5GInOSEG

Integrating 5G with an Indoor GNSS Signal Manipulator and Repeater for Seamless Indoor/Outdoor PNT

Final Presentation

Presenters:

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IGASPIN: Rüdiger Hein (CEO)
IGASPIN: Amir Tabatabaei (CTO)

Place: Online
Date: November 18th, 2022 (10:00 – 12:00)

Agenda

- **Topics**

10:00	Welcome and introduction
10:05	General objective
10:07	Proposed product
10:10	Literature and market review
10:20	5G/GNSS/IMU receiver
10:30	Indoor GNSS Signal Manipulator and Repeater
10:40	Experimental results
10:55	Conclusions
11:00	Q & A

IGASPIN GmbH

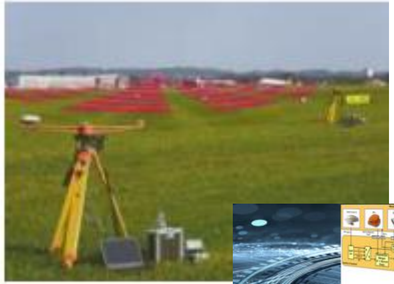
Privately owned company (SME)

- Founded in 2015, operational since 05/2016
- Legal form: GmbH (gründungspriviligiert)
- Located in GRAZ, Austria

IGASPIN GmbH

Focused on

- ✓ Satellite navigation,
- ✓ GNSS interference detection, mitigation, and localization,
- ✓ GNSS software receiver (with exclusive right to develop and sell IFEN SX3 software receiver).
- ✓ Artificial intelligence in GNSS realm.



Personnel

- Currently 5 employees
- ➢ *IGASPIN is looking for more personnel.*

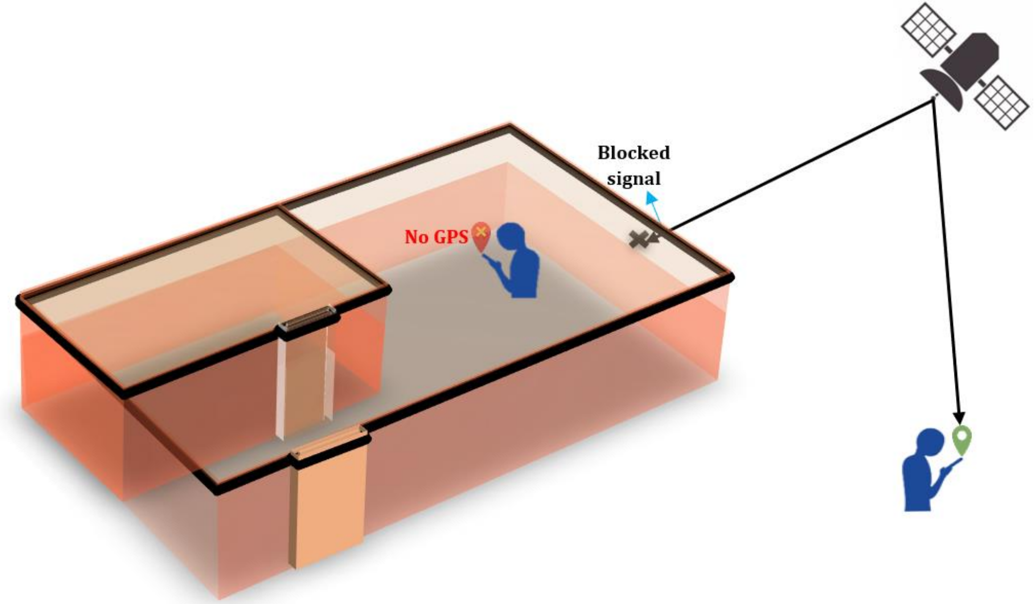
General Objectives

Objectives of NAVISP call for 5G PNT projects

Implementation of pilot projects to **demonstrate the viability of 5G PNT solutions** in use cases representative of Industry 4.0, smart cities and critical users demanding a robust back-up to satellite navigation positioning and timing.

Problem definition

Seamless indoor/outdoor positioning and timing



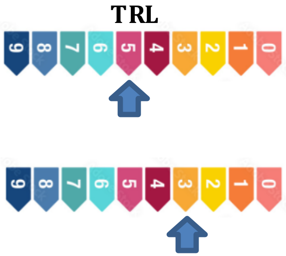
Proposal by IGASPIN

Integrating 5G with an Indoor GNSS Signal Manipulator and Repeater for seamless indoor/outdoor PNT

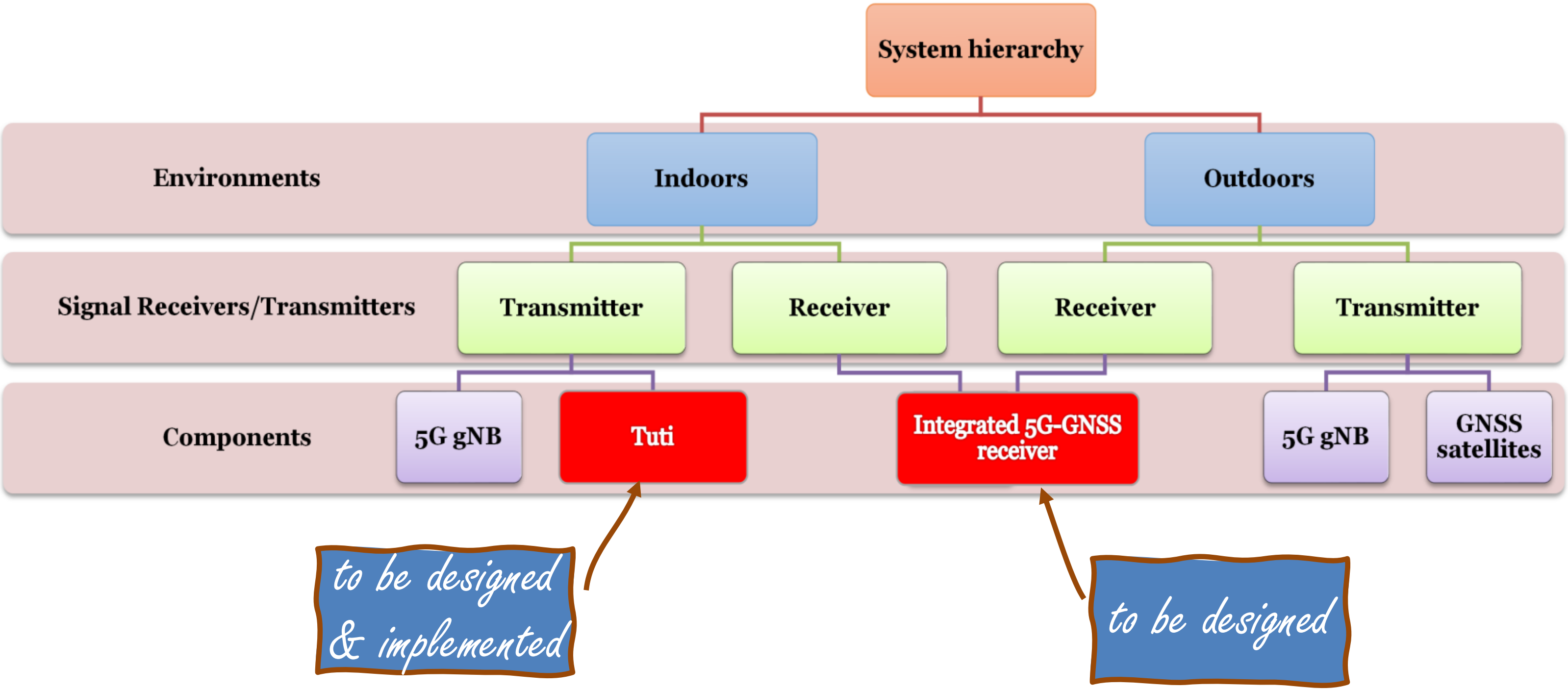
(5GInOSEG)

1. Design and implement an advanced indoor GNSS signal manipulator and repeater (**Tuti**)

2. Design an integrated 5G/GNSS receiver equipped with IMU and monitoring modules



Proposed system hierarchy

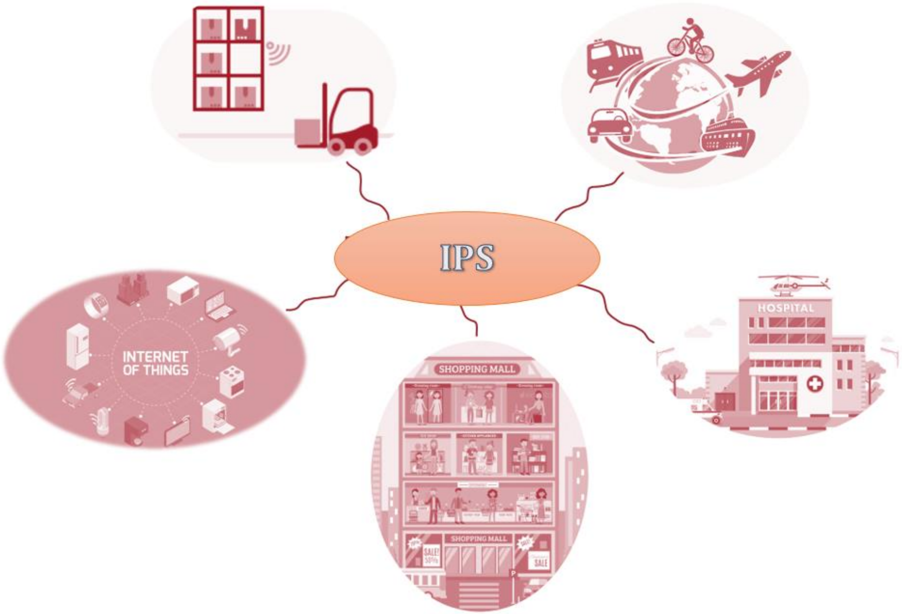


Indoor positioning

principles and algorithms

Review indoor positioning: principles and algorithms

- **Indoor positioning applications**
  - Factories
  - Airports and railway stations
  - Supermarkets and shops
  - Hospitals
  - Tunnels



Review indoor positioning: principles and algorithms

Positioning technology	Stand-aloneness	Accuracy	Coverage (range of the positioning signals)	Cost of the Infrastructure	Privacy
GNSS	Stand-alone	4m – 7m	Generally available outdoors	Billions of Pounds (but already existing)	High
Pseudolite	Stand-alone	3m-7m	~50km	~£100000 per transmitter	High
Mobile networks	Stand-alone	1m	~ A few km	Millions of Pounds (but already existing)	Medium
WiFi RSS	Stand-alone	2m – 4m	10cm-50m	20£-(more than £50) per Access Point	Medium
WiFi TOF/AOA	Stand-alone	1.7m– 10m	~25m	>£50 (AP Prices)	Medium
UWB TOF	Stand-alone	15cm	~5m-175m	Expensive laboratory equipment	Medium
RFID active	Stand-alone	1m-3m/	30 – 100m	>£10 per tag	Medium
RFID passive	Stand-alone	15cm-50cm	~2m	~£200 >£1000 per reader	Low
Bluetooth RSS	Stand-alone	2m-5m	(125m, 150m in open fields)	£5-£30 per tag	High
Barometer	Assistive	33cm-0.2m	Ubiquitously	Not applicable	High
Sound	Stand-alone	1cm-1m	~3m-10m/	£10-£100 per node	Medium
IR marker or reflective element	Stand-alone	10cm6m(for active Badges	~6m (depends on tag placement)	£1 (marker)-£10 (camera)	Low (for environment)/ high (for user with the camera)
IR Light Image feature matching	Stand-alone	0.2 – 0.8m	~6m- 10m	~£1 per thermopile- €8000 micro-bolometer camera	Low (for environment)/ high (for user with the camera)
Magnetometer	Stand-alone (needs magnetic maps)	1mm for permanent magnet	1m magnetic fingerprint map	>£2*n	High for sensor but low for user if carrying a magnet
Electromagnet ic system	Stand-alone	1% of the range	~ 5m- 20m	~£16 per mm^2	Low
Light Image marker	Stand-alone and Assistive	1mm-30cm	~6m (resolution dependent)	>£10 for marker amount	High (if user carries the camera)
Light Image feature matching	Stand-alone	~10cm (1% drift for odometer)	~6m (resolution dependent)	~£10-£100 per camera	High (odometer and user carrying)
Tactile On user device	Assistive		Ubiquitously		High
Tactile Environment	Stand-alone	4cm-40cm	Ubiquitously	~£100 (per 3x2m^2 area)	Low
Tactile Odometer	Assistive		Ubiquitously		High

Ref:
Basiri, Anahid, Elena Simona Lohan, Terry Moore, Adam Winstanley, Pekka Peltola, Chris Hill, Pouria Amirian, and Pedro Figueiredo e Silva. "Indoor location based services challenges, requirements and usability of current solutions." *Computer Science Review* 24 (2017): 1-12.

1. Over the past few years, the 3GPP has been developing the 5G - also known as NR - as the next wireless communication system.

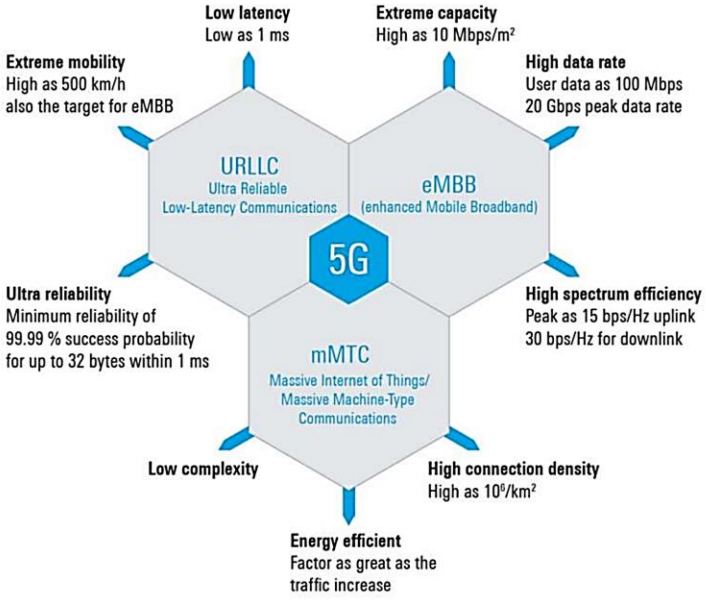
5G

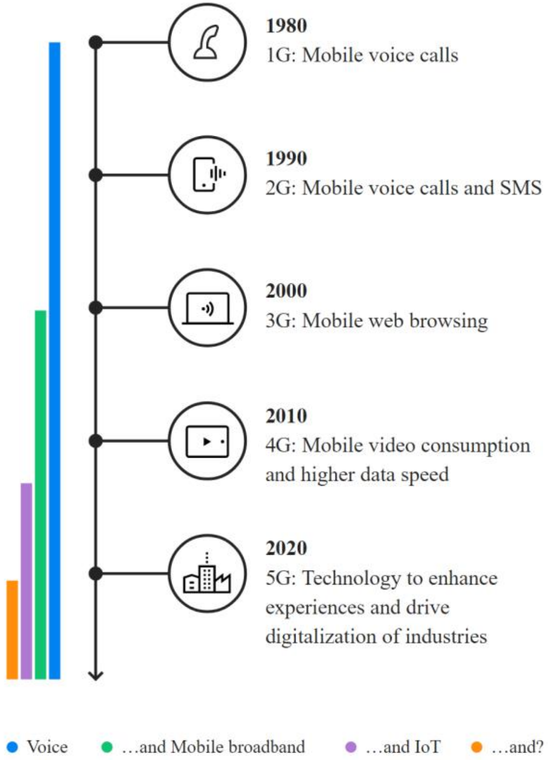
2. This is particularly regarding time- and angle-based positioning methods.

3. However, these methods also suffer different problems such as multipath and low signal power in different scenarios for example indoors.

5G Positioning Technology

- **5G evolution**





5G Positioning Technology

- The evolution of positioning support in 3GPP standardization

	4G LTE based positioning				5G NR based positioning 5G Inter-RAT based positioning			
3GPP Releases	Rel. 9	Rel. 11	Rel. 13	Rel. 14	Rel. 15	Rel. 16	Rel. 17	Rel. 18
Key positioning features	Support for LTE positioning	UTDOA support for LTE	Study LTE enhancement to cover the requirements for indoors	Indoor positioning enhancements, LTE-M, NB-IOT support	GNSS RTK and NSA NR support, sensor measurement reporting	Positioning framework with NR	Industrial IOT integrity for positioning	TBD

5G Positioning Technology

- LTE positioning
  - Over-the-Top
  - AGNSS
  - Cell ID
  - Enhanced Cell ID
  - Downlink Observed Time Difference of Arrival
  - Uplink Time Difference of Arrival

5G Positioning Technology

- Comparison of LTE location determination technologies

	AGNSS	CID	ECID	DL-OTDOA	UTDOA	Hybrid AGNSS
UE impact	Yes	No	Same as normal (TA, RSRP/RSRQ, etc), but additional measurements for location	Yes (receive PRS from eNBs and process)	No	Yes
eNB impact	No	No	Yes	Yes	Yes	Yes
Air interface capacity impact	Moderate (assistance to and reporting of AGPS data by UE)	No	Moderate (reporting of TA and RSRP, RSRQ to eNB)	High ~1% due to PRS	Minimal (incremental SRS for LBS)	High (same as OTDOA)
UE battery impact	High	None	None	Low	None	High
Accuracy	5–20 m (outdoor)	Sector size ~50–1000 m (least accurate)	~0.16 tri-sector cell site radius (~50–1000 m)	50–300 m	50–300 m	5–300 m (both in/outdoors)
Indoor UE support and performance	Poor	If service exists, very good with or without indoor cells.	Outdoor cells: environment dependent. Indoor cells serving local UEs: good.	Outdoor cells: environment-dependent. Indoor cells: good.	Outdoor cells: environment-dependent. Indoor cells: good.	Good.
3GPP Release	R9	R8	R9	R9	R11	R9 (assuming OTDOA or ECID)
Scalability to all UE Positioning	Will significantly increase network traffic	Will add minimal additional traffic	Will increase network traffic	Will increase network traffic	Will add minimal additional traffic	Will significantly increase network traffic
Timeliness of information	UE has to be requested	Near real-time	UE has to be requested, faster response	UE has to be requested	Fairly quick (~seconds) gated by processing	UE has to be requested
Network dependency	UE centric can bypass operator	Network-centric	Network-centric but UE dependent	Network-centric but UE dependent	Network-centric technique	UE centric but network-dependent

Ref: Cherian, Suma S., and Ashok N. Rudrapatna. "LTE location technologies and delivery solutions." Bell Labs Technical Journal 18, no. 2 (2013): 175-194.

5G Positioning Technology

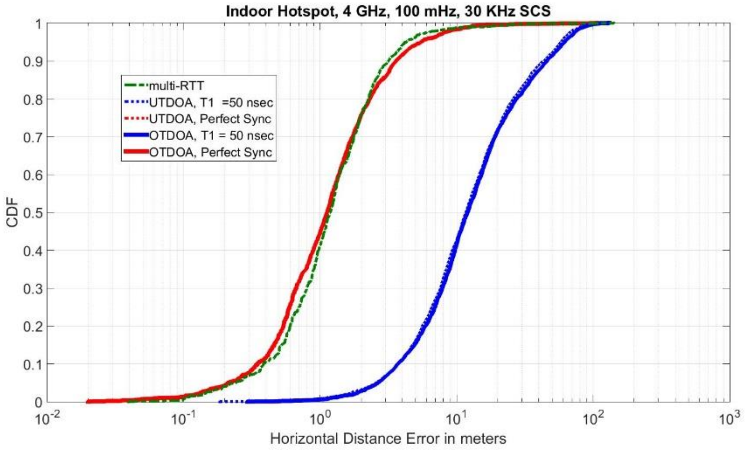
- Specific signals for 5G positioning
  - To enable more accurate positioning measurements than LTE, new reference signals were added to the NR specifications:
    - **Downlink positioning reference signal (DL-PRS)**
      - Each base station can then transmit in different sets of subcarriers to avoid interference.
      - several base stations can transmit at the same time without interfering with each other, this solution is also latency efficient.
    - **Uplink sounding reference signal (UL-SRS)**
      - The SRS is transmitted by the UE for uplink channel sounding, which includes the channel estimation and synchronization.
      - Both UE and gNB must know the SRS to utilize the channel sounding function.

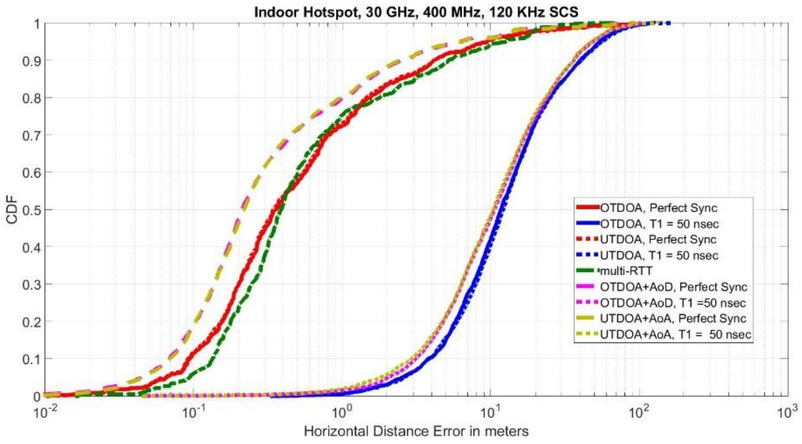
5G Positioning Technology

- NR positioning methods
  - Downlink Time Difference of Arrival (DL-TDOA) Positioning
  - Downlink Angle-of-Departure (DL-AOD) Positioning
  - Uplink Time Difference of Arrival (UL-TDOA) Positioning
  - Uplink Angle-of-Arrival (UL-AOA) Positioning
  - Multi-Round-Trip-Time (Multi-RTT) Positioning
  - Enhanced Cell-ID (E-CID) Positioning

5G Positioning Technology

- Comparison





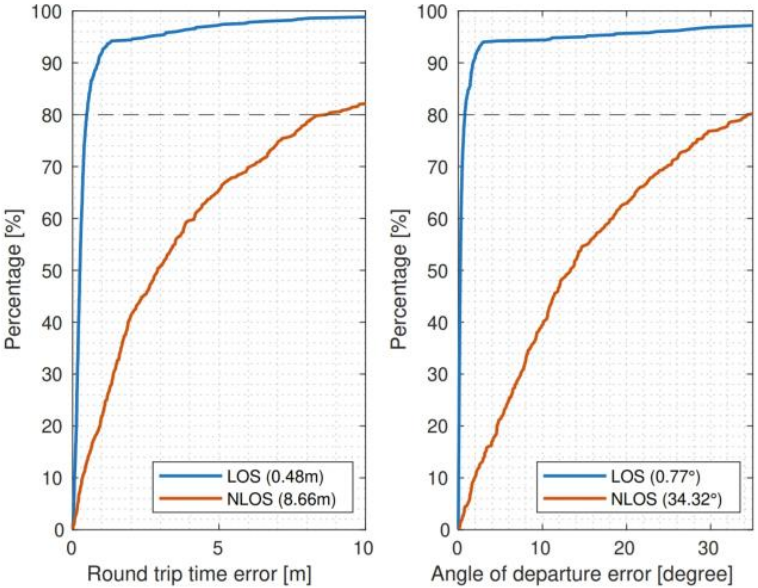
Ref: R1-1903021, "Evaluation results for RAT-dependent positioning Techniques", Qualcomm Incorporated.

5G/GNSS Integrated Receiver Design

- Problem definition
  - The 5G system is very attractive by design for navigation purposes due to the following reasons:
    - ✓ High carrier frequencies
      - ➢ Precise carrier phase and
      - ➢ Lower multipath effects due to high path signal loss.
    - ✓ Abundance
      - ➢ Lower signal path loss of mmWaves by using beamforming techniques and small cells.
    - ✓ Geometric diversity
      - ➢ Cellular towers have favorable geometry by the construction of the cells to provide better coverage.
    - ✓ Large bandwidth
      - ➢ Less susceptible to multipath errors.
    - ✓ High received power
      - ➢ More than 20 dB-Hz stronger than GPS signals.

5G/GNSS Integrated Receiver Design

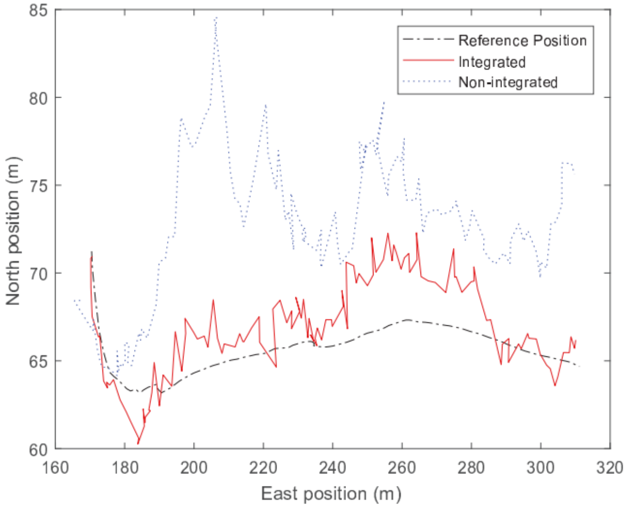
- Problem definition
  - ☒ However, 5G still suffers the multipath and NLOS interferences.



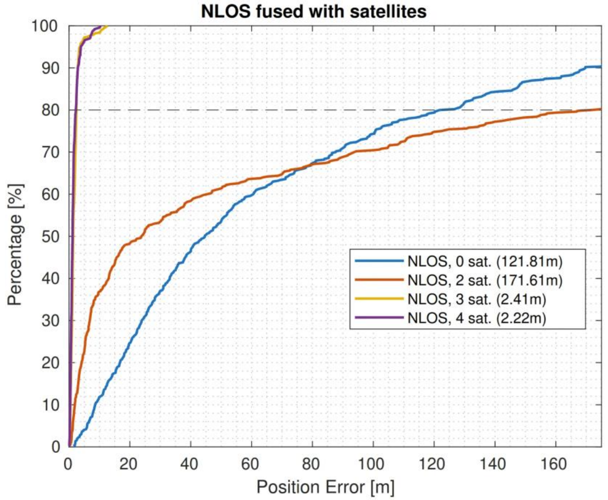
Carl Rydholm and William Pommer, “Hybrid Positioning Solution Using 5G and GNSS”, M.Sc. Thesis, Department of Electrical Engineering, Linköping University, 2021.

5G/GNSS Integrated Receiver Design

- One solution:
  - GNSS+5G



Yin, Lu, Qiang Ni, and Zhongliang Deng. "A GNSS/5G integrated positioning methodology in D2D communication networks." IEEE Journal on Selected Areas in Communications 36, no. 2 (2018): 351-362.

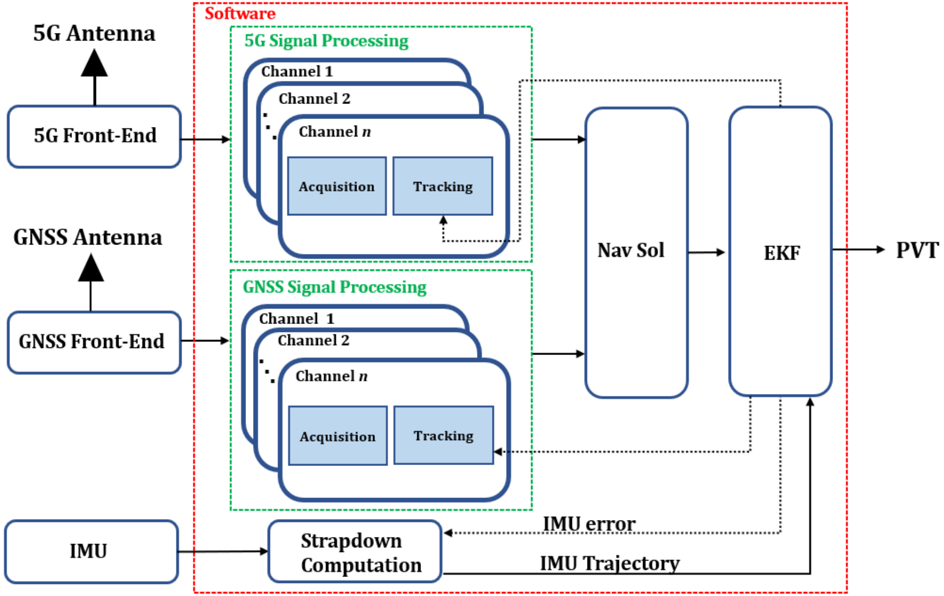


Carl Rydholm and William Pommer, "Hybrid Positioning Solution Using 5G and GNSS", M.Sc. Thesis, Department of Electrical Engineering, Linköping University, 2021.

5G/GNSS/IMU Integrated Receiver Design

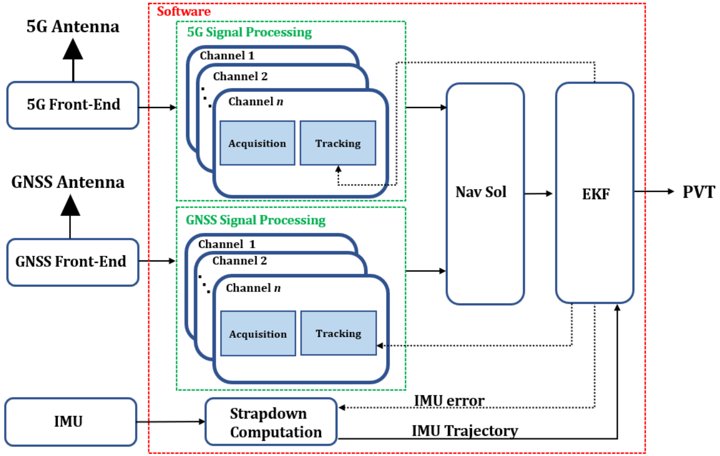
5G/GNSS/IMU Integrated Receiver Design

- **Design of a GNSS/5G/IMU receiver-Software and methodology**
  - High-level architecture



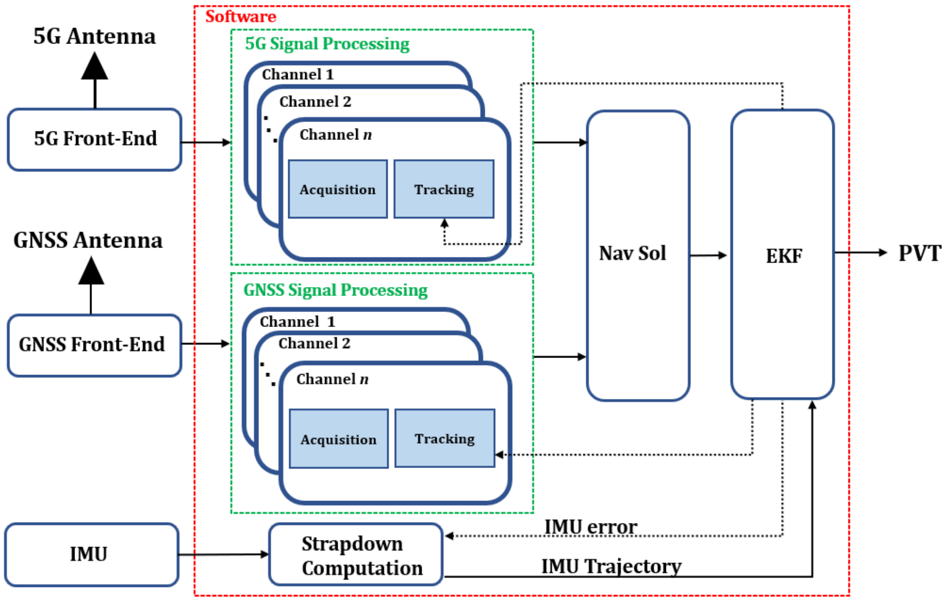
5G/GNSS/IMU Integrated Receiver Design

- **Integration**
  - IMU integration
    - The IMU trajectory is passed to the EFK and serves there as the base trajectory.
    - The GNSS signal tracking process is controlled by the EKF using the principles of vector tracking.



5G/GNSS/IMU Integrated Receiver Design

- **Monitoring**
  - Stream-based algorithms
    - Spectral monitoring
  - Receiver-based algorithms
    - PVT monitoring
  - Channel-based algorithms
    - Signal power monitoring



5G/GNSS/IMU Integrated Receiver Design

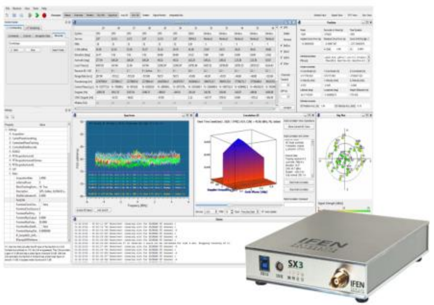
- **Design a GNSS/5G/IMU receiver-Hardware**
- GNSS section
  - GNSS antenna
    - a simple, cheap, and small omnidirectional antenna

Example:

uBlox ANN-MB-00-00, multi-band (L1, L2/E5b/B2I) active GNSS antenna for BeiDou, Galileo, GLONASS, GNSS, GPS signal reception

5G/GNSS/IMU Integrated Receiver Design

- **Design of a GNSS/5G/IMU receiver-Hardware**
- GNSS section
  - GNSS front-end
    - IGASPIN GmbH has the exclusive rights in the last 8 years to use, modify and adapt the SX3 Navigation Software Receiver



SX3 software and hardware

Software Receiver	GPS L1 C/A	Galileo E1BC	Multi-correlator	Real-time	Acquisition and Tracking	PVT estimation
SX3	yes	yes	yes	yes	yes *	yes
ARAMIS	yes	yes	yes	yes	yes	yes
SoftGNSS v3.0	yes	no	no	no	yes	yes
GNSS-SDR	yes	yes	no	yes	yes *	yes
Galileo Satellite Navigation Ltd.	yes	yes	yes	yes	yes	yes

* Several different acquisition and tracking strategies are possible

5G/GNSS/IMU Integrated Receiver Design

- **Design of a GNSS/5G/IMU receiver-Hardware**
- 5G section
  - Antenna





Some famous 5G antennas in the market

Company	Product	Frequency	Operating band	Gain	Dimensions	VSWR
MC Technologies	162020(MC014526-5G)	617-960MHz / 1710-6000MHz	GSM/ISM/UMTS/LTE/5G/WLAN	2 dBi – 7 dBi	164mm, Ø 48mm	< 2.5:1
Quectel	YE0001BA 5G	600–6000MHz	Worldwide 5G/LTE band coverage	≤ 5 dBi	221mm × 26.95mm × 13.5mm	≤ 3.0
NET MODULE	Antenna-Coach-5G-4L4W	2408 - 2480, 5150 - 5850	4 x Dual-band WLAN 2.4/5 GHz	4 dBi (WLAN 2.4) / 1 dBi (WLAN 5)	112 mm × 90 mm 550 g	≤ 2
JIROUS	JIROUS JRC-24 MIMO	5.4 – 5.9 GHz	5G	23,6 ± 0,6dBi	Ø 38 cm	≤ 1,5
panorama-antennas	WMM2GG-6-60-5SP	2x 617-960/1710-6000	4G/5G	26 ± 3 dBi	20-50/(0.78 - 1.96)	< 2.7
Laird	FTRA6971M5PB-001	829MHz, 1,561GHz, 2,1975GHz, 3,75GHz, 5,2GHz, 6,5625GHz	5G	6.4 dBi	84.00 mm	< 2.0:1

5G/GNSS/IMU Integrated Receiver Design

- **Design of a GNSS/5G/IMU receiver-Hardware**
- 5G section
  - Front-end

Some famous 5G devices to be used as 5G section in the proposed receiver.

Company	Product	RF frequency range	Bandwidth	Noise	Gain	Price	GPS-Disciplined Oscillator
NATIONAL INSTRUMENTS	USRP-2955	10 MHz to 6 GHz	80 MHZ	<5 dB in (10 MHz / 3 GHz) <4 dB in (3 GHz to 5 GHz) <8 dB in (5 GHz to 6 GHz)	0 dB to 95 dB	15,500.00	Yes
MYTEK	UD Box 5G	RF: 24 – 44 GHz IF: 0.01 to 14 GHz	100MHZ	<13.8 dB in (28 GHz to 39 GHz)	NA (Conv-ersion Loss 12 dB)	NA	NO (100MHz input /output)
XILINX	Zynq RFSoC DFE	Up to 7.125GHz	400MHz	NA	NA	NA	NO

5G/GNSS/IMU Integrated Receiver Design

- **Design of a GNSS/5G/IMU receiver-Hardware**
- IMU section

Some important features of the potential sensors

Manufacturer part number	Manufacturer	Price ($)	DOF	Accelero-meter Range (g)	Gyro range (°/sec)	Power (Watts)	Supply voltage (Volts)	Size (in cm)	Weight (g)	Extra Sensors	Output type
HG1120AA50	Honeywell Aerospace	999	9	±16	±500	<0.4	3.0-5.5	4.7 x 4.4 x 1.4	54	Magneto-meter	CAN, SPI, UART
TARS-HCASS	Honeywell Sensing and Productivity Solutions	300	6	±78	±245	<0.5	4.5-5.5	13.8 x 13.8 x 2.8	170	-	CAN
ADIS16505	Analog Devices	270	6	±8	±2000	<0.2	3.3-3.6	1.5 x 1.5 x 5.0	1.3	-	SPI
BMI088	Bosch Sensortec	3	6	±24	±2000	<0.02	2.4-3.6	0.45 x 0.30 x 0.09	NA	-	I2C, SPI
M-G364	EPSON	NA	6	±3	±200	<0.05	3.3	2.4 x 2.4 x 1.0	10	Temperat-ure Sensor	SPI, UART
FSM-9	Hillcrest Laboratories, Inc.	276	9	±8	±1833	NA	SPI=3 USB=5	3.7 x 2.3 x 9	NA	Magneto-meter	SPI, USB
NavChip	Thales Visionix-InterSense	450	6	±16	±2000	<0.22	3.25-5.5	1.25 x 2.45 x 0.54	3	Temperat-ure Sensor	SPI, TTL, UART
ICM-20689	TDK InvenSense	7	6	±16	±2000	<0.1	1.71-3.45	0.4 x 0.4 x 0.09	NA	Temperat-ure Sensor	I2C, SPI
µIMU-I	Northrop Grumman LITEF GmbH	NA	6	±30	±1000	<8	5.0	Ø85 x H60	680	-	RS422, HDLC
Ellipse 2 Micro IMU	SBG Systems	NA	9	±16	±450	<0.4	4-15	2.68 x 1.88 x 0.95	10	Magneto-meter	RS232, CAN
ISM330DLC	STMicro-electronics	10	6	±16	±2000	<0.003	1.71-3.6	0.25 x 0.30 x 0.08	NA	-	I2C, SPI
MTi-1	XSens Technologies BV	151	9	±16	±2000	<0.1	2.19-3.6	1.21 x 1.21 x 0.2	0.6	Magnetometer	I2C, SPI, UART

Target receiver specifications

GNSS Software Unit	
Satellite Tracking	GPS L1 C/A & L1C GPS L2P & L2C GPS L5 Galileo E1 B & C Galileo E5a Galileo E5b Galileo E5ab AltBOC Galileo E6 B & C GLONASS G1 GLONASS G2 BeiDou B1 BeiDou B2 BeiDou B3 QZSS L1CA & L1C QZSS L2C QZSS L5 QZSS NavIC(IRNSS) L5 NavIC(IRNSS) S-band SBAS L1
Measurement rate	up to 25 Hz
Measurement latency	< 70 ms
Acquisition sensitivity	19 dBHz
Tracking sensitivity	10 dBHz
Code accuracy	< 20 cm
Carrier accuracy	< 1 mm
Mean TTFF	< 1 s with ephemeris & position < 10 s with ephemeris < 55 s cold start
GNSS Front-End	
Real-IF sample rates	20, 100, and 200 MHz
IF-sample bits	2, 4, or 8 bits
RF bandwidth	50 MHz

Target receiver specifications

5G Software Unit	
Subcarrier Spacing (kHz)	15
Symbol duration (us)	66.7
Bandwidth (MHz)	50
Number of slots in a subframe	1
5G Front-End	
Frequency range	10 MHz to 6 GHz
Frequency step	<1 KHz
Gain range	0 dB to 95 dB
Gain step	1 dB
Frequency accuracy	2.5 ppm
Maximum input power (Pin)	+10 dBm
Maximum instantaneous real-time bandwidth	80 MHz
Noise	10 MHz to 3 GHz <5 3 GHz to 5 GHz <4 5 GHz to 6 GHz <8
Analog-to-digital converter (ADC)	Resolution 14 bit

Target receiver specifications

IMU	
Gyroscope	Standard full range: 450 deg/s In-run bias stability: 10 deg/h Noise density: 0.01 º/s/√Hz
Accelerometer	Standard full range: 20g In-run bias stability: 15 µg Noise density: 60 µg/√Hz
Magnetometer	Available
Interfaces	
Interface to computer	USB 3.0
2 RF in (GNSS-5G)	TNC female (50 Ohm) for Single/Dual-RF, SMA for Quad-RF
1 PPS out	BNC female (50 Ohm)
1 external trigger in	BNC female
10 MHz external oscillator in	BNC female (50 Ohm)
10 MHz internal reference out	BNC female
IF-samples for post-processing	from file
Processor	
Computer system	High-performance Intel Core-i7 based HW
Supported operating system	Windows 10
Configuration and control	local GUI or remote via TCP/IP
Power Supply	
Power	12V -36W

Target receiver sepecifications

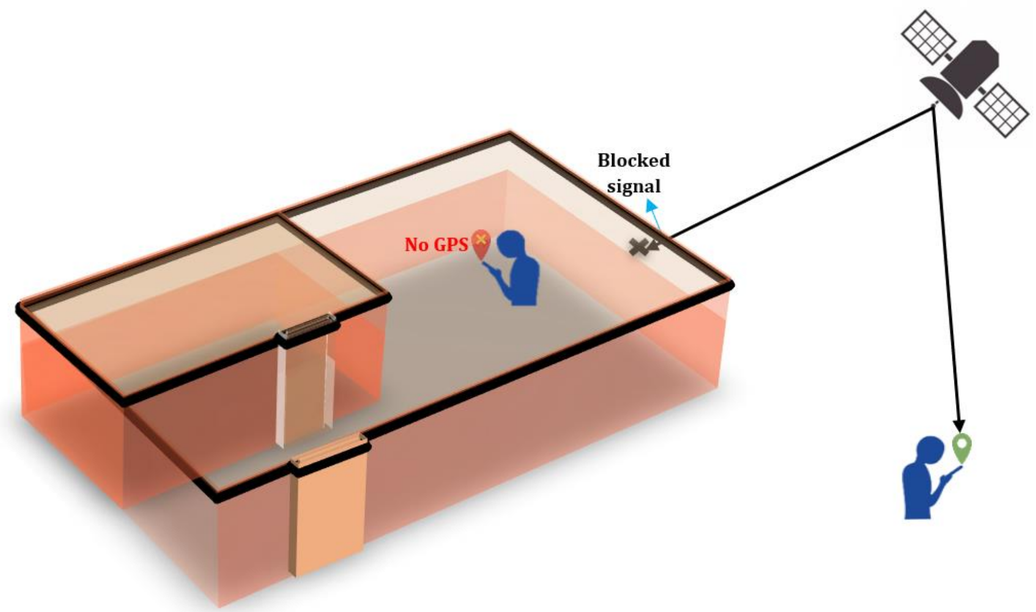
General performance	
Positioning accuracy (open sky)	<3m
Positioning accuracy (indoor)	<5m

Indoor GNSS Signal Manipulator and Repeater

Tuti

Problem definition

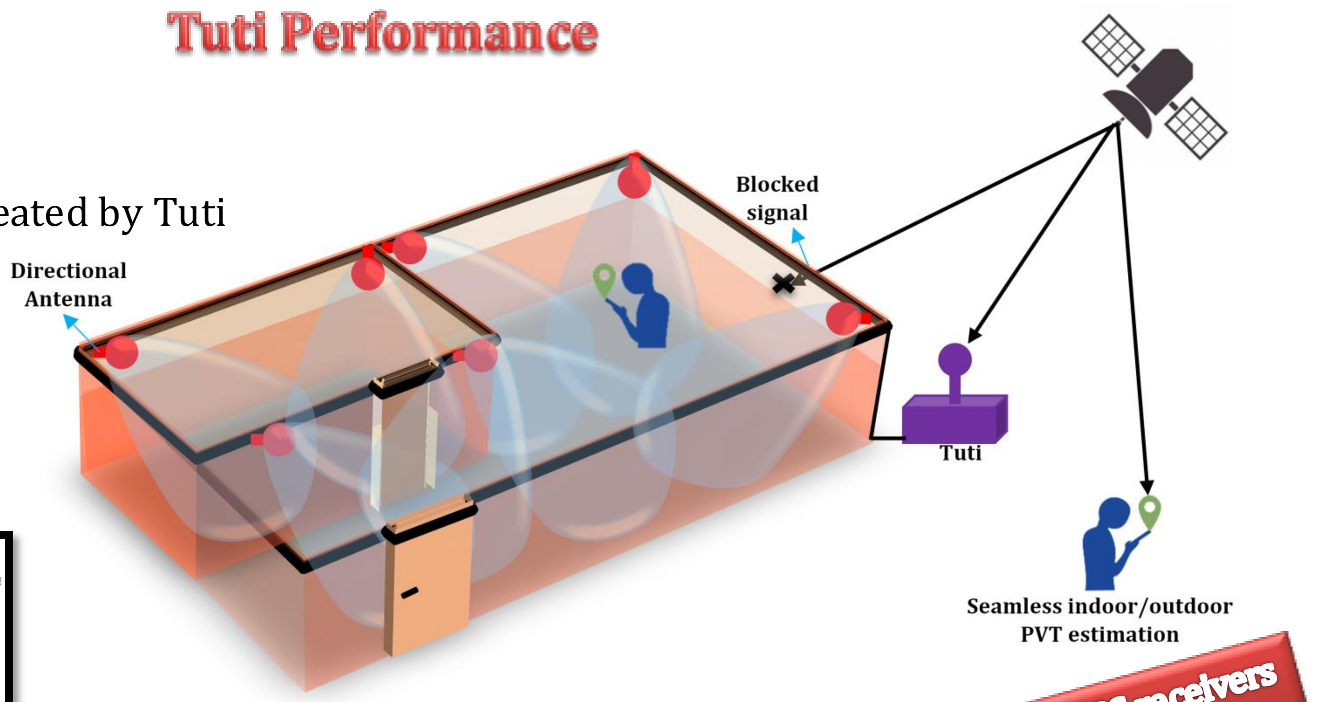
Seamless indoor/outdoor positioning and timing

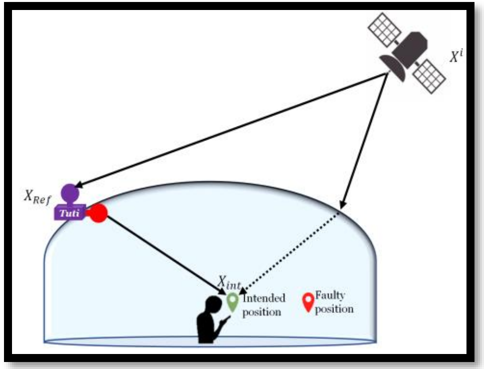


PATENT PENDING

Tuti Performance

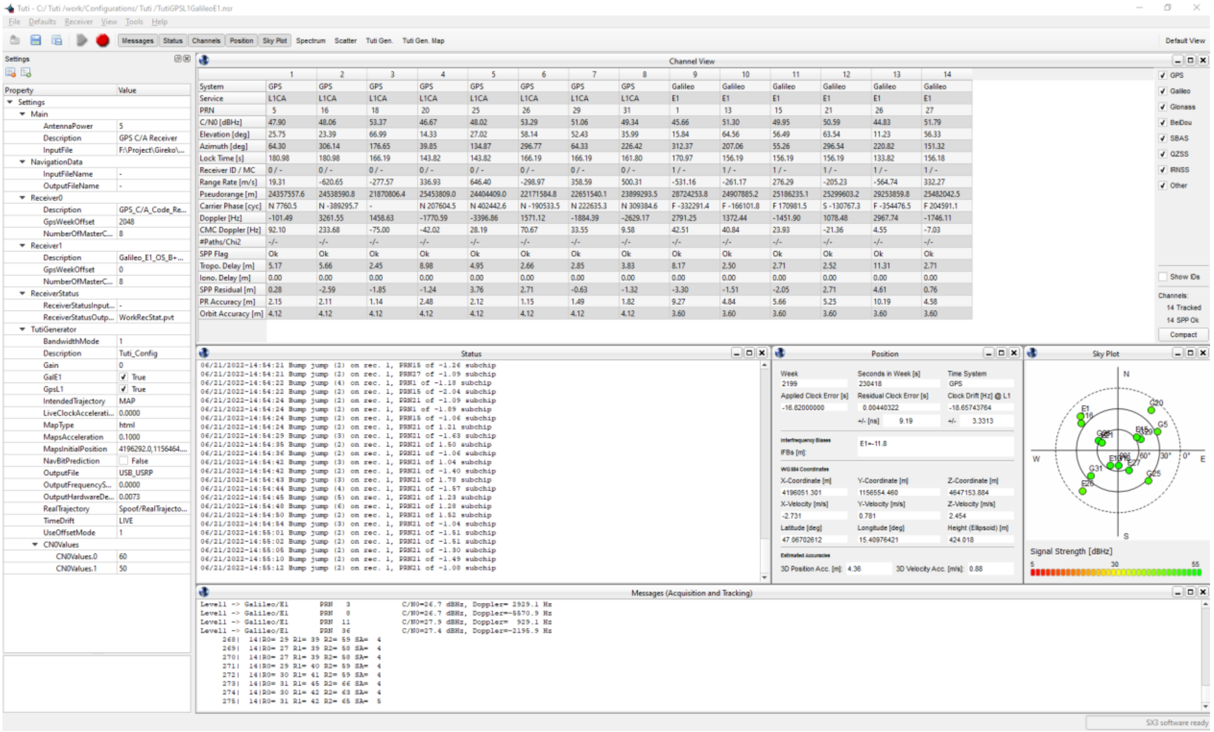
- The infrastructure created by Tuti



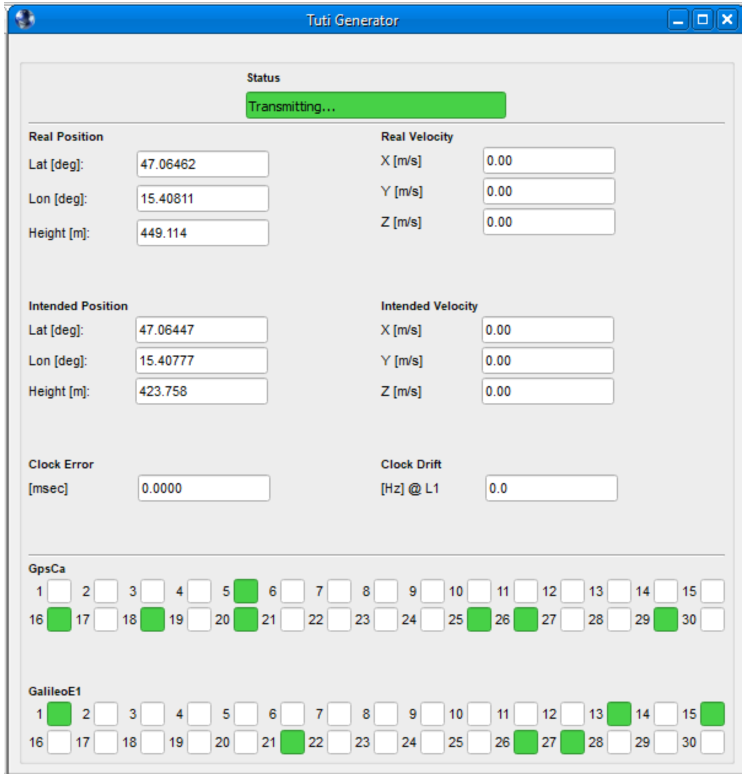


Tuti is compatible with all GNSS receivers and there is no limitation.

GUI-Main window



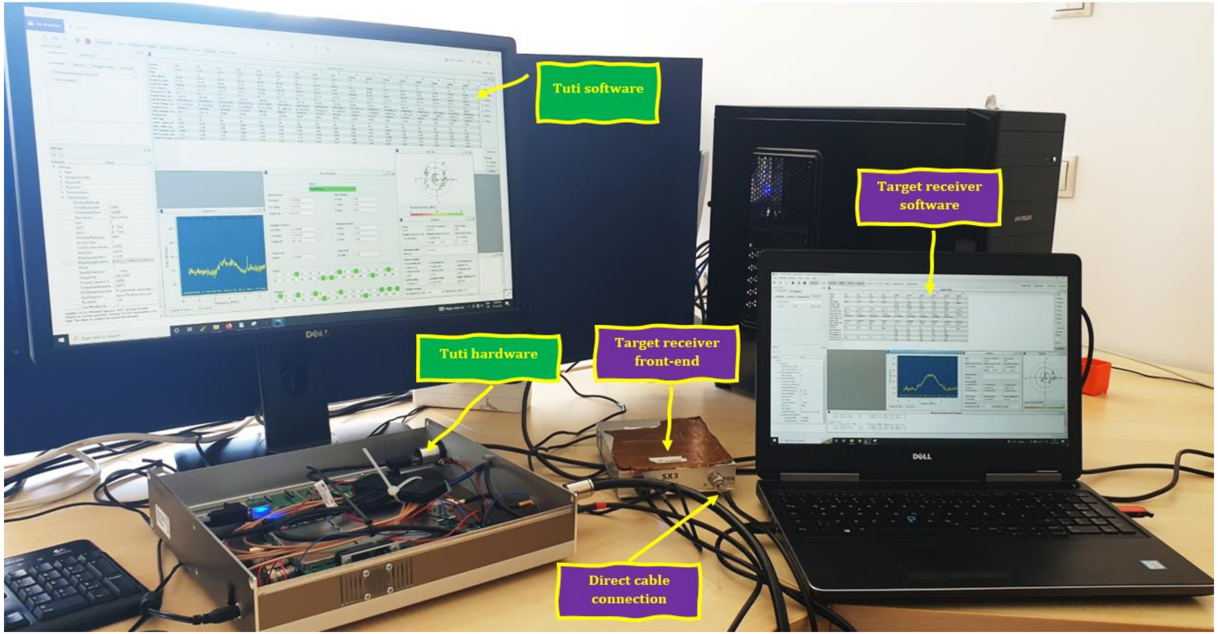
GUI-Tuti Generator window



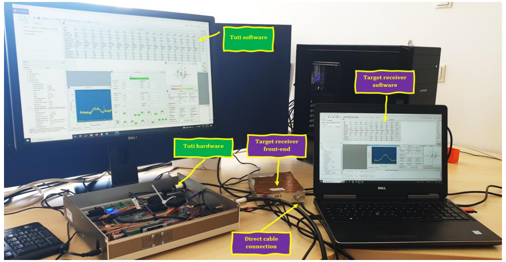
Experimental Test

Unit test

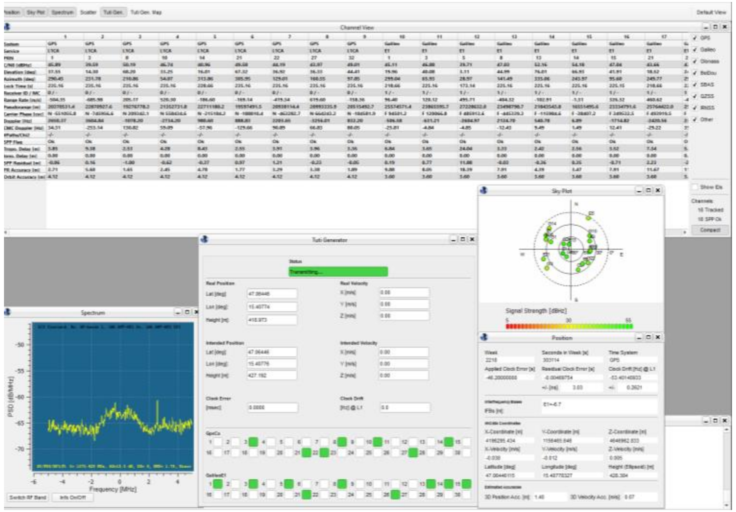
- **Generator**



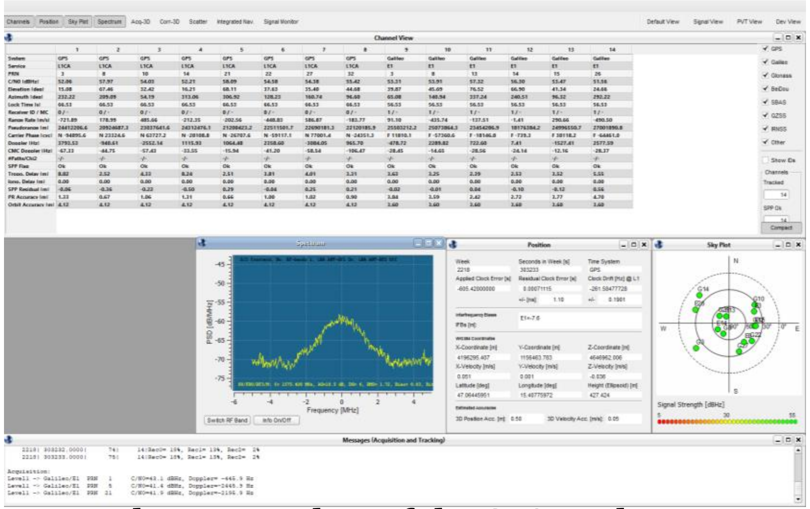
Unit test



- Generator



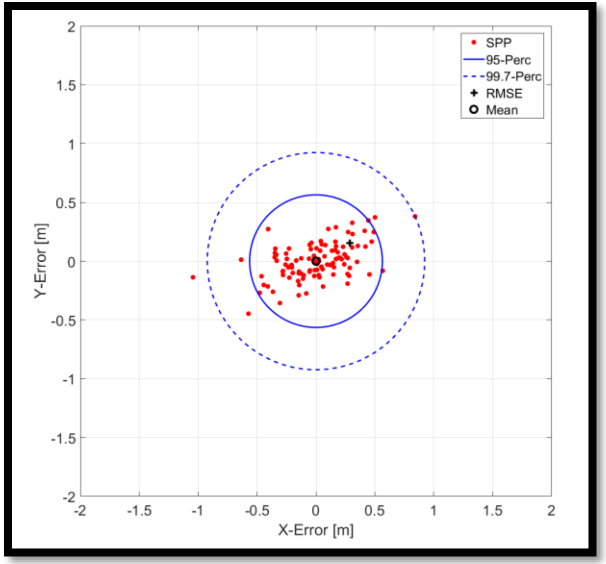
The screenshot of the Tuti GUI.



The screenshot of the SX3 as the target receiver in the test of a direct cable connection to Tuti.

Unit test

- Generator



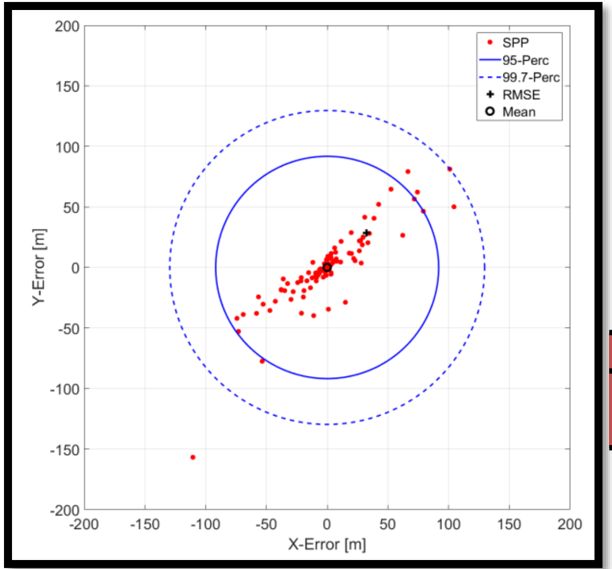
The positioning error scatter of SX3 under deep indoor condition.

Statistical results in the test of direct cable connection to Tuti.

Parameter	SDRR	Target receiver
RMS [m]	2.31	0.89
STD	1.35	0.66

Unit test

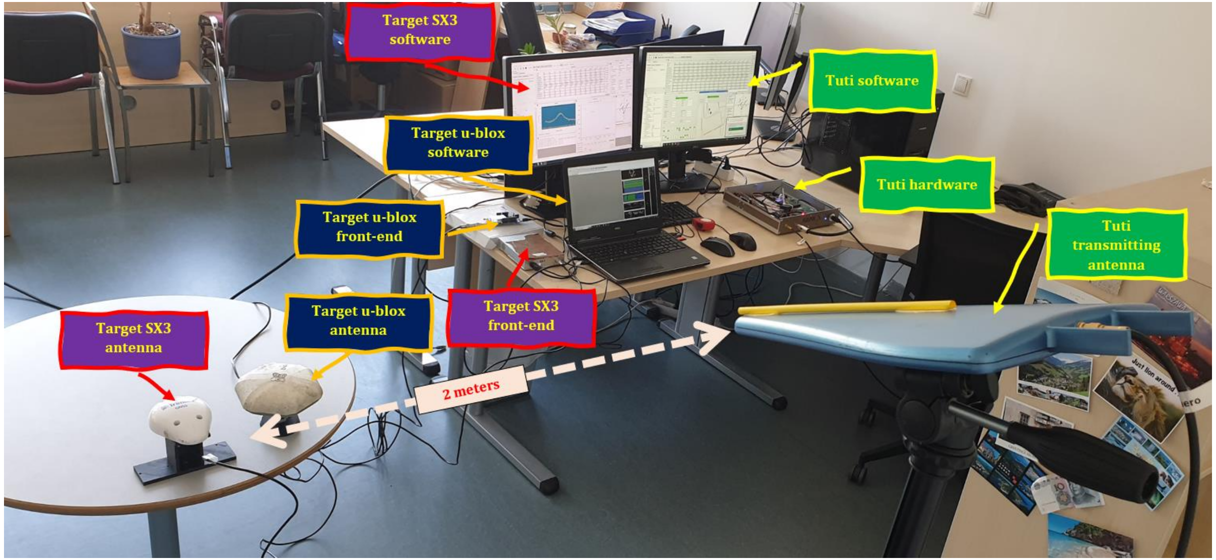
- **SDRR**
  - Goal: to analyze the effect of the SDRR and its front end on the performance of Tuti.
  - Method: the Tuti reference antenna together with a 9 dB attenuator.



Statistical results in the test of direct cable connection to Tuti which is receiving weak signals.

Parameter	SDRR	Target receiver
RMS [m]	17.66	51.35
STD	15.55	44.38

Integrated system test (Fixed user in a deep indoor)

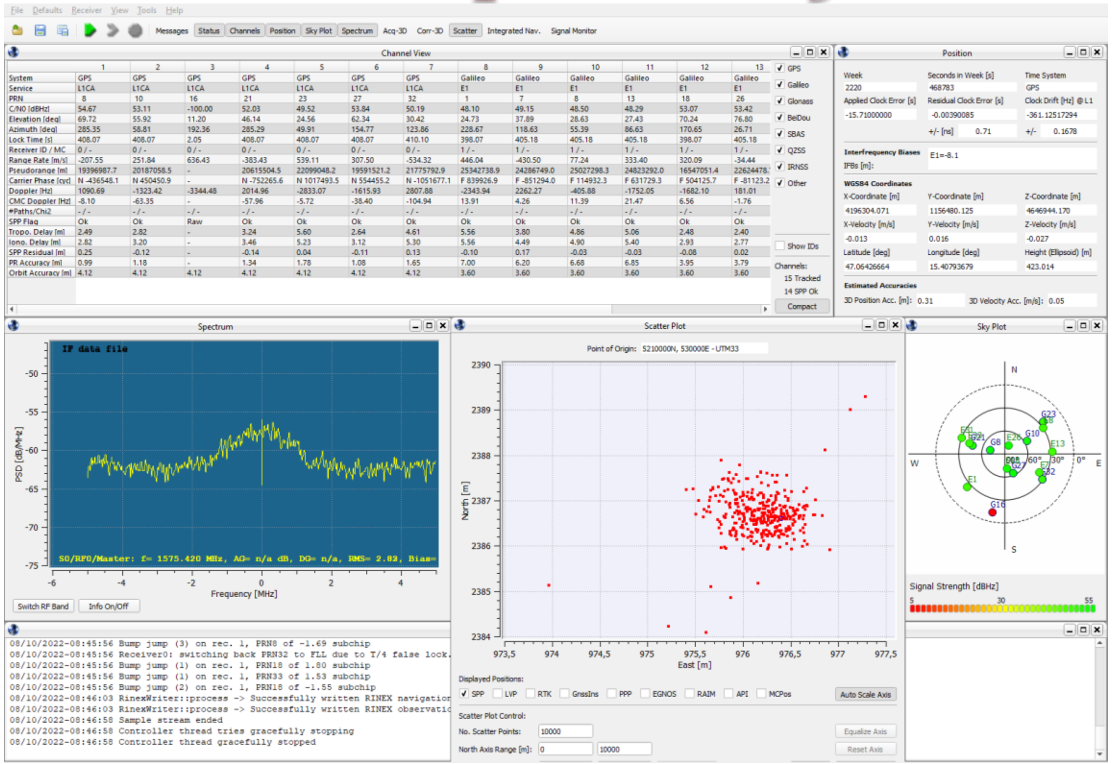


intended location = [4196304.0, 1156480.0,4646944.0]

Integrated system test (Fixed user in a deep indoor)

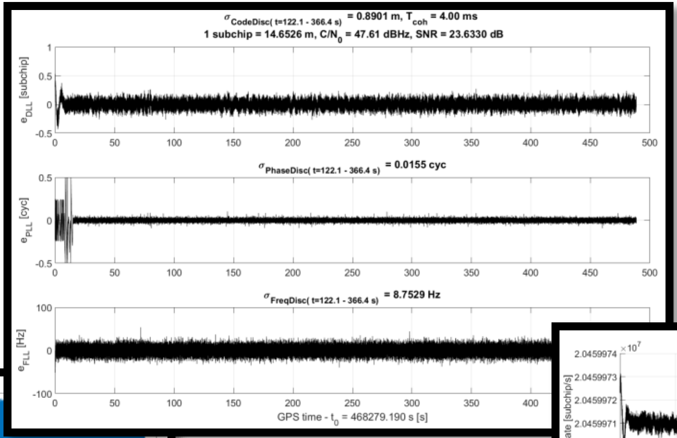
SX3 GUI:

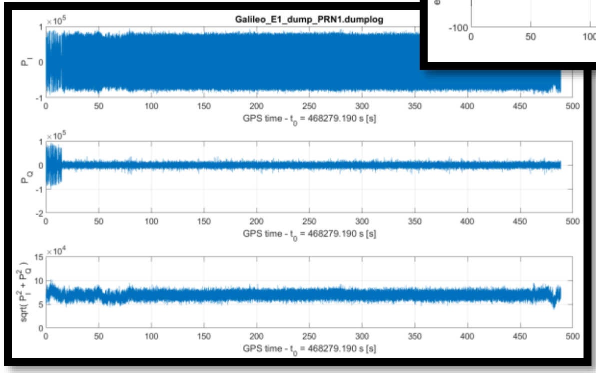
The status of the SX3 GUI when it is tracking the signals received from Tuti under deep indoor condition.

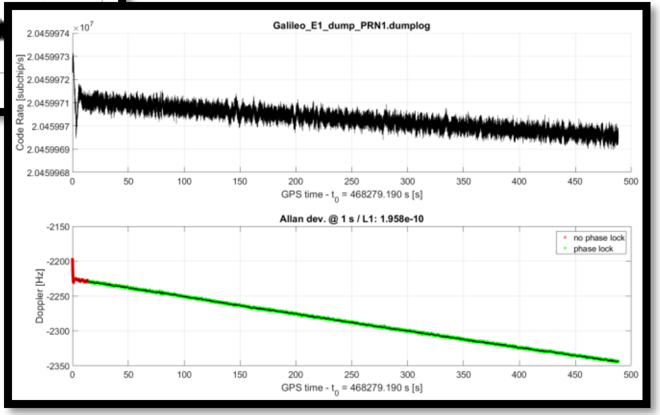


Integrated system test (Fixed user in a deep indoor)

Tracking status:

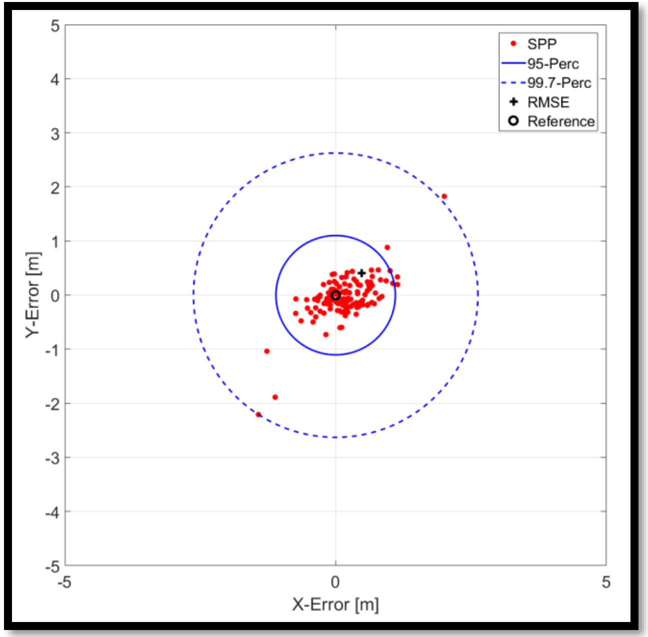




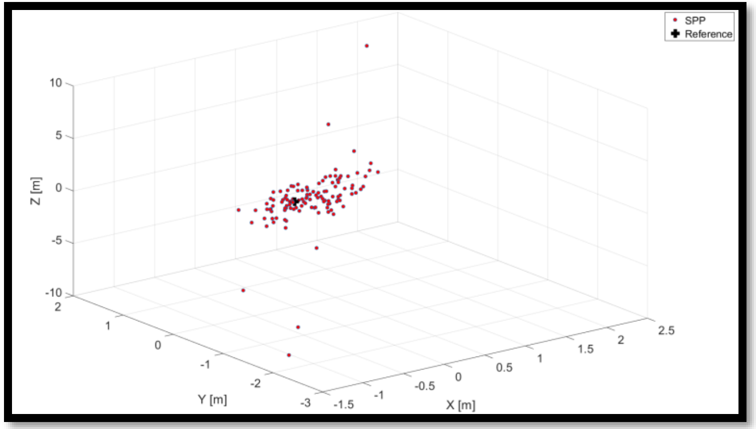


Integrated system test (Fixed user in a deep indoor)

SX3 positioning resutls:

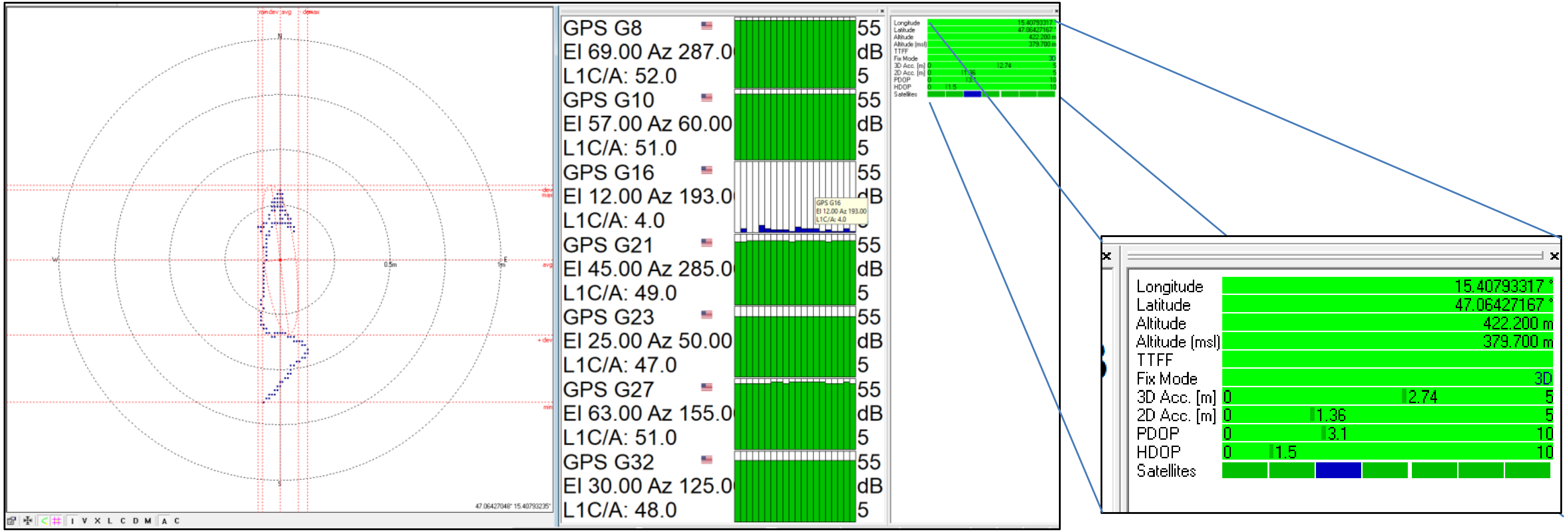


RMS [m]	0.86
STD	0.62



Integrated system test
(Fixed user in a deep indoor)

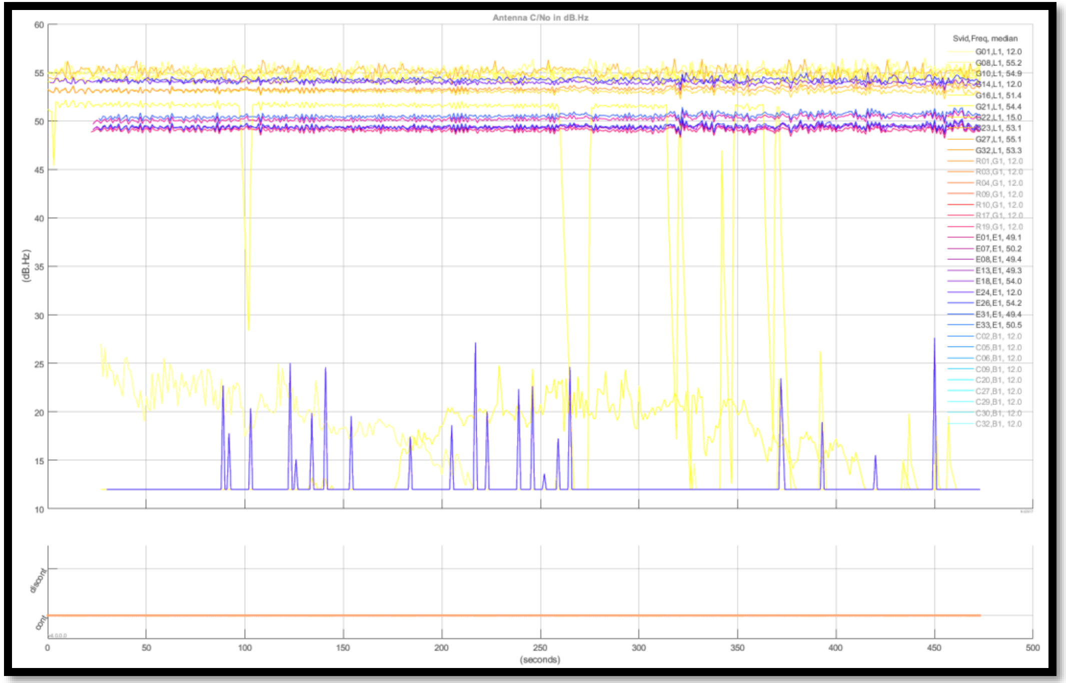
u-blox positioning resutls:



Integrated system test (Fixed user in a deep indoor)

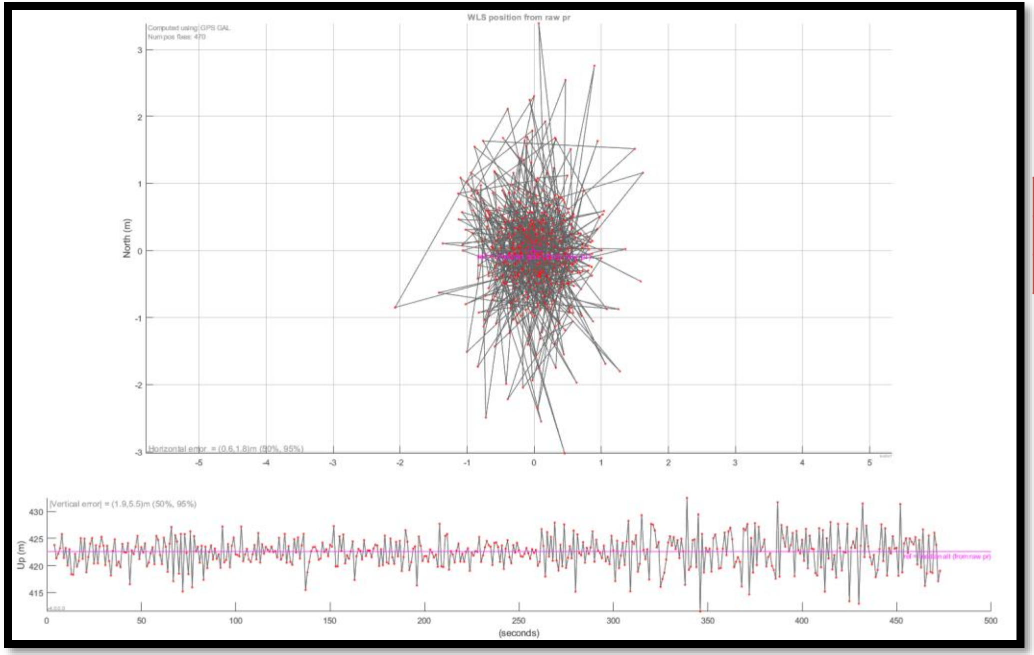
Smartphone tracking resutls:

GNSSLogger application on smartphones



Integrated system test
(Fixed user in a deep indoor)

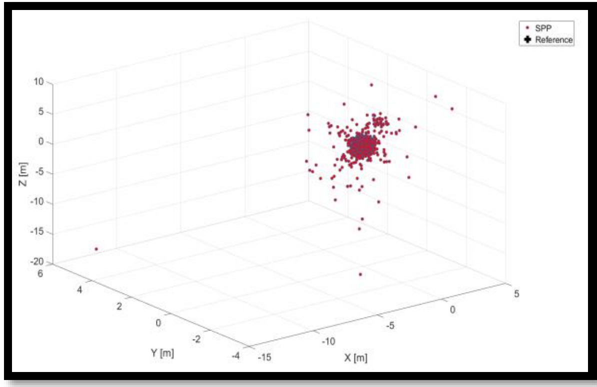
Smartphone positioning resutls:



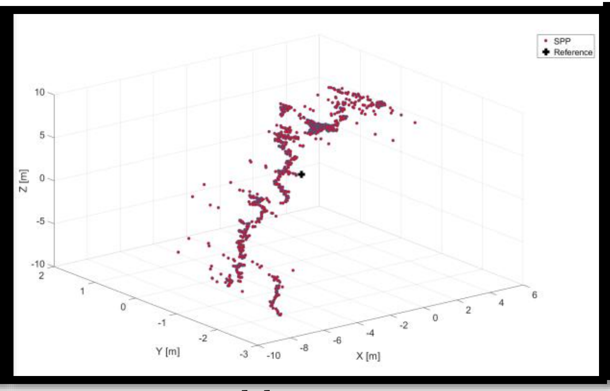
Horizontal Error		Vertical Error	
50%[m]	95% [m]	50%[m]	95% [m]
0.6	1.8	1.9	5.5

Integrated system test (Fixed user in a long deep indoor)

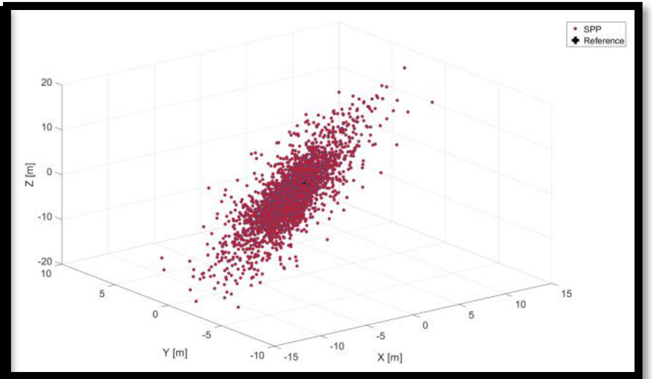
1h test result:



SX3



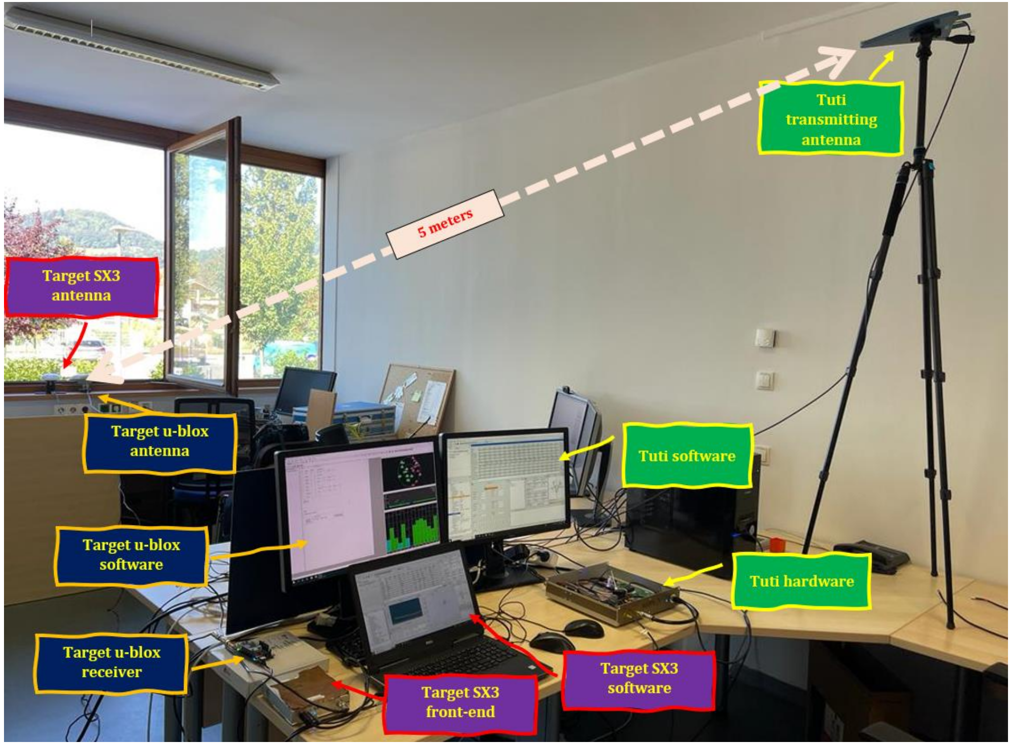
ublox



smartphone

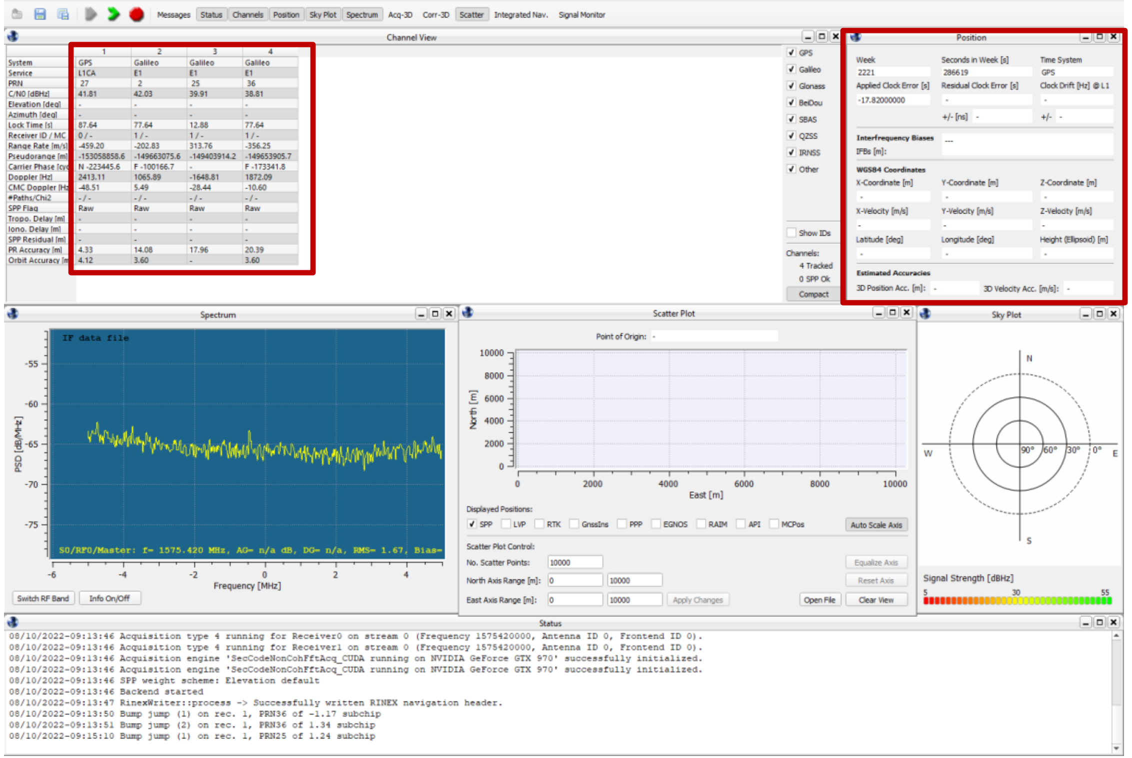
Parameter	SX3	Ublox	Smartphone
RMS [m]	1.54	5.55	5.82
STD [m]	1.43	5.52	5.26
95-percent [m]	3.33	7.29	8.17
Max [m]	22.05	11.56	22.66

Integrated system test (Fixed user in a normal indoor)



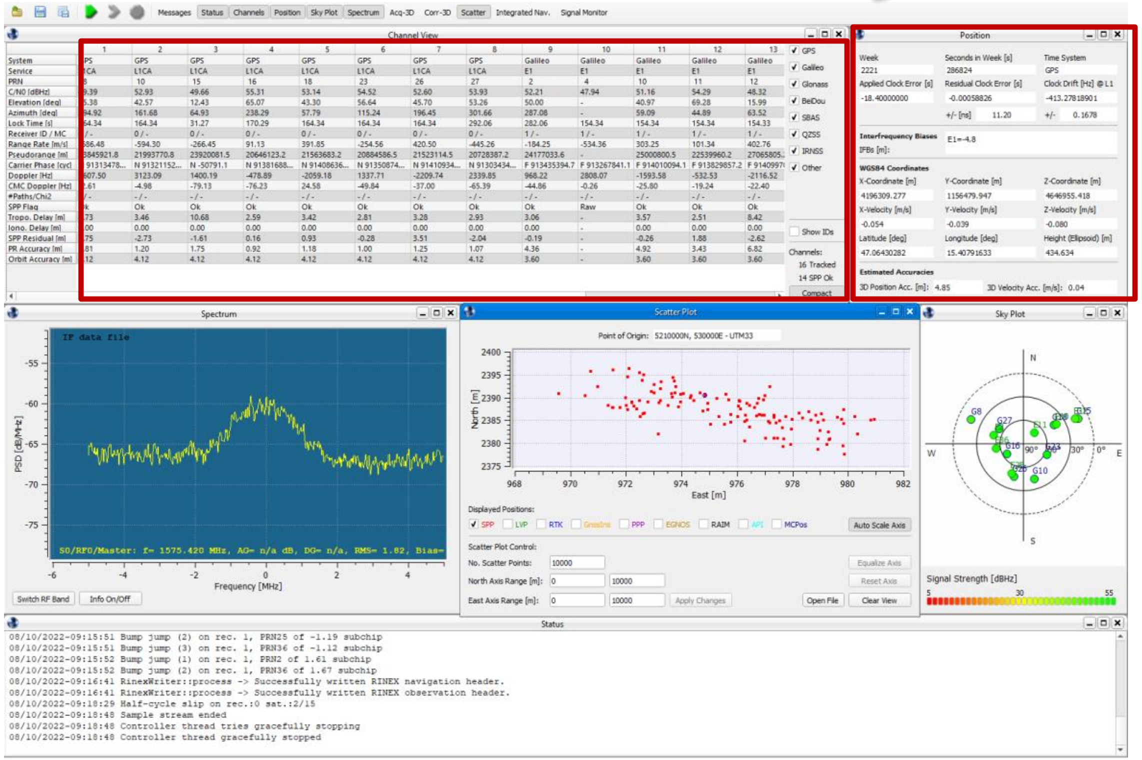
Integrated system test (Fixed user in a normal indoor)

SX3 in normal indoor before Tuti transmission:



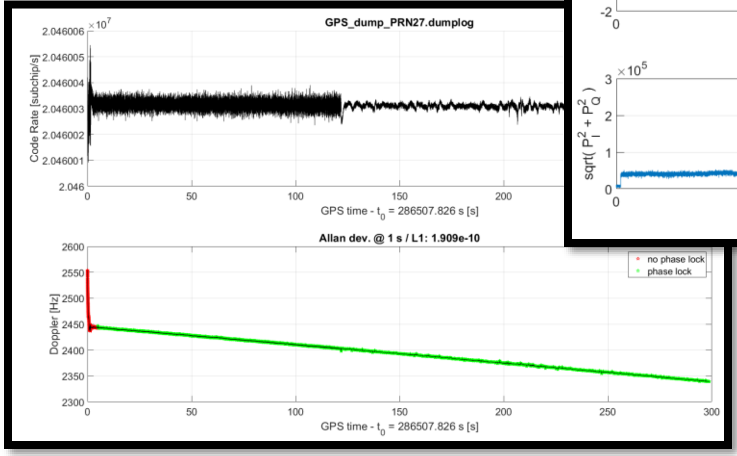
Integrated system test (Fixed user in a normal indoor)

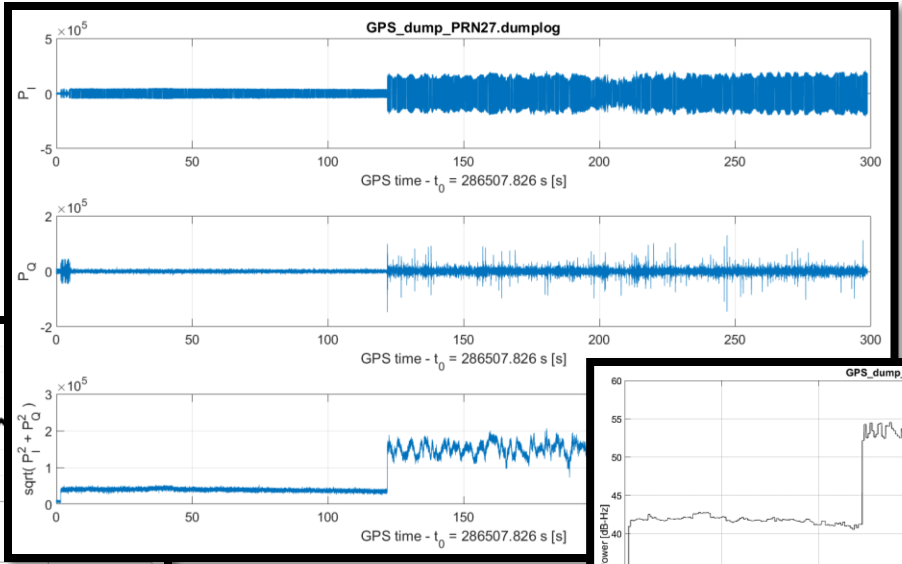
SX3 in normal indoor after Tuti transmission:

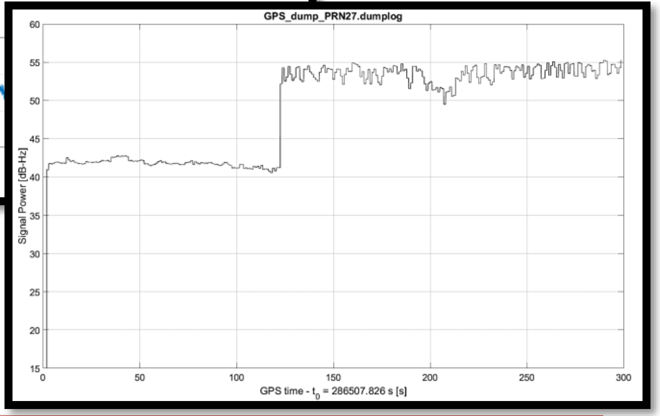


Integrated system test (Fixed user in a normal indoor)

Tracking status:

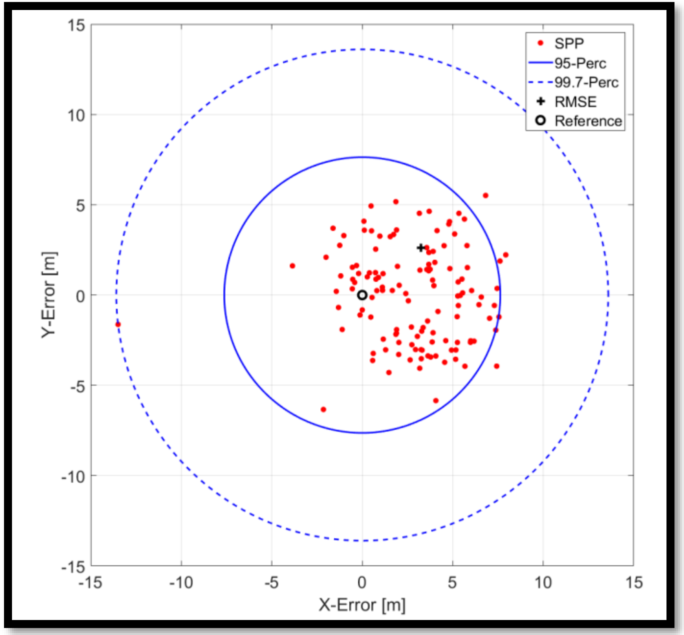




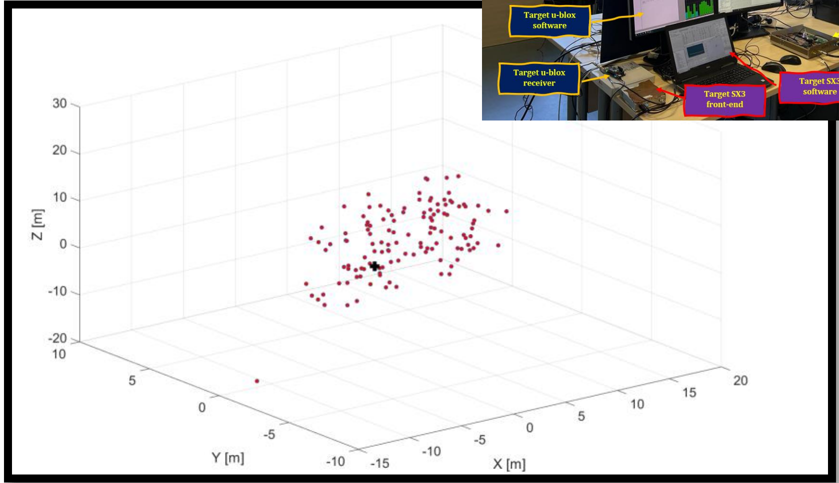


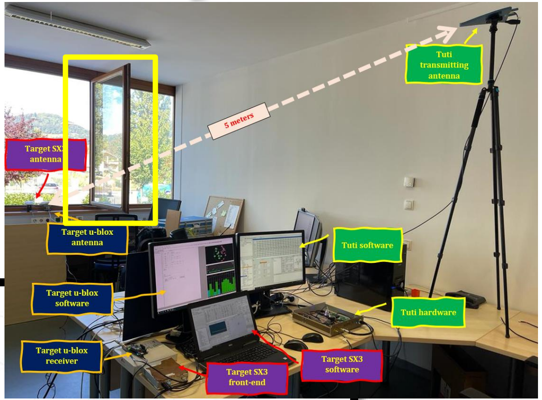
Integrated system test (Fixed user in a normal indoor)

SX3 positioning resutls:



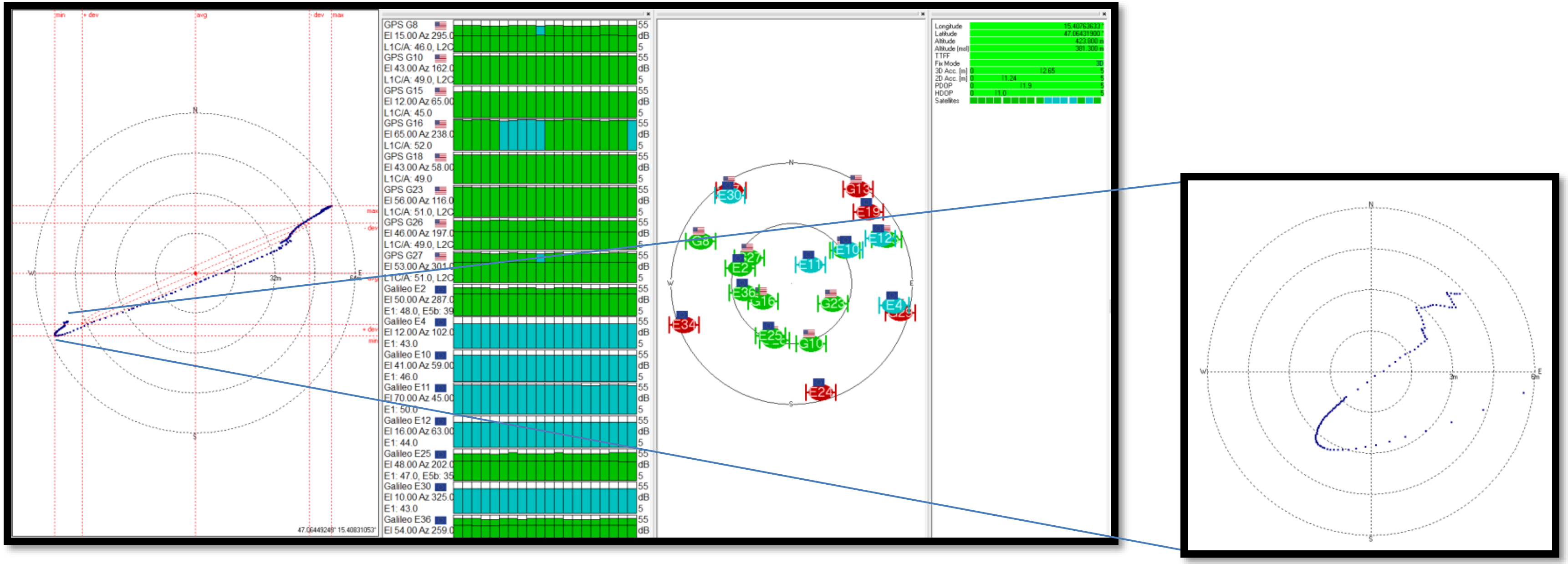
RMS [m]	9.25
STD [m]	7.65





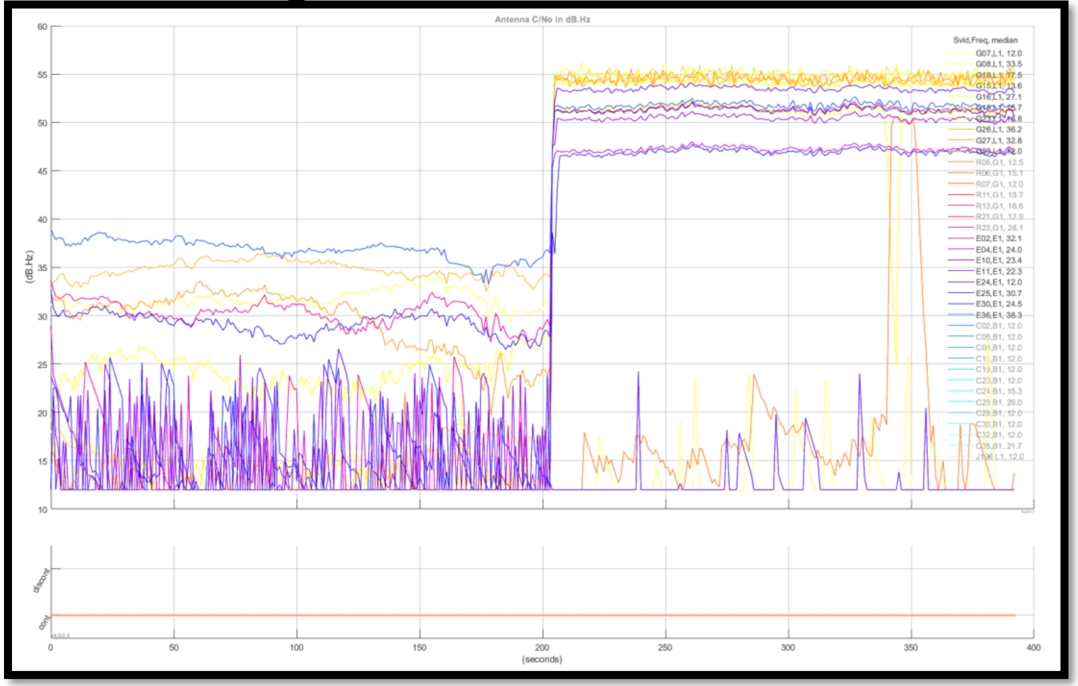
Integrated system test (Fixed user in a normal indoor)

u-blox positioning resutls:



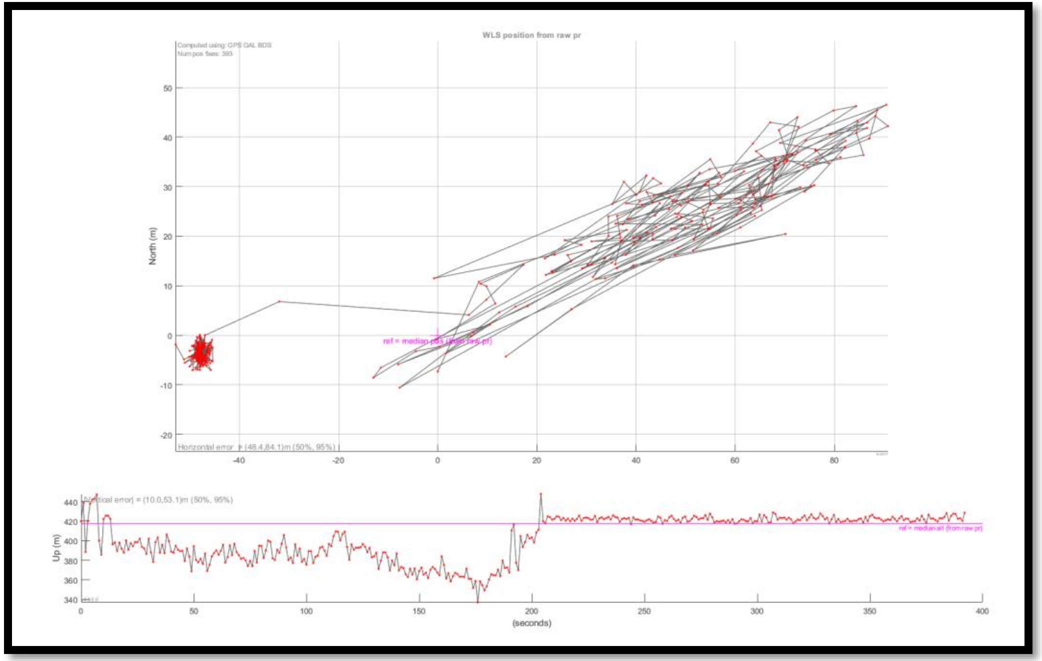
Integrated system test (Fixed user in a normal indoor)

Smartphone tracking resutls:



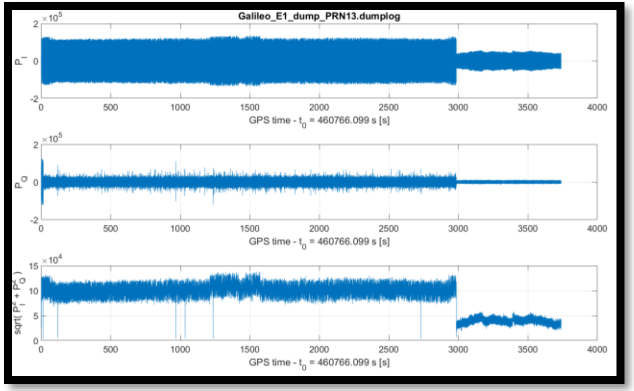
Integrated system test (Fixed user in a normal indoor)

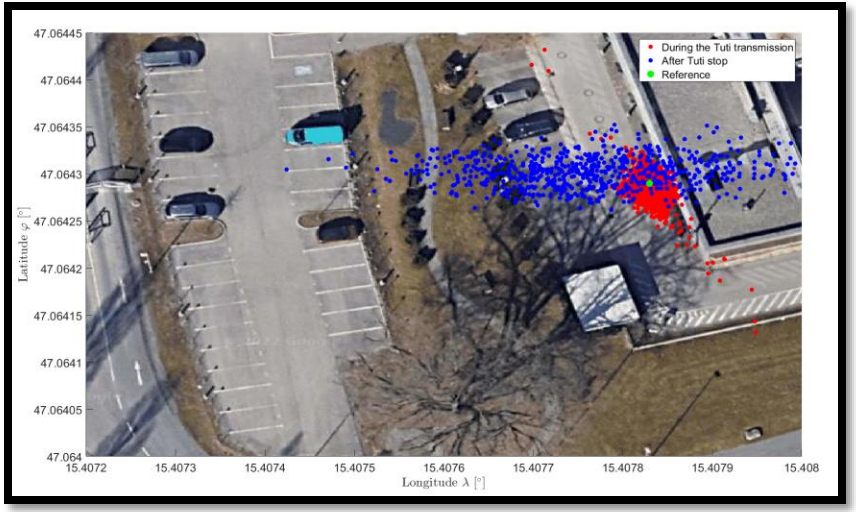
Smartphone positioning results:



Integrated system test (Fixed user in a long normal indoor)

- 1h SX3 test



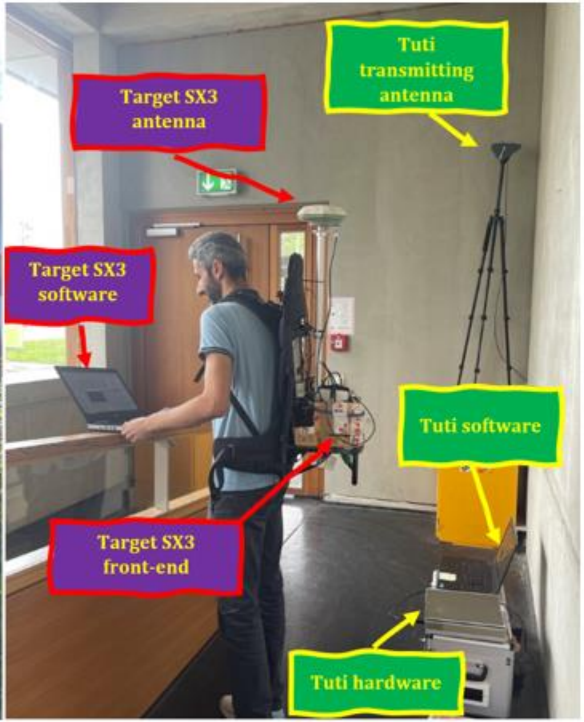


	During Tuti transmission	After Tuti stop
RMS [m]	3.13	16.25
STD [m]	3.12	10.49
95-percent [m]	5.29	20.07
Max [m]	48.24	35.09

Integrated system test
(Mobile user in transition-Out ⇆ deep In)

Outdoors

Transition

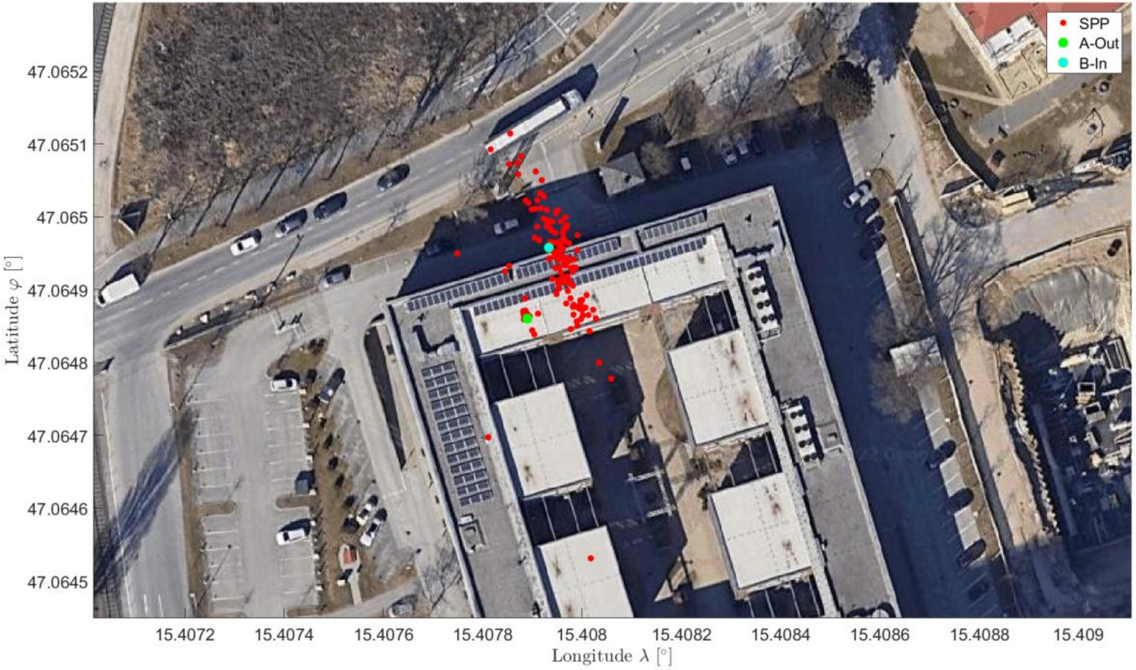


Deep Indoors

Integrated system test (Mobile user in transition/out to deep in)

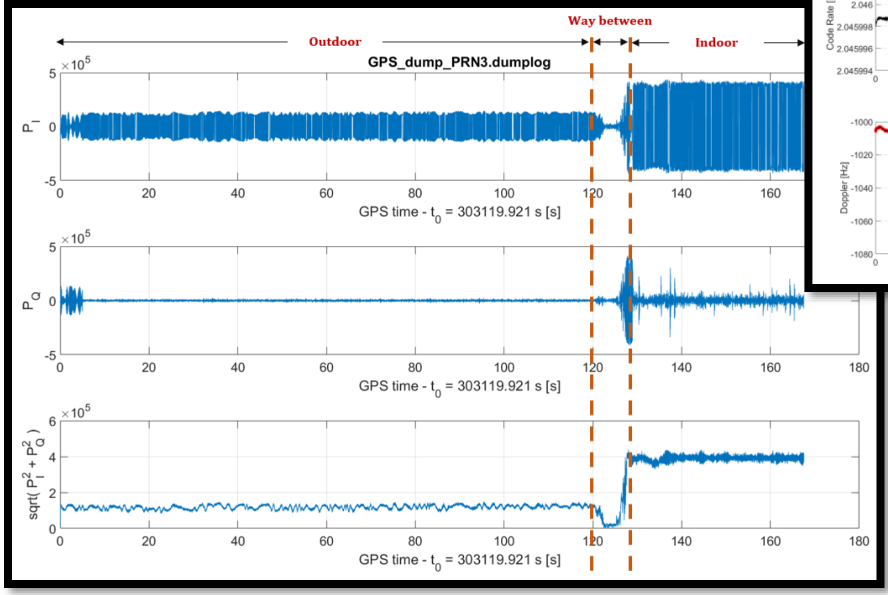
SX3 positioning resutls:

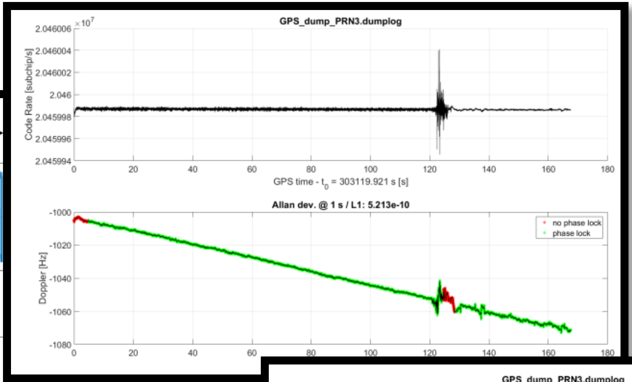
	Outdoor	Indoor
RMS [m]	18.56	1.04
STD [m]	9.95	1.00

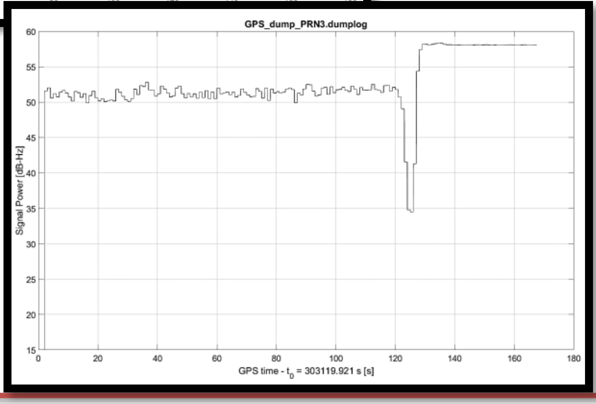


Integrated system test (Mobile user in transition/out to deep in)

Tracking status:

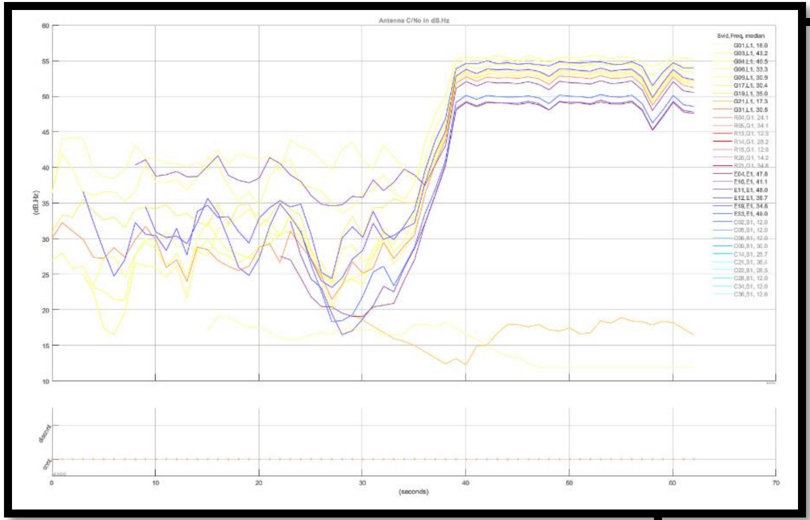


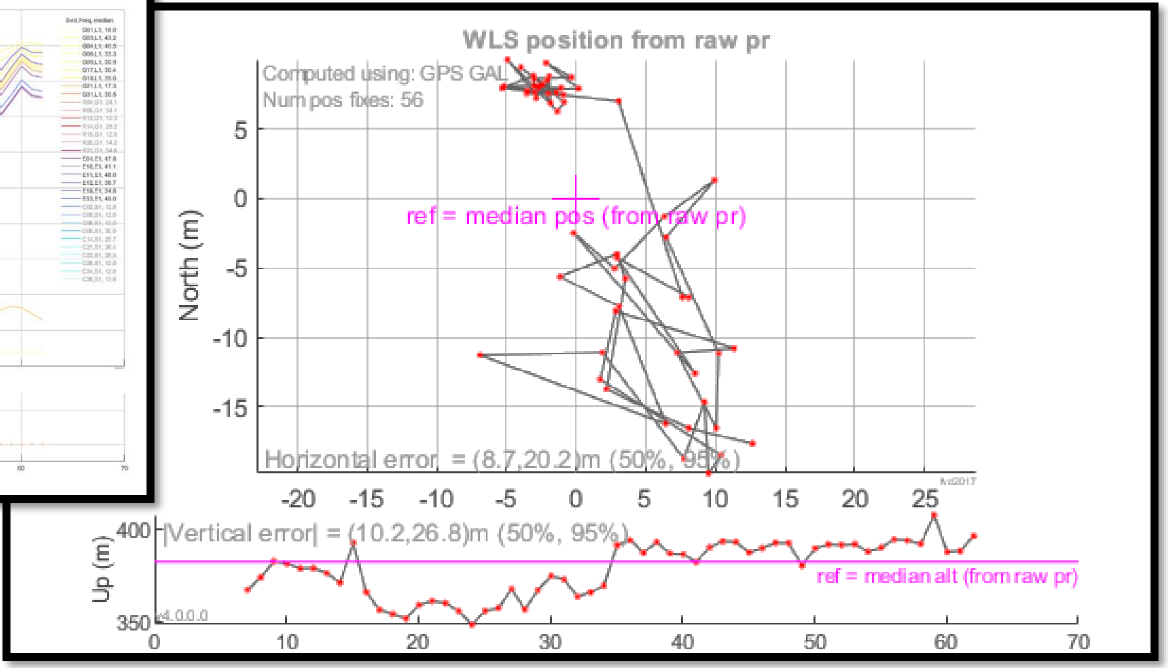




Integrated system test
(Mobile user in transition/out to deep in)

Smartphone positioning resutls:

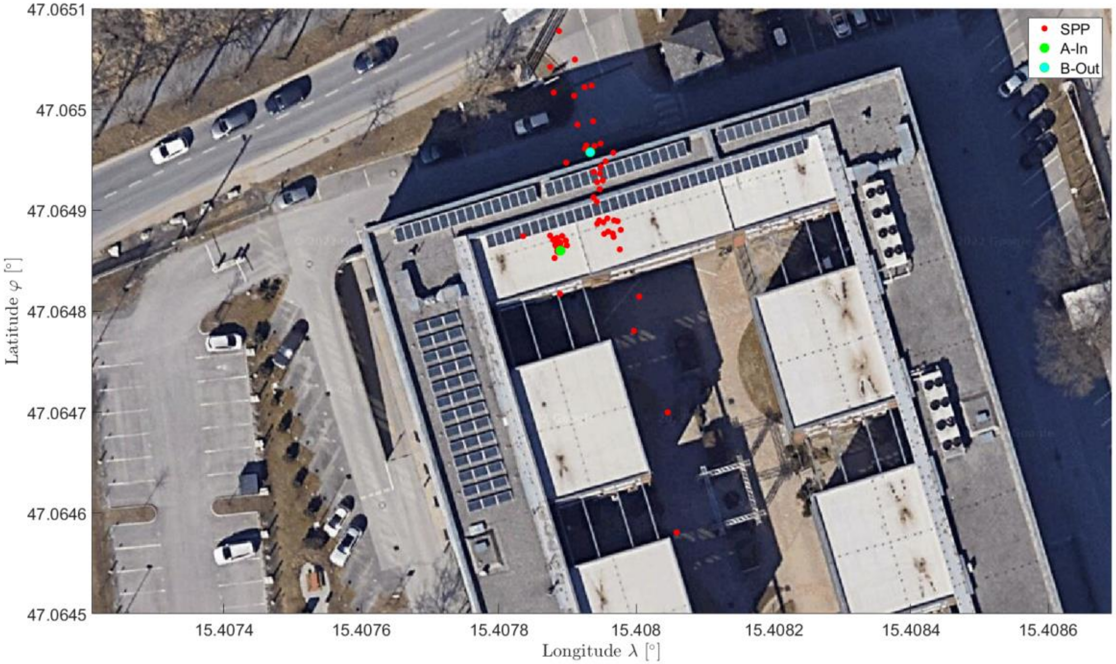




Integrated system test
(Mobile user in transition/deep in to out)

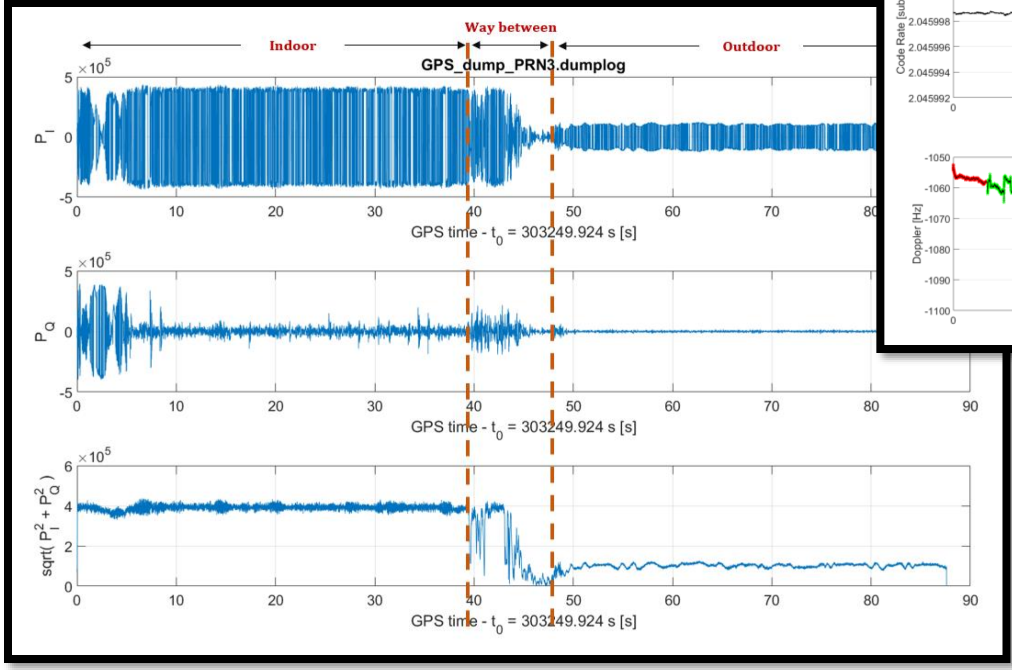
SX3 positioning resutls:

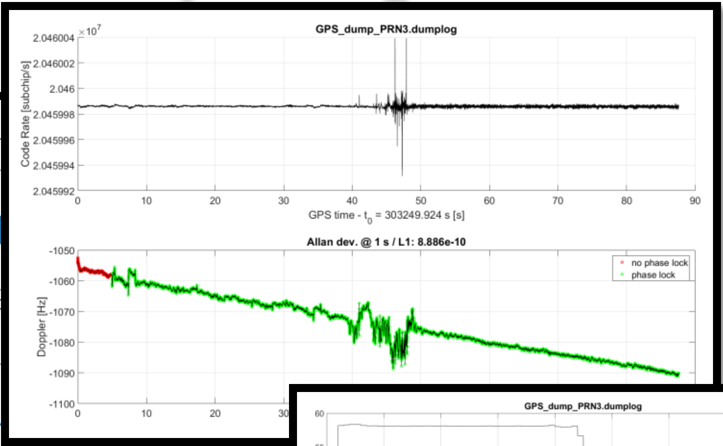
	Outdoor	Indoor
RMS [m]	17.25	1.08
STD	15.71	1.73

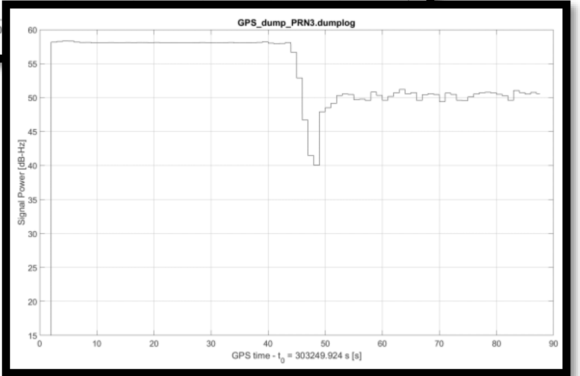


Integrated system test (Mobile user in transition/ deep in to out)

Tracking status:

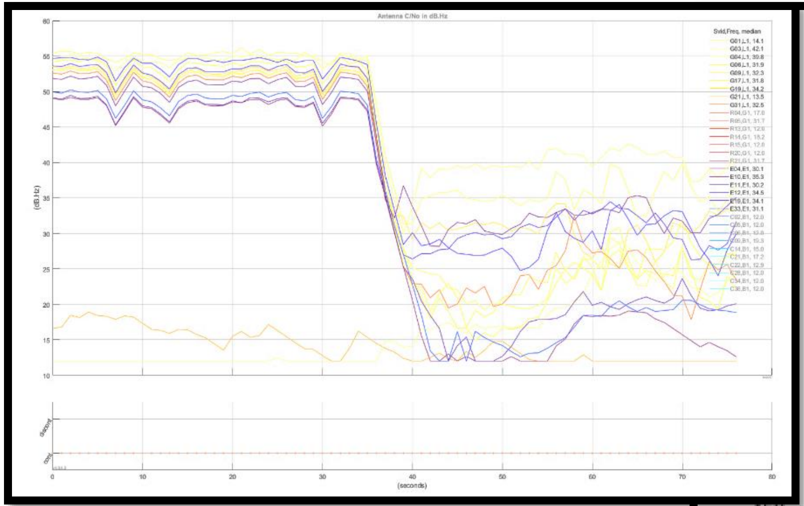


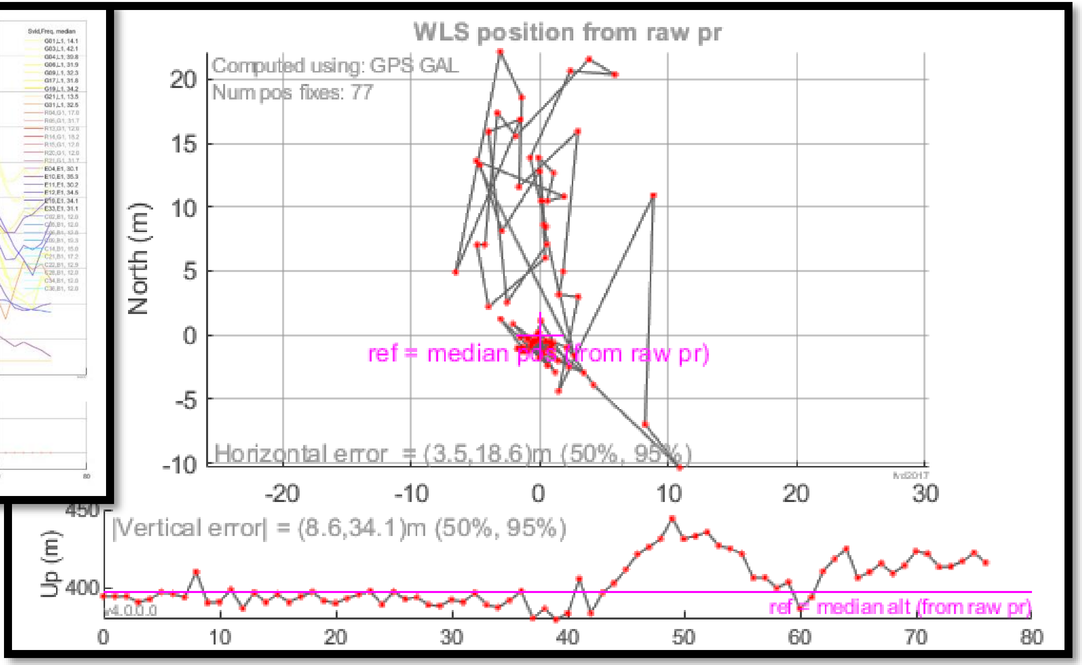




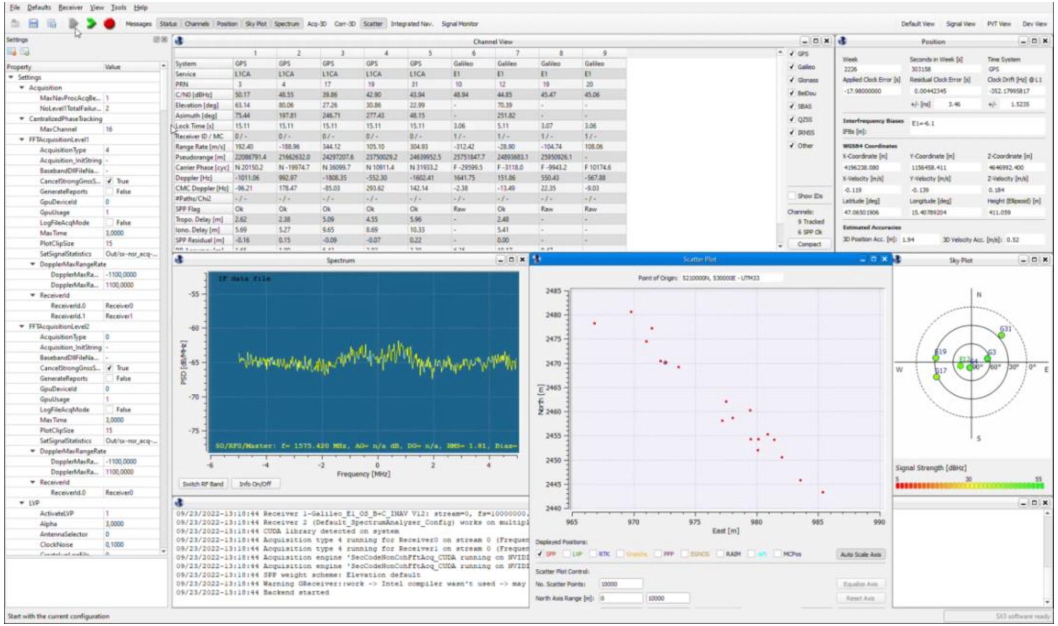
Integrated system test (Mobile user in transition/ deep in to out)

Smartphone positioning resutls:



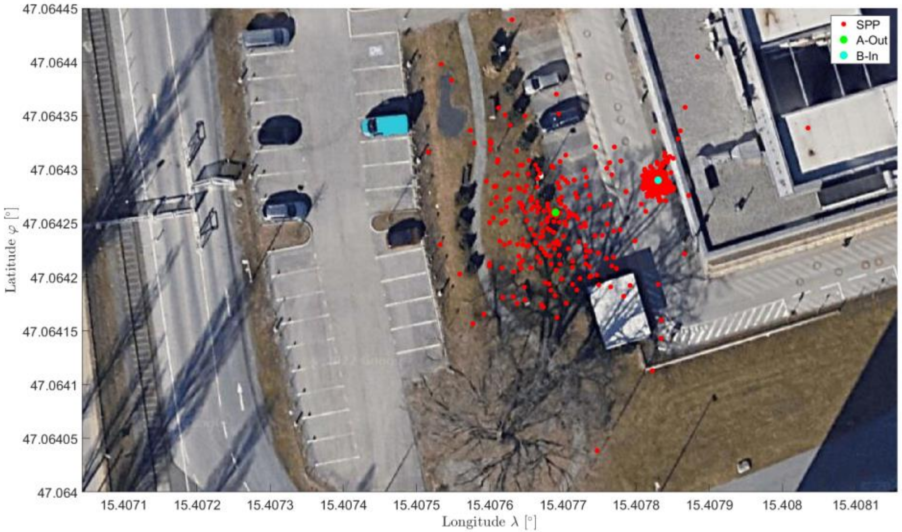


Integrated system test (Mobile user in transition)



Integrated system test (Mobile user in transition)

- **Outdoor to normal indoor**



	Outdoor	Indoor
RMS [m]	22.72	5.96
STD [m]	19.96	3.31

Integrated system test (Mobile user in transition)

- **Normal indoor to outdoor**

	Outdoor	Indoor
RMS [m]	44.04	5.96
STD [m]	29.45	3.92

Conclusion

- A 5G/GNSS/IMU receiver designed up to TRL3.
- The Tuti was designed and implmented up to TRL5.
- The Tuti system was tested in different scenarios successfully:
  - Deep Indoor
  - Normal Indoor
  - Transition: Out ⇆ In (normal and deep)
  - Indoors with two engines (not in the framework of 5GInOSEG project).

Contact us

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