GINTO5G
Hybridizing GNSS with Sensors and Terrestrial Technologies for Positioning in 5G

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SESSION C1: Land-Based Applications

European Space Agency

Telefónica Investigación y Desarrollo

Universitat Autònoma de Barcelona

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INNOVATING SOLUTIONS

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- **PNT landscape in next mobile technology generation (5G)**
- **GINTO5G General Overview**
- **GINTO5G Tasks:**
  - **Field Platform and Experimental Tests**
    High Accuracy - Autonomous cars
  - **Simulation Platform**
- **Conclusions and Next Steps**

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PNT Landscape in 5G

BACKGROUND

- **5G a new mobile revolution**
  - 5G technology is expected to be a new mobile revolution in wireless market combining different wireless technologies (4G LTE, WiFi and 5G newly defined air interfaces) to cover new use cases and exploiting new frequency bands.

- **New types of users**
  - Contrary to previous mobile technologies, 5G is no longer all about smartphones and increased mobile broadband capacity (though still a key point). With the advent of 5G new families of use cases are being addressed: Ultra Reliable Low Latency Communications (**URLLC** – e.g. Connected Vehicles, etc.) and Massive Machine Type Communications (**mMTC** – smart cities, Factory 4.0, etc.)

- **PNT an integral feature in 5G**
  - Demand for localisation is increasing in different market segments: **Positioning, Navigation and Timing** (PNT) is progressively considered as an enabler, with a high level of expectations from the users
  - PNT is expected to be an integral feature in 5G, either provided by non 5G-based technologies (GNSS, …) or 5G-based technologies (Cell-ID, OTDOA, UTDOA, …), or most likely, through a hybrid approach combining the two categories.

- **ESA** took in 2016 the initiative to contribute to 3GPP works on 5G positioning. The objective is to identify:
  - user requirements in emerging uses cases,
  - capabilities of 5G-based positioning techniques and
  - the nature of GNSS – 5G relationship.

5G Positioning

- **A Context shaped by very diverse verticals**

Past

911

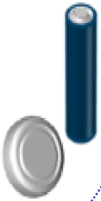
Present

911

Autonomous vehicles, UAV, Rail, Road-tolling, etc.


Machine control, industry automation, asset tracking, etc.



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General Overview of the Activity

HIGH LEVEL VIEW

- **GINTO5G** project is funded by the European Space Agency as part of this initiative under the **European GNSS Evolutions Programme** (EGEP 107)

European Space Agency

- **Scope**:
  - Assess trough field and laboratory experiments what is the role GNSS is expected to play in the 5G technology
  - Support ESA in its efforts dealing with standardisation of GNSS support in 3GPP

- Consortium (led by GMV):

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- Collaborators:

SONY · NovAtel · Deutsche Telekom

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EVALUATION METHODOLOGY

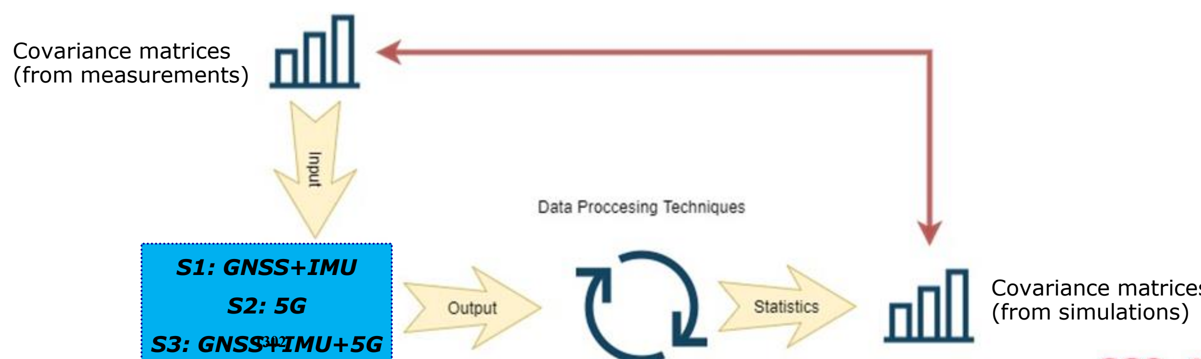
Use Cases Definition:
- Automotive
- UAV
- IoT

Field campaigns execution

Data processing:
Generate individual error models

Simulation tool for hybrid PNT based on GNSS-5G:
Loose coupling fusion

Tool validation:
Before and after statistics comparison



Technologies:
- Multi-constellation high-accuracy **GNSS** (RTK, NRTK, PPP, PPP-RTK)
- **Wireless** network solutions (LTE, 5G)
- Additional **sensors** (different IMU-grades)

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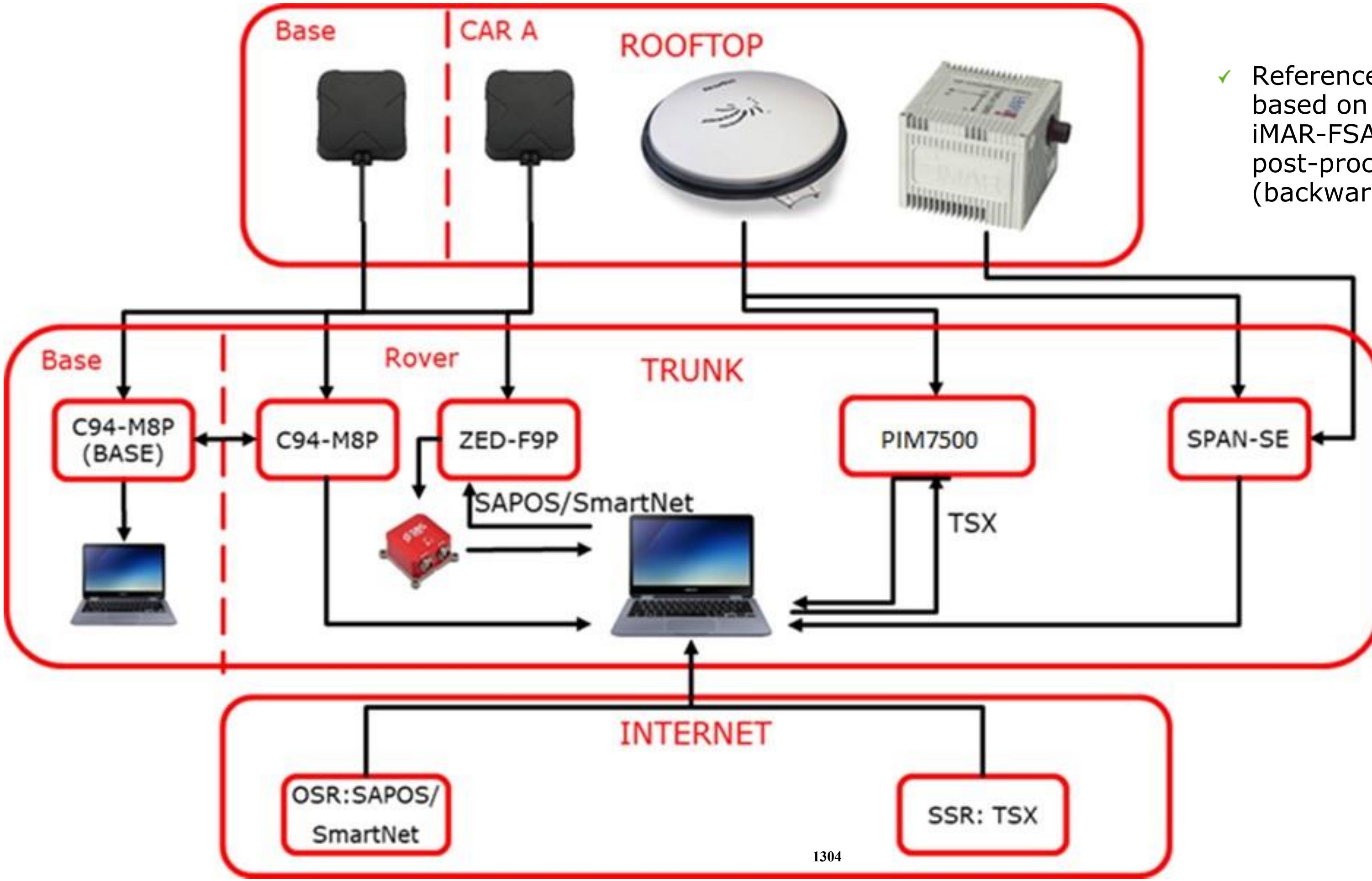
Field Experiments

HA-Autonomous Cars

HA-AC GNSS PLATFORM DESIGN



- ✓ Reference solution (ground truth) based on NovAtel SPAN-SE + iMAR-FSAS IMU (GPS+GLO) post-processing solution (backwards + forwards, PPK…)

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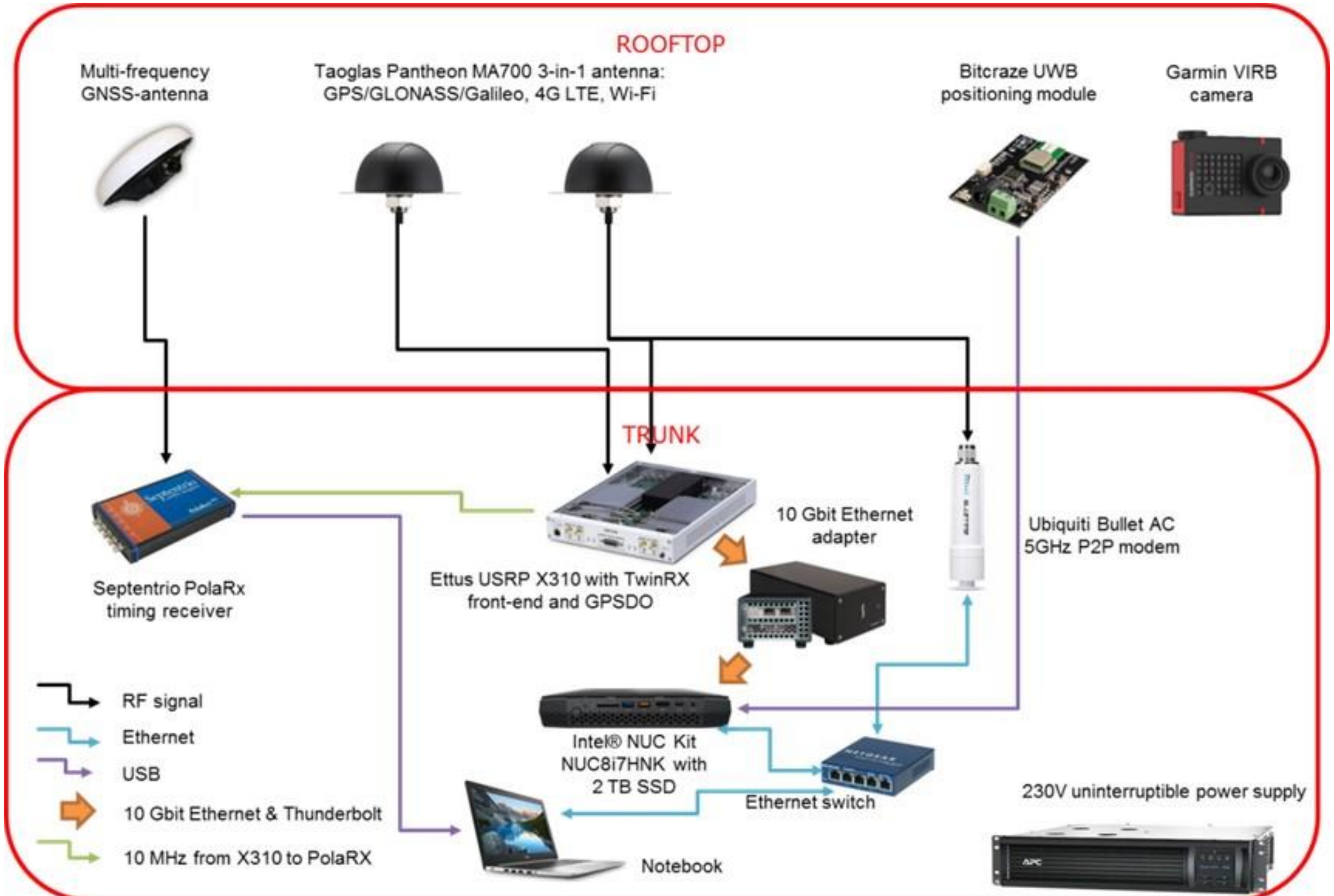
HA-AC 5G PLATFORM DESIGN



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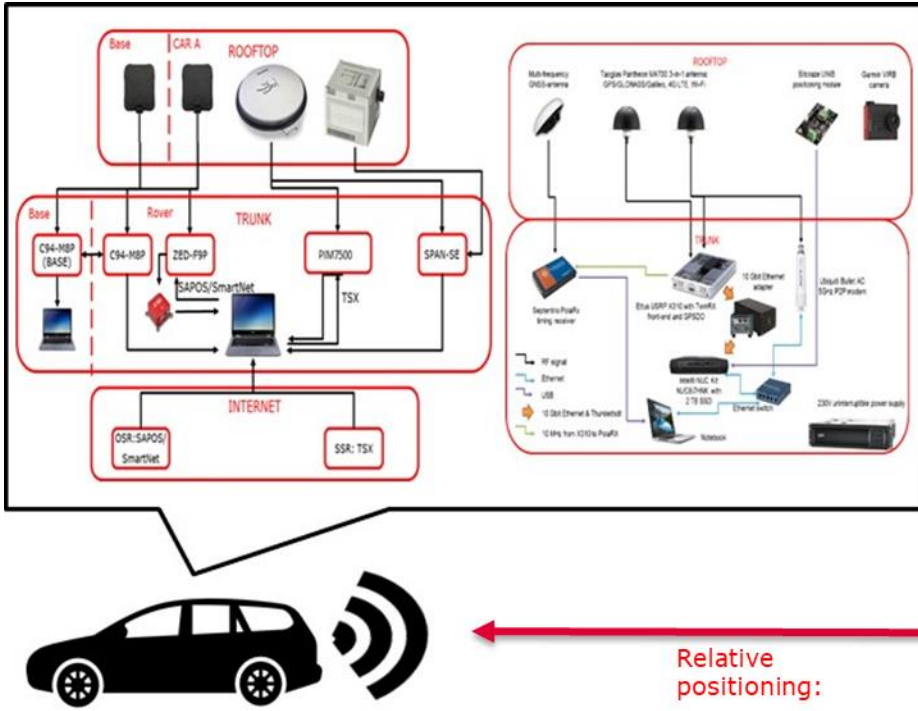
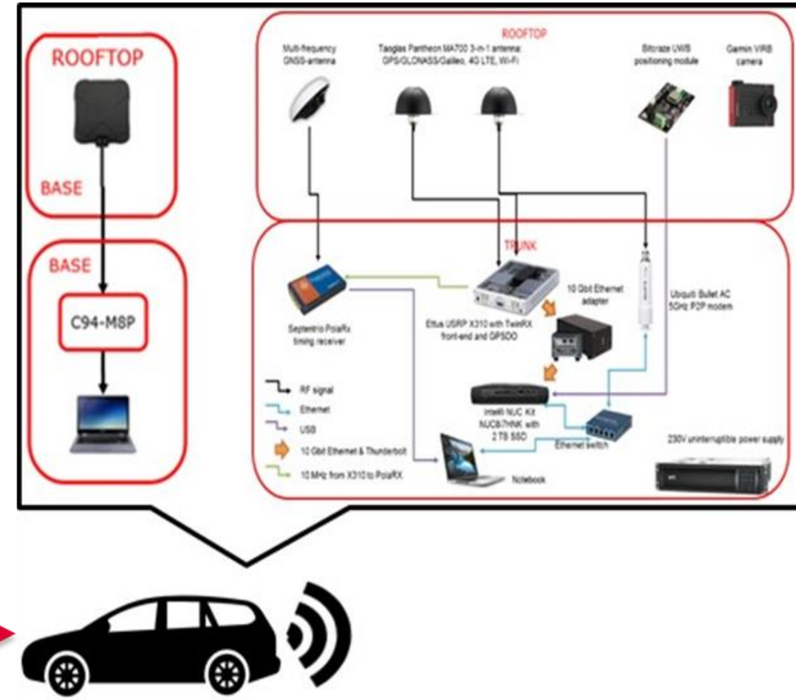
HA-AC JOINT PLATFORM DESIGN





Relative positioning:

UWB-based RTT

Moving base RTK

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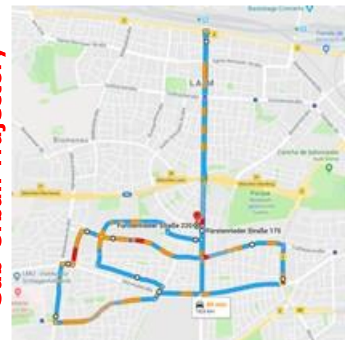
HA-AC JOINT PLATFORM

HA-AC JOINT CAMPAIGN

- Concurrent acquisition of GNSS signals and LTE CRS signals (with support from Deutsche Telekom)
- Three scenarios representative of user location were selected in **Munich and outskirts**, plus an additional one for transitions to evaluate a change in the signal characteristics and environment:

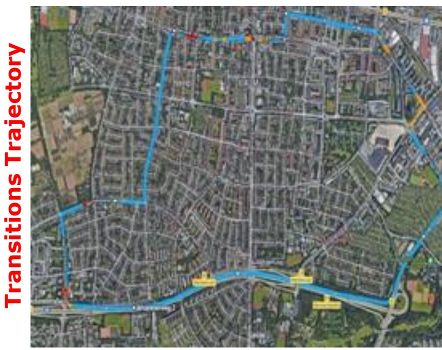
Open-Sky Trajectory

Sub-Urban Trajectory



Urban Trajectory

Transitions Trajectory



Scenario	Total track length
HA_AC_Open	224 km
HA_AC_Suburban	72 km
HA_AC_Urban	64 km
HA_AC_Transition	100 km

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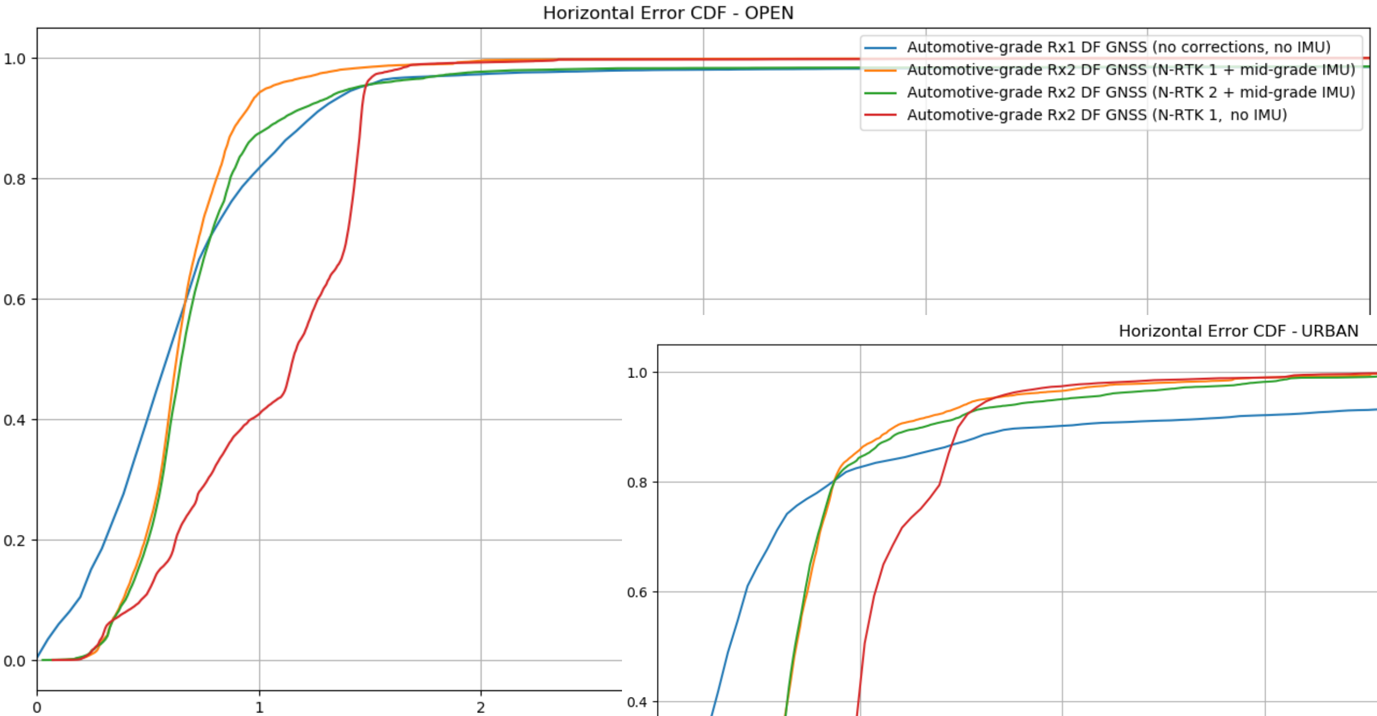
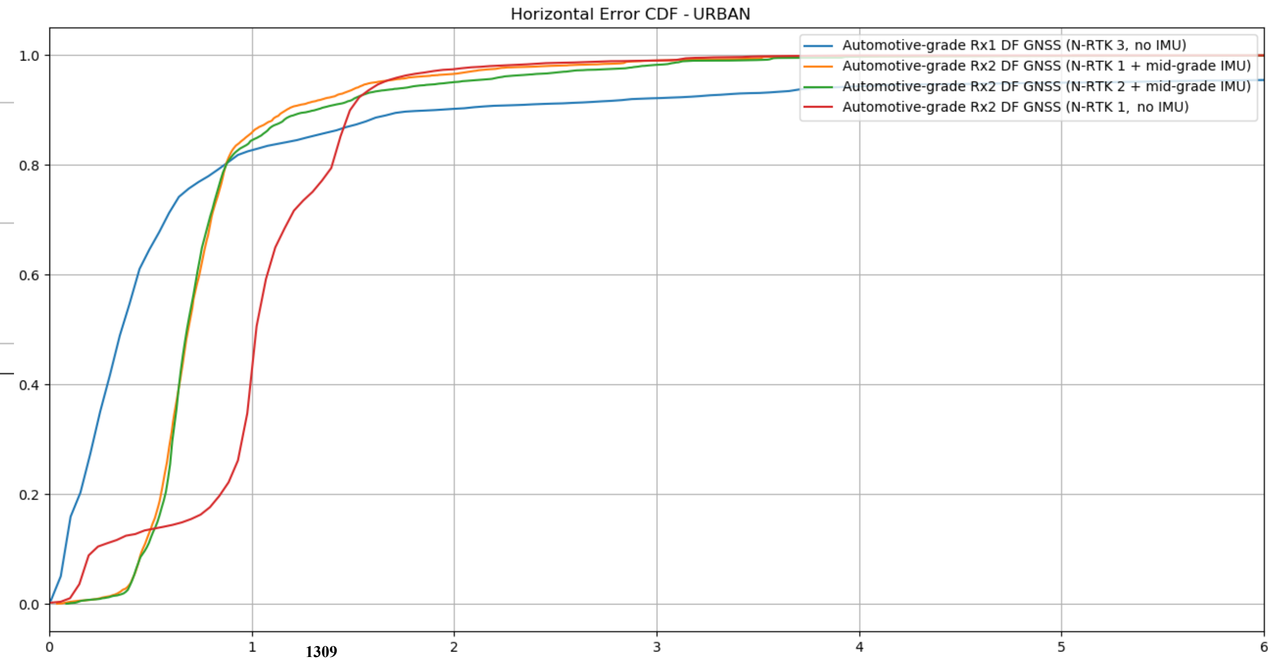
HA-AC: GNSS RESULTS





- **Very good performance of HA-GNSS**

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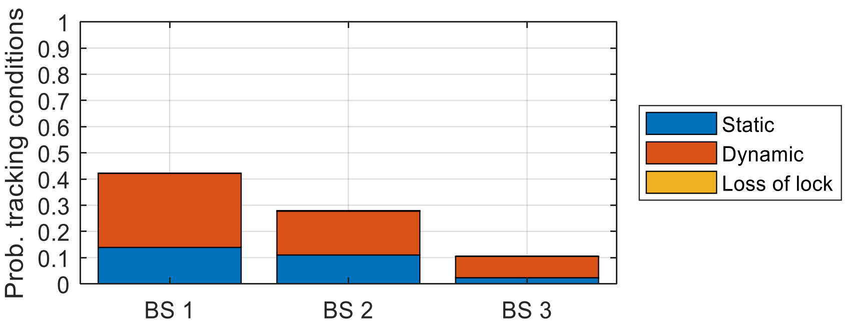
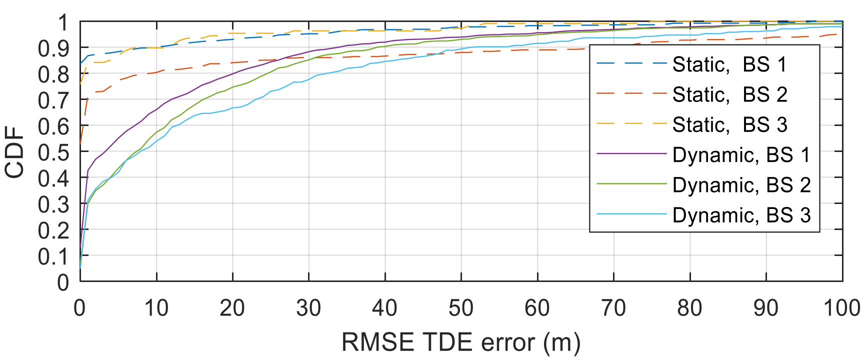
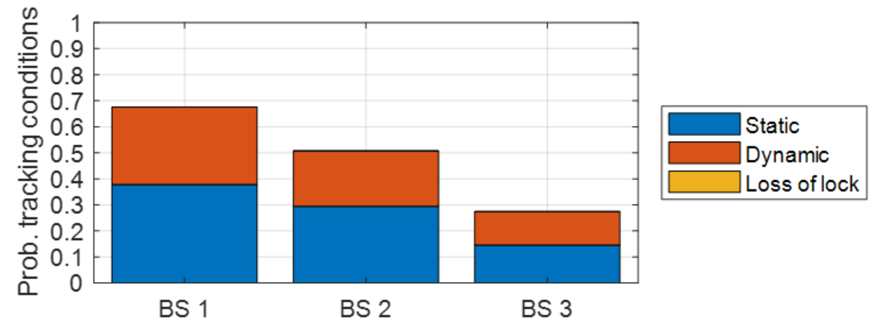
HA-AC: RANGING ERRORS with LTE CRS

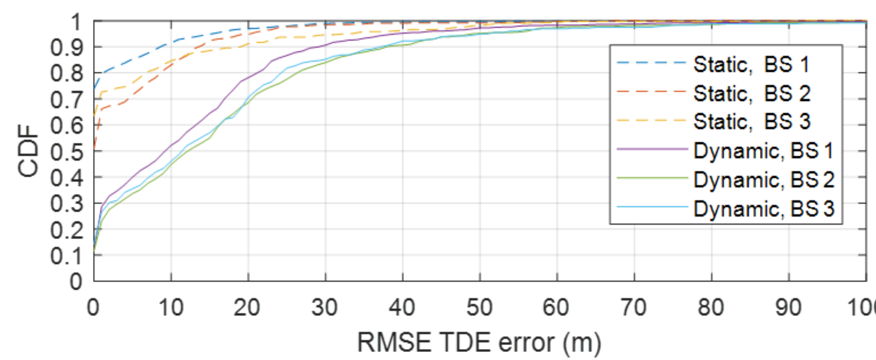
- **Rural**





- **Urban**





- Multipath is the major source of error (especially in urban): Non-line-of-sight conditions are predominant ⇒ High ranging errors

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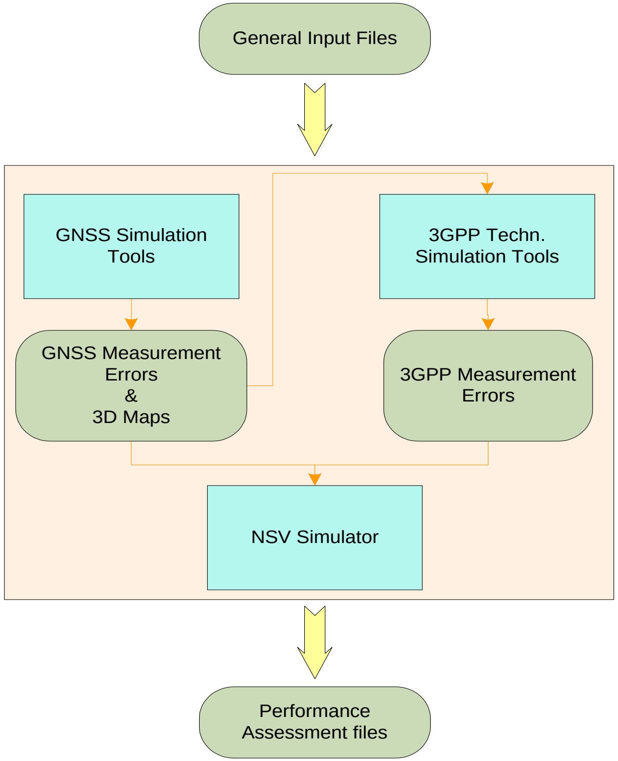
Simulation Platform

PoPeCoT Design and Implementation

PoPeCoT: Global System Description



General Inputs

- 2D Maps
- Trajectory/Coverage
- **Configuration:** based on the characterization obtained from the field tests

GNSS Simulation Tools

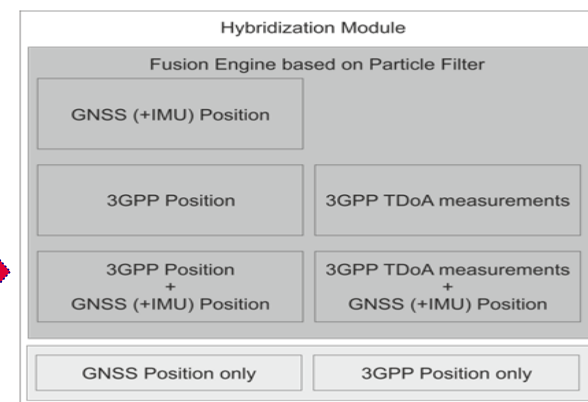
- GNSS Measurement Errors
- 3D Maps

3GPP Techn. Simulation Tools

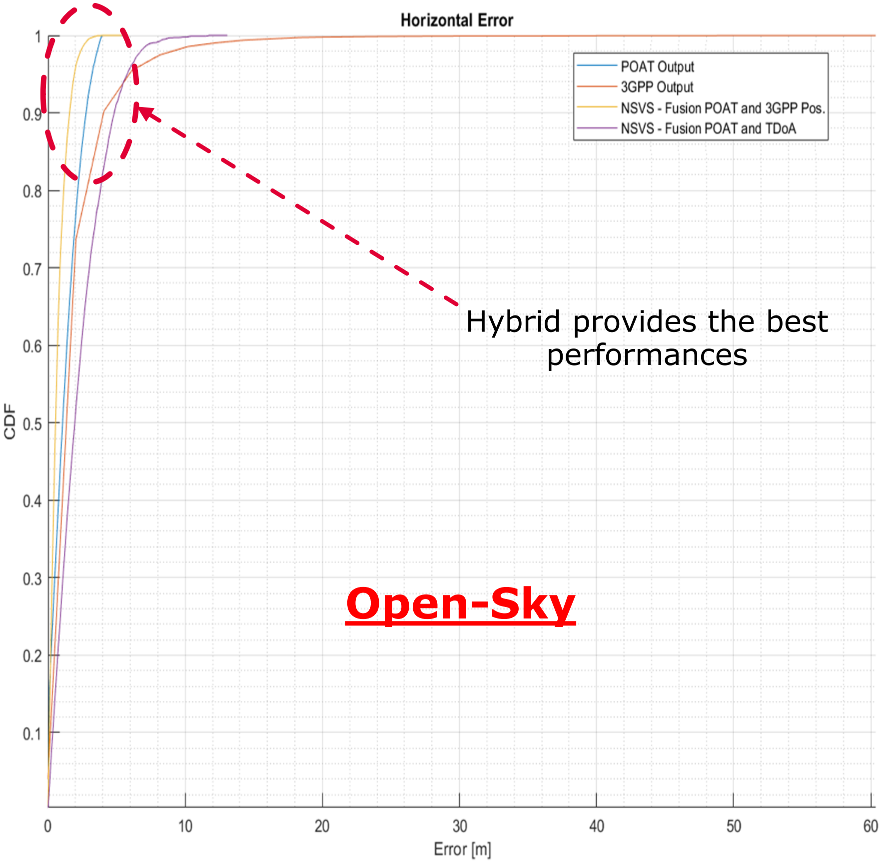
- 3GPP Measurement Errors:
  - ToA errors, C/N0, NLoS flag
- 3GPP PVT solution
- Power consumption levels

NSV Simulator

- Hybrid estimated positions
- Position errors
- Error Statistics & Graphics



PRELIMINARY SIMULATION RESULTS



Validation of GNSS module

1,4546	0,2370	0,3417
0,2370	1,0741	-0,1032
0,3417	-0,1032	2,3094

Covariance matrix: experiments

vs

1,561	0,1605	0,3403
0,1605	1,12	0,0801
0,3403	0,0801	2,536

Covariance matrix: simulations

	Experimentation std	PoPeCoT std	Difference (%)
East	1,206	1,205	-0,07
North	1,036	1,039	0,27
Up	1,52	1,539	1,25

PVT errors comparison

Validation of 5G module

Not yet validated

Validation of GNSS-5G module

Not yet validated

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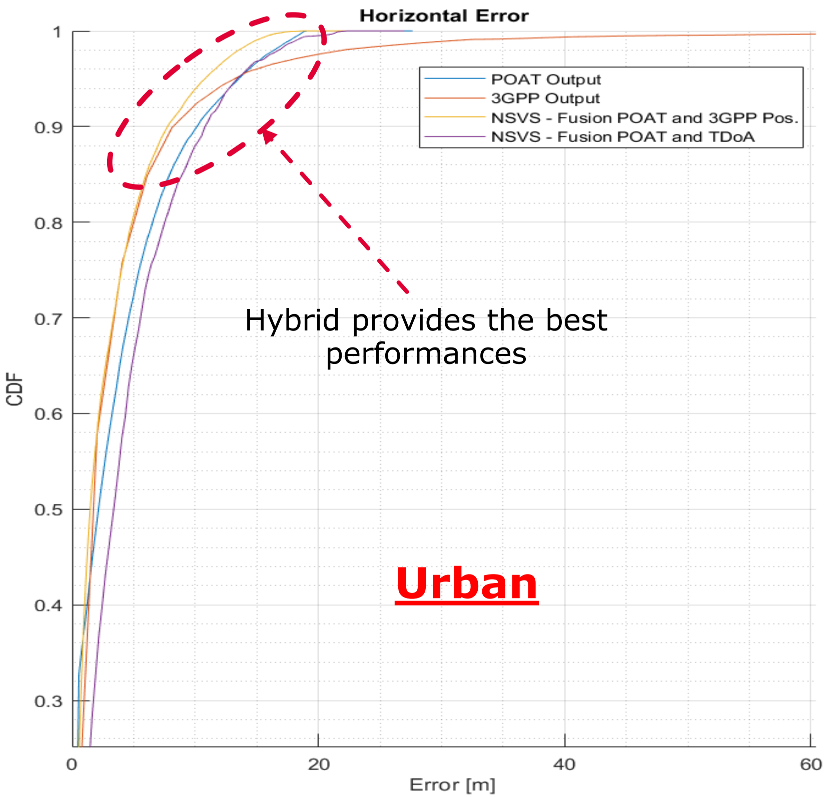
PRELIMINARY SIMULATION RESULTS



Validation of GNSS module

7,6865	1,2758	1,2085
1,2758	11,9094	3,0541
1,2085	3,0541	36,1214

Covariance matrix: experiments

VS

7,4181	1,3817	1,1419
1,3817	11,7686	3,6094
1,1419	3,6094	38,4133

Covariance matrix: simulations

	Experimentation std	PoPeCoT std	Difference (%)
East	2,772	2,793	1,99
North	3,451	3,505	1,22
Up	6,01	5,094	-16,01

PVT errors comparison

Validation of 5G module

Scenario		Perfect synchronization (0 ns)	Tight network synchronization (50 ns)
Urban Macro (UMa)	No NLoS bias	1.32 m	18.57 m
	With NLoS bias	19.66 m	>30 m
Urban Micro (UMi)	No NLoS bias	1.61 m	18.38 m
	With NLoS bias	4.15 m	19.54 m

Validated based on comparison with 3GPP simulations

Validation of GNSS-5G module

Not yet validated

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Conclusions and Next Steps

Conclusions and Next Steps

- GINTO5G project <u>conclusions</u>:
  - ***HA-GNSS can achieve performance of below 1m at 95% (rural and sub-urban) and 2m at 95% (urban European city).***
  - There is no 4G positioning techniques and signals deployed in Europe (and 5G is only about to be rolled out) => ***field evaluation of network-based positioning is not straightforward*** and assumptions on base stations location error and transmitters synchronisation error have to be made.
  - Based on simulation results it could be noticed that ***5G based positioning can add a benefit to HA-GNSS but only under perfect synchronisation (0ns), large percentage of LoS measurements, wide bandwidth (100 MHz!!!),*** and no errors in antenna location. Of course, these are difficult to meet in reality (e.g. ITU requirements for network synchronisation is 1µs!!!, LTE signals have 20MHz!!!).
  - The ***simulation tool performs well*** with respect to field data, and it can be used to assess performance in other cases without field tests.

- GINTO5G project <u>next steps</u>:
  - Validation of ***5G empirical model***
  - New ***experiments in indoor using 5G*** positioning signals (PRS)
  - Hybrid GNSS – 5G for ***transition indoor - outdoor***
  - ***Performance assessment*** with the simulation platform

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THANK YOU

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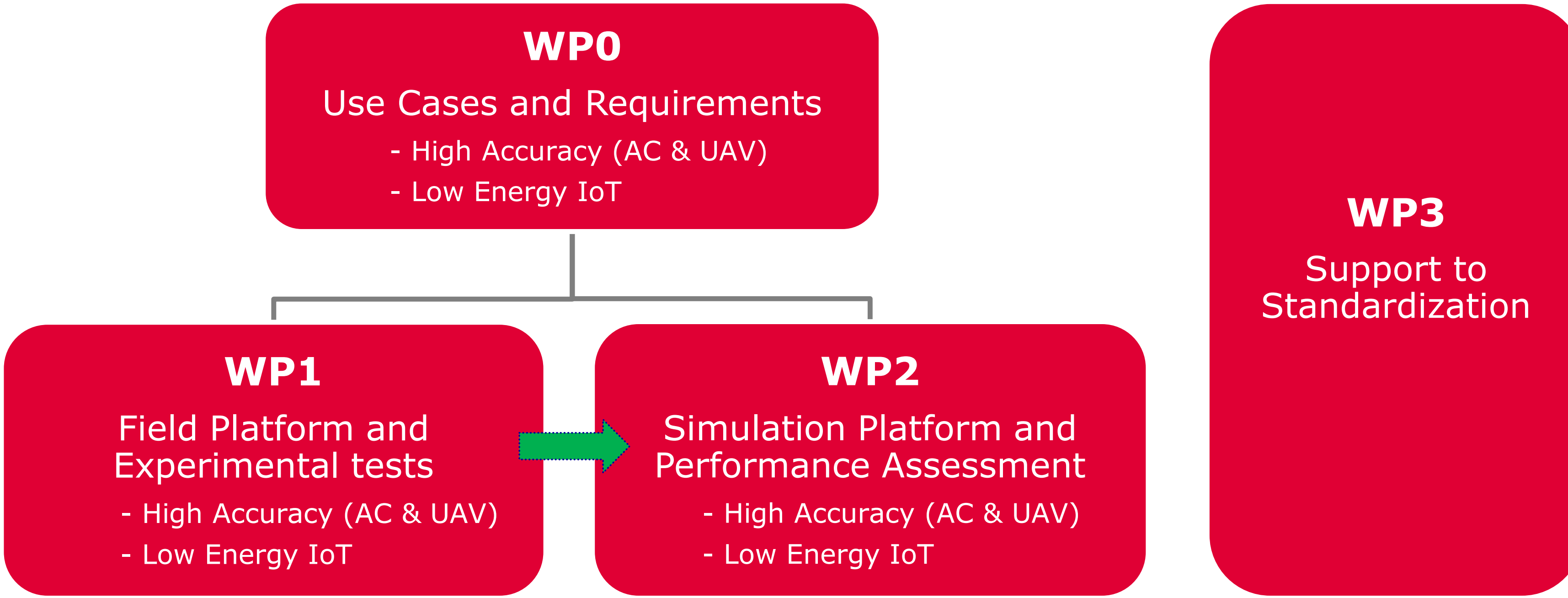
ANNEX: ADDITIONAL INFO

WORK LOGIC



Technologies:

- Multi-constellation **GNSS** including different GNSS receiver grades and differential techniques
  - [RTK, NRTK, PPP, PPP-RTK]
- **Wireless** network solutions (LTE, 5G)
- Additional **sensors** (different grades of IMUs)

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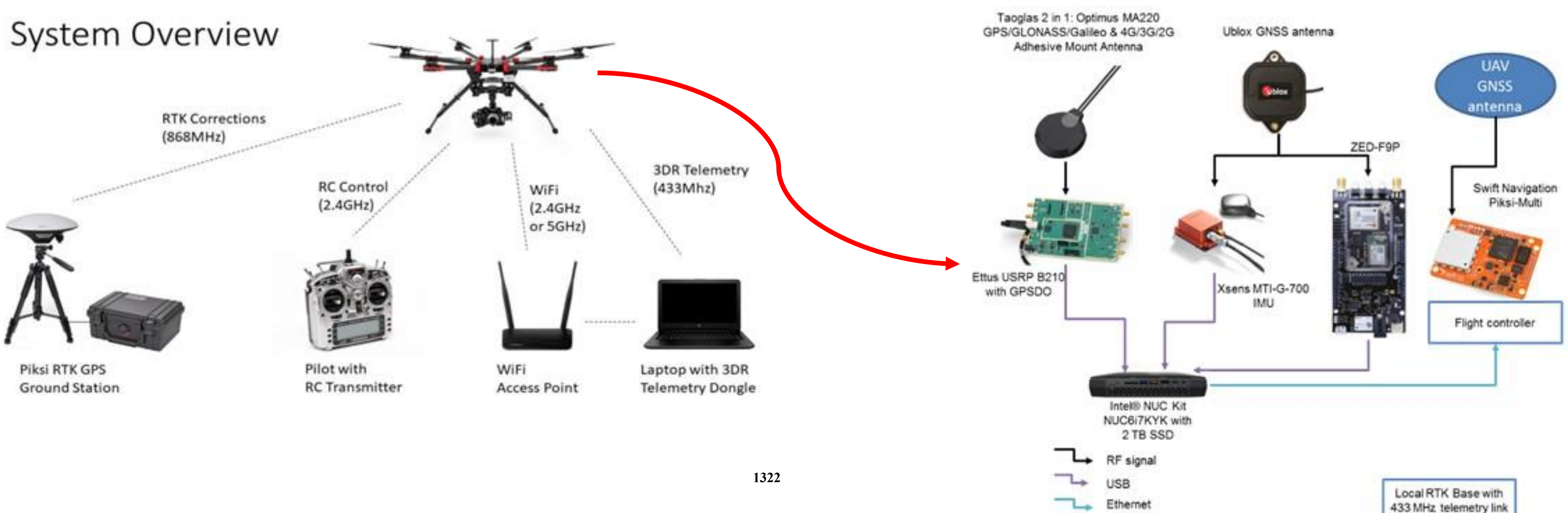
WP1: Field Experiments

HA-UAV

HA-AC UAV PLATFORM FEATURES

- Same approach as for Automotive campaign, with a reduce configuration:
  - GNSS HA-UAV platform main features:
    - ✓ Device Under Test: u-blox ZED-F9P evaluation module (fed by N-RTK corrections)
    - ✓ Reference Trajectory: Swift-Navigation Piksi-Multi dual-frequency RTK
  - LTE/3GPP HA-UAV platform main features:
    - ✓ 1-channel LTE signal reception from one antenna
    - ✓ Signal: LTE CRS band 3 (1815 MHz from DT network)



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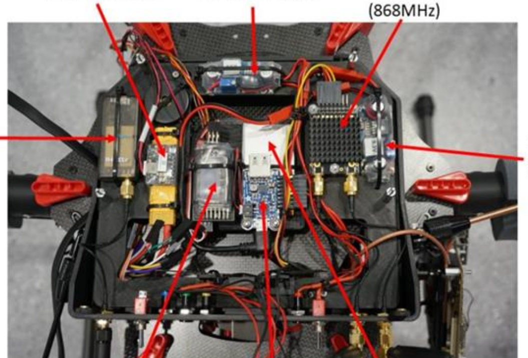
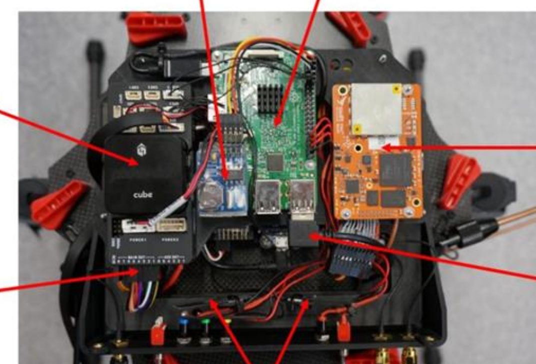
HA-AC UAV PLATFORM





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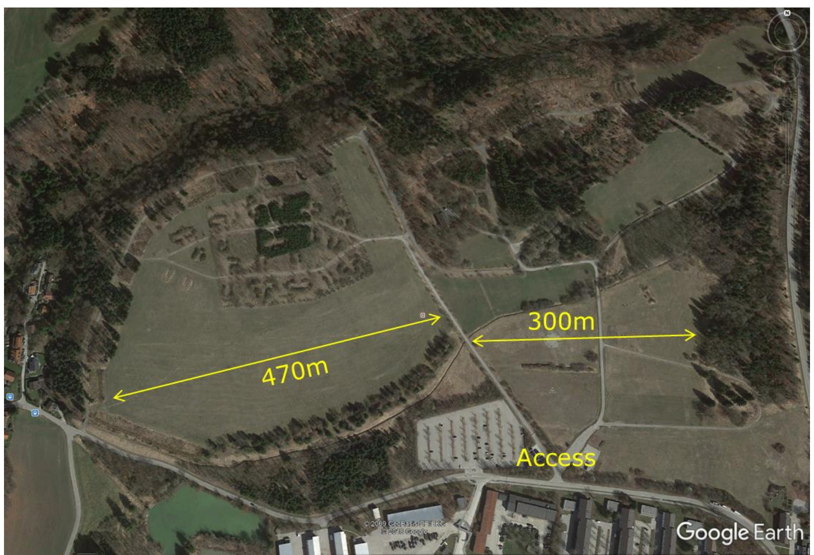
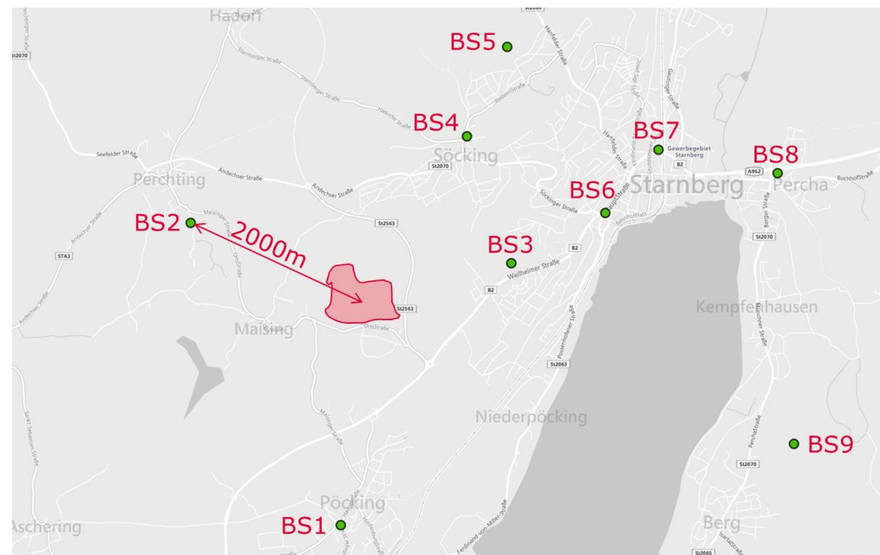
HA-UAV CAMPAIGN

- Experiment area: open area on a German army site accessible for DLR and with no flight constraints (except altitude < 100m)
- 3GPP tests:
  - Base station information (position and IDs) extracted from cellmapper.net
    - Only few base stations around the experiment area
  - Cross-verification of base station position based on
    - Google Maps and an on-site visit to verify validity on Google Maps





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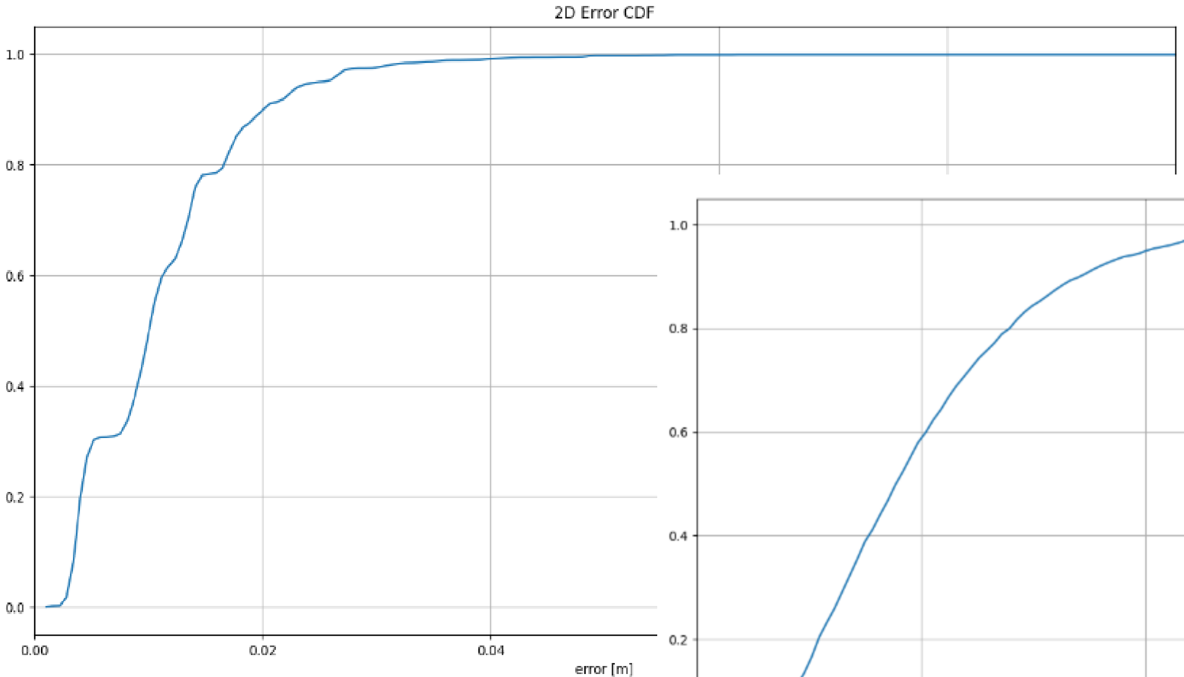
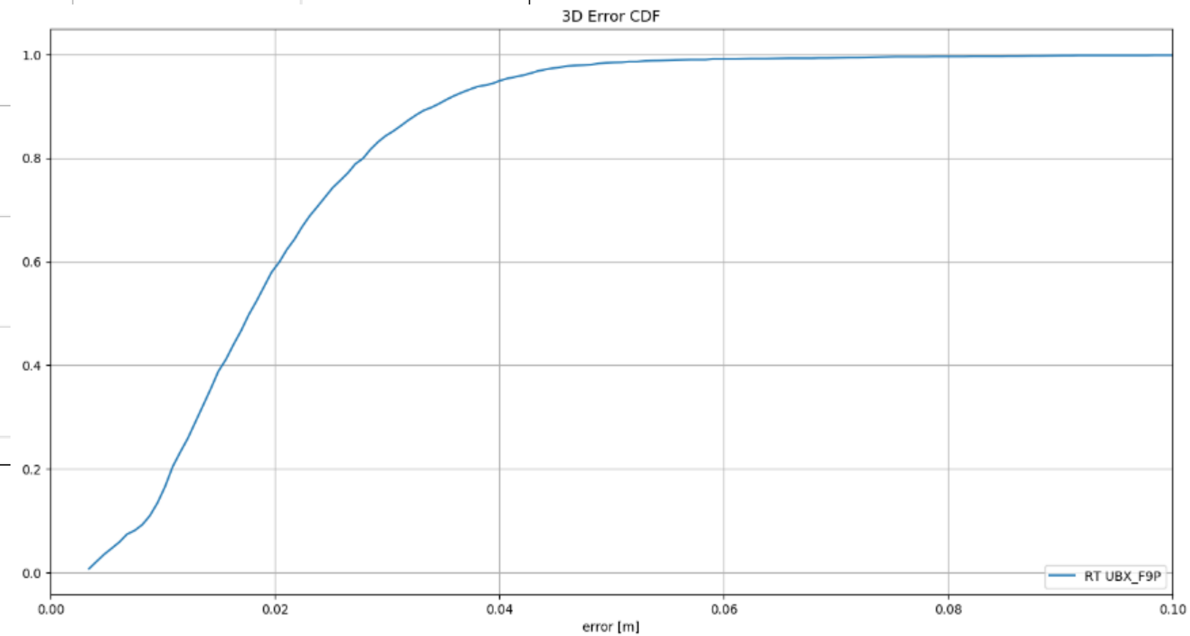
HA-UAV: GNSS RESULTS

- Summary Results: Comparison between reference (Piksi-Multi) and F9P **under 5cm horizontal and 10cm vertical**





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- Very good performance of HA-GNSS

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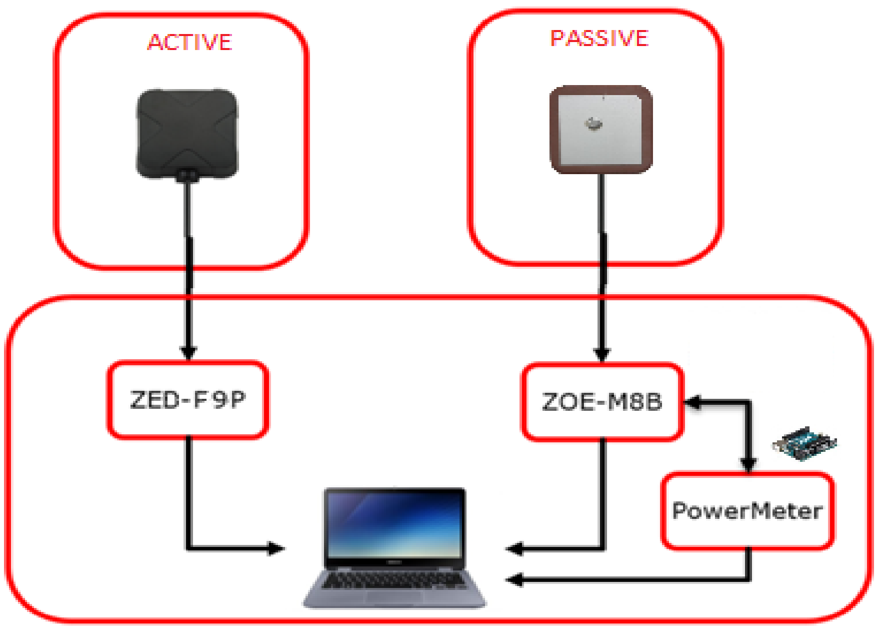
WP1: Field Experiments

Low Energy IoT

LE-IoT PLATFORM

- GNSS LE-IoT platform:
  - ✓ ZOE-M8B LE-IoT device under test to be configured with 7 different duty-cycle + constellation configurations and with two different antenna connections (with LNA/ without LNA)
  - ✓ Reference solution (ground truth) based on ZED-F9P (GPS+GLO+GAL) post-processing solution with NovAtel Inertial Explorer (backwards + forwards, RTK/PPP)



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LE-IoT CAMPAIGN

- Two scenarios representative of user location were selected in Madrid:
  - Open sky
  - Urban canyon (narrower streets and taller buildings)
- Each test repeated with LNA and without LNA considering different duty cycles and for 1-3 constellations.

Open-Sky Trajectory

Urban Trajectory

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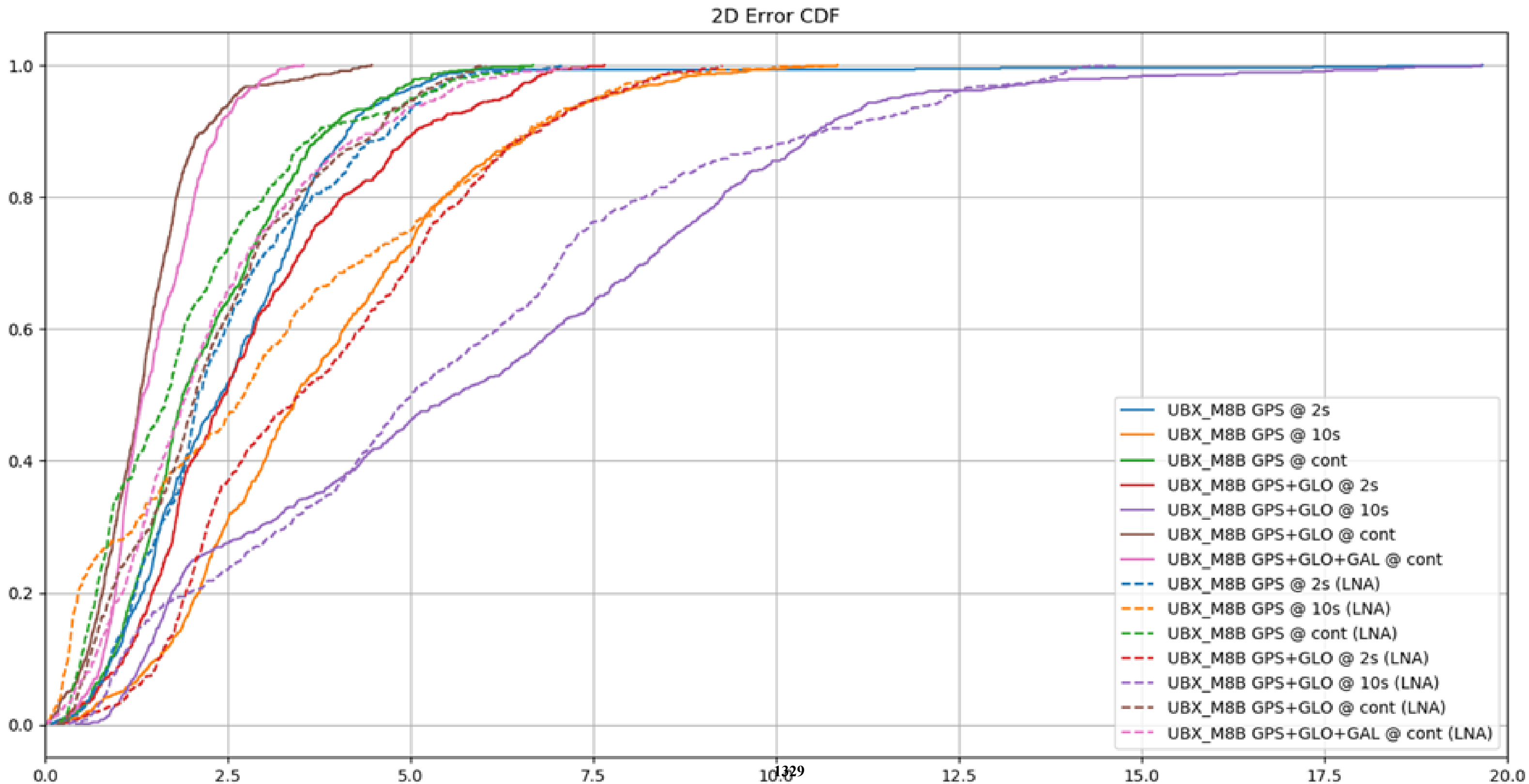
Low Energy IoT: GNSS – Open Sky

Open Sky scenario summary results (dashed with LNA):

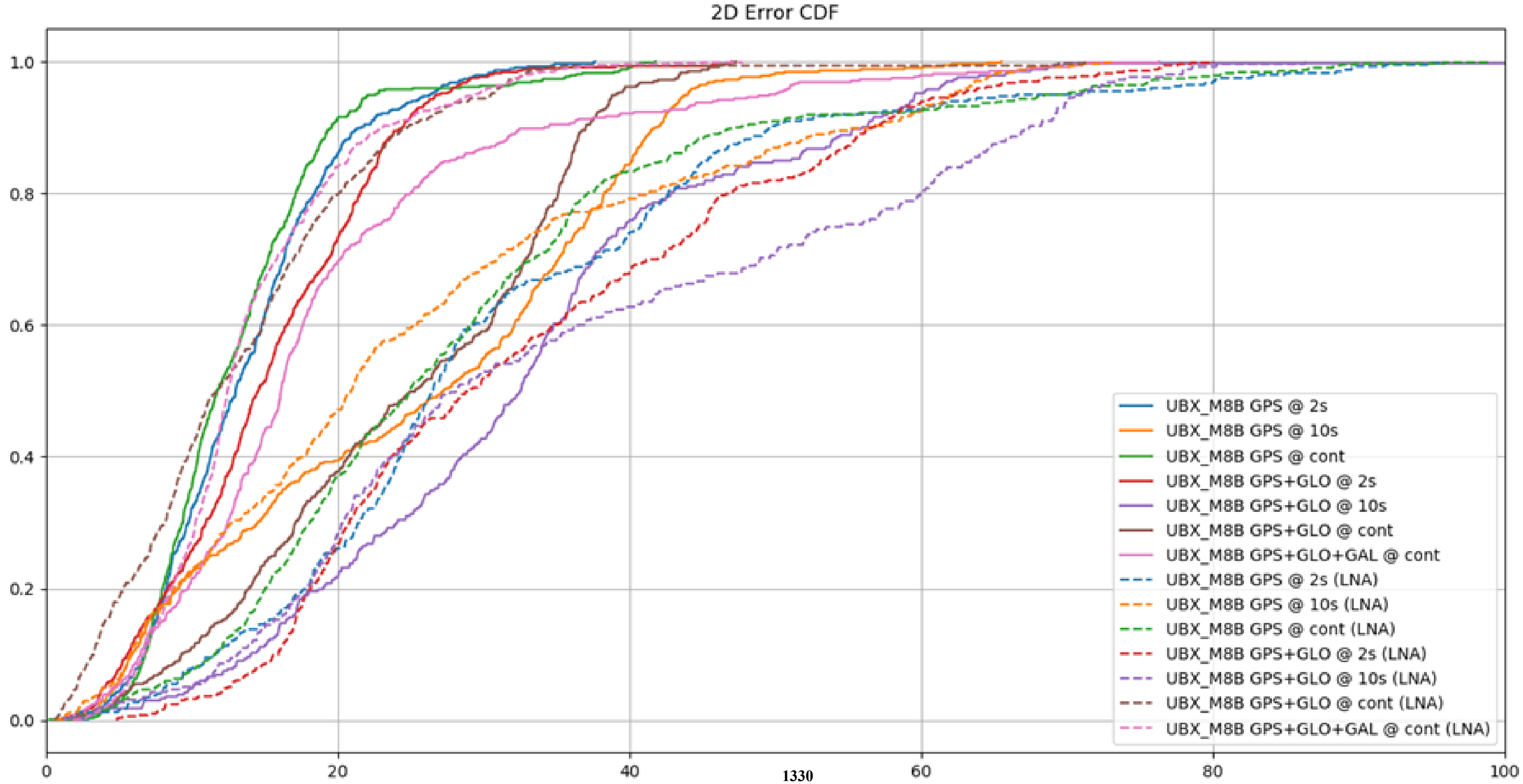
- Similar accuracy with/without LNA
- Higher errors GPS+GLO vs GPS @ 10s



Low Energy IoT: GNSS - URBAN

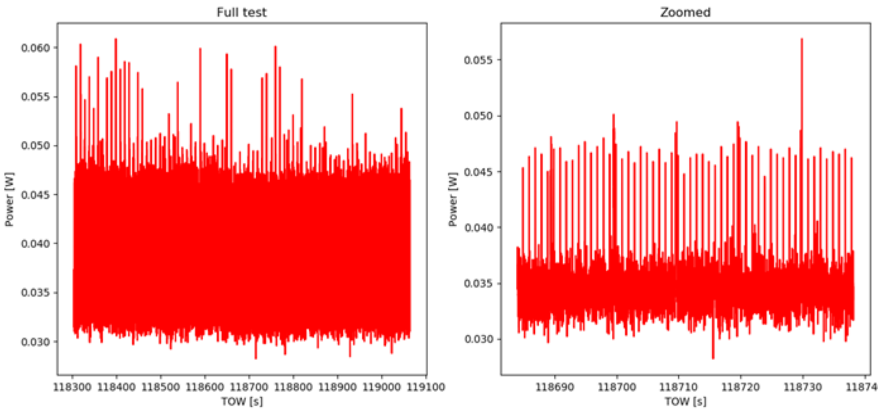
Urban scenario summary results (dashed with LNA):

- No representative positioning error values
- Higher power consumption than in open field scenario due to duty cycle changes.

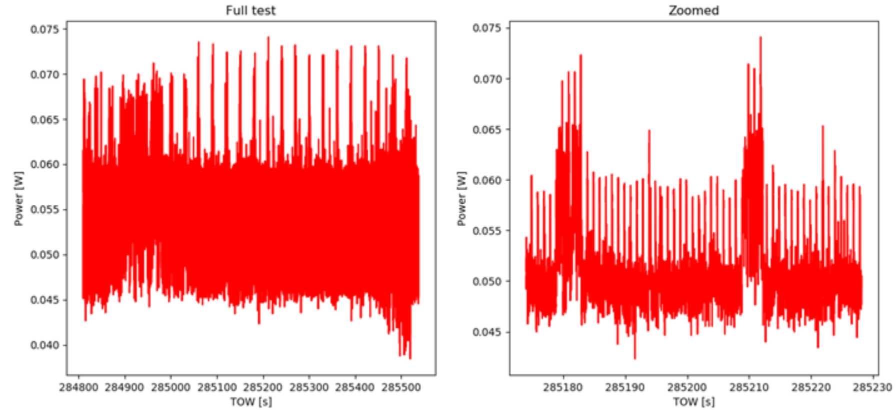


Low Energy IoT: GNSS – Power Consumption

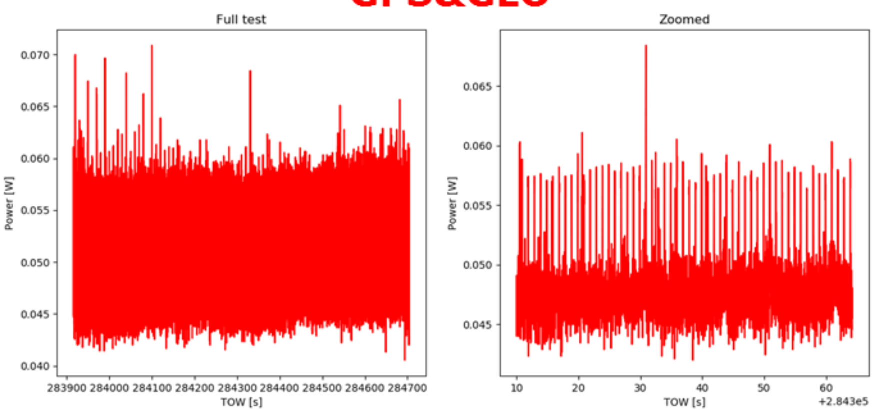
GPS



GPS&GLO&GAL



GPS&GLO



- Almost no power consumption increment with Galileo (3-5mW)
- Considerable increment in power consumption with Glonass (12-14 mW)
- No a priori relationship between increment in SV and power consumption
- No a priori power consumption difference with LNA and without LNA

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WP3 Support to Standardization

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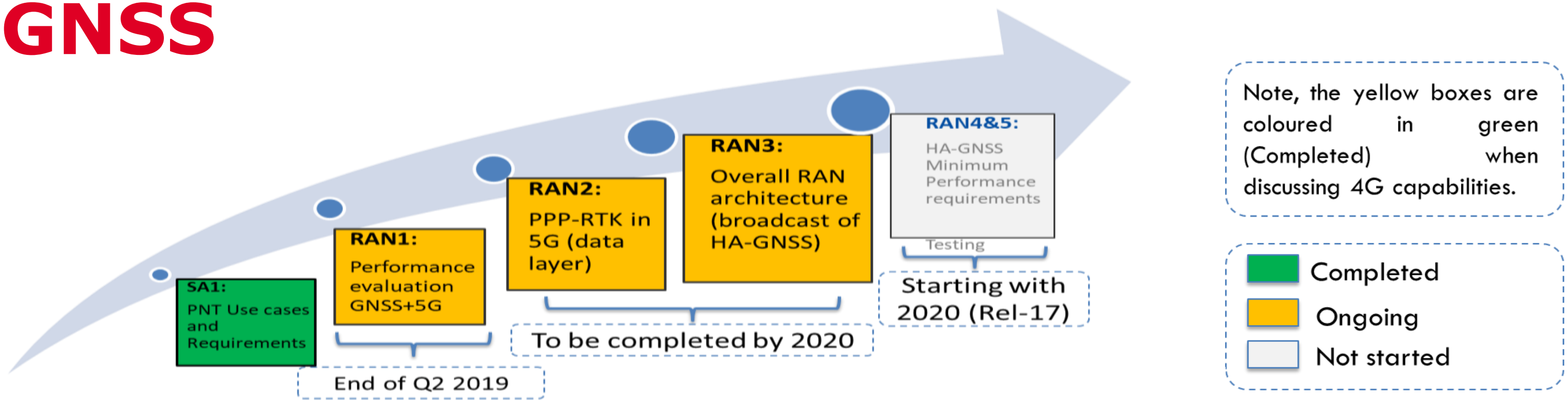
WP3 Support to the Standardization of GNSS



- Support to the standardization in 3GPP – **RAT Independent Positioning** (main topic):
  - **SA1:** [**FS_5G_HYPOS**] and [**5G_HYPOS**]:
    - SA1 Use cases and positioning service level requirements
  - **RAN1&RAN2&RAN3:** [**FS_NR_Pos**] and [**NR_Pos**]:
    - Transfer LTE hybridisation capabilities (**LPP**) to NR (**NPP**) including RTK/PPP corrections
    - **Broadcast** corrections for HA-GNSS including PPP-RTK
    - Promote the benefit of **hybridization** between RAT-dependent and GNSS

- Other topics of interest in the standardization:
  - PPP-RTK, NB-IoT, V2X, 5G Network Synchronization and Security & Authentication

5G Positioning

- **SA1: 5G positioning service levels requirements**

Positioning service level	Absolute(A) or Relative(R) positioning	Accuracy (95 % confidence level)		Availability	Latency	Coverage, environment of use and UE velocity		
		Horizontal Accuracy	Vertical Accuracy (note 1)			5G positioning service area	5G enhanced positioning service area (note 2)	
							Outdoor and tunnels	Indoor
1	A	10 m	3 m	95 %	1 s	Indoor - up to 30 km/h Outdoor (rural and urban) up to 250 km/h	NA	Indoor - up to 30 km/h
2	A	3 m	3 m	99 %	1 s	Outdoor (rural and urban) up to 500 km/h for trains and up to 250 km/h for other vehicles	Outdoor (dense urban) up to 60 km/h Along roads up to 250 km/h and along railways up to 500 km/h	Indoor - up to 30 km/h
3	A	1 m	2 m	99 %	1 s	Outdoor (rural and urban) up to 500 km/h for trains and up to 250 km/h for other vehicles	Outdoor (dense urban) up to 60 km/h Along roads up to 250 km/h and along railways up to 500 km/h	Indoor - up to 30 km/h
4	A	1 m	2 m	99.9 %	15 ms	NA	NA	Indoor - up to 30 km/h
5	A	0.3 m	2 m	99 %	1 s	Outdoor (rural) up to 250 km/h	Outdoor (dense urban) up to 60 km/h Along roads and along railways up to 250 km/h	Indoor - up to 30 km/h
6	A	0.3 m	2 m	99.9 %	10 ms	NA	Outdoor (dense urban) up to 60 km/h	Indoor - up to 30 km/h
7	R	0.2 m	0.2 m	99 %	1 s	Indoor and outdoor (rural, urban, dense urban) up to 30 km/h Relative positioning is between two UEs within 10 m of each other or between one UE and 5G positioning nodes within 10 m of each others (note 3)		

NOTE 1: The objective for the vertical positioning requirement is to determine the floor for indoor use cases and to distinguish between superposed tracks for road and rail use cases (e.g. bridges).
NOTE 2: Indoor includes location inside buildings such as offices, hospital, industrial buildings.
NOTE 3: 5G positioning nodes are infrastructure equipment deployed in the service area to enhance positioning capabilities (e.g. beacons deployed on the perimeter of a rendezvous area or on the side of a warehouse).

TBS/WLAN

Proprietary solutions (e.g. UWB) (and opportunities for 5G NR)

Multi-GNSS or Hybridized Multi-GNSS

1334 *Service levels and service areas with best opportunities for 5G NR / HA-GNSS hybridization*