NAVISP-EL2-051 - SRX Final Presentation

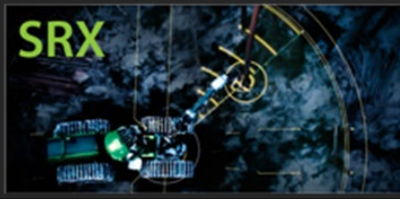
12.11.2024, 10:00 – 11:30 CEST

ESA Contract No. 400128264/19/NL/MP for ‘SRX-SW-Defined Receiver for eXact PNT’

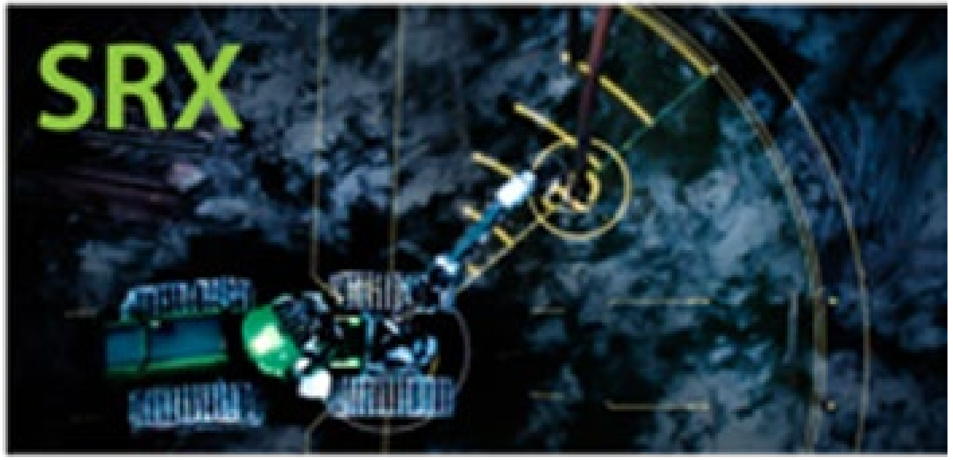
SRX - Agenda

Time	Topic	Speaker
10:00-10:05	Welcome	G. Martin de Mercado (NAVISP Element 2 Manager, ESA)
10:05-10:10	Project Introduction	H. Sobreira (Technical Officer, ESA)
10:10-11:00	**Project Implementation and Results**	Jürgen Pielmeier, Michael Bodenbach (IFEN) Amir Tabatabaei (IGASPIN)
11:00-11:25	Questions and Answers	Moderator: H. Sobreira (Technical Officer, ESA)
11:25-12:00	Outlook and Events	G. Martin de Mercado (NAVISP Element 2 Manager, ESA)

SRX – Objectives Overview



Objective 1 – Support of Forest Application Scenario



- No precise GNSS PVT solution so far in forest (5 -10 m today)
- But need for PVT solution supporting digital flow chain
- Driving test environment, functional and accuracy requirements

Objective 2 – Transition from 3rd gen. SDR receiver to 4th gen. prototype receiver

- GNSS SDR receiver with improved SWaP, higher flexibility, increased scalability
- Phase synchronization of RF paths
- ‘Standard’ PVT & heading using high-bandwidth signals

Objective 3 – High-Precision Algorithm R&D

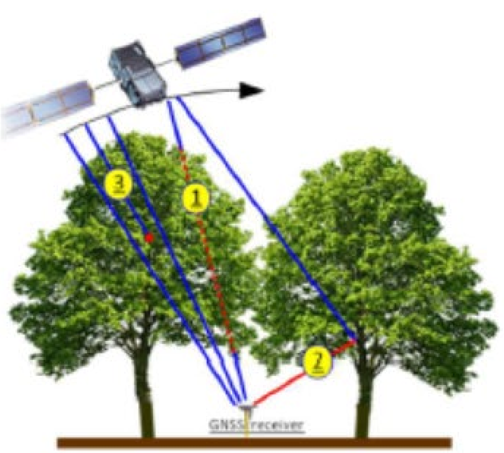
- Algorithm research for improved PVT capability based on RTK
- Further enhanced through sophisticated processing algorithms
- Tuning of algorithms through forest trials with real SIS using a software receiver

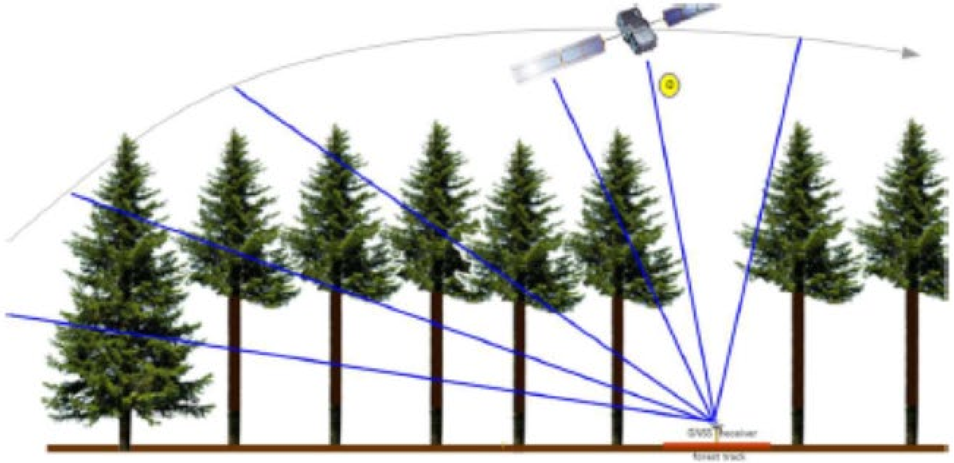
SRX – Objective 1 Forest Context

Adverse Forest Signal Environment

- Degraded signals above ~ 32° elevation are usable
- Only signals above 60° - 80° are open sky
  - mixture of signal quality for PVT (and by far more complex)

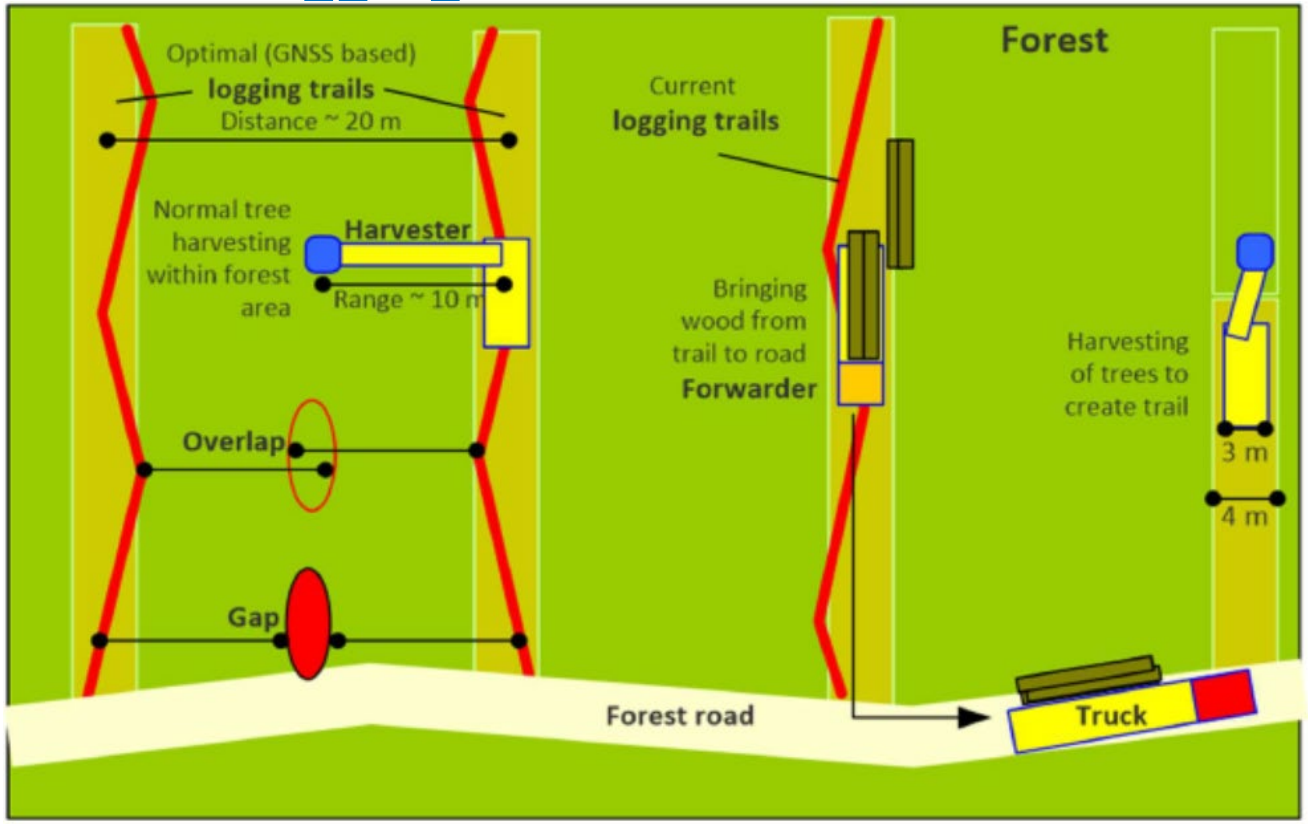
→ At least 2 GNSS constellations with 6 SV visible





Accuracy of 0,5 m with high availability to meet logging-trail needs in forest

- When generating a logging-trail
- To find logging-trail again
- To keep harvester/forwarder track on logging-trail
- To log cut-tree positions from harvester to forwarder



SRX – Research & Development Topics

Objective 2

Development 1: Prototype Receiver

- Multi-GNSS, Multi-Frequency & Dual-RF Receiver
  - Development of SRX 4th gen. early prototype receiver
  - Further extension to SRX-P prototype receiver

  → SFX4 receiver

Development 2: PVT & Heading

- PVT in forest environment with wideband signals
  - Using RTK (initially; if failed, DGNSS is backfall option)
  - DGNSS: Dual-frequency E1/E5ab Galileo & B1C/B2ab BeiDou

  → DGNSS: L1/L5 GPS, E1/E5a Galileo & B1C/B2a BeiDou
- GNSS heading determination with dual-antenna
  - Using E5ab wideband signals

IFEN

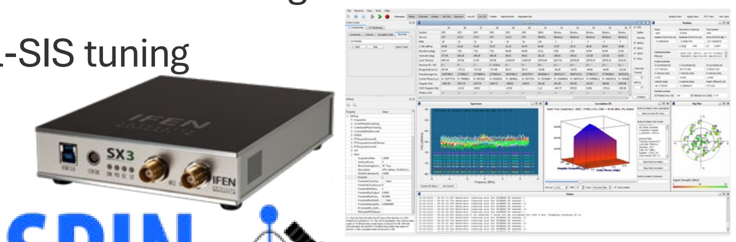
Objective 3

Research 1: Algorithm Prototyping

- PVT in harsh environments using
  - Advanced software receiver architecture
  - Innovative mitigation methods against anomalies (e.g. MP)
  - Multi-correlator based methods
  - Environmentally-adaptive tracking loops

Research 2: Algorithm Tuning

- Using 'SX3' Dual-RF GNSS SW Receiver
  - With MEMS-IMU integration
  - New firmware type 6 with 20 MHz signal bandwidth
  - For end-to-end real-SIS tuning
  - Urban & forest

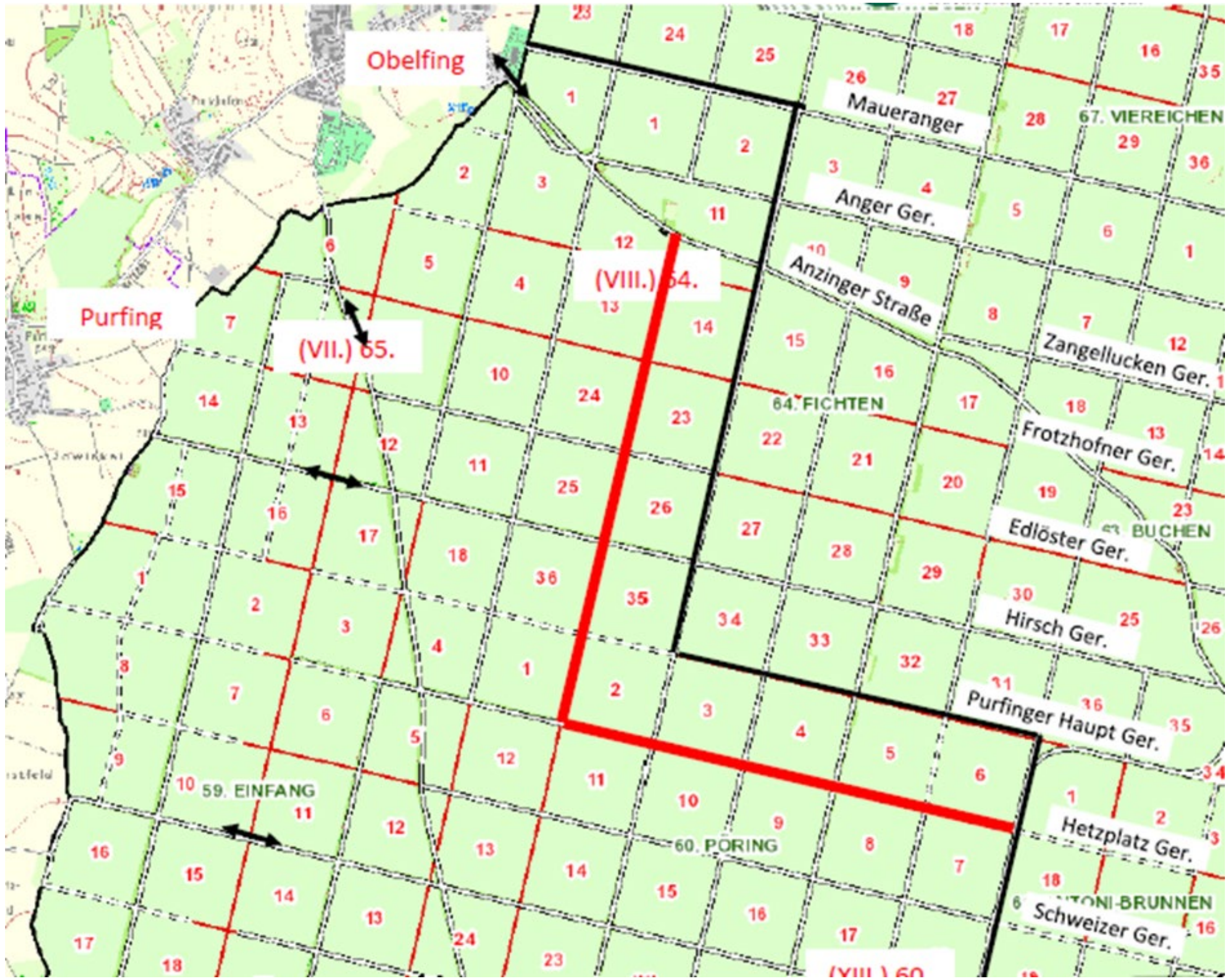


IGASPIN

SRX – Test Environments & Setups

Forest Test Environment

- **Red line** is the official test route in forest

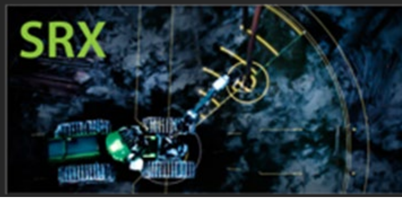


Vehicle Test Setup

Laboratory Test Setup

- ‚NCS NOVA‘ RFCS
- Dual-RF output
- GPS/Galileo/BDS

IGASPIN Overview



Focused on

- Satellite navigation
- GNSS interference detection, mitigation, and localization
- GNSS software receiver
- Meta-Signals

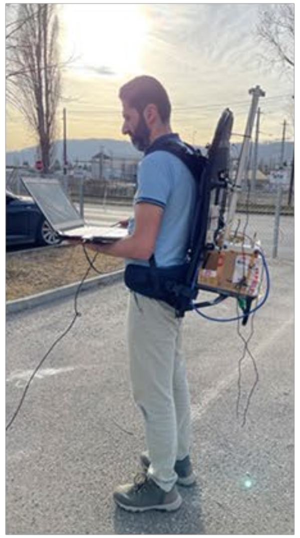
Located in Graz, Austria

- Since 2015

Personnel

- Join the Team!

→ *Awaiting your application*



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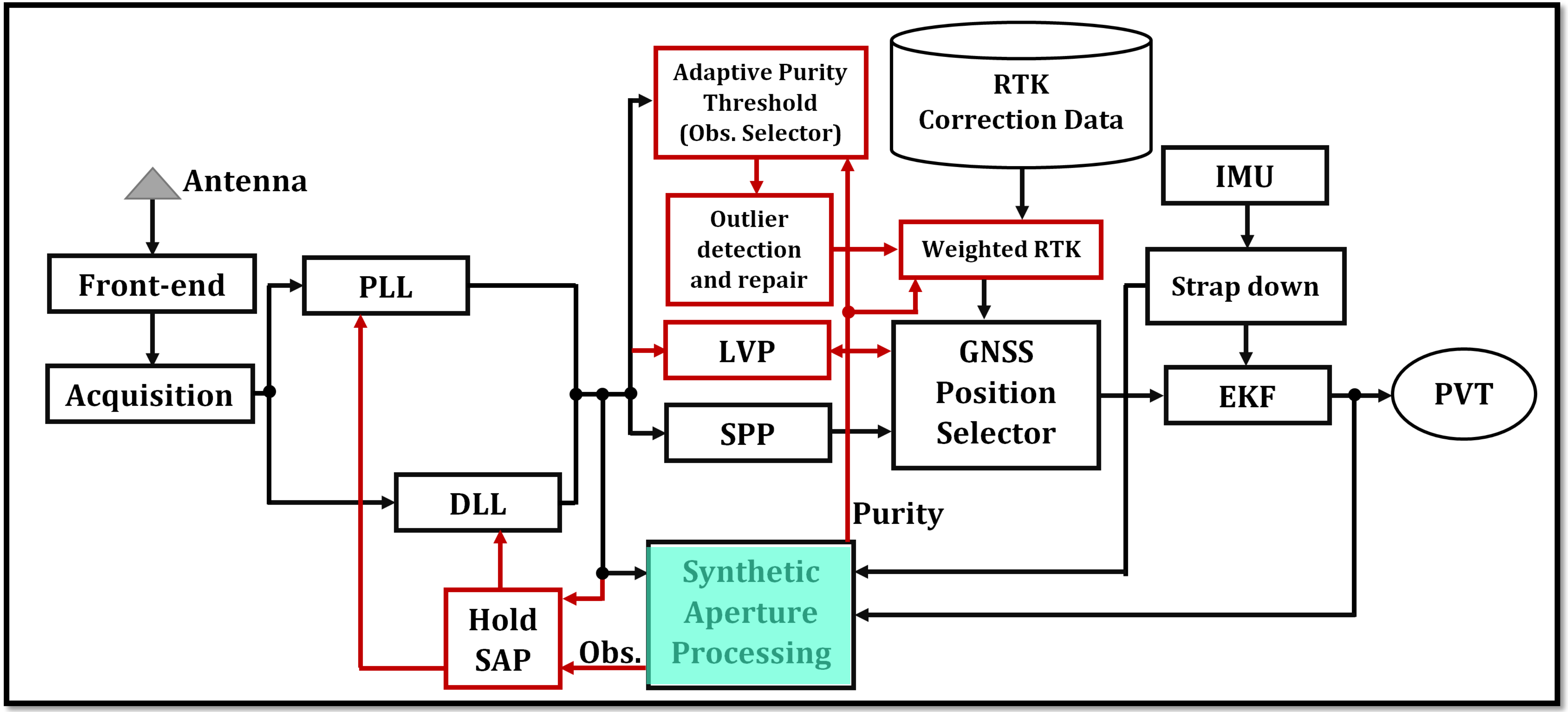
Algorithm Prototyping (1)

Summary of the important methods developed/adapted within SX3

Category	Description	Purpose
Correlator-based multipath mitigation	Narrow correlator	Multipath mitigation
	SBME	Multipath detection and mitigation
	DOME	Detection and mitigation of multipath and faulty lock
SAP	Hold SAP	Avoiding error penetration among the channels
RTK	SAP with RTK fixed initialization	Very precise PVT for projection
	Adaptive purity threshold	Using high-quality signals for positioning
	Weighted RTK	Increasing the accuracy of float solutions and therefore the success rate of integer ambiguity resolution
LVP	LVP with RTK fixed correction	Increasing the accuracy of EKF outputs when the number of observations are not sufficient for positioning
	LVP and RTK float priorities	Giving higher priority to weighted RTK float compared to LVP
Cycle-slip detection and repair	Carrier phase monitoring and repair	Cycle-slip detection and repair
	Pilot signals	Decreasing the cycle-slip occurrence probability
	New modulations	Lower vulnerability to multipath

Algorithm Prototyping (2)

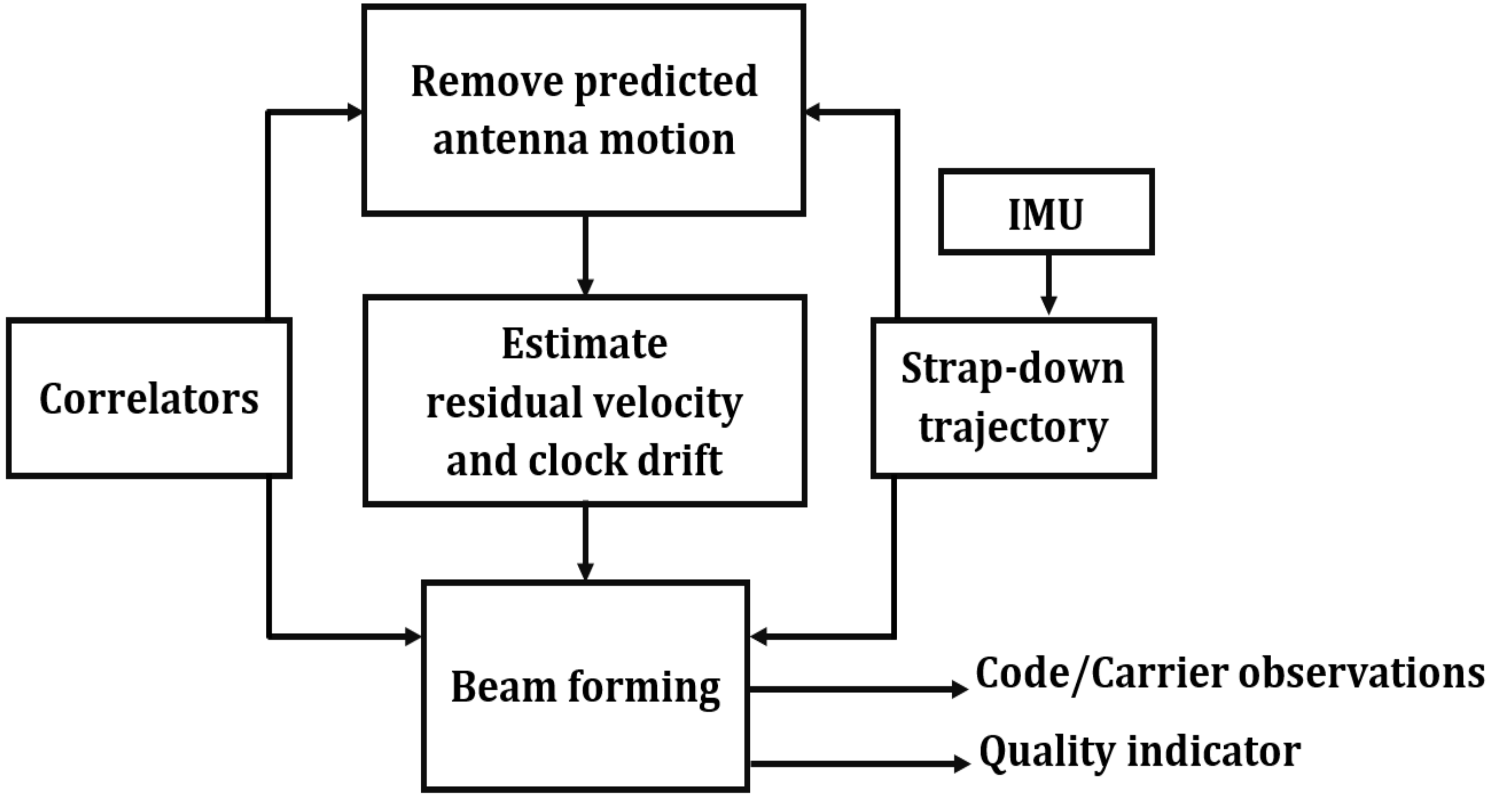
- The SX3 software receiver architecture extended for SRX project



Algorithm Prototyping (3)

SAP (Synthetic Aperture Processing)

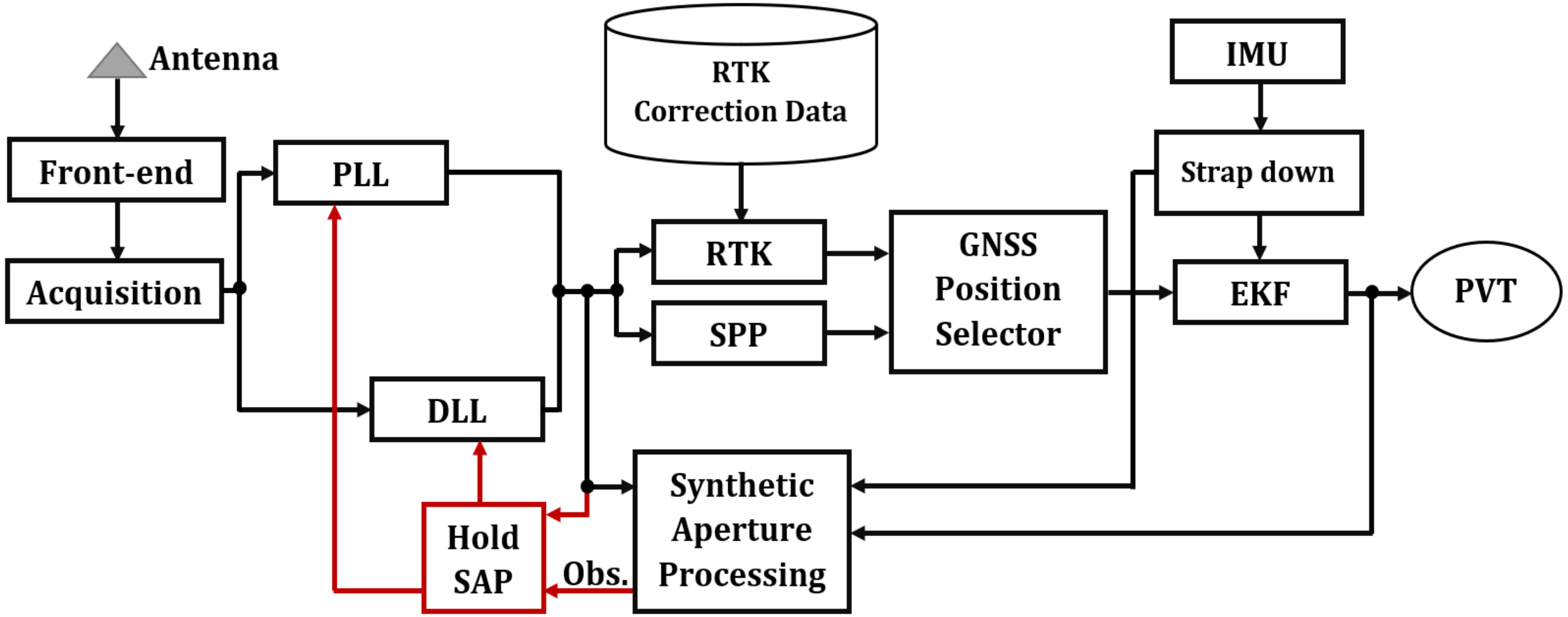
- SAP is realized as a coherent summation of correlation values for each satellite over the so-called ‘beamforming interval’.
- The resulting values represent a coherent correlation value maximizing the LOS signal power.



Algorithm Prototyping (4)

‘Hold SAP’

- The shared information in vector tracking may become problematic when the wrong information penetrates from one channel to the other ones.
- In order to solve this problem, [RD-1] proposes ***vector-hold tracking*** approach.
- Vector-hold tracking continuously compares the instantaneous independent code-phase/Doppler values against nominal values derived from the receiver’s PVT estimate.
- We also use the same concept and propose a new system architecture called “***Hold SAP***”.

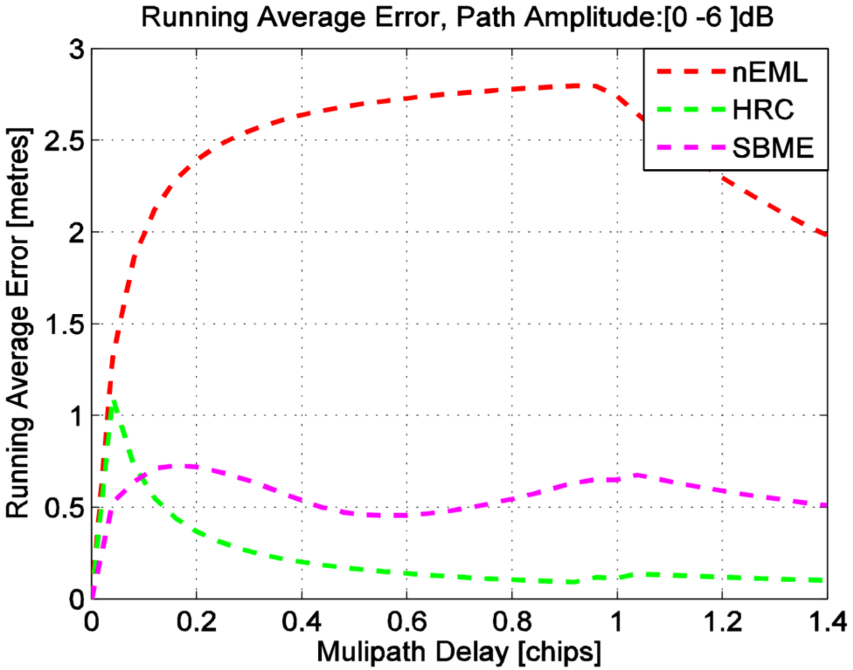


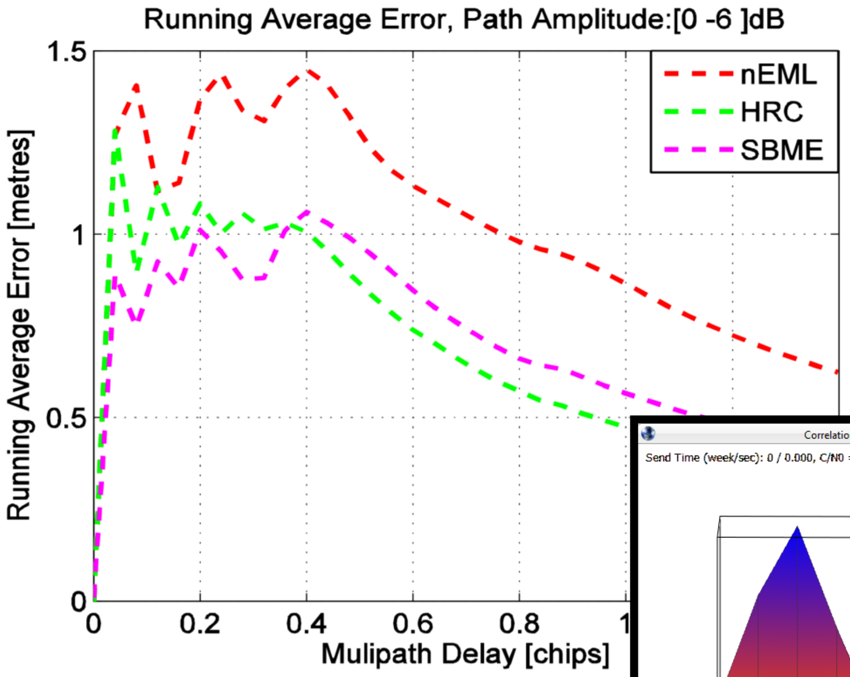
Pany, Thomas. *Navigation signal processing for GNSS software receivers*. Artech House, 2010.

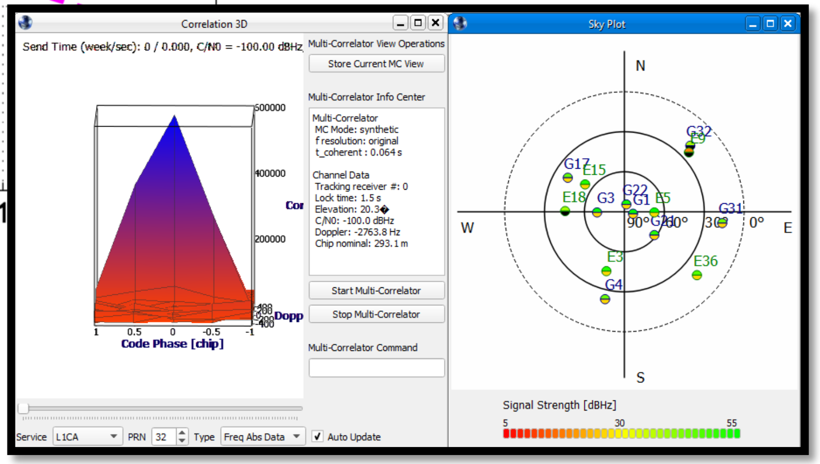
Algorithm Prototyping (5)

SBME

- first derives a multipath estimation equation by utilizing the *correlation shape of the ideal normalized correlation function*, then compensates for the multipath bias of a nEML tracking loop.







Running average error for 2-pat static channel model in a BPSK signal (left) and a CBOC(-) signal (right) [*]

HRC	High-Resolution Correlator
SBME	Slope-based Multipath Estimator

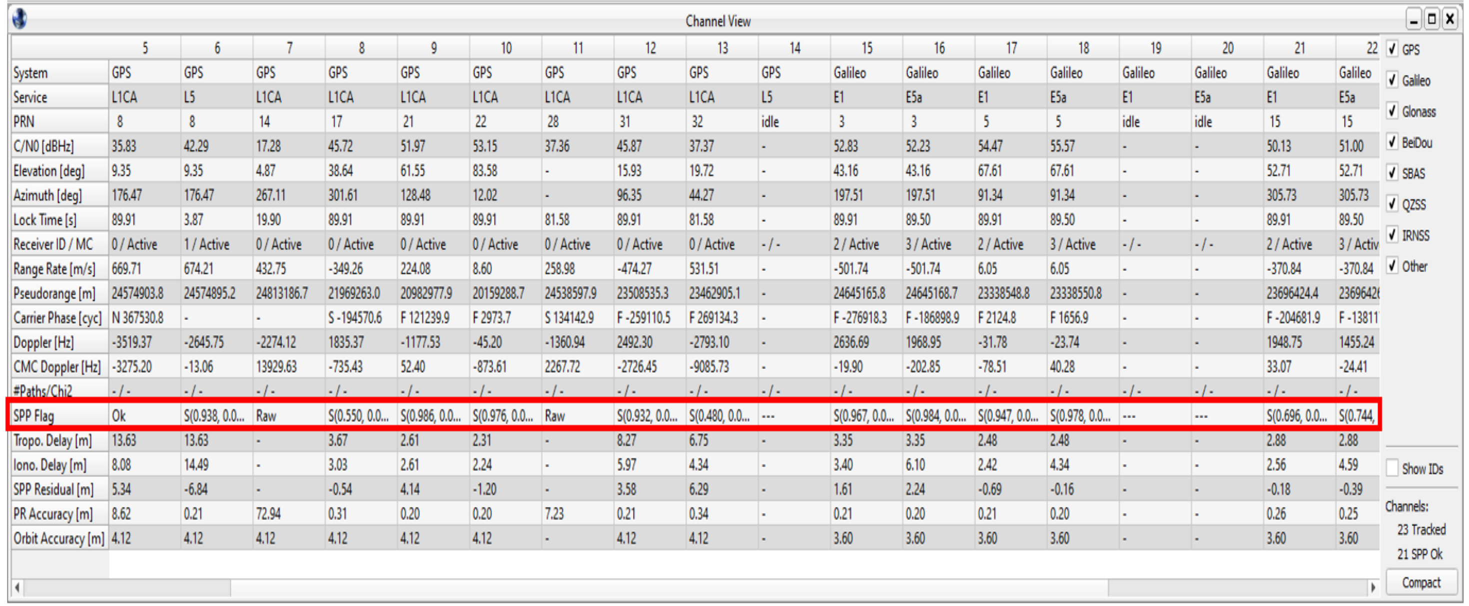
* Bhuiyan, Mohammad Zahidul H., Elena Simona Lohan, and Markku Renfors. "A slope-based multipath estimation technique for mitigating short-delay multipath in GNSS receivers." In *Proceedings of 2010 IEEE International Symposium on Circuits and Systems*, pp. 3573-3576. IEEE, 2010.

Algorithm Prototyping (6)

Adaptive purity threshold

- One of the SAP outputs is the purity of the signal in the channel.
- This quantity shows which portion of the received signal power belongs to the LOS.
- The signal is fed to RTK engine as an input observation, only if the purity of the signal exceeds this threshold.
- The choice of the purity threshold is a trade-off between signal availability and accuracy.

Adaptive threshold determination module finds the most suitable threshold ***adaptively based on the values of the signal purity in all channels***

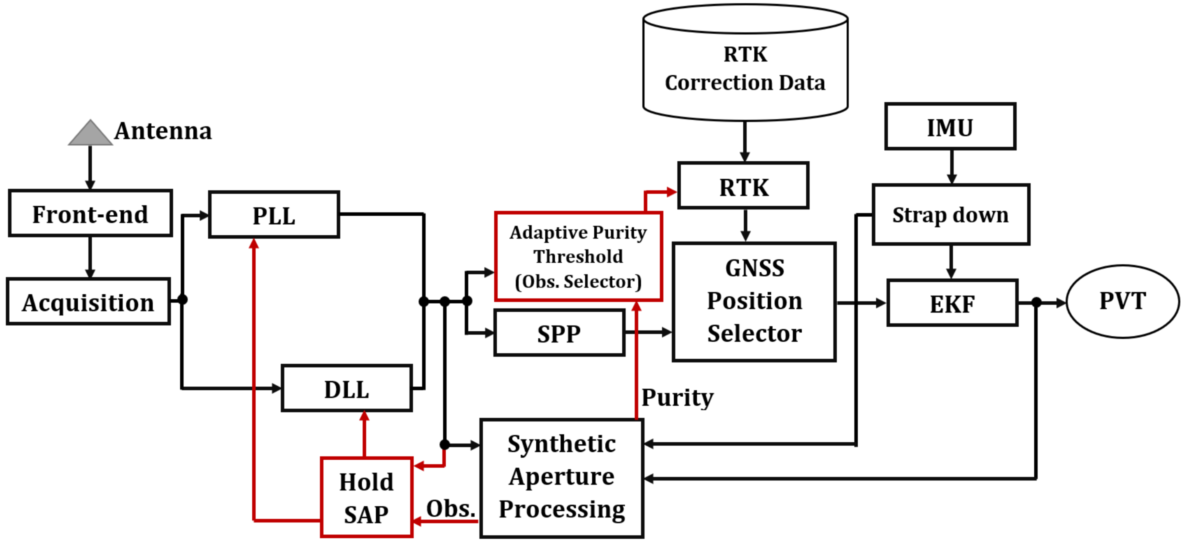


Channel View

	5	6	7	8	9	10	11	12	13
System	GPS	GPS	GPS	GPS	GPS	GPS	GPS	GPS	GPS
Service	L1CA	L5	L1CA	L1CA	L1CA	L1CA	L1CA	L1CA	L1CA
PRN	8	8	14	17	21	22	28	31	32
C/N0 [dBHz]	35.83	42.29	17.28	45.72	51.97	53.15	37.36	45.87	37.37
Elevation [deg]	9.35	9.35	4.87	38.64	61.55	83.58	-	15.93	19.72
Azimuth [deg]	176.47	176.47	267.11	301.61	128.48	12.02	-	96.35	44.27
Lock Time [s]	89.91	3.87	19.90	89.91	89.91	89.91	81.58	89.91	81.58
Receiver ID / MC	0 / Active	1 / Active	0 / Active	0 / Active	0 / Active	0 / Active	0 / Active	0 / Active	0 / Active
Range Rate [m/s]	669.71	674.21	432.75	-349.26	224.08	8.60	258.98	-474.27	531.51
Pseudorange [m]	24574903.8	24574895.2	24813186.7	21969263.0	20982977.9	20159288.7	24538597.9	23508535.3	23462905.1
Carrier Phase [cyc]	N 367530.8	-	-	S -194570.6	F 121239.9	F 2973.7	S 134142.9	F -259110.5	F 269134.3
Doppler [Hz]	-3519.37	-2645.75	-2274.12	1835.37	-1177.53	-45.20	-1360.94	2492.30	-2793.10
CMC Doppler [Hz]	-3275.20	-13.06	13929.63	-735.43	52.40	-873.61	2267.72	-2726.45	-9085.73
#Paths/Chi2	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -
SPP Flag	Ok	S(0.938, 0.0...	Raw	S(0.550, 0.0...	S(0.986, 0.0...	S(0.976, 0.0...	Raw	S(0.932, 0.0...	S(0.480, 0.0...
Tropo. Delay [m]	13.63	13.63	-	3.67	2.61	2.31	-	8.27	6.75
Iono. Delay [m]	8.08	14.49	-	3.03	2.61	2.24	-	5.97	4.34
SPP Residual [m]	5.34	-6.84	-	-0.54	4.14	-1.20	-	3.58	6.29
PR Accuracy [m]	8.62	0.21	72.94	0.31	0.20	0.20	7.23	0.21	0.34
Orbit Accuracy [m]	4.12	4.12	4.12	4.12	4.12	4.12	-	4.12	4.12

	14	15	16	17	18	19	20	21	22
System	GPS	Galileo	Galileo	Galileo	Galileo	Galileo	Galileo	Galileo	Galileo
Service	L5	E1	E5a	E1	E5a	E1	E5a	E1	E5a
PRN	idle	3	3	5	5	idle	idle	15	15
C/N0 [dBHz]	-	52.83	52.23	54.47	55.57	-	-	50.13	51.00
Elevation [deg]	-	43.16	43.16	67.61	67.61	-	-	52.71	52.71
Azimuth [deg]	-	197.51	197.51	91.34	91.34	-	-	305.73	305.73
Lock Time [s]	-	89.91	89.50	89.91	89.50	-	-	89.91	89.50
Receiver ID / MC	- / -	2 / Active	3 / Active	2 / Active	3 / Active	- / -	- / -	2 / Active	3 / Activ
Range Rate [m/s]	-	-501.74	-501.74	6.05	6.05	-	-	-370.84	-370.84
Pseudorange [m]	-	24645165.8	24645168.7	23338548.8	23338550.8	-	-	23696424.4	2369642
Carrier Phase [cyc]	-	F -276918.3	F -186898.9	F 2124.8	F 1656.9	-	-	F -204681.9	F -13811
Doppler [Hz]	-	2636.69	1968.95	-31.78	-23.74	-	-	1948.75	1455.24
CMC Doppler [Hz]	-	-19.90	-202.85	-78.51	40.28	-	-	33.07	-24.41
#Paths/Chi2	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -
SPP Flag	---	S(0.967, 0.0...	S(0.984, 0.0...	S(0.947, 0.0...	S(0.978, 0.0...	---	---	S(0.696, 0.0...	S(0.744,
Tropo. Delay [m]	-	3.35	3.35	2.48	2.48	-	-	2.88	2.88
Iono. Delay [m]	-	3.40	6.10	2.42	4.34	-	-	2.56	4.59
SPP Residual [m]	-	1.61	2.24	-0.69	-0.16	-	-	-0.18	-0.39
PR Accuracy [m]	-	0.21	0.20	0.21	0.20	-	-	0.26	0.25
Orbit Accuracy [m]	-	3.60	3.60	3.60	3.60	-	-	3.60	3.60

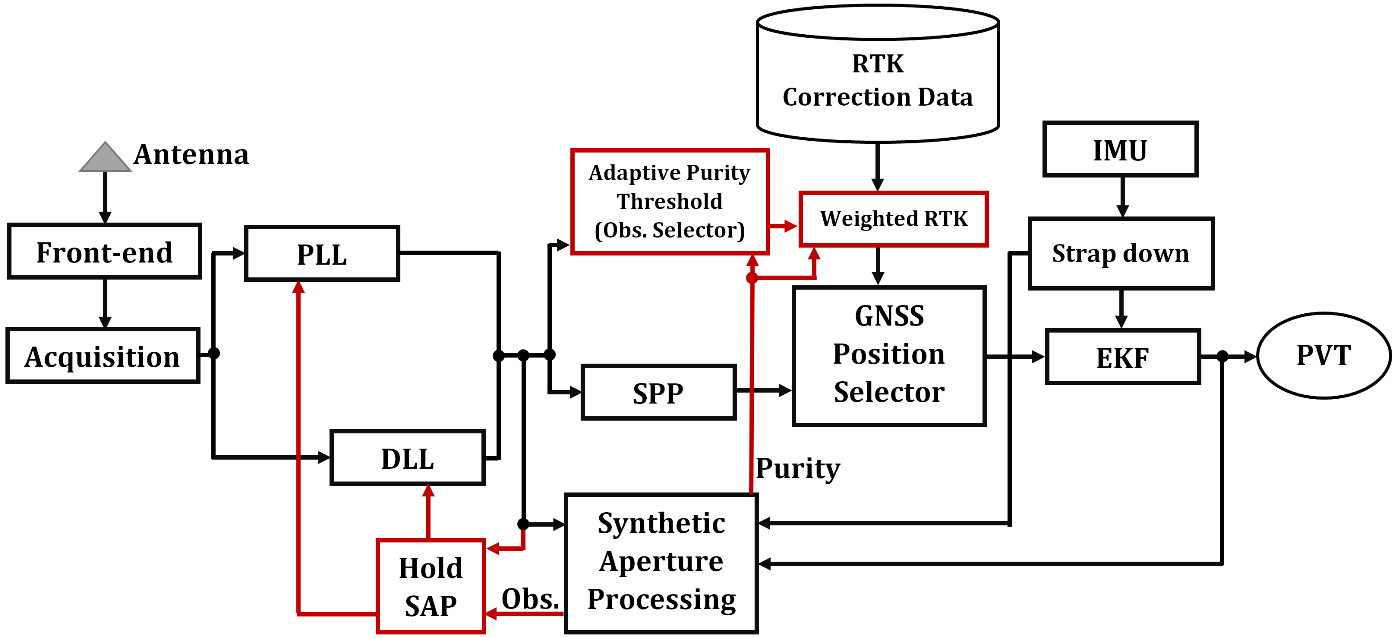
GPS
Galileo
Glonass
BeiDou
SBAS
QZSS
IRNSS
Other
Show IDs
Channels:
23 Tracked
21 SPP Ok
Compact



Algorithm Prototyping (7)

Weighted RTK

- Based on [*], improving the performance of the float estimation will enable the guidance of the integer ambiguity search and enhance its success ratio.
- In the enhanced SX3 processing architecture, the ***weighted RTK is proposed***.
  - Here, the EKF gives more weight to the input observation which has more purity

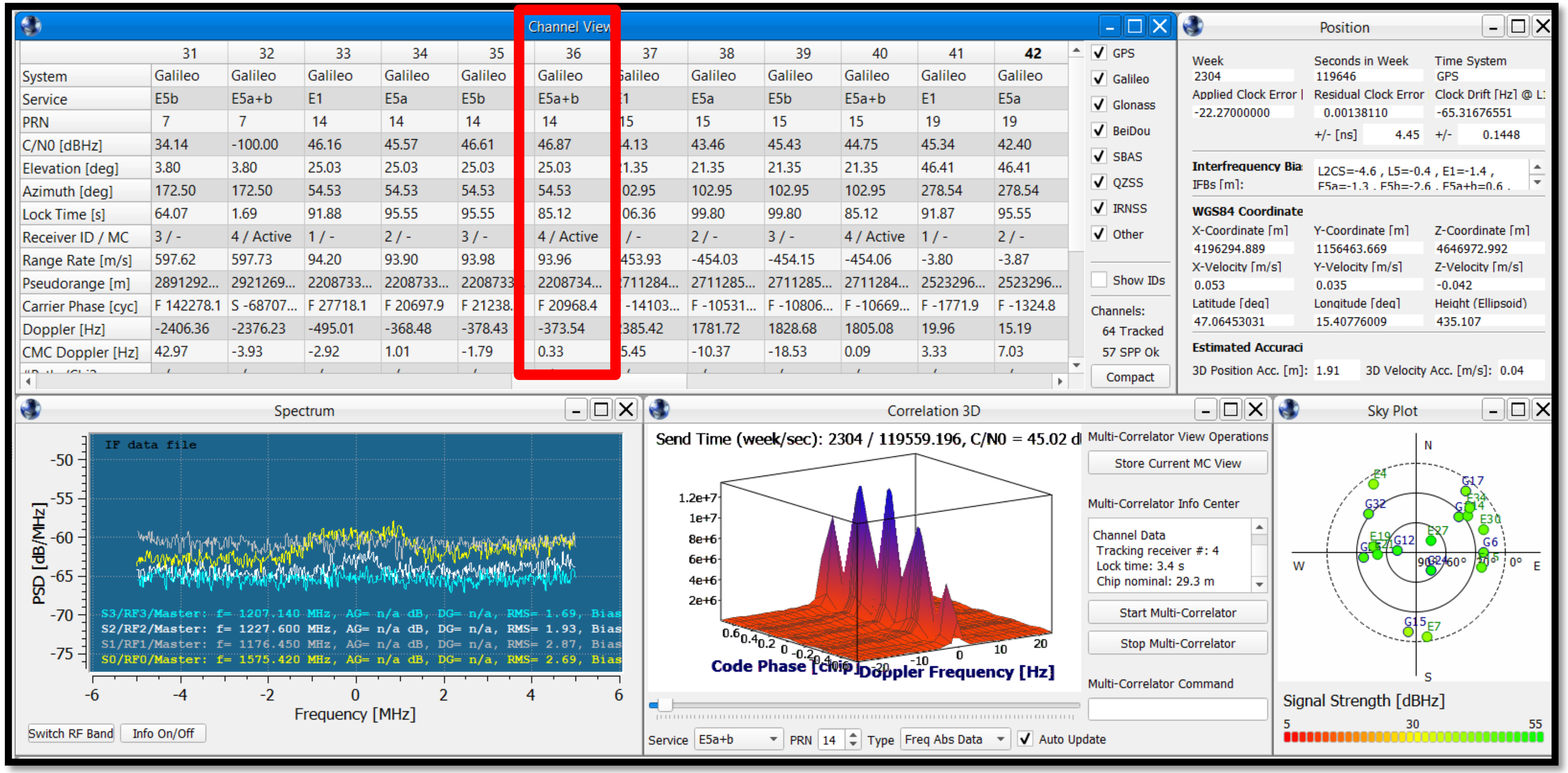


* *Li, Haoqing, Daniel Medina, Jordi Vilà-Valls, and Pau Closas. "Robust Kalman Filter for RTK Positioning Under Signal-Degraded Scenarios." In Proceedings of the 32nd International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS+ 2019), Miami, FL, USA, pp. 16-20. 2019.*

Algorithm Prototyping (8)

Meta-signal Processing

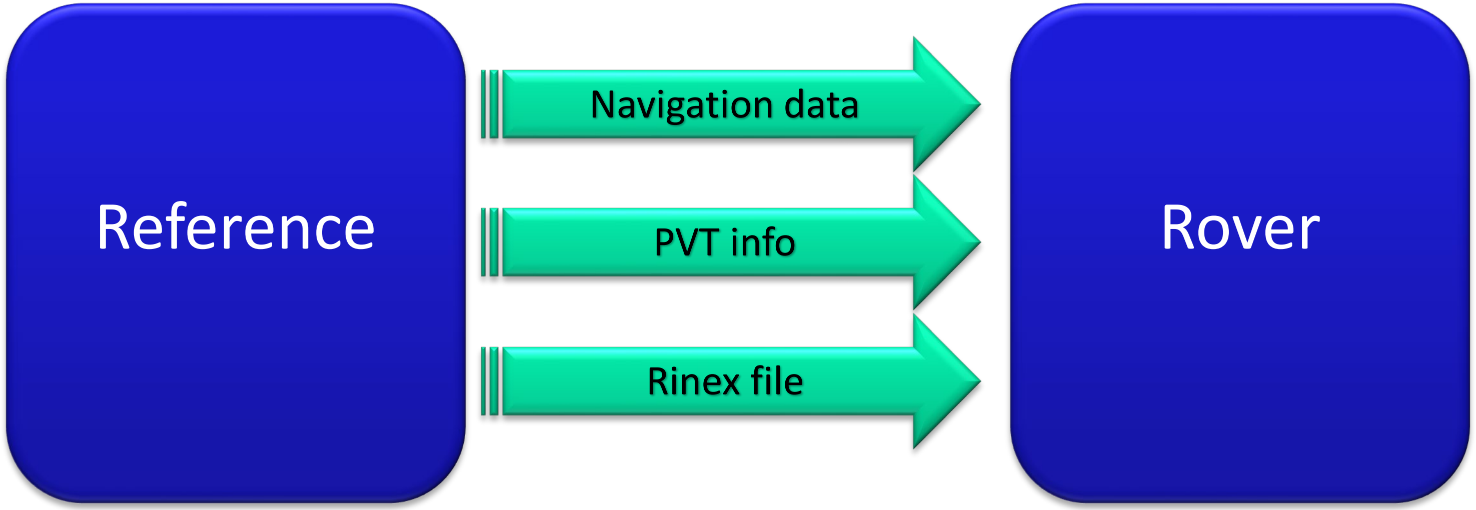
- Meta-signal processing mitigates multipath interference and weak signals in harsh environments by combining and optimizing signals from multiple frequencies.
- Galileo E5a+E5b



Related IGASPIN's Project:
1- HANDS-CD: ESA 2022-2024
2- INSPIRE: ESA 2024-2026

Algorithm Tuning (1)

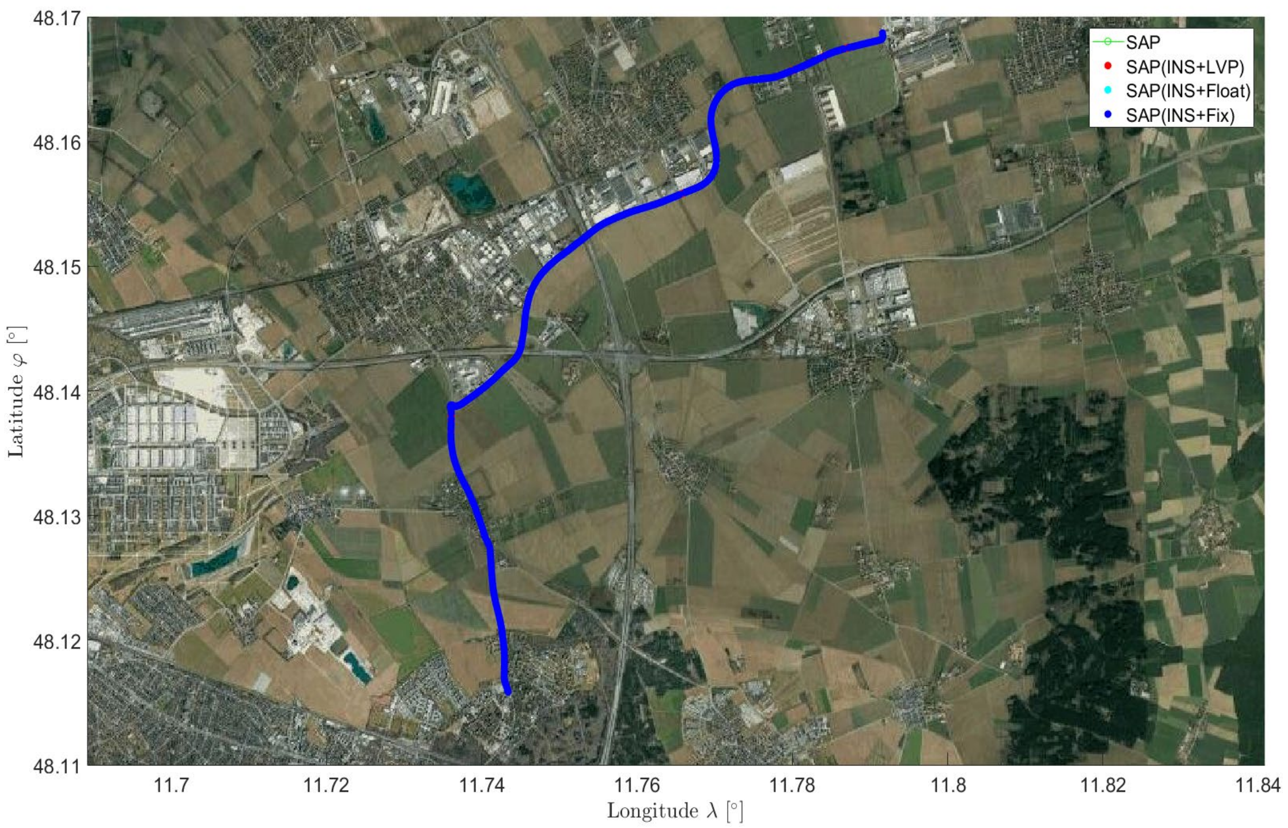
- **Test**



Recorded signals: GPS L1/L5, Galileo E1/E5a/E5b/E5ab, and Beidou B1C/B2a.
Sampling frequency: 20 MSPS.

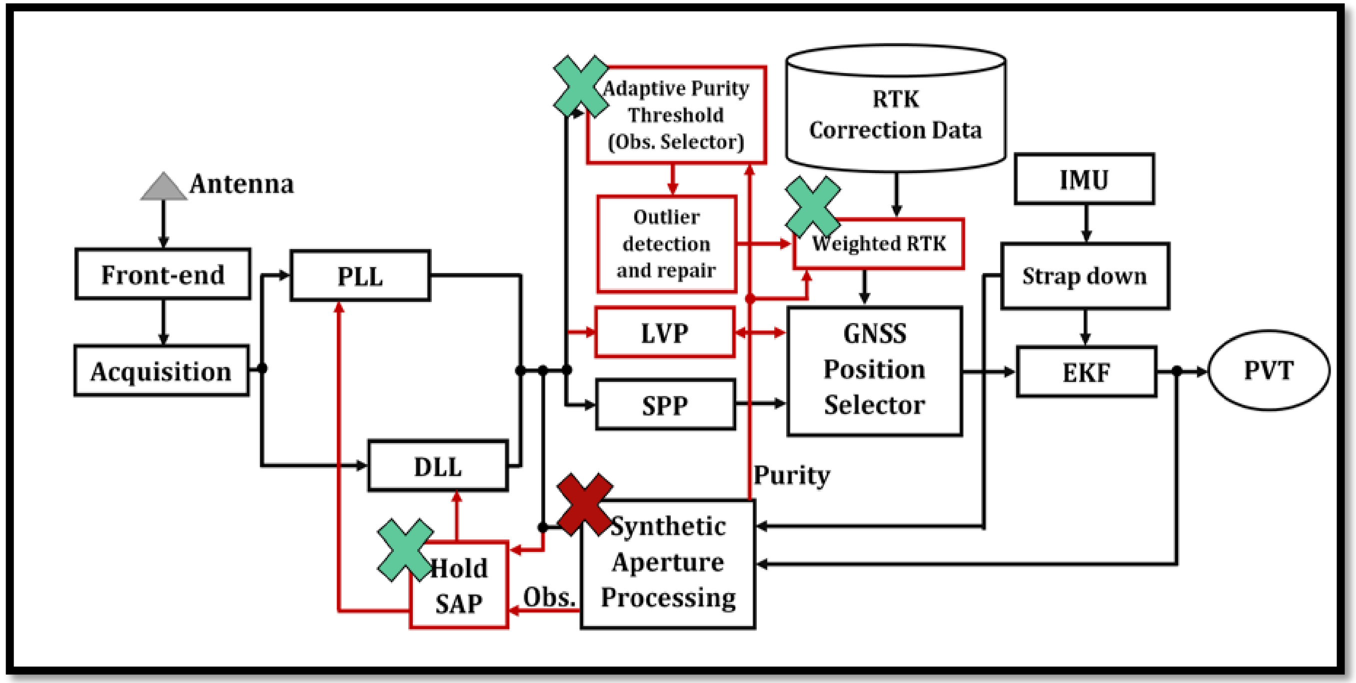
Algorithm Tuning (2)

Urban Test



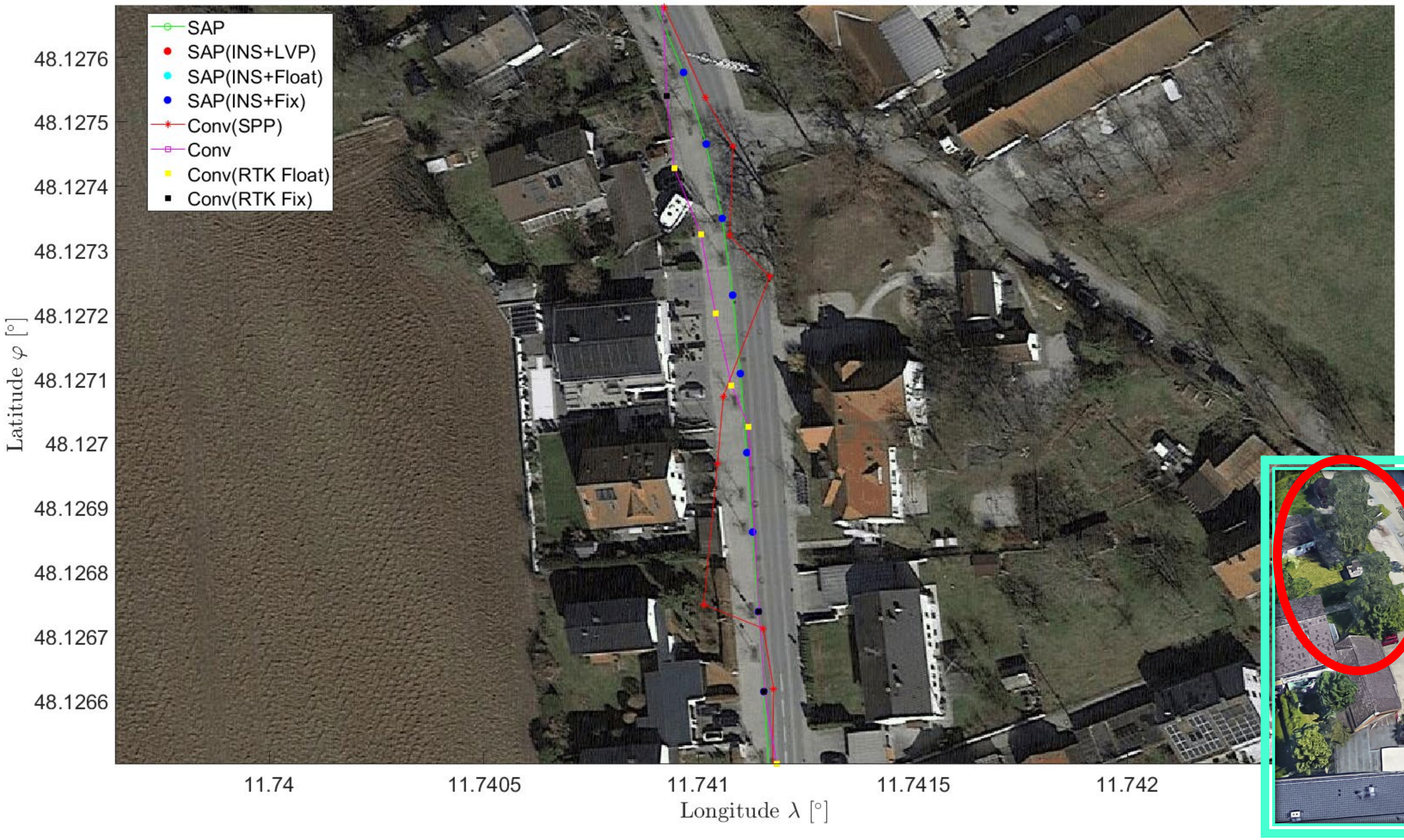
Tracking method	SAP	Conventional
RTK Fix	93.21%	57.87%
RTK Float	0.55%	23.67%
LVP	6.24%	18.47%

Conventional tracking = Architecture with deactivated SAP.



Algorithm Tuning (3)

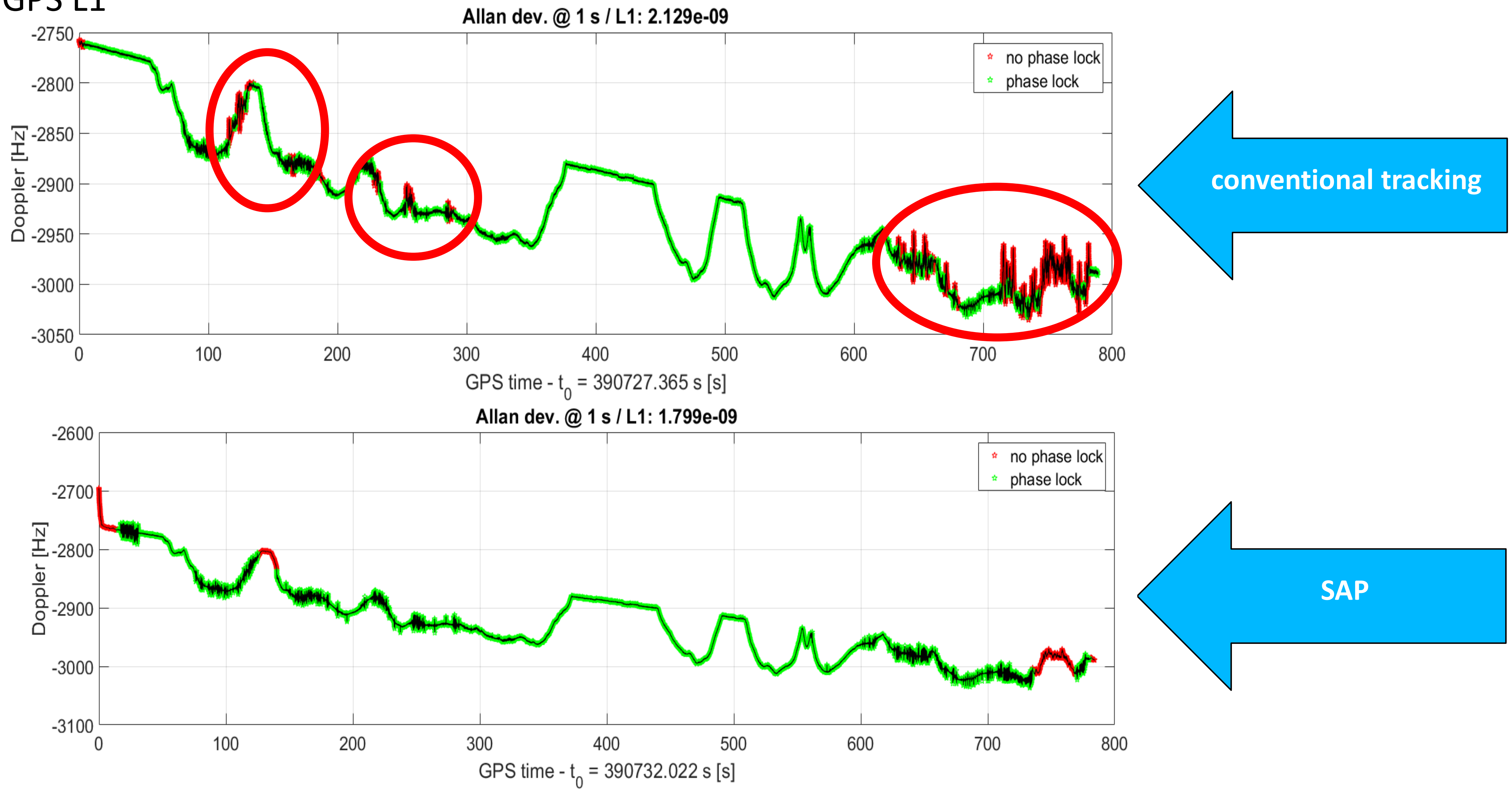
Urban Test- Test case 1



Algorithm Tuning (4)

Tracking in SAP vs Conventional

- PRN32 - GPS L1

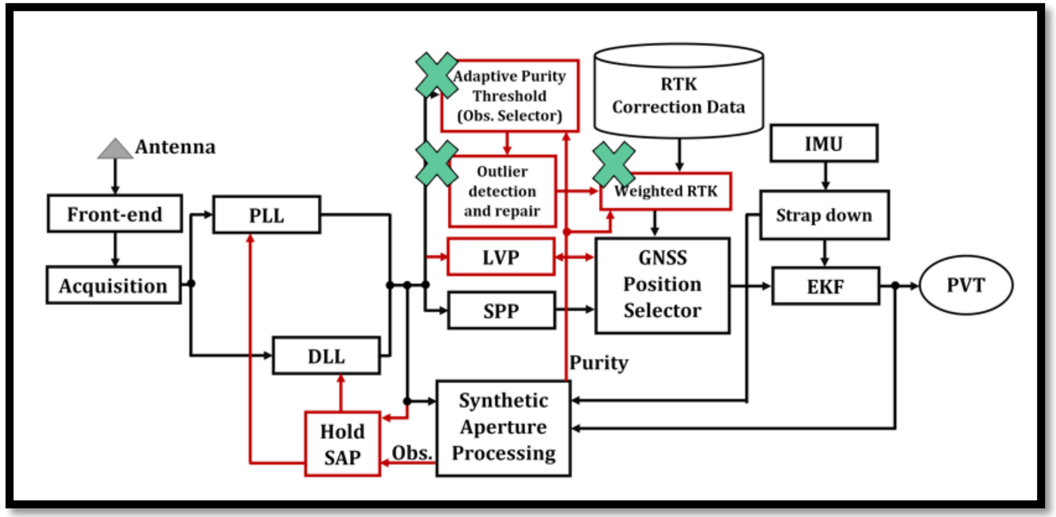


Algorithm Tuning (5)

SAP vs SAPE

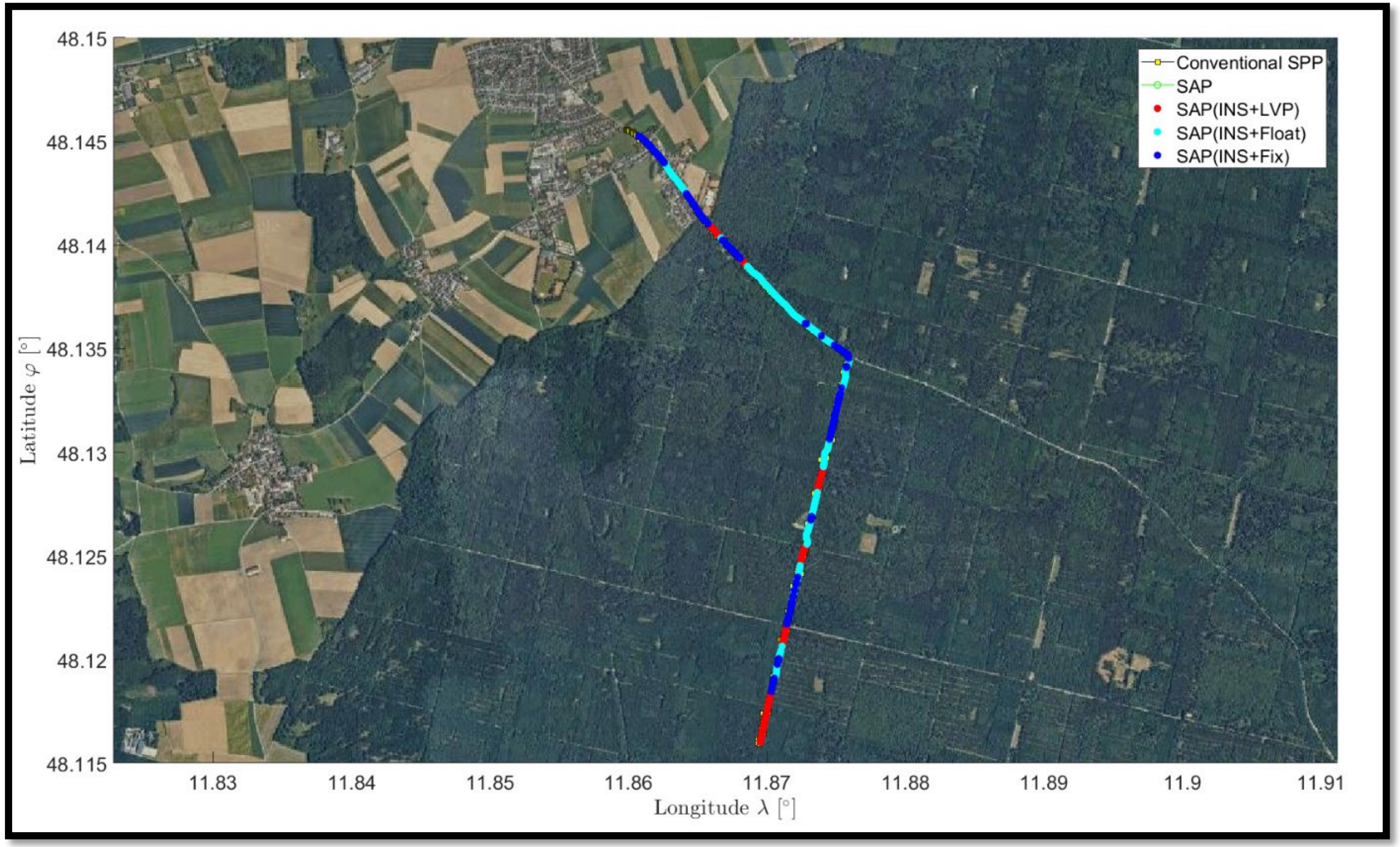
	SAP	SAPE
RTK Fix	93.21%	79.86%
RTK Float	0.55%	1.11%
LVP	6.24%	19.03%

SAPE = SAP without weighted RTK, adaptive purity threshold, and carrier phase monitoring and repair



Algorithm Tuning (6)

Forest Test



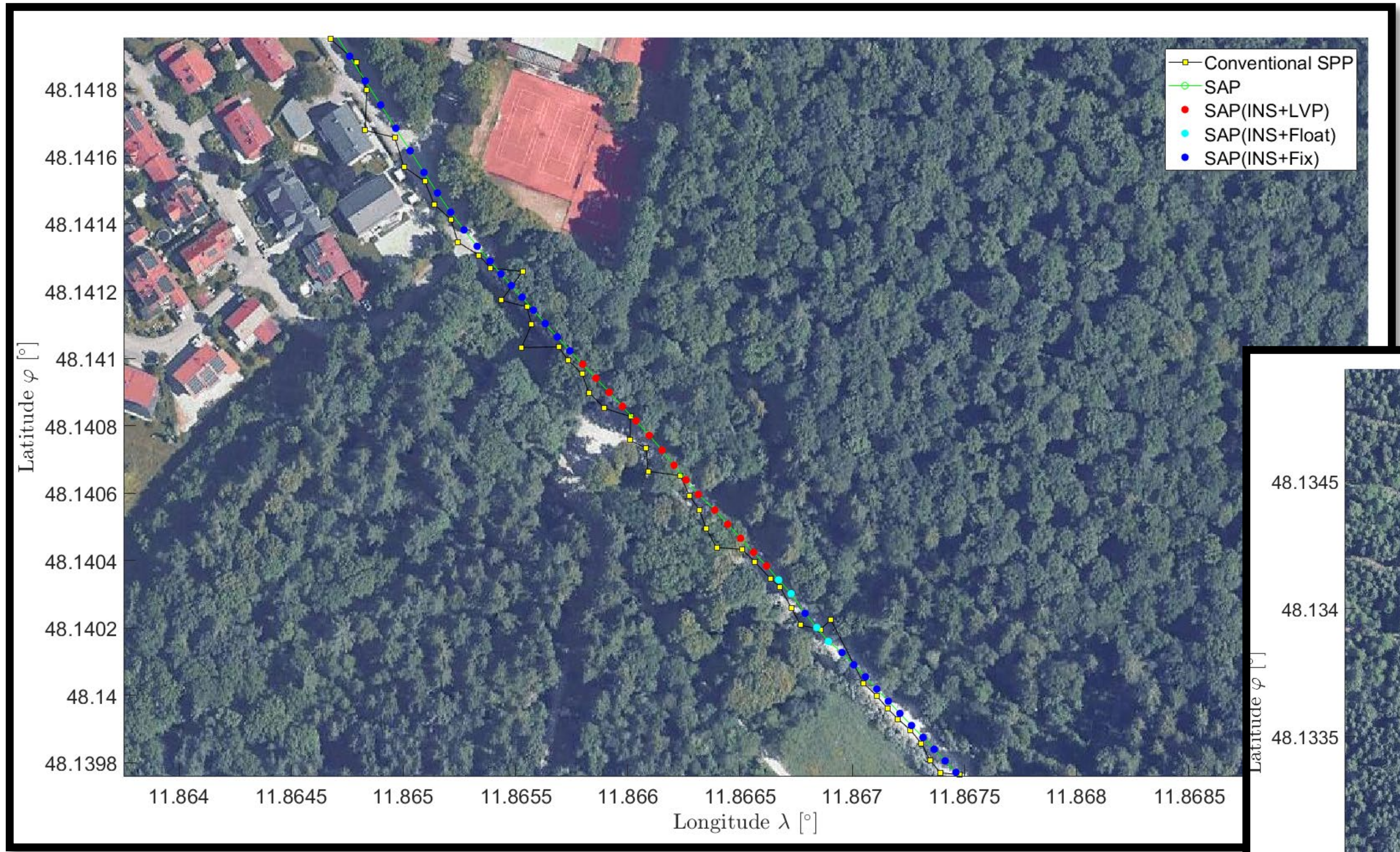
Positioning results of the improved SX3 receiver and a conventional receiver on a rover in a forest.

The statistics of the solutions by the SAP in the forest test.

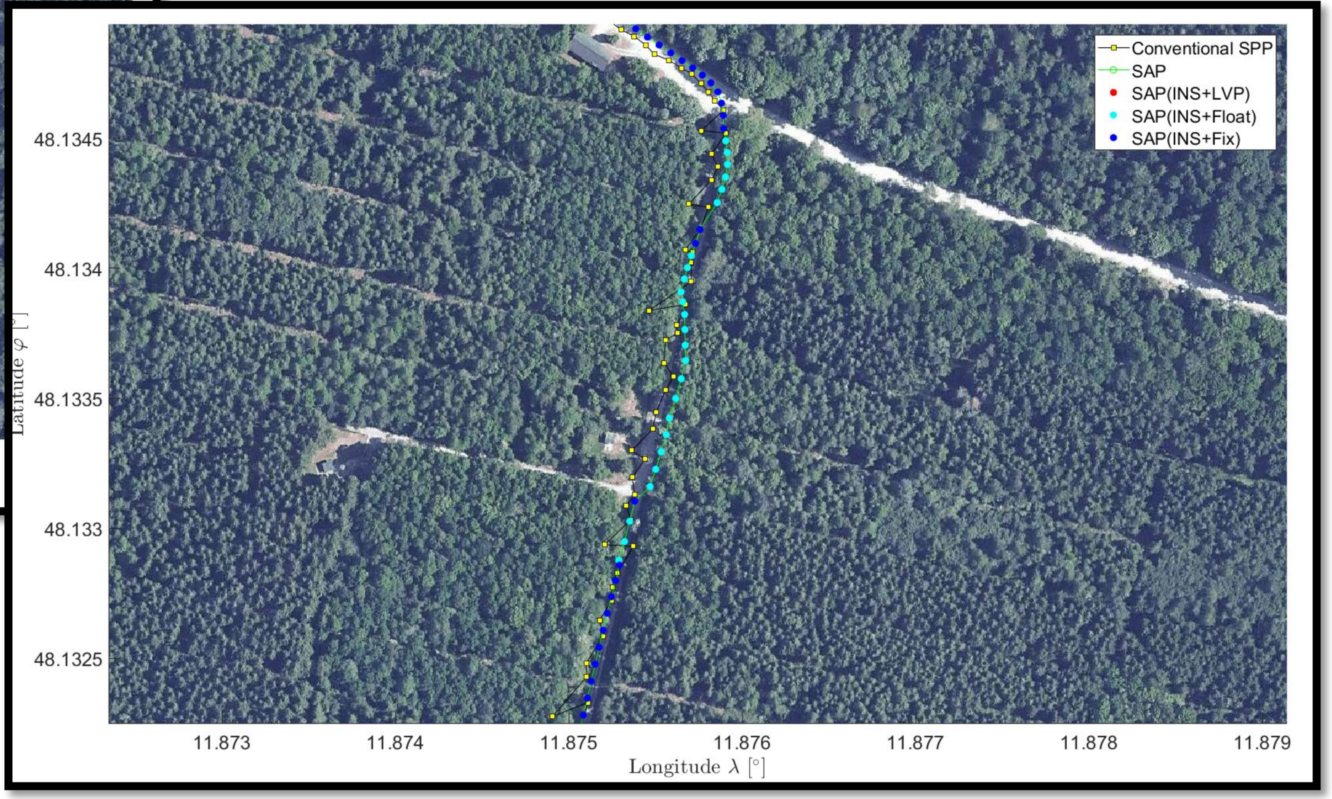
Tracking method	SAP
RTK Fix	30.17%
RTK Float	44.67%
LVP	25.17%

Algorithm Tuning (7)

Test Cases



Case 1



Case 2

Algorithm - Conclusions

Summary Conclusions on Algorithms

- Advanced Positioning: SRX enhances precise GNSS positioning in challenging environments through SAP, RTK, and EKF integration, excelling in forests and urban canyons
- Effective Multipath Mitigation: SBME and other implemented methods mitigate signal interference, ensuring cleaner tracking and greater accuracy
- Adaptive Accuracy: Adaptive purity thresholds, weighted RTK, and SAP ensure consistent accuracy even with limited signals
- Proven Performance: Real-world tests validate SRX's superior accuracy and reliability over conventional receivers
- Future Focus: Expanding GNSS support, optimizing purity thresholds, and preparing for commercial adoption will further strengthen SRX's capabilities

SRX – Receiver Development (1)

IFEN

SRX

Long experience in GNSS SDR receiver

- Supplier for all Galileo payload test receiver (1st. Gen for IOV, 2nd gen. for FOC)
- 3rd gen. NTR receiver since 2014 (IRNSS payload & TUR, EU contracts preparing OSNMA, HAS, ACAS)
- Due to obsolescence of major components, replacement was required

SRX-EP receiver

- ‚Early Prototype‘ for SRX, strongly improving SWaP compared to NTR
- Supporting phase-synchronization of different RF-paths
- Validated of integration of processing capability using MPSoC based approach

SRX-P prototype receiver

- Further SWaP optimization
  - using RF-ASIC (replacing current discrete RF-chains) and AMD ACAP Versal MPSoC (replacing SRX-EP used AMD ZYNQ Ultrascale+)
- Further improvement for use forest case
  - MEMS-IMU integration, harsh environment capable TCXO (trade-offs of available solutions)

SRX – Receiver Development (2)

NTR 3rd gen. receiver

- Discrete 4 RF-paths with 50 MHz BW each
- Complex 7-boards solution
- Obsolescence of major components

SRX-EP 4th gen. prototype receiver

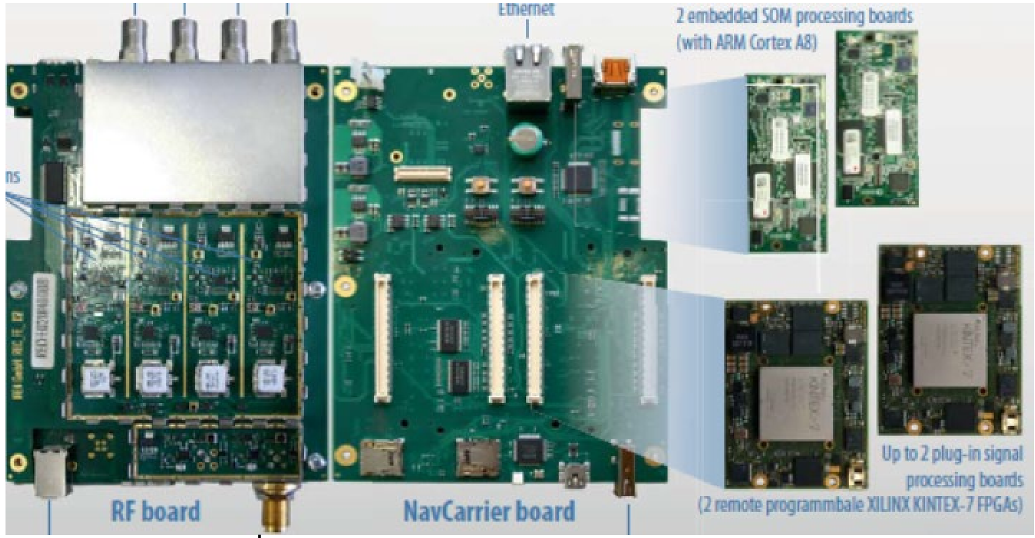
- Discrete 4 RF-path with 50 MHz BW and phase-sync.
- 2-boards solution using MPSoC
- TCXO with low G-sensitivity
- Added support for GPS L1C and BDS3 B2a signals

SRX-P (SRX target receiver)

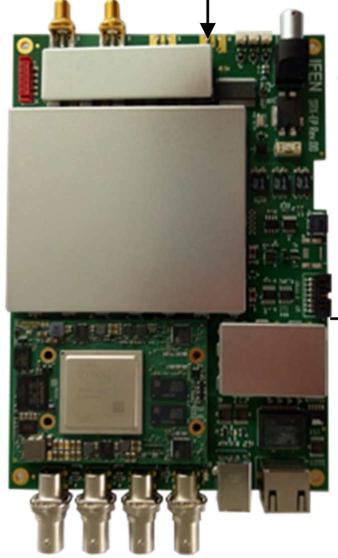
- Using 2 x prototype RF-ASICs → SRX-P developed

→ PVT achieved → but RF-ASIC too instable for usage

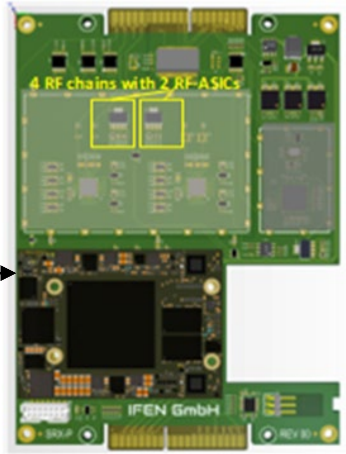
- AMD ACAP Versal MPSoC → not available



NTR



SRX-EP



SRX-P

SRX – Receiver Development (3)

IFEN

Finally, the SFX4 receiver is used as baseline for testing in the SRX project

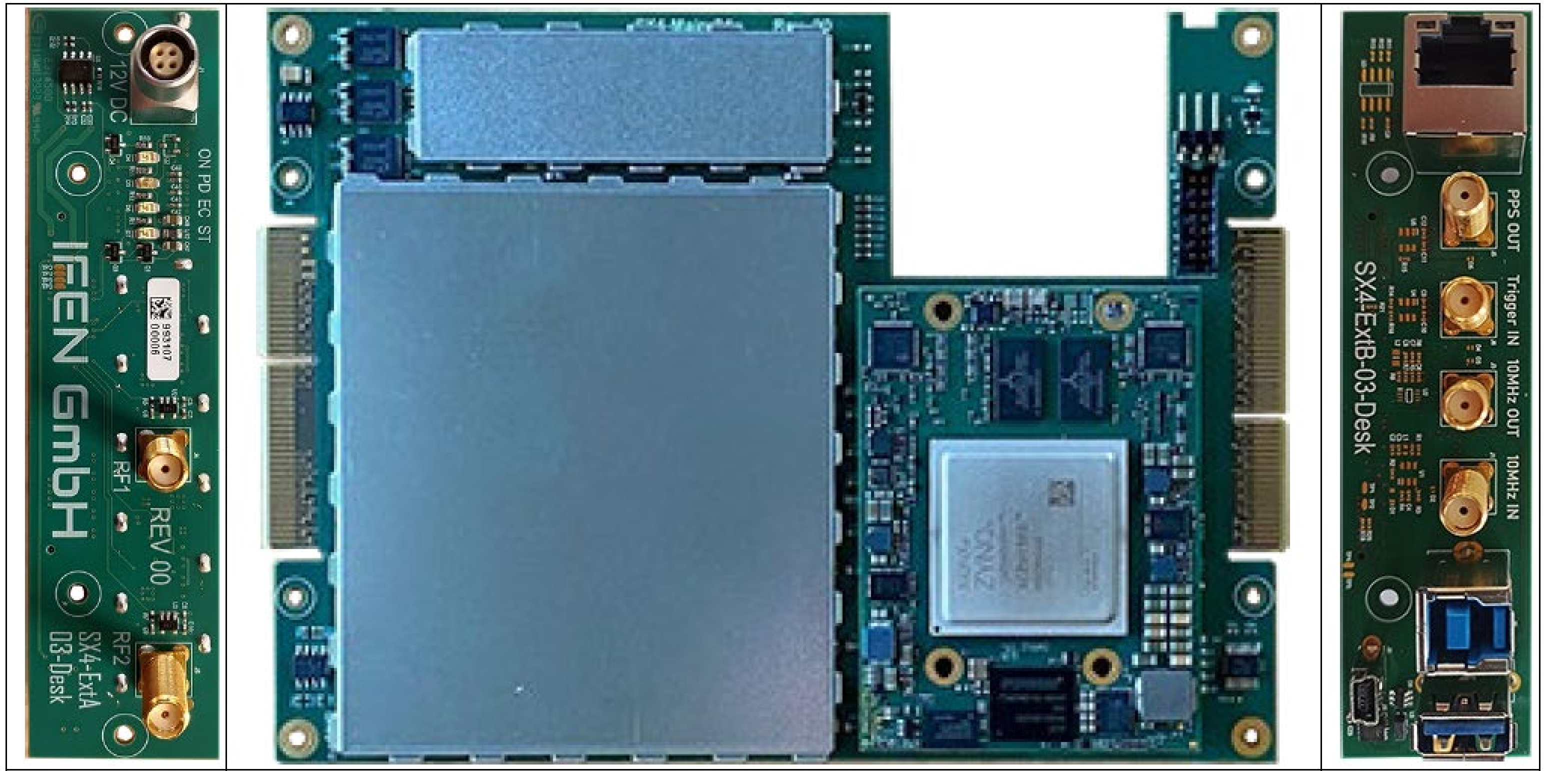
- Driven by the need to support different applications, the commercial SFX4 receiver was derived from the SRXEP
- Added **modularity** to design, by separating the IO-parts from the complex core module

Adaptable RF-IO Plug-In board

- Standard is 2-RF-inputs and 12 VDC power
- Easy customization for customer needs
  - 4-RF inputs for attitude, ...
  - Suppression lines in com. environment
  - 2-stage LNA for high-power testing
  - Other power supply if required (5 VDC, 9-28 VDC)

Adaptable Data-IO Plug-In Board

- Standard Data-IO setup is:
  - 1 x ETH, 2 x USB, 10-MHz-in/out, 1-pps-out, trigger-in
- Easy customization for customer needs
  - IMU integration, CAN-bus, storage, communication,...
  - E.g. 2nd ETH-Port for ext. PVT (G2G TURN) or SM for PRS



RF Flex-IO board	SFX core board	Data Flex-IO board

SRX – PVT Developments (1)

IFEN SRX

RTK

- Working RTK in adverse signal conditions is a known problem, due to disrupted carrier-phase measurements
- Initial RTK tests in forest confirmed unavailability of RTK based precise solutions

Original DGNSS Approach

- For this probable case of RTK issues, usage of code based DGNSS as a backfall solution was foreseen
- Originally planned was the usage of Galileo E1C/E5ab AltBOC in combination with BDS B1C/B2ab ACE-BOC
- To take advantage of low-codes noise of Galileo E5ab and BDS B2ab signals (to minimize code noise multiplication in ionosphere-free dual-frequency combination, removing 1st order ionosphere errors, with the cost of increased noise by a factor of ~ 3)

Final DGNSS Approach

- No usage of BDS3 B2ab ACE-BOC (missing ICD) and insufficient number of visible satellites
- Switch to triple-constellation GPS L1/L5, Galileo E1/E5a and BDS2 B1C/B2a DGNSS DF approach
- Finally used for testing driven to maximize number of visible satellites at ‘high’ elevation (→ low DOP)

SRX – PVT Developments (2)

DGNSS Conclusions

- Objective is to achieve ~ 95% availability within the 50 cm accuracy target
- Achieved availability of ~ 50 cm ☑ accuracy, but only with ~ 50% availability ☒
- But this is just an initial result with a very few tests
- As GNSS signal quality in ‘forest environment’ is very dependent on the type of trees, geographic location, weather conditions and especially the season when recording the measurements, many more trials are necessary to achieve representative results
- Even then in a different forest environment different results could be obtained!

Way Forward

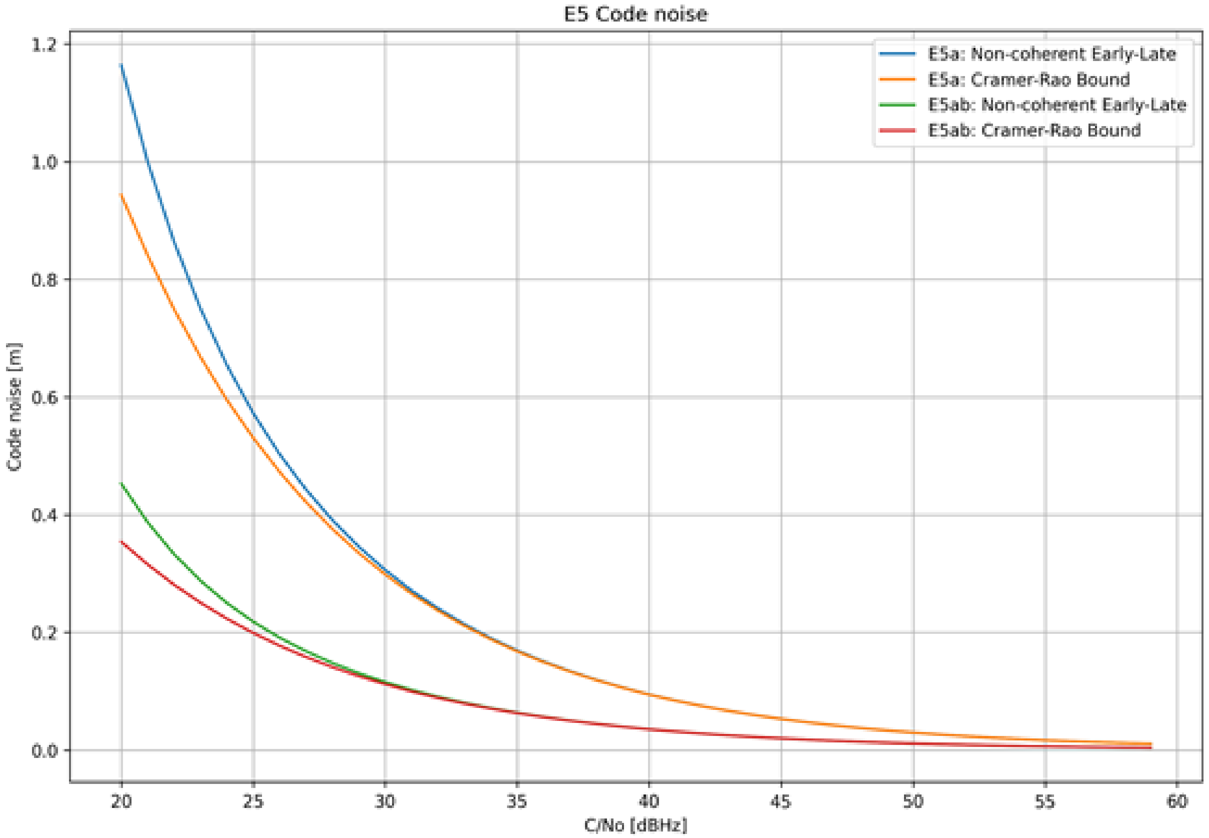
- Increase number of available Galileo satellites (further increase until end of this year)
- Improve receiver configuration (using pilot signals up to 20 ms coherent integration time for low C/N0,...)
- Integrate with IMU for data-gap bridging
- Switch to meta-signal processing on E1, enabling lower code noise, thus minimizing the ‘noise penalty’ in DF

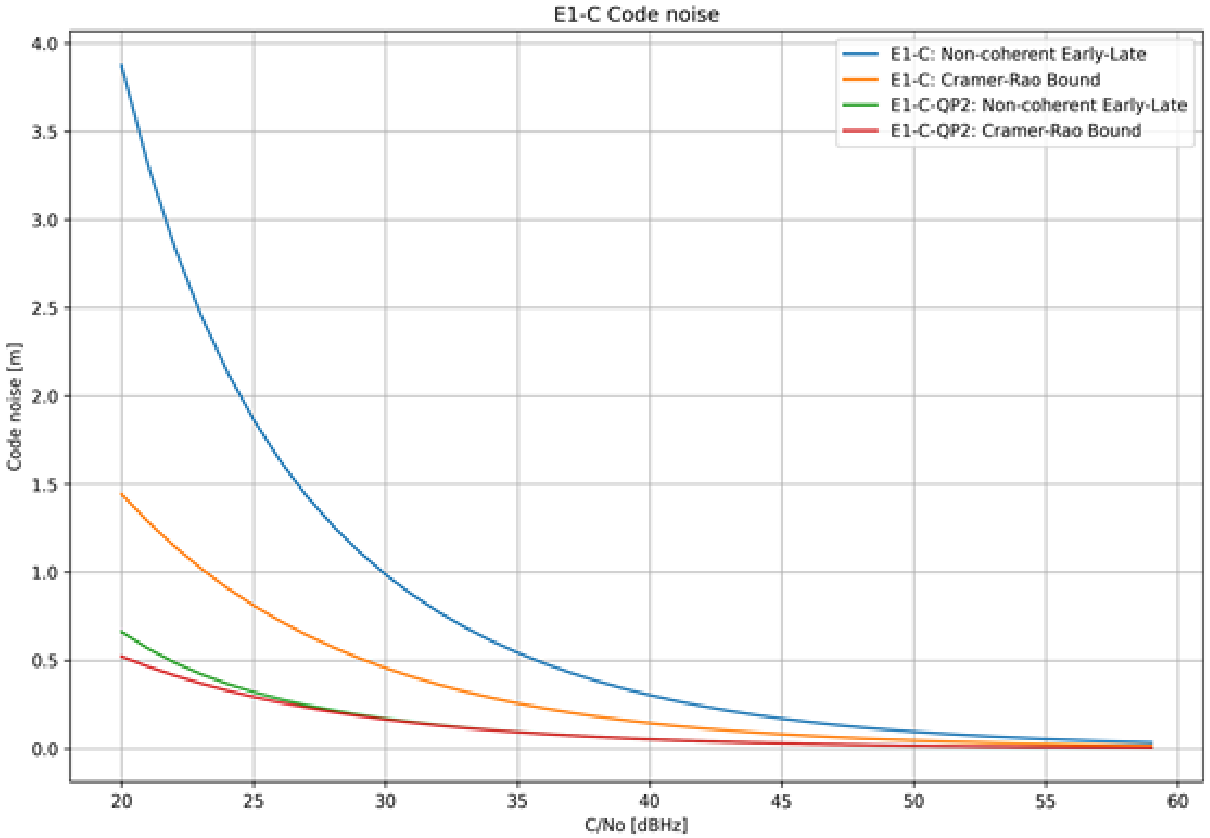
SRX – PVT Developments (3)

Improvement through Meta-Signal Processing

- With G2G Meta-Signal on E1 (E1C combined with E1 QP signal), lower code noise on E1 can be achieved
- Can be processed ‘phase-coherent’ within the same RF-band using SFX4 receiver
- Processing similar to AltBOC, so only ‘simple’ upgrade of processing (IFEN development in ESA G2G TURN)

‘Code Noise’ improvement by Meta-Signals





SRX – PVT Developments (4)

'Heading' in Forest Application

- 'Heading' support for generating 'logging-trails' simplifies operations, as vehicle speed is < 5 km/h (typically < 3 km/h), preventing to generate heading solution based on 'follow-on position solutions'
- Usage of E5ab signals was planned, to minimize 'multipath' impact on heading solution
- However, due to 'adverse' carrier phase measurements, heading is not working in forest
- So, heading tests were limited to laboratory (using IFEN 'NCS NOVA' RFCS) and rural environment

SFX4 receiver is supporting 'Heading' Determination

- Support of 'phase synchronized RF-mixer' and synchronized ADC for all 4 RF-paths
- RF-IO can be configured for L1/L5 on both RF-inputs (used on SFX4 test receiver for SRX)

Test Results

- The distance between both antennas of the test setup was 0,82 m
- The obtained initial heading accuracy was ~ 0,2°, in accordance with expected accuracy
- Further tests required to confirm initial test results

SRX – Acknowledgement

- SRX Team acknowledges the excellent ESA technical support for the challenging SRX project
  - Olivier Smeyers (initial Technical Officer)
  - Hugo Sobreira (current Technical Officer)

- IFEN acknowledges the financial support of DLR e.V. for SRX

- IGASPIN acknowledges for the financial support of FFG for SRX

Extra Slides

- **Review of the correlator-based multipath mitigation methods according to their number of used correlators.**

Correlator-based approaches for multipath mitigation

- 3 correlators
  - nEML [RD-38]
  - Early1/Early2 (E1/E2) [RD-39]
- 4 correlators
  - A-Posteriori Multipath Estimation (APME) [RD-40]
  - SBME [RD-41]
- 5 correlators
  - Double-Delta (ΔΔ) [RD-42]
    - High Resolution Correlator (HRC) [RD-43]
    - Strobe Correlator (SC) [RD-44]
    - Pulse Aperture Correlator (PAC) [RD-45]
  - EML-Slope [RD-42]
  - Multipath Elimination Technique (MET) [RD-46]
- 7 correlators
  - Multiple Gate Delay (MGD) Correlator [RD-47]

Extra Slides

nEML approach:

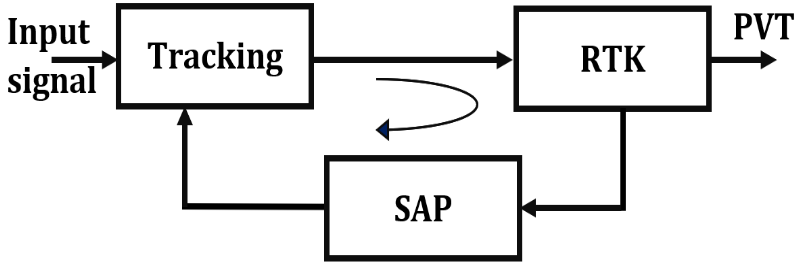
- The nEML method based on many papers is one of the simplest ways to mitigate the multipath error.
- Using option “Reciever*.CorrelatorPositions” in SX3 configuration file, the user can easily define the position of the correlators.

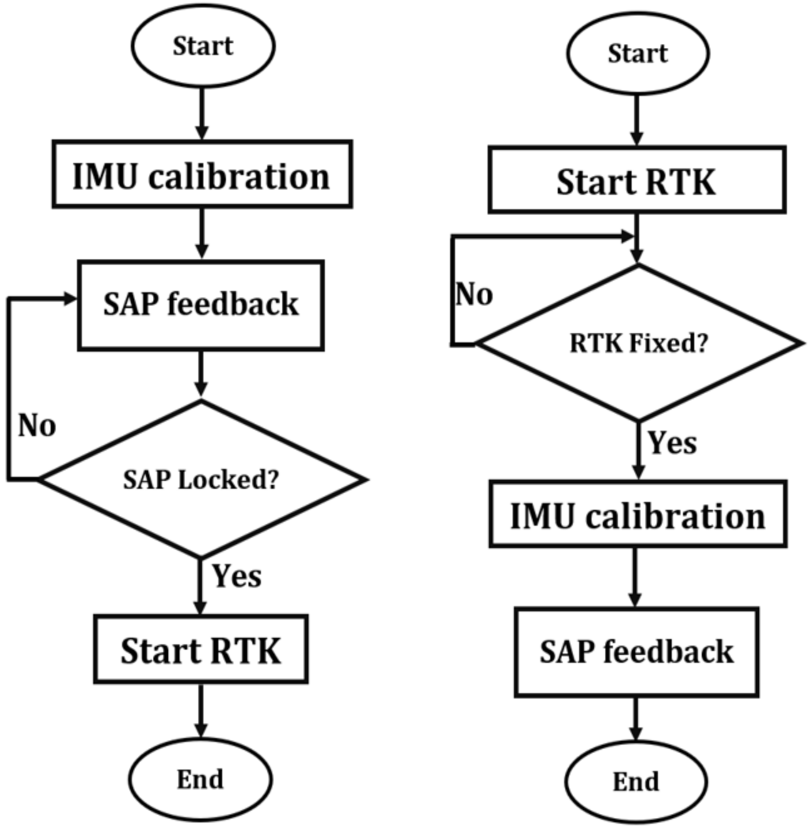
SBME (Slope-based Multipath Estimator)

- The results of the papers show that multipath with the delays between ± 0.1 chips (which is about 29.3 m for Galileo E1 open-service signal) cannot be easily rejected by normal approaches.
- While in forests, the vegetation and obstacles are very close to the receiver, absolutely less than 30 m.

RTK and SAP cooperation

- **1- Initilization and calibration**
  - In the current procedure as shown bellow (a), the error of positioning penetrates to tracking, and sequentially from tracking to again positioning.
  - In SRX version,
    - As soon as the time when RTK mod is “fix and hold”, the initialization of IMU starts.
    - After IMU calibration, SAP automatically starts working.





(a) (b)

Procedure of initialization in (a) the current version of SX3 and (b) the extended SX3 version.

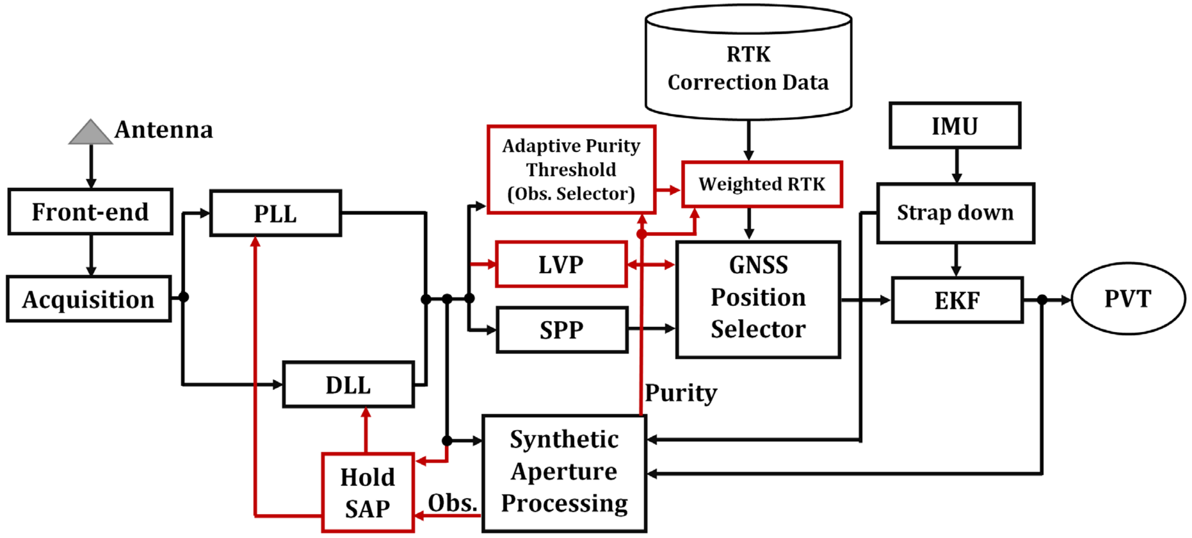
- **2- If we go out of RTK fix:**
  - Under this condition, the SAP continues working.
  - If the RTK output mod does not become to fix after a period of time defined by the user, the SAP stops.

Extra Slides

LVP (Low-Visibility Positioning)

- LVP is a module which has been previously implemented in SX3
- It is for the scenarios when the number of observations is not sufficient for positioning.

Improvements for SRX:



1 - Correction with RTK fix

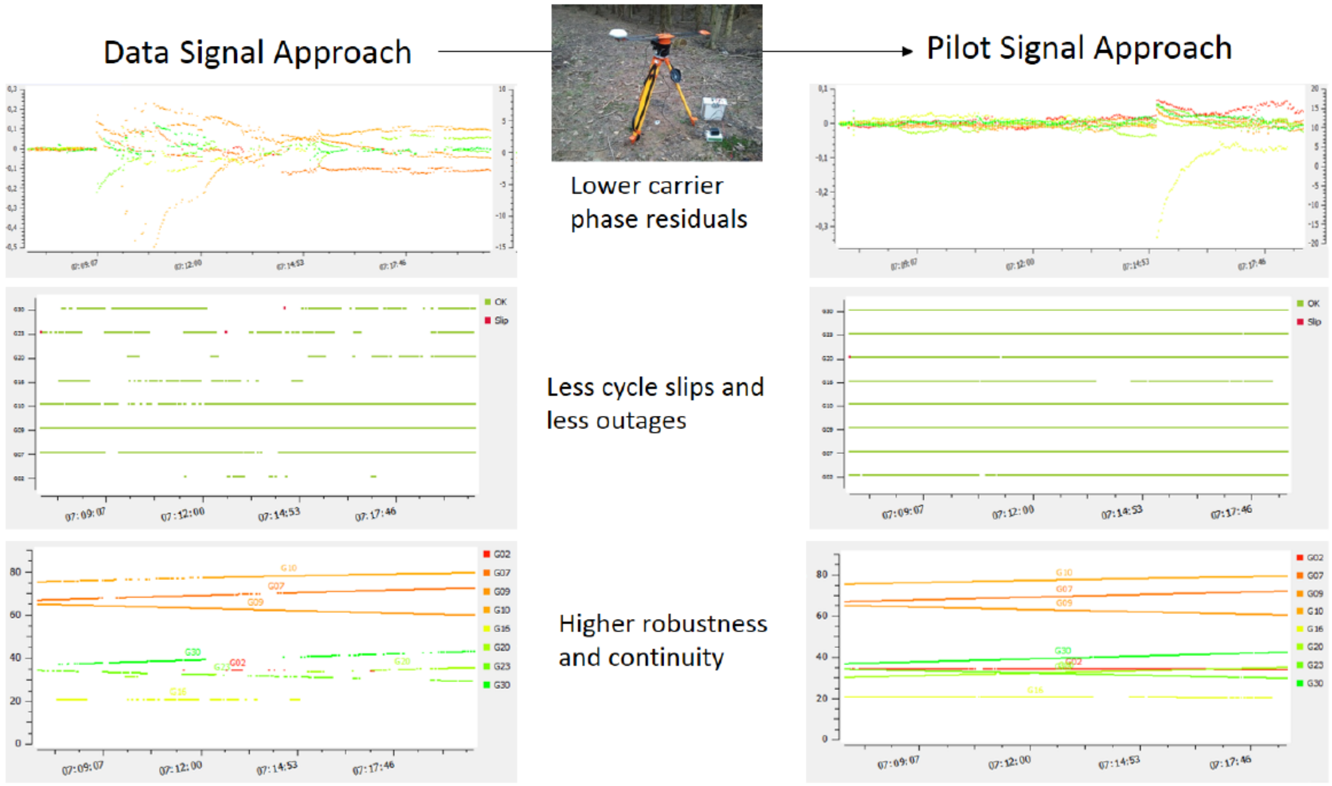
- Currently, the LVP output is compared with RTK fixed result and then corrected based on a weighted average.
- However, the tests in SRX projects showed
  - *if we update the EKF in LVP with the RTK fixed output, this will improve the results when there is no output from neither RTK nor SPP.*

2 - Priorities of the PVT outputs for the feedback

- Different tests in different scenarios showed that the float result of the proposed weighted KF has better and more accurate results in contrary to LVP solution.

Extra Slides

Pilot Signals



Improvement of the pilot signal approach evaluated with the rotational antenna in the forest [*].

- In SX3 software receiver, there is an option called “CentralizedPhaseTracking.OnlyPilot” to use only pilot signals of the services for SAP.
- If one service does not contain any pilot component, it is possible to wipe the navigation data off via option “Receiver*.DataWipeOff”.

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