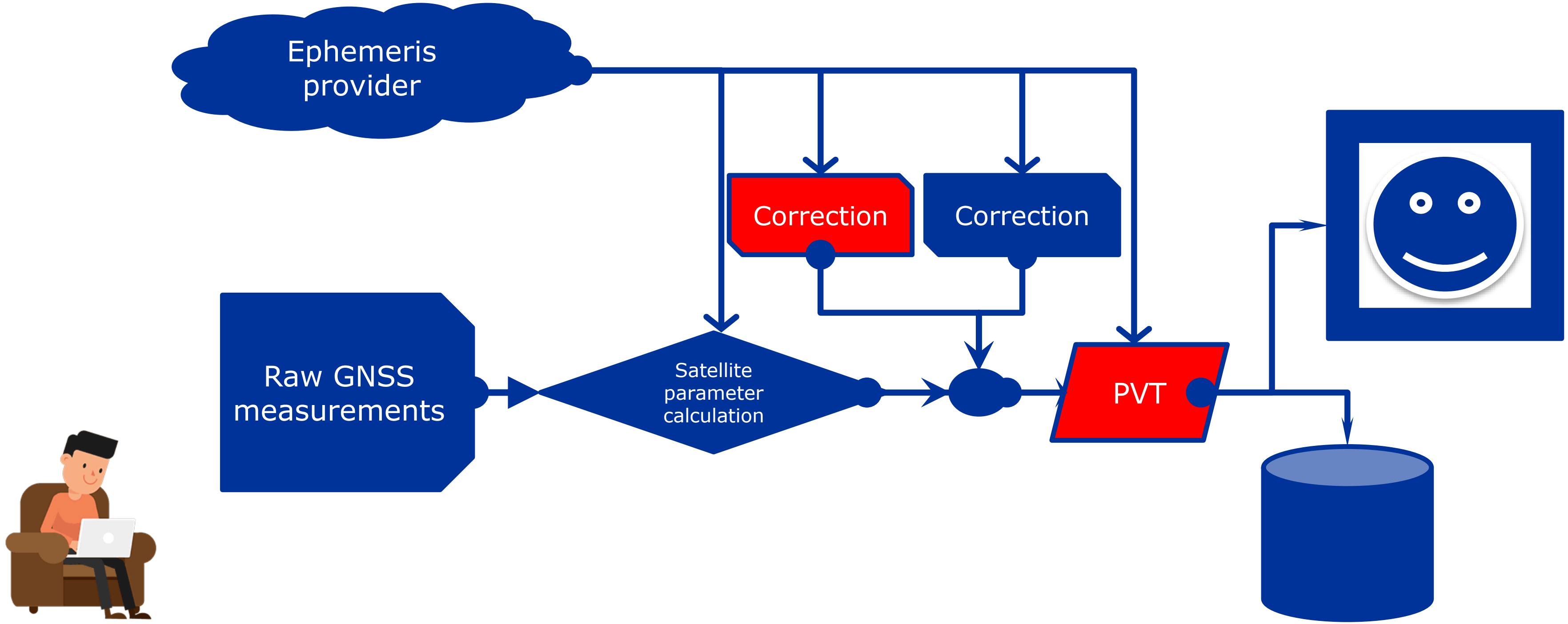
Monitoring satellite C/N0

EKF trajectory while in a bus



WLS vs. EKF

GNSS Compare – **Open Source** Code framework



→ **GNSS Compare source code available from** https://github.com/TheGalfins/GNSS_Compare

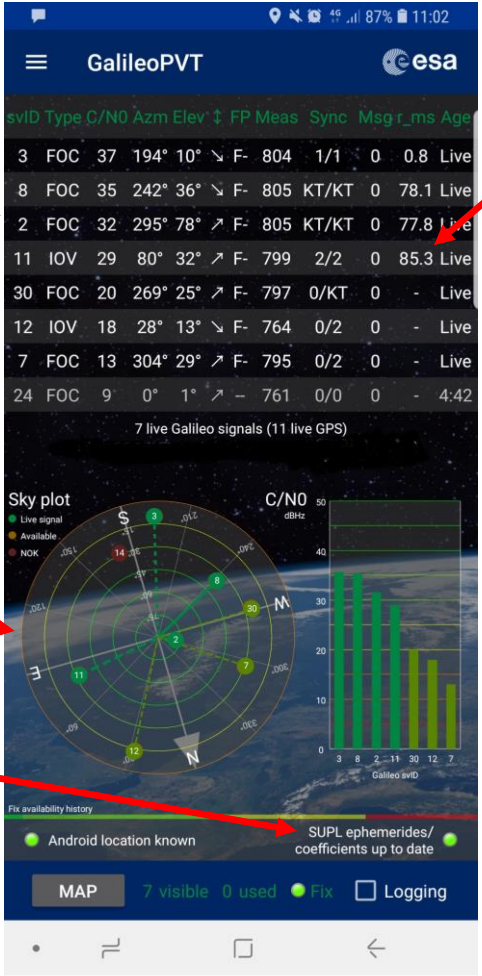
GalileoPVT App

List of satellites seen, includes signals no longer being received

List ordered by signal strength, also plotted

Prediction of satellite visibility and visualisation of satellites on a **sky plot**

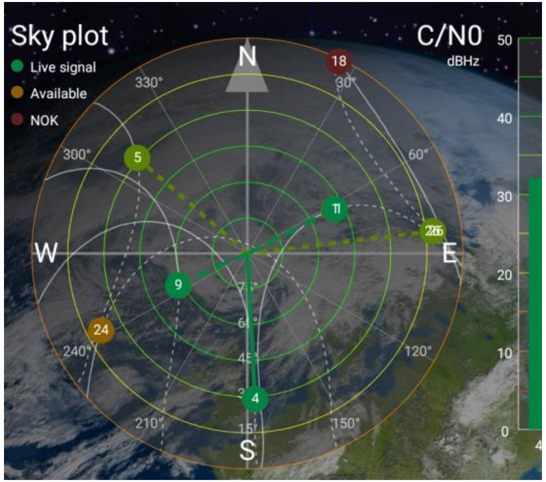
Download of Ephemeris and SV clock data from SUPL 2.0 server



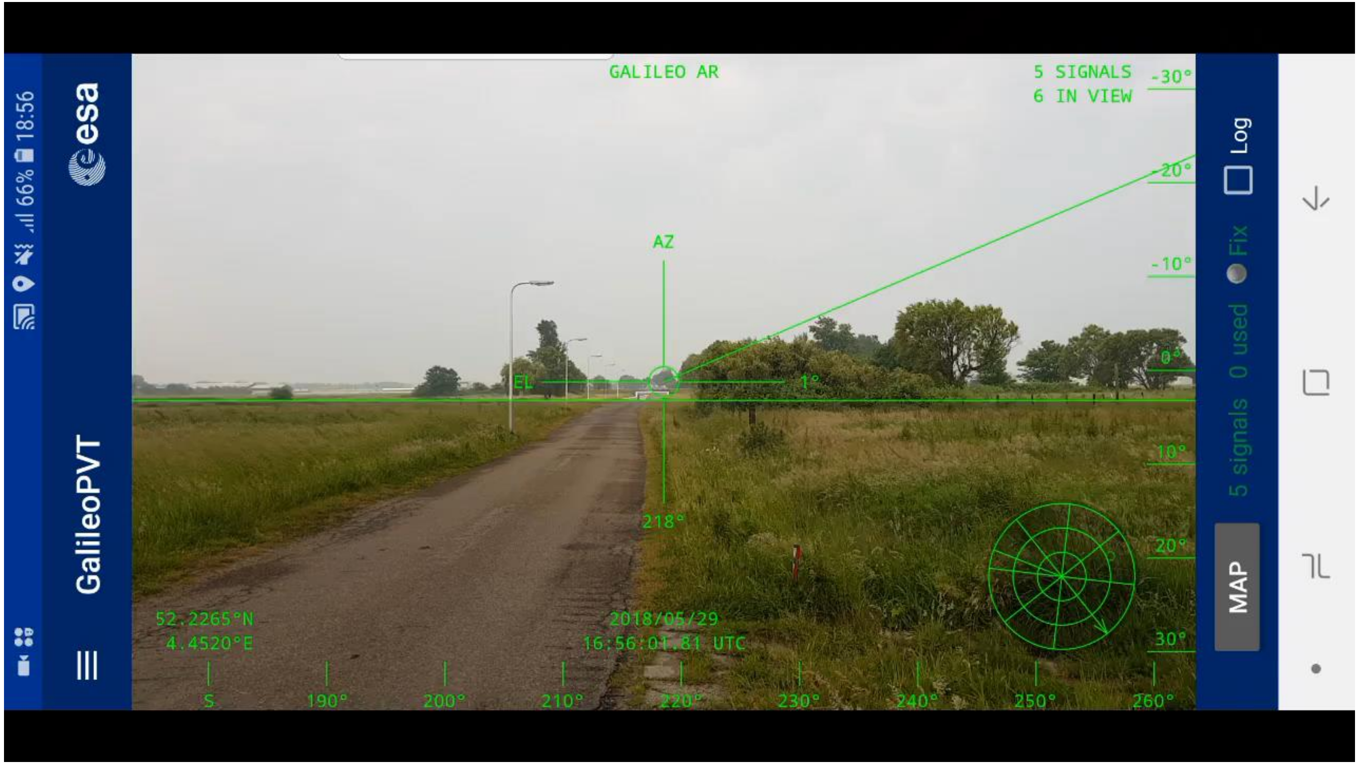
Includes signal sync status (current/best), and calculated pseudorange (ms)

Sky plot rotates to point North

Visualisation of satellite health, signal sync status and satellite paths

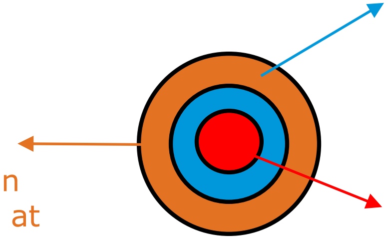


GalileoPVT - Augmented Reality View



Galileo App Competition 2018/2019

- Objectives of the competition



Form teams
(3 to 5 persons)

Students from European universities and trainees at European R&D organisations

Design an Android application that processes GNSS raw measurements

Galileo only, GPS only and Galileo+GPS PVT functionalities
(GLONASS and BeiDou optional)

Dual frequency vs single frequency, sub metre accuracy worldwide in open sky condition

- Prize: ESA/JRC International Summerschool on GNSS 2019 in Portugal

EVENT	DATE
Announcement of Competition	24 Sep. 2018
Registration deadline for Information Day	8 Oct. 2018
Information Day	16 Oct. 2018
Proposal submission deadline	12 Nov. 2018
Announcement of selected teams to proceed to development phase	26 Nov. 2018
App Development	Nov. 2018 - Mar. 2019
Competition Final at ESTEC (with live web streaming and on-line voting)	**18 Apr. 2019**

Smartphone-based positioning

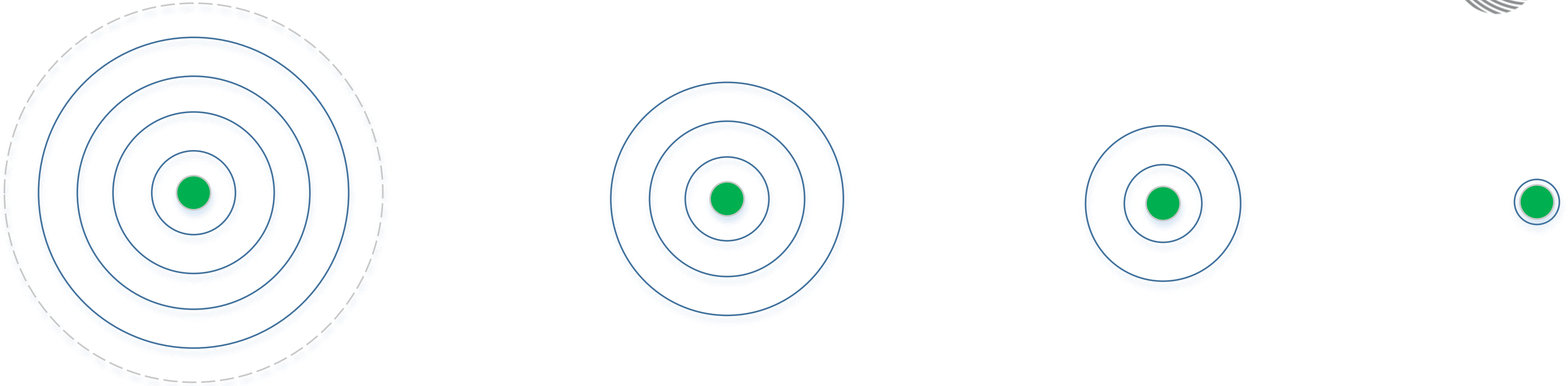
Last generation chips combine GNSS and sensors through tight integration in a single location hub, providing very smooth and accurate solutions

There are 3 families of smartphone based positioning:

1. **Satellite based signals (GNSS, SBAS)**
2. **Sensors**
3. **Terrestrial based RF signals**

Technology is evolving towards a indoor/outdoor seamless positioning solution on smartphones.

Typical Outdoor Open Sky Positioning Accuracy



METER-LEVEL | METER/SUB-METER | DECIMETER | CENTIMETER

SINGLE FREQUENCY multi-GNSS

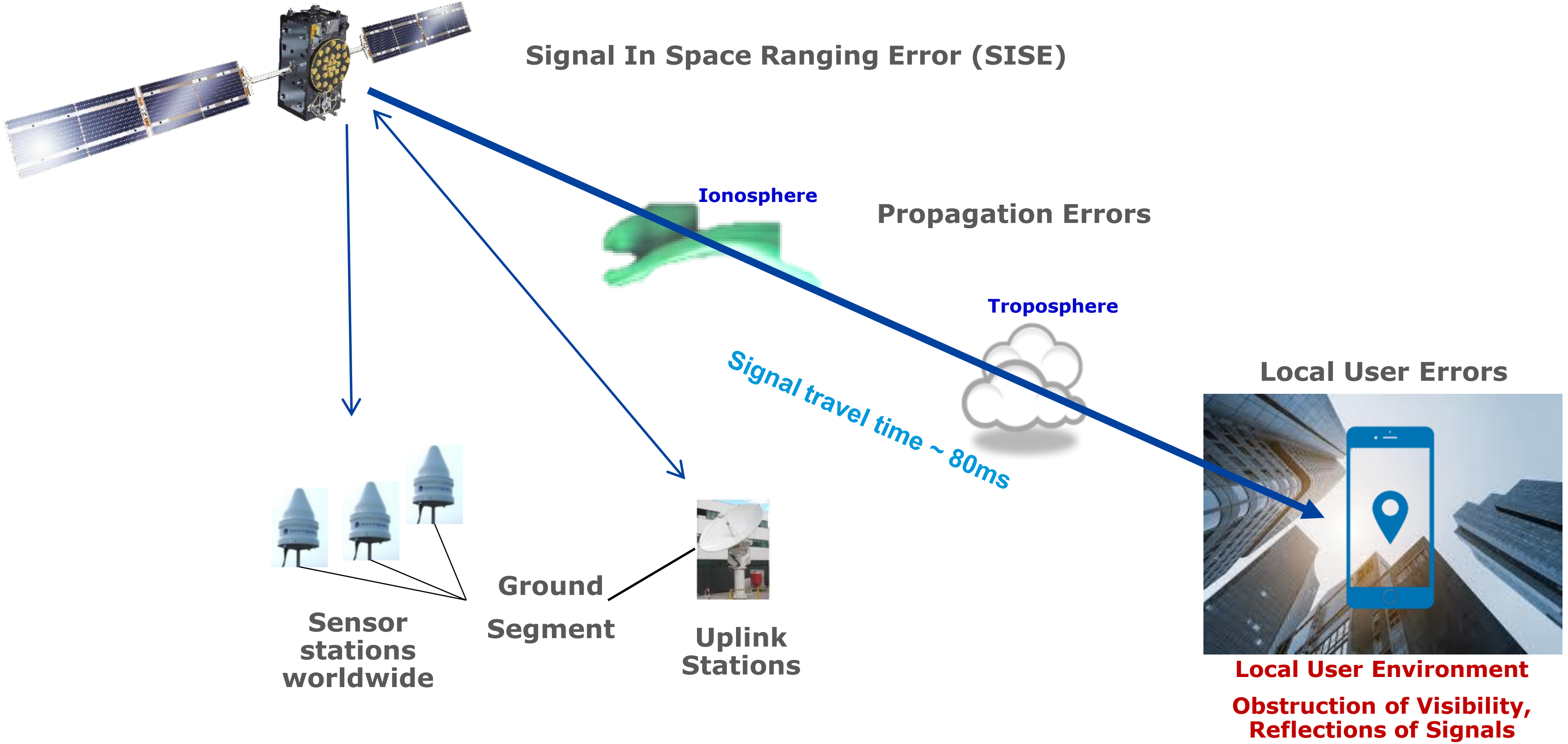
DUAL FREQUENCY multi-GNSS

PPP/RTK

PPP/RTK

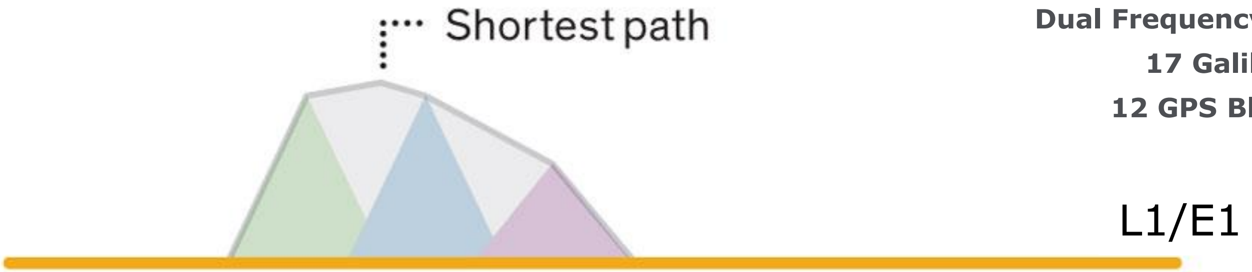
Only commercial/professional apps for real time solution

GNSS positioning – Error Sources



How does the second frequency L5/E5 help?

GNSS receivers track the peak of a spreading code correlation vector with a Delay Lock Loop (DLL)



Slow code rate signals have wide peaks, creating a multipath "blob"

High code rate signals generate sharper correlation peaks (10.23Mhz compared to 1.023Mhz for L1/E1). The earliest correspond to the shorter path

Dual Frequency Satellites available:

17 Galileo (E1/E5) +

12 GPS Block IIF (L1/L5)

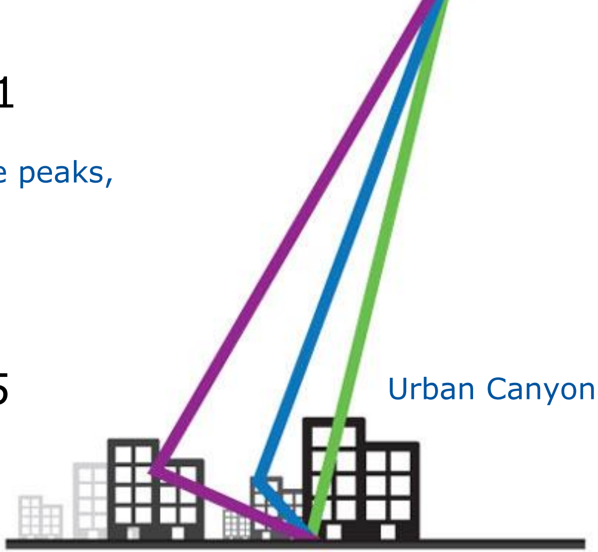


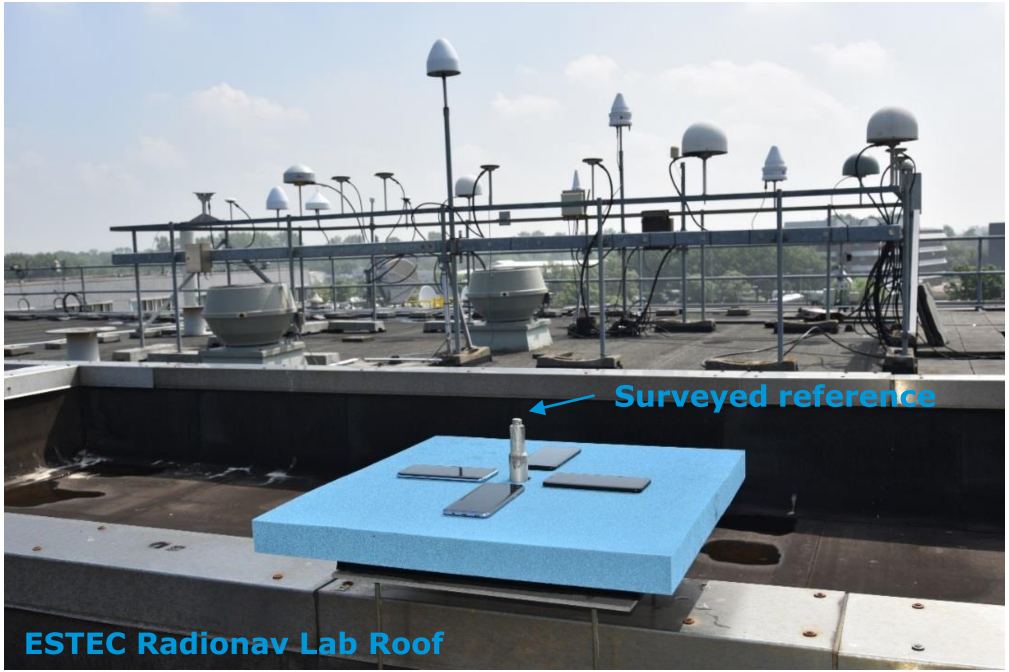
Illustration: S.K. Moore, IEEE Spectrum

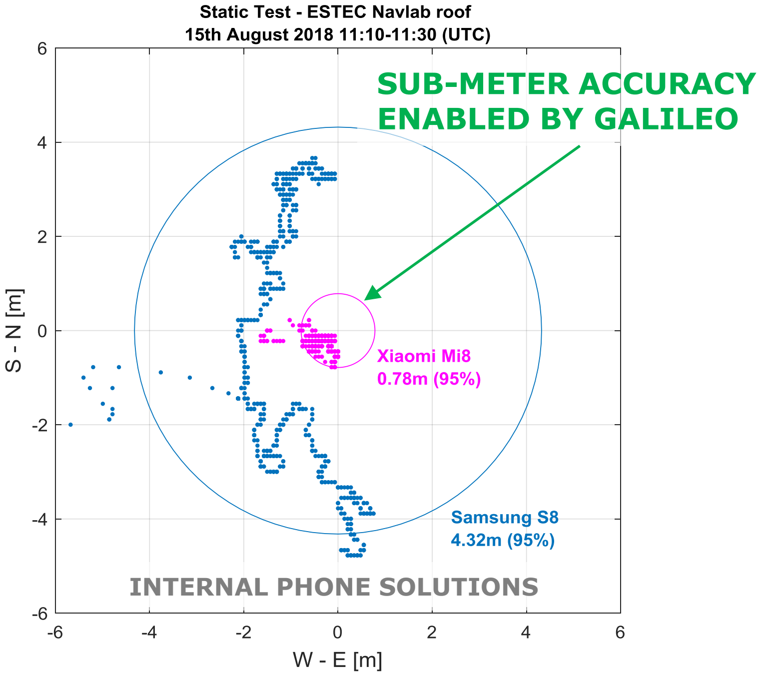
Smartphone Testing scenarios

Several phones used: Samsung Galaxy S8, S8+, Huawei P10, Xiaomi Mi8. Also the Broadcom Dual Frequency GNSS chip (BCM4775) evaluation kit + Professional Antenna tested.

1) **Static**, ESA-ESTEC radio-navigation lab rooftop
2) **Pedestrian**, ESA-ESTEC football field
3) **Vehicular**, sub-urban and urban environments

Sub meter static positioning accuracy with DF GNSS chipset



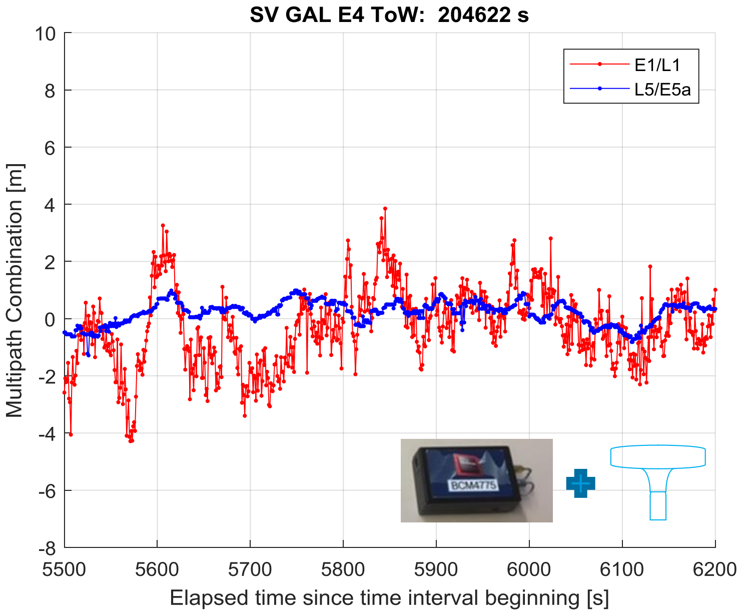


Multi-GNSS solution GPS+Galileo+GLONASS+BeiDou

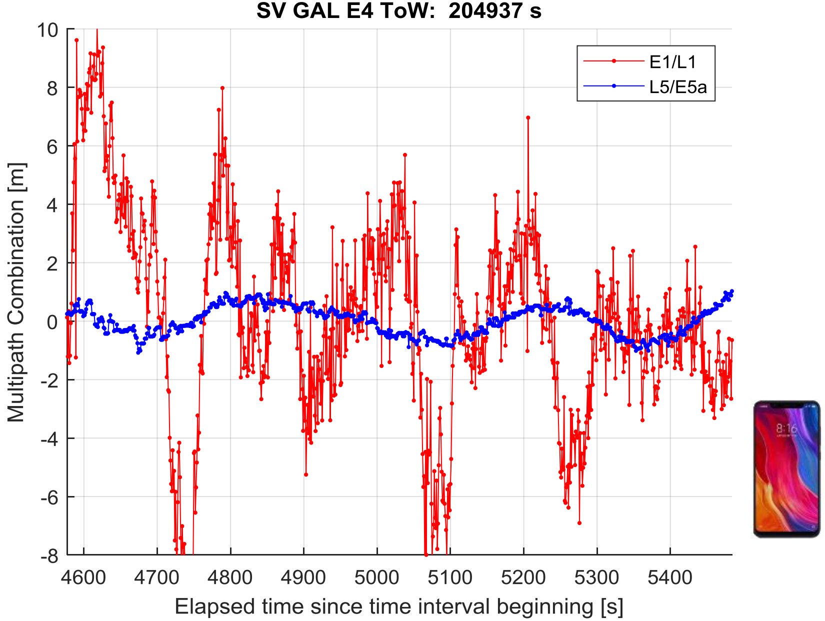
5 GPS DF + 8 Galileo DF in view during this test

Multipath error signatures on Galileo E1, E5a (1/2)

Dual Frequency GNSS chip (BCM4775) + Professional Antenna

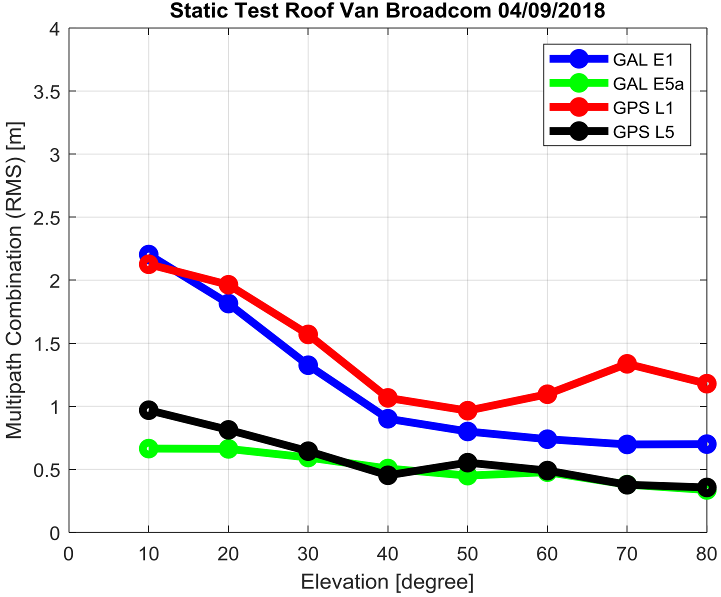


Xiaomi Mi8 smartphone (integrated antenna)

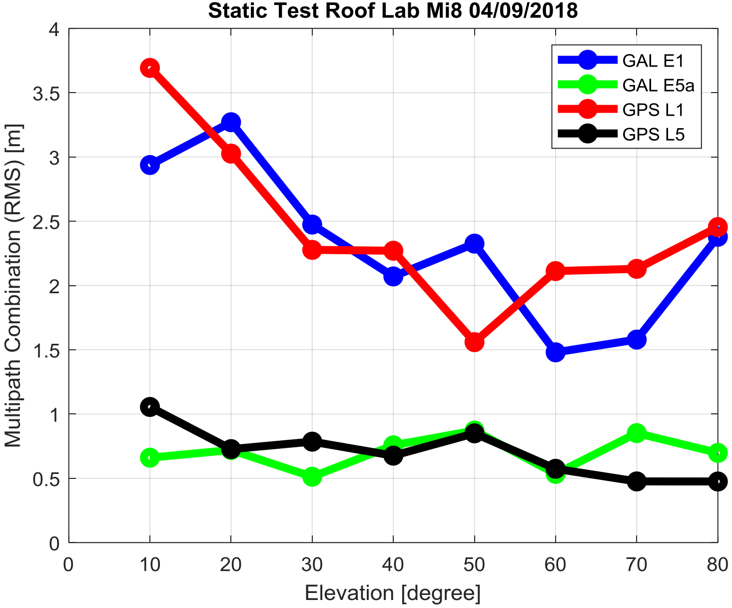


Multipath error signatures on Galileo E1, E5a (2/2)

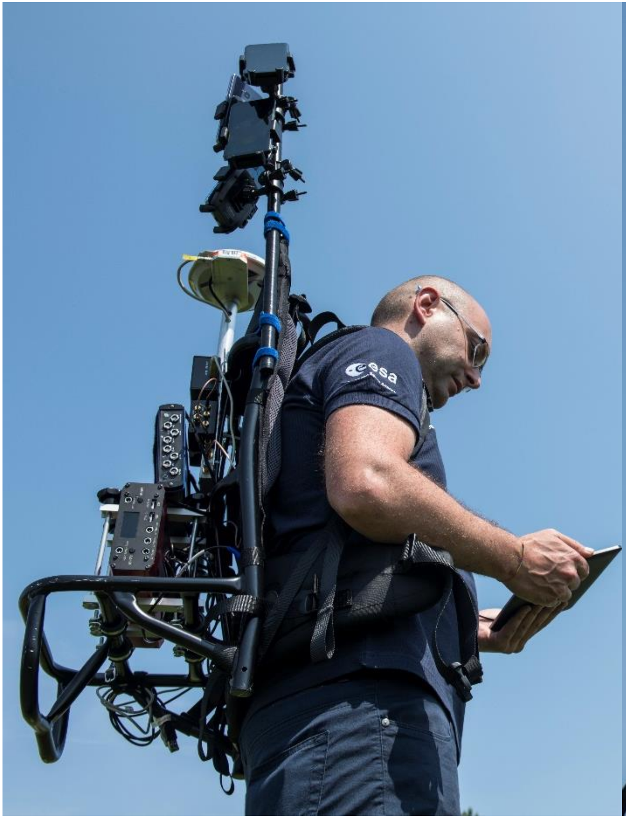
Dual Frequency GNSS chip (BCM4775) + Professional Antenna

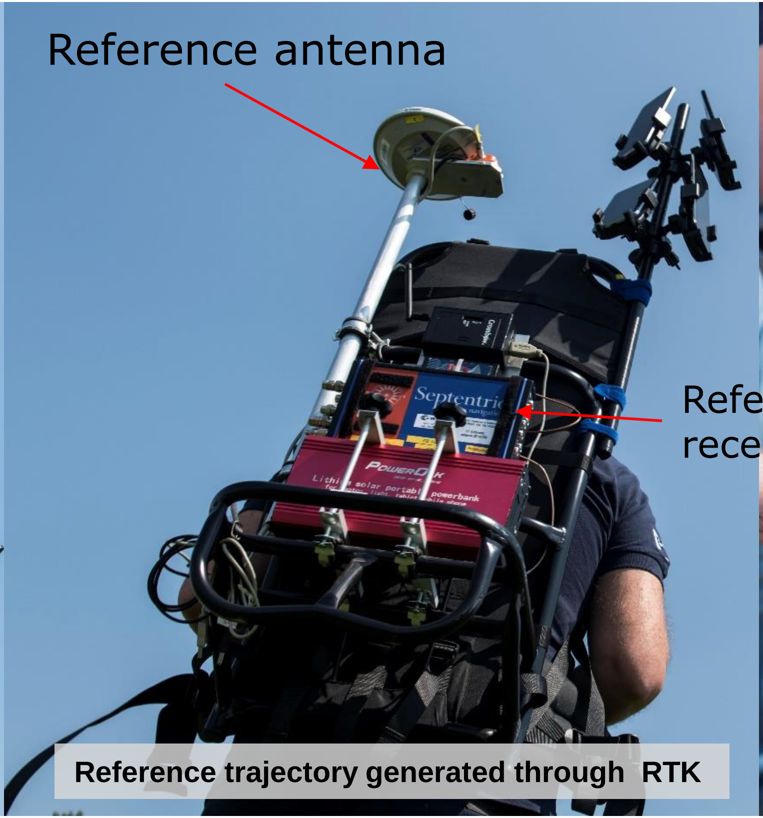


Xiaomi Mi8 smartphone (integrated antenna)

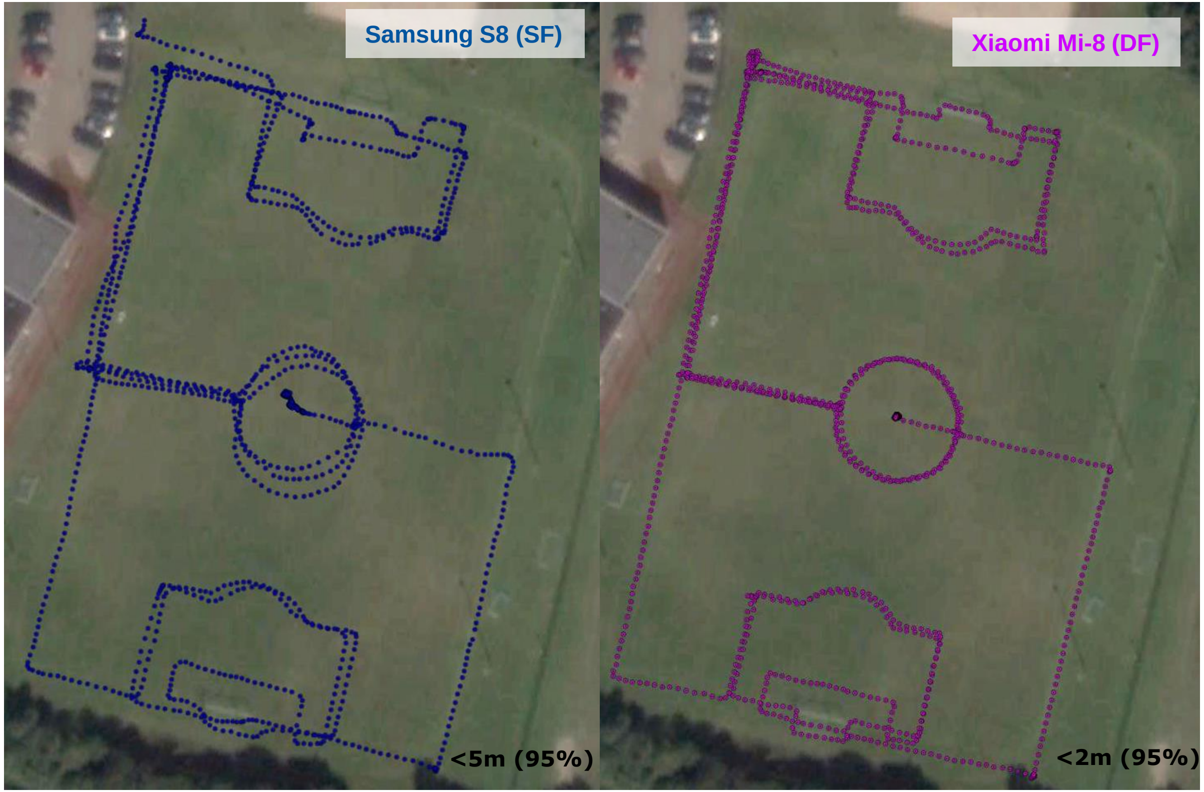


Pedestrian test setup





Opens Sky Pedestrian test SF vs DF GNSS chipsets



TEST #1 15-08-2018
6-8 Galileo satellites in view during the test

INTERNAL PHONE SOLUTIONS

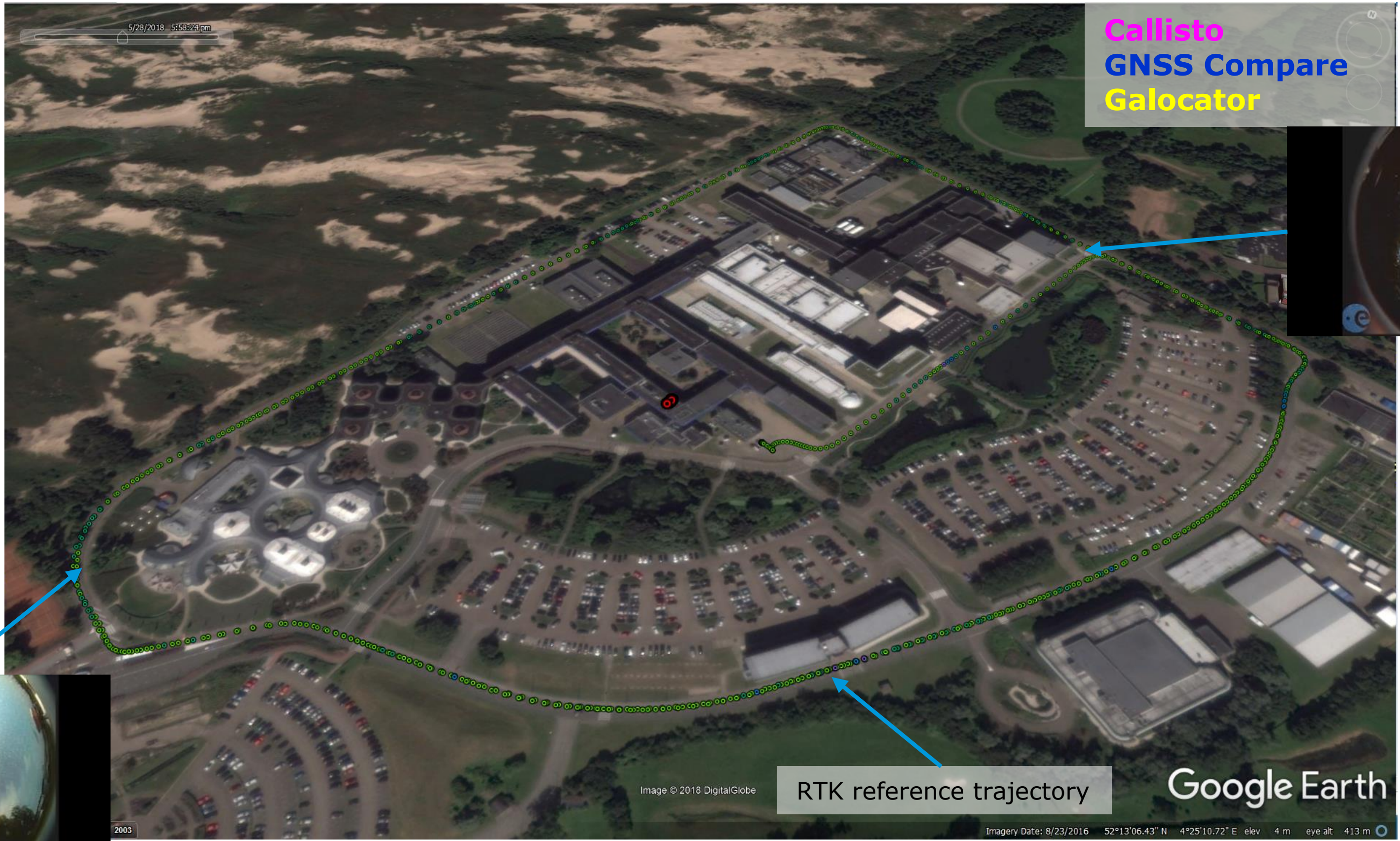
TEST #2 14-09-2018

→ Dual Frequency (DF) measurements along with GNSS chipset algorithmic enhancements enable a significant reduction of positioning error

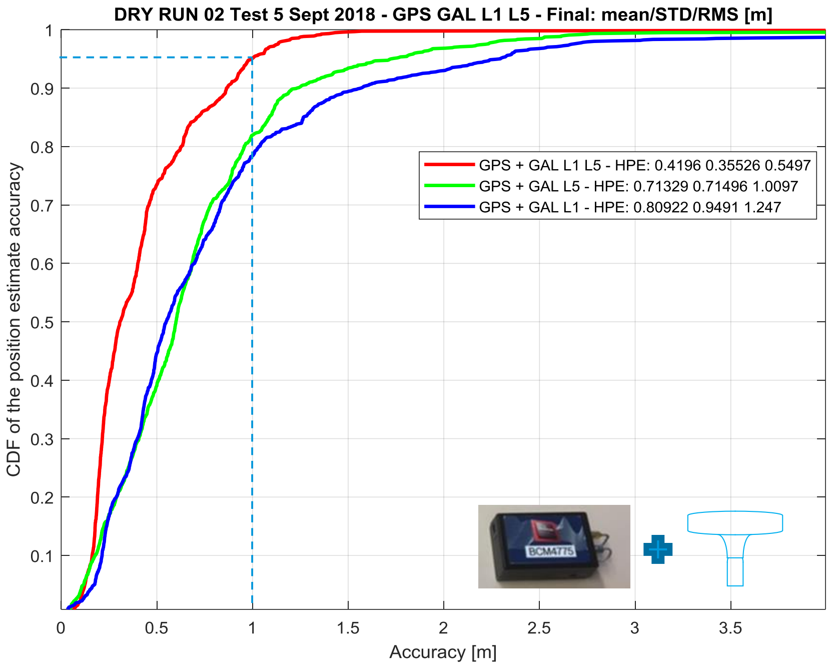
Vehicular test setup

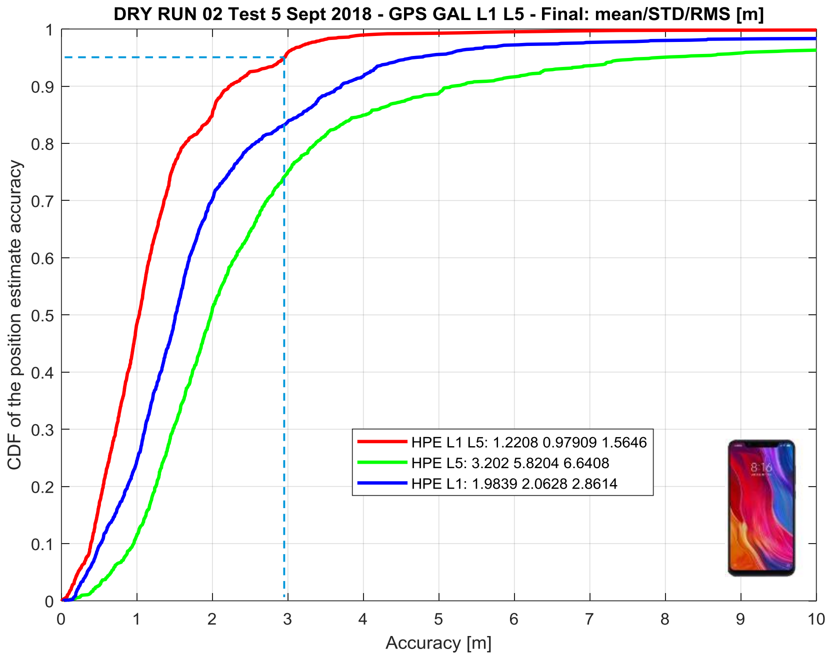
→ Reference trajectory generated through RTK
→ SPAN® GNSS Inertial Navigation System

Vehicular Test at ESTEC (Mild scenario)



Accuracy Mi8: Final BCOM vs Final Mi8





Ingredients for High Accuracy Apps

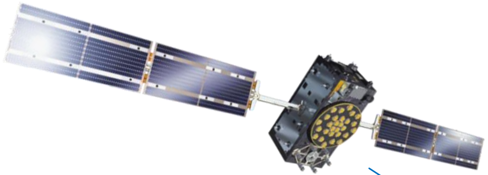
- **GNSS Raw Measurements**, available since **Android N**
- **Continuous Carrier Phase measurements** (no power duty cycling)
- **Dual frequency chips (L1 and L5) for fast convergence** of RTK/PPP algorithms
- Real time data stream of High accuracy GNSS corrections enabling Precise Point Positioning (PPP) / Real Time Kinematic (RTK)
- End user algorithms (RTK/PPP)

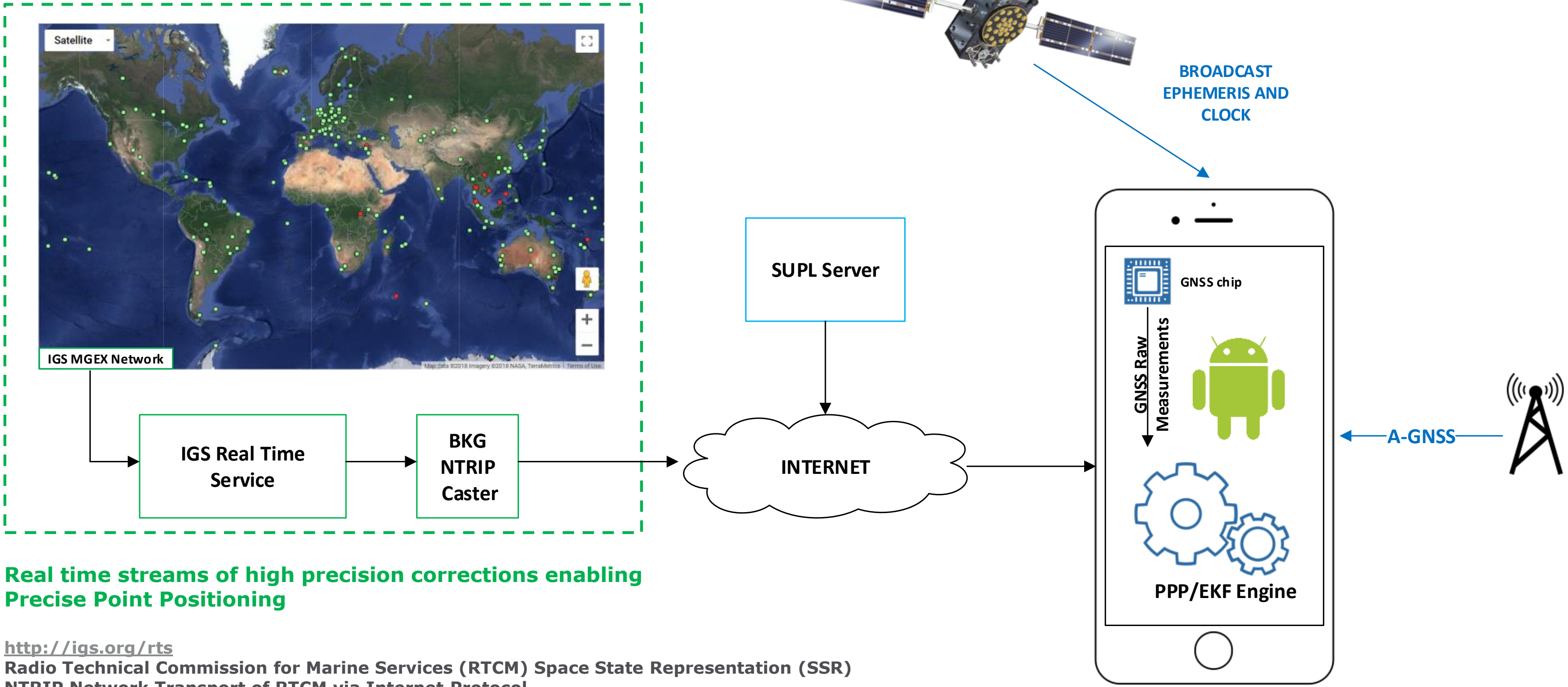
Potential for high accurate positioning with ultra low cost GNSS chipsets, exploiting raw measurements.

→ **From professional grade receivers and software to ultra low cost devices**

→ **Centimeter-level accuracy possible with low cost devices or decimeter-level accuracy on ultra low cost devices.**

Real-time PPP with RT-IGS

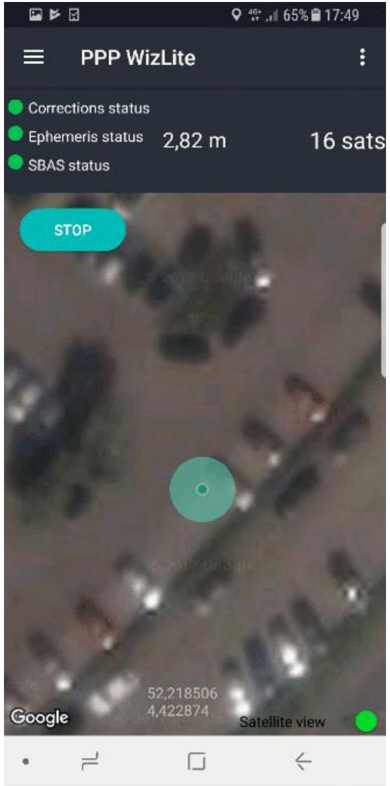




Real time streams of high precision corrections enabling Precise Point Positioning

http://igs.org/rts
Radio Technical Commission for Marine Services (RTCM) Space State Representation (SSR)
NTRIP Network Transport of RTCM via Internet Protocol

CNES PPP WizLite, first example of high accuracy app



Samsung S8 test in ESTEC car parking

CNES Precise Point Positioning WizLite engine implemented on Android devices exploiting multi constellation raw measurements.

- **From conventional smartphone accuracy of about 5m (95%) to sub-meter positioning for static user and meter level for dynamic mode. Convergence time is below 10 minutes.**

- PPP enabled using precise orbit, clock and ionosphere corrections (VTEC) from the **IGS Real Time Service** (RTCM format).

- GPS, GLONASS and GALILEO supported. SBAS enabled.

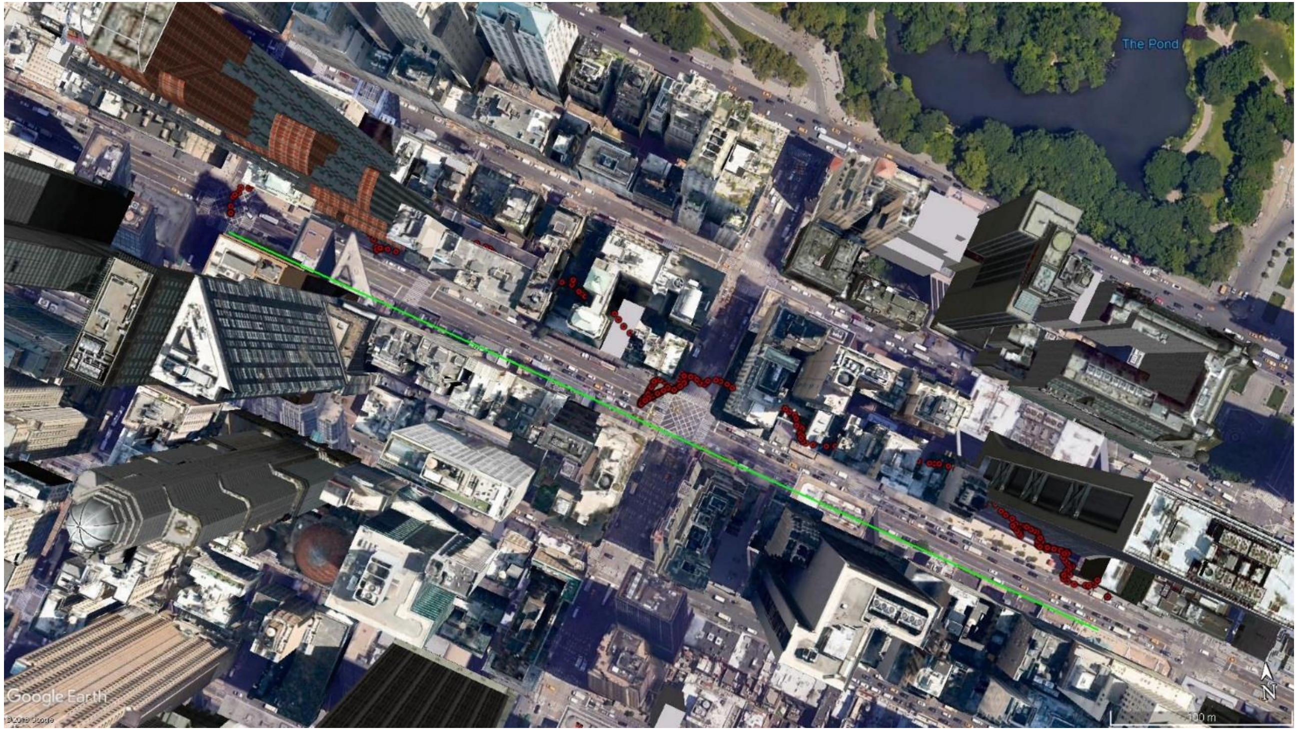
- Only code and Doppler measurements processed in this demonstration. Carrier phase not yet exploited due to limitations associated to power duty cycle in smartphones.

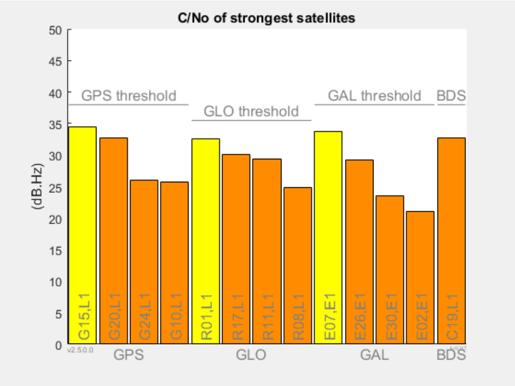
https://play.google.com/store/apps/details?id=jocs.fr.gnss_ppp&hl=nl
Based on raw GNSS measurements, the app combines RTK library and very high level algorithms developed by the French Space Agency (CNES PPP-Wizard)

Challenges of high accuracy on smartphones

- → Demonstrations leading to sub-meter accuracy carried out mainly in **open sky conditions**
- → Poor measurements quality due to code noise (multipath), mainly driven by linear polarized antenna, hiding the benefits of more accurate clocks and orbital data**. The performance of the integrated antenna dominates the error budget**
- → Tests with professional grade antenna show good results
- → **Need for algorithms optimization for low cost hardware**, with increased code and phase measurements noise. Customize software from professional receivers to low-cost or ultra low-cost hardware.
- → Power consumption. High accuracy feature, depending on the application, possibly not needed continuously.

Urban Canyon – Pedestrian Test



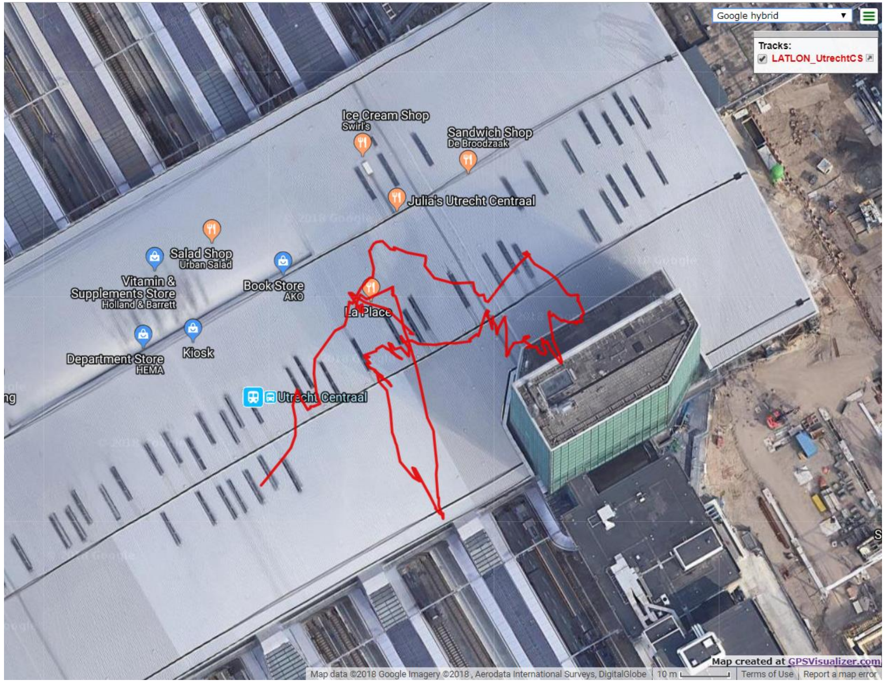


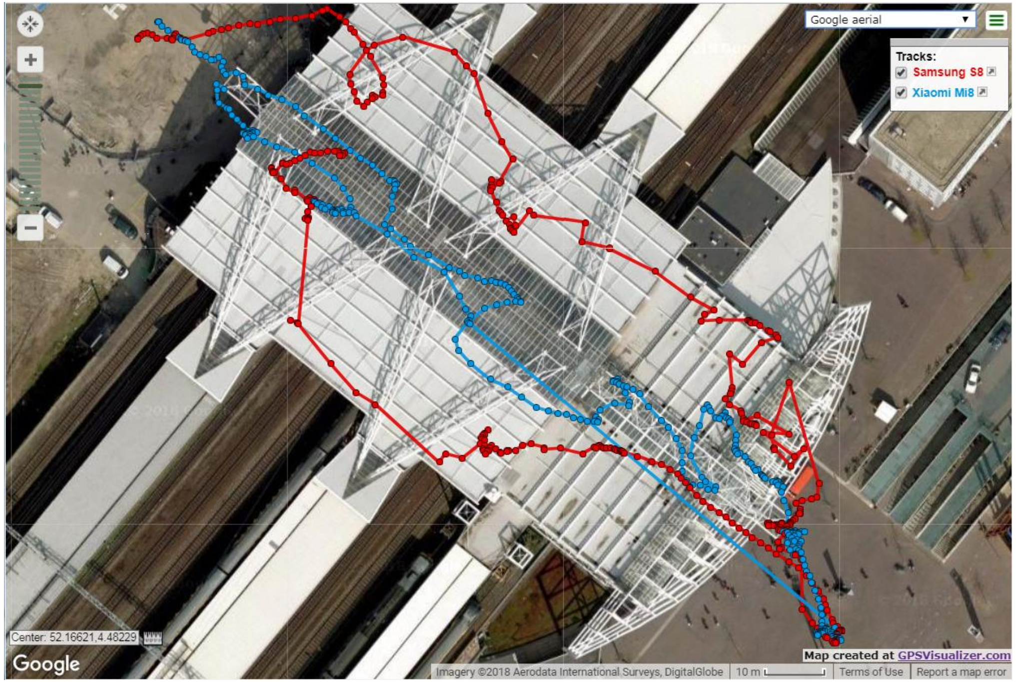
In open sky conditions C/No should be around 40-45 dB-Hz

→ **Significant attenuation in urban environment**, marginal signals <20dB-Hz

→ **Impact of Multipath**

Indoors test – Current smartphone accuracy

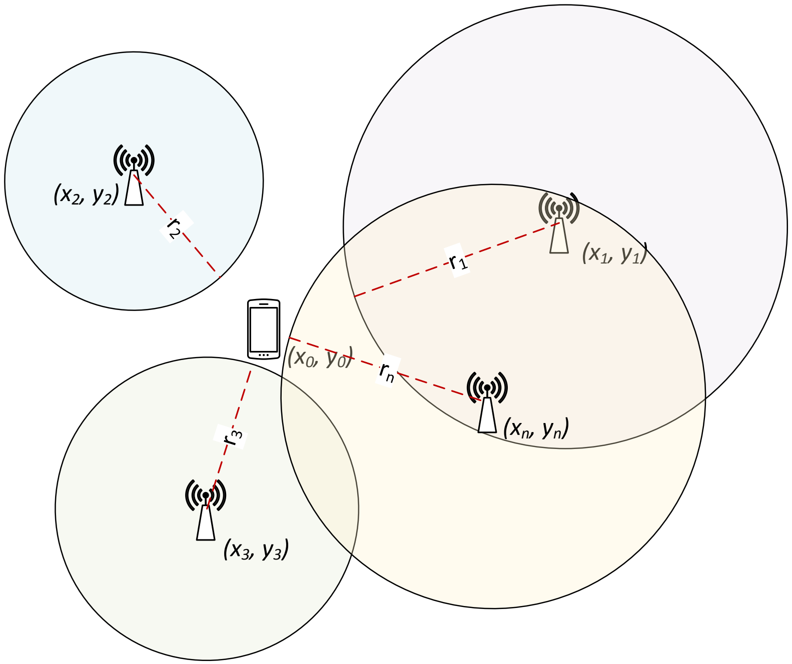




→ Walking along straight lines

→ Observed positioning deviations as large as 10-20m

Indoors Wi-Fi Round Trip Time (RTT)



TRI/MULTILATERATION

WiFi 802.11mc

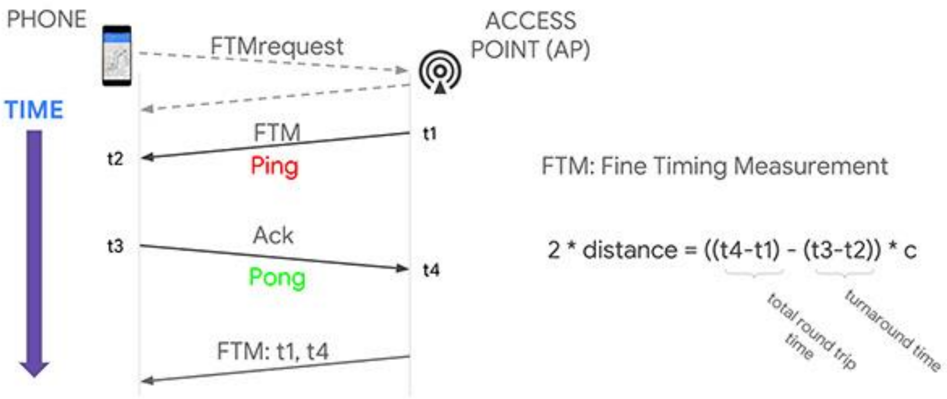


Image credit: *Frank van Diggelen, Roy Want and Wei Wang,* Google

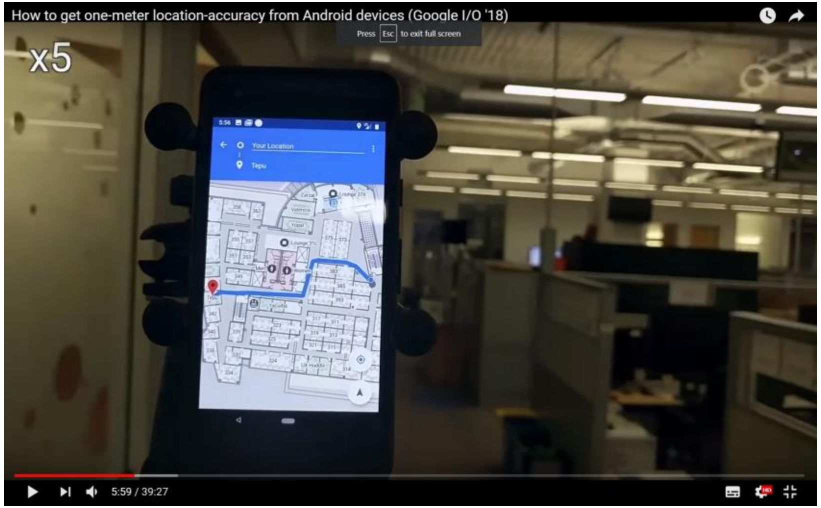
- No exact solution due to range estimate errors
- Multilateration techniques to minimize error

$$(x_0 - x_i)^2 + (y_0 - y_i)^2 = r_i^2$$

Android P WiFi RTT API RangingResult

Public methods	
`int`	`describeContents()` Describe the kinds of special objects contained in this Parcelable instance's marshaled representation.
`boolean`	`equals(Object o)` Indicates whether some other object is "equal to" this one.
`int`	`getDistanceMm()`
`int`	`getDistanceStdDevMm()`
`MacAddress`	`getMacAddress()`
`int`	`getNumAttemptedMeasurements()`
`int`	`getNumSuccessfulMeasurements()`
`PeerHandle`	`getPeerHandle()`
`long`	`getRangingTimestampMillis()`
`int`	`getRssi()`
`int`	`getStatus()`
`int`	`hashCode()` Returns a hash code value for the object.
`void`	`writeToParcel(Parcel dest, int flags)` Flatten this object in to a Parcel.

https://developer.android.com/guide/topics/connectivity/wifi-rtt

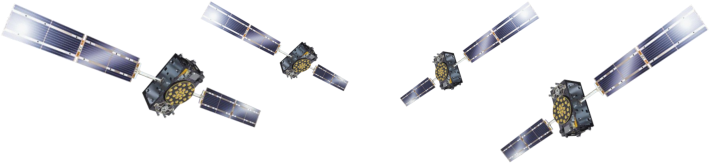


Google I/O developer conference May ‘18

→ 1 meter accuracy expected indoors

REQUIRED: Access Point infrastructure supporting **WiFi 802.11mc**

Logging and Post Processing



GNSS Logger

```
# Header Description:
#
# Version: v2.0.0.1 Platform: 8.1.0 Manufacturer: Xiaomi Model: MI 8
#
#
Raw,ElapsedRealtimeMillis,TimeNanos,LeapSecond,TimeUncertaintyNanos,FullBiasNanos,BiasNanos,BiasUncertaintyNanos,DriftNanosPerSecon
d,DriftUncertaintyNanosPerSecond,HardwareClockDiscontinuityCount,Svid,TimeOffsetNanos,State,ReceivedSvTimeNanos,ReceivedSvTimeUncer
taintyNanos,Cn0DbHz,PseudorangeRateMetersPerSecond,PseudorangeRateUncertaintyMetersPerSecond,AccumulatedDeltaRangeState,Accumulated
DeltaRangeMeters,AccumulatedDeltaRangeUncertaintyMeters,CarrierFrequencyHz,CarrierCycles,CarrierPhase,CarrierPhaseUncertainty,Multi
pathIndicator,SnrInDb,ConstellationType,AgcDb,CarrierFrequencyHz
#
# Fix,Provider,Latitude,Longitude,Altitude,Speed,Accuracy,(UTC)TimeInMs
#
# Nav,Svid,Type,Status,MessageId,Sub-messageId,Data(Bytes)
#
Raw,314776,14492000000,,,-
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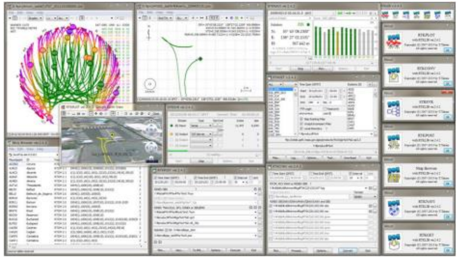
RAW MEASUREMENTS LOG

```
     3.02           OBSERVATION DATA    M: Mixed            RINEX VERSION / TYPE
SMARTPHONE                              20170510 094734 UTC PGM / RUN BY / DATE
format: android N                                           COMMENT
                                                            MARKER NAME
                                                            MARKER NUMBER
                                                            MARKER TYPE
European Space Agency TEC-ESN                               OBSERVER / AGENCY
                                                            REC # / TYPE / VERS
                                                            ANT # / TYPE
   Unknown    Unknown    Unknown                            APPROX POSITION XYZ
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
G    6 C1C L1C S1C C5Q L5Q S5Q                              SYS / # / OBS TYPES
R    3 C1C L1C S1C                                          SYS / # / OBS TYPES
E    6 C1C L1C S1C C5Q L5Q S5Q                              SYS / # / OBS TYPES
C    3 C2I L2I S2I                                          SYS / # / OBS TYPES
  2018     8    13    11    58   52.9999531     GPS         TIME OF FIRST OBS
G                                                           SYS / PHASE SHIFT
R                                                           SYS / PHASE SHIFT
E                                                           SYS / PHASE SHIFT
C                                                           SYS / PHASE SHIFT
                                                            END OF HEADER
> 2018  8 13 11 58 52.9999531  0 18
G10  21035793.422       10403.8350         34.882    21035803.914       44037.5430         41.721
G13  25390647.617       55782.9560         22.647
G15  24382072.941       39682.3640         46.174
G16  22629742.553       73013.6490         44.055
G20  21214638.208       49934.3610         35.320
G21  23853813.445       78206.5020         37.440
G26  24822745.667       79628.0990         42.781    24822746.867      220967.1100         39.660
G27  20078757.262       34440.7480         38.757    20078754.566      146588.4660         34.500
G30  24594518.165       27061.9140         19.967    24594503.476      115158.0890         23.069
R07  22618892.165       73249.6020         41.296
R08  20626229.557       14849.7700         40.176
R16  24180785.089      -34861.3680         24.436
R23  20203574.955       62017.8810         42.661
R24  19606162.037        8795.5400         30.271
E01  26493696.192       46206.9320         41.033    26493698.892      -40288.0150         28.591
E07  25937544.608       -7276.8830         38.225    25937549.407      -34974.6240         35.147
E08  24419158.767       25248.5680         39.756    24419154.867       89292.8620         22.888
E26  21807385.158       24740.2920         42.397    21807385.760        8623.6050         39.152
> 2018  8 13 11 58 53.9999531  0 18
```

RINEX

→ POST PROCESSING

Google GNSS Analysis Tool
https://developer.android.com/guide/topics/sensors/gnss#analyze



RTKLIB
www.rtklib.com

Smartphone Sample Measurements Logs

- Xiaomi Mi8 Static Test 15-08-2018 & 14-09-2018
  - GNSS Log
  - RINEX files
  - Precise orbit and clock files

Reference location precise coordinates, derived through PPP with professional antenna and receiver (altitude over the geoid)
52.2184738778421 N, 4.41938961176881 E, 14.5485263950398 H [deg, deg, m]

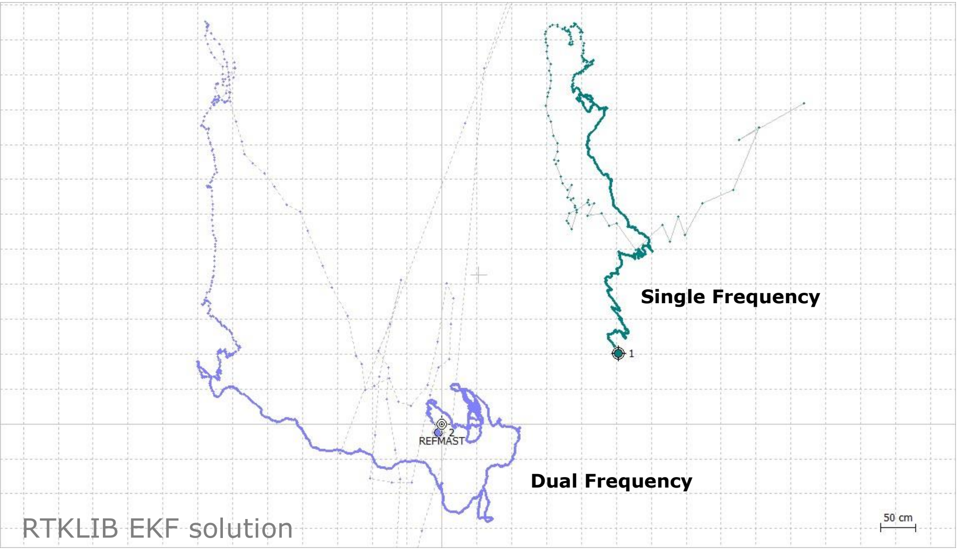
- DOWNLOAD data esabox

https://esabox.esa.int/owncloud/index.php/s/vvO4yCHgTu3kARG

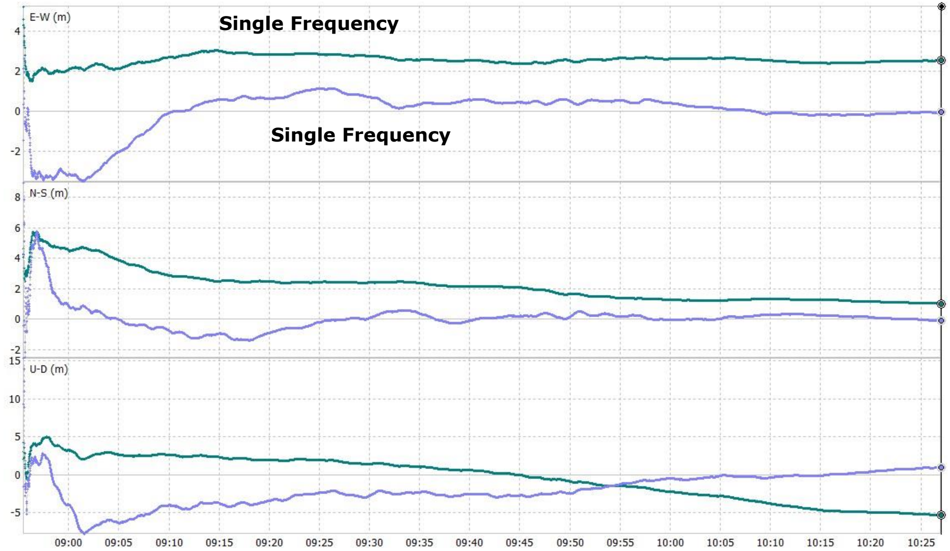
password @IPIN2018

Surveyed reference

Single Frequency vs Dual Frequency static test (Xiaomi Mi8)



ROOFTOP TEST 04-09-2018

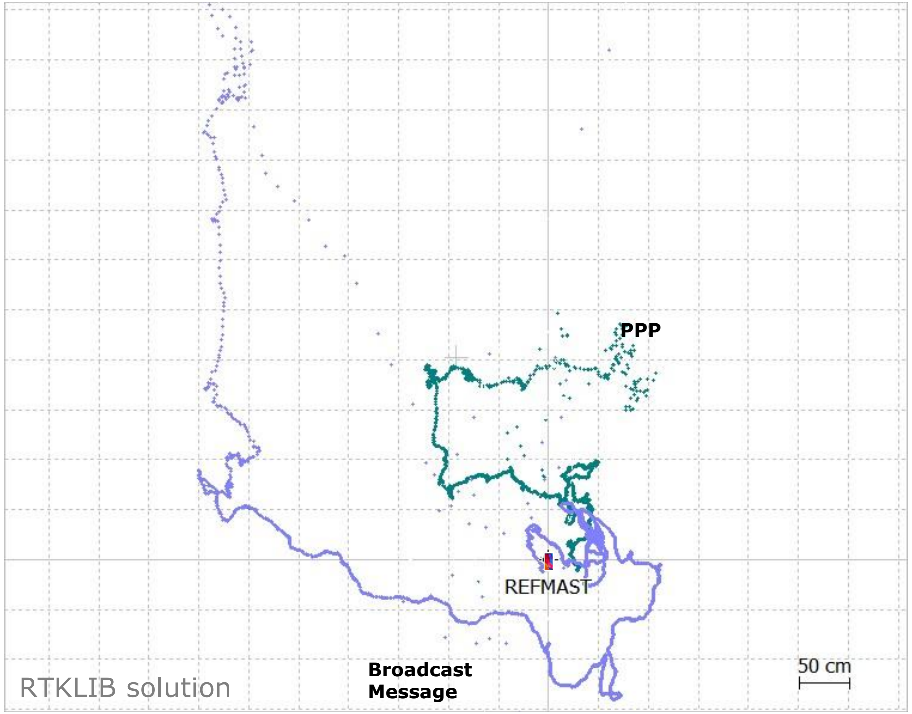


→ SUB-METER accuracy achieved in less than 10 minutes using DF, without PPP corrections

GPS+Galileo solution

Time window maximizing Galileo satellites visibility (6-8 satellites visible)

Standard vs. PPP solution (Xiaomi Mi8)



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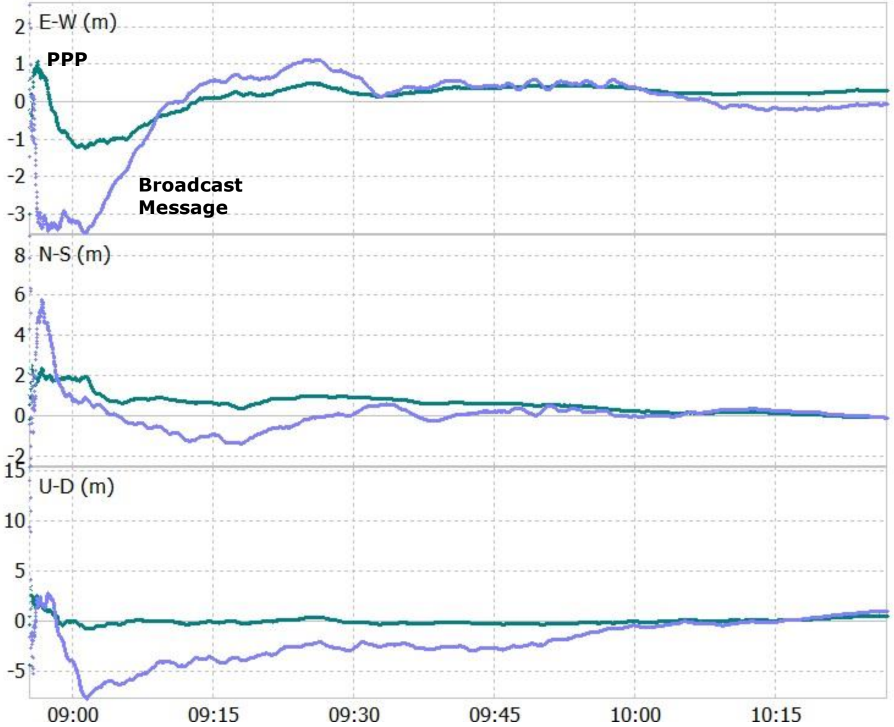


ESA Career Web Page

STUDENT OPPORTUNITIES

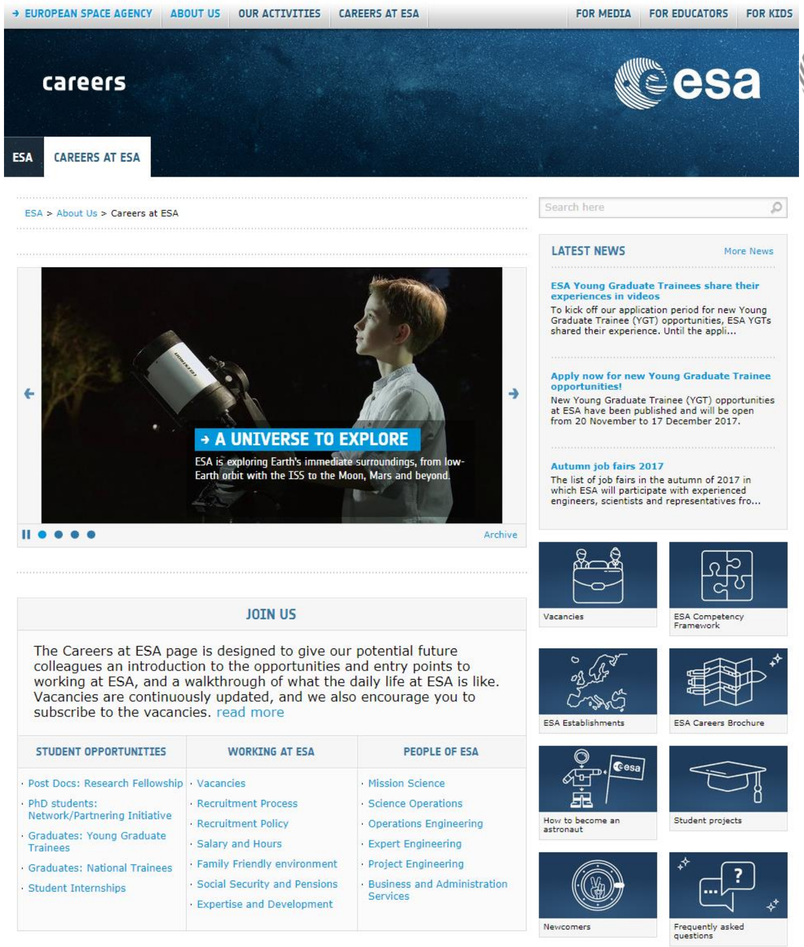
Post Docs: Research Fellowship

PhD students: Network/Partnering Initiative

Graduates: Young Graduate Trainees

Graduates: National Trainees

Student Internships



https://www.esa.int/About_Us/Careers_at_ESA

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- Sebastian Ciuban
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Additional Resources

- White Paper on using GNSS Raw Measurements on Android devices (GSA)
- P. Crosta et alia, Dual Frequency mass-market chips: test results and ways to optimize PVT performance, ION GNSS+ 2018
- F. Van Diggelen, M. Khider, GNSS Analysis Tools from Google, *InsideGNSS* March/April 2018
- F. Van Diggelen Keynote, Android GNSS Measurements Update, GNSS Raw Measurements- From research to commercial use-May2018
- Miguel Torroja, Dual Frequency performance in mass market, GNSS Raw Measurements- From research to commercial use-May2018
- Javier de Salas, Miguel Torroja, Carrier phase positioning experiences in consumer GNSS devices, *International Conference on Localization and GNSS (ICL-GNSS)* 2016
- Innovation: Examining precise positioning now and in the future, *GPS World* March 2018
- S. Riley et alia, Positioning with Android GNSS Observables, *GPS World*, Vol. 29, No. 1, January 2018
- S. Banville and F. Van Diggelen, Precision GNSS for Everyone: Precise Positioning Using Raw GPS Measurements from Android Smartphones, *GPS World*, Vol. 27, No. 11, November 2016
- GPS on phones could get more pin-point accuracy, https://www.radionz.co.nz/news/national/365464/gps-on-phones-could-get-more-pin-point-accuracy
- Innovation: Mobile-Phone GPS Antennas, *GPS World*, February 2010 http://gpsworld.com/professional-oemcomponent-technologiesinnovation-mobile-phone-gps-antennas-9457/
- L. Wang et alia, Validation and Assessment of Multi-GNSS Real-Time Precise Point Positioning in Simulated Kinematic Mode Using IGS Real-Time Service
- http://www.ppp-wizard.net/ssr.html
- NAVIPEDIA: https://gssc.esa.int/navipedia/index.php/GNSS:Tools