Ambiguity Fixing Results on an SDR Configured Notebook

R. Capua, A. Caporale, L. Gattuso

Stanford PNT Symposium 2014

29 October 2014

Agenda

- Sogei GNSS SDR Objectives and Requirements
- Sogei GNSS SDR Architecture
- Pseudorange and Carrier Phase measurements
- RTK Processing
- Ambiguity Fixing Results
- Conclusions and Remarks

The Mission

In 2003 Sogei's unique shareholder (the Italian Ministry of Economy and Finance) committed Sogei to follow the development of **GNSS Advances**

Sogei's R&D team began working in advanced GNSS technology for Institutional Applications developments

Since 2004, Sogei is member of the Galileo Services Association

Institutional Applications – General Requirements

Low Cost Terminals

Customized data formats

Reconfigurability

Security
Anti-fraud
Anti-Jamming
Anti-Spoofing

GNSS SDR on Notebooks,Tablets, Smarthphones

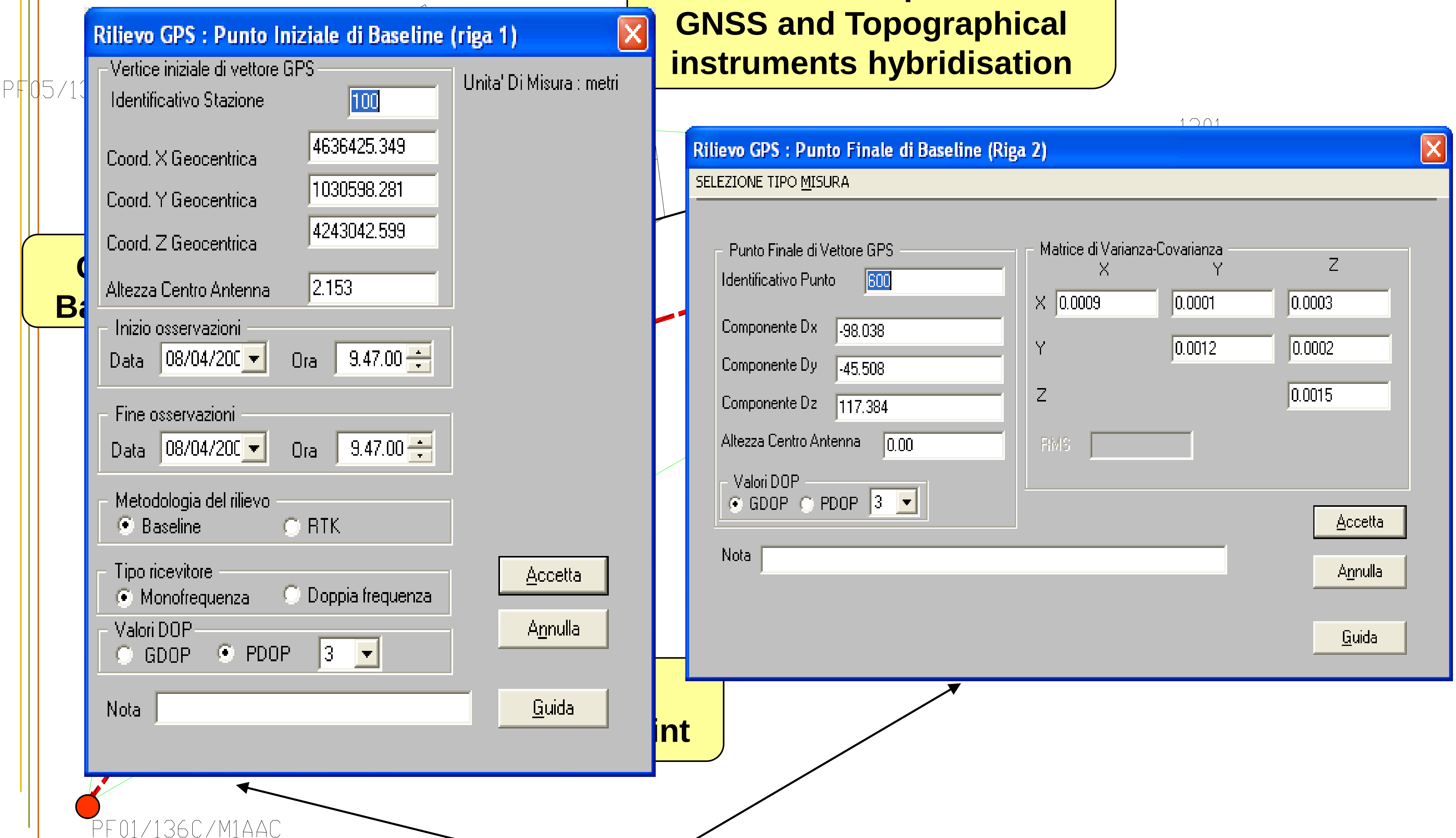
High numbers

No Licensing Constraints

Backward Compatibility
Existing workflows
Legacy systems

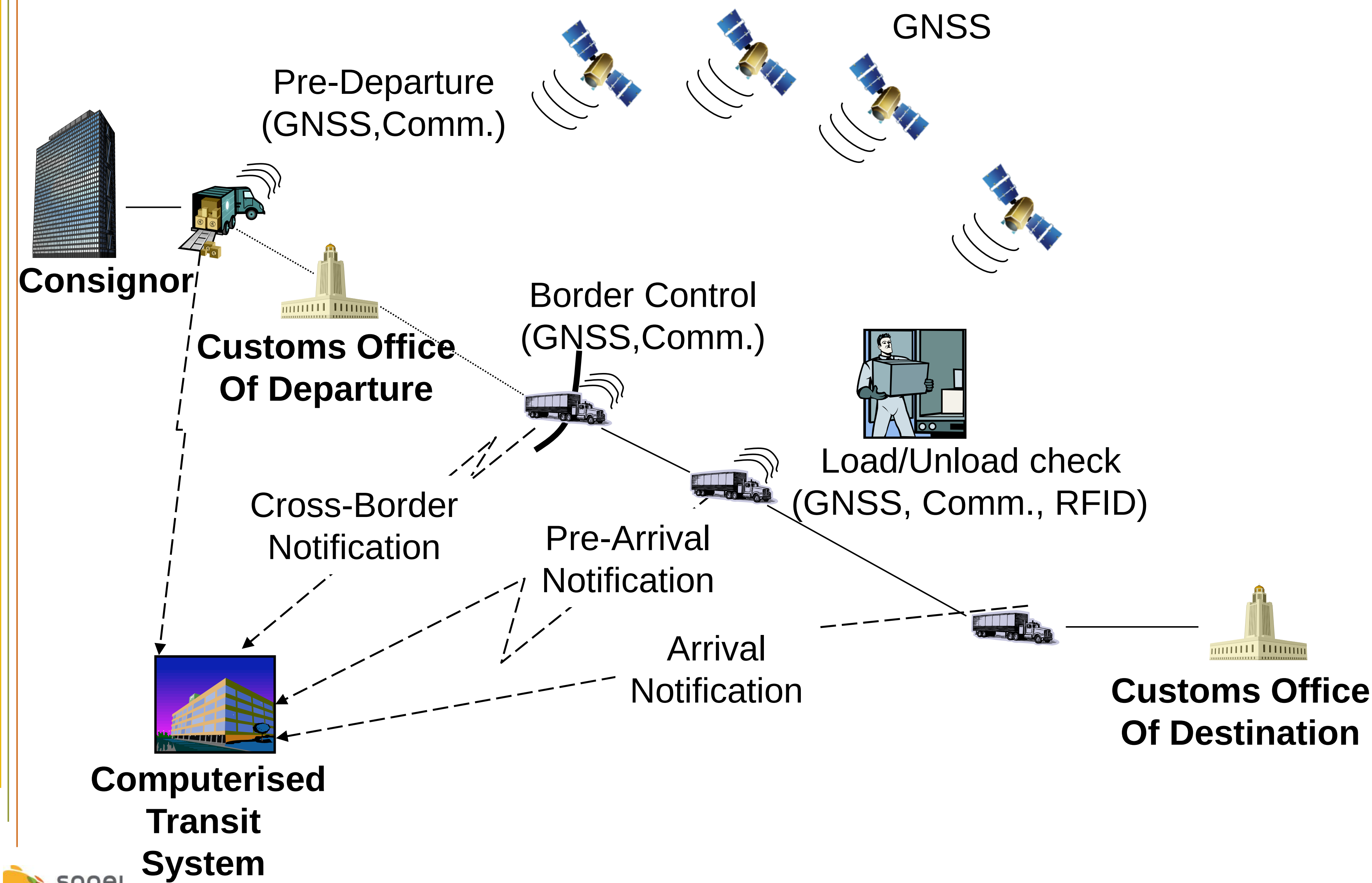
Institutional High Precision Surveying - GNSS Cadastral Surveying

Shadowed points:
GNSS and Topographical instruments hybridisation



Institutional Cadastral Surveying Software (PREGEO)

Customs Tracing and Tracking



Sogei GNSS R&D pillars

- GRDNet (GNSS R&D Network) Solution- Independent **GNSS High Precision Augmentation**
- High Precision Software Receivers with **A/J and A/S**: **Sogei GNSS SDR**
- **Ubiquitous Outdoor/Indoor positioning**

Sogei GNSS SDR progresses

Software Receiver on General Purpose Technology

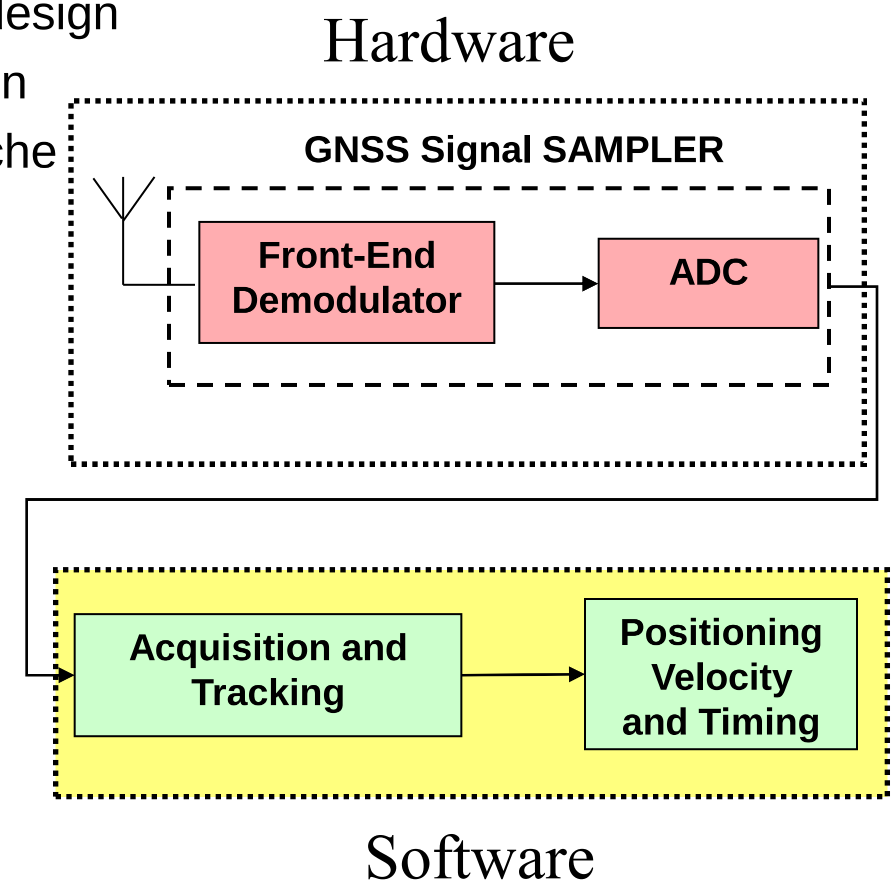
Roberto Capua

26 September 2014

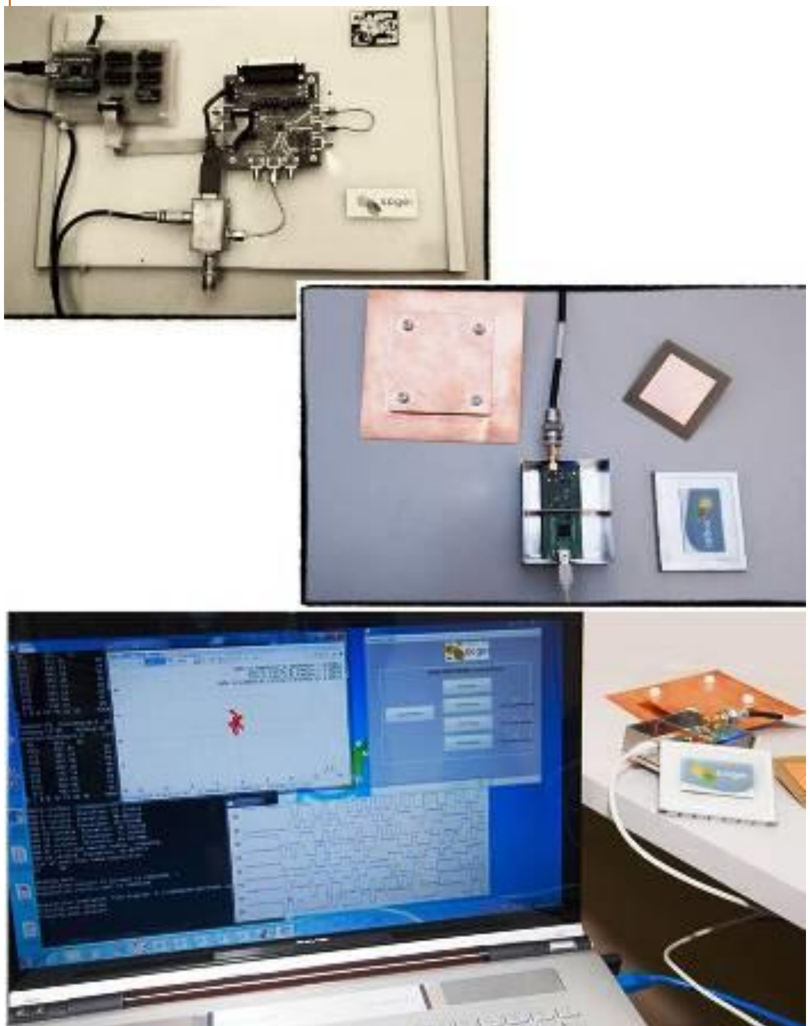
The SOGEI GNSS SDR Platform

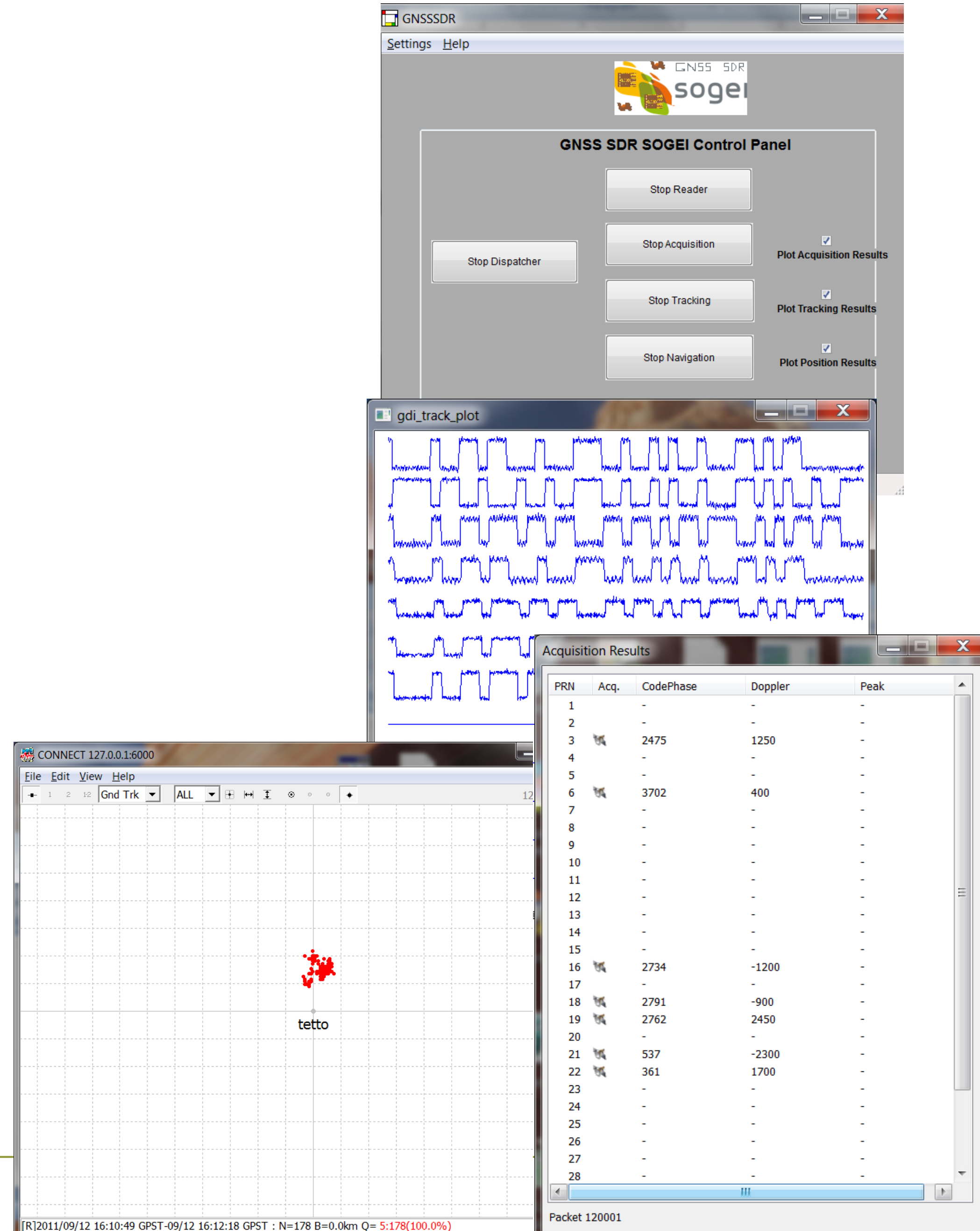
- Objective: *Developing a low cost, flexible and free of license GNSS receiver for governmental applications running on **General Purpose Processors***

- L1/E1, WAAS/EGNOS, Code
- COTS Antennas and GNSS Front-End design
- TCP/IP Sockets Modules Communication
- Code/Carrier Look-Up Tables within Cache
- Development Language and tools:
  - C/C++
  - SIMD instructions
  - Parallel Programming
- **Fully Real-Time on a Notebook**
- **No FPGA/DSP**

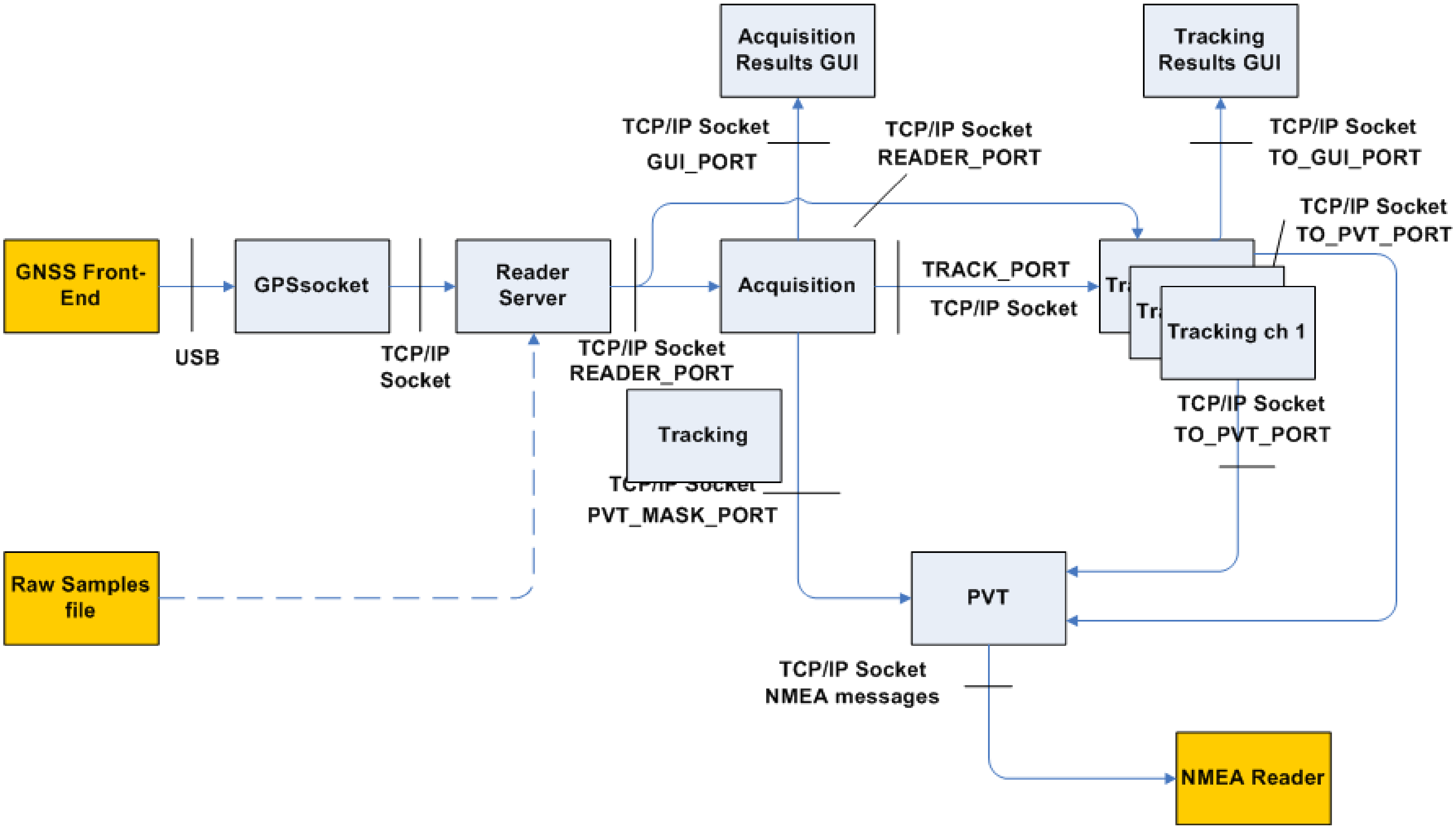


GNSS Front-End and GUIs





GNSS SDR Architecture



Tracking Module

- GPS/SBAS channels
- *32-bits word input samples parallelization*
- Early-Minus-Late Correlation
- Multiplications by XOR and pre-computed logical operations
- Loops Filters specifications:

	Filter	Discriminator
DLL	2^{nd} order DLL	$D_{code} = \frac{I_{EL} I_P + Q_{EL} Q_P}{2(I_P{}^2 + Q_P{}^2)}$
PLL	2^{nd} order PLL (3^{rd} order selectable)	Atan(Q/I)
FLL	1^{st} order FLL (Switch-On/Switch-Off)	Atan2(cross,dot)/(2πT))

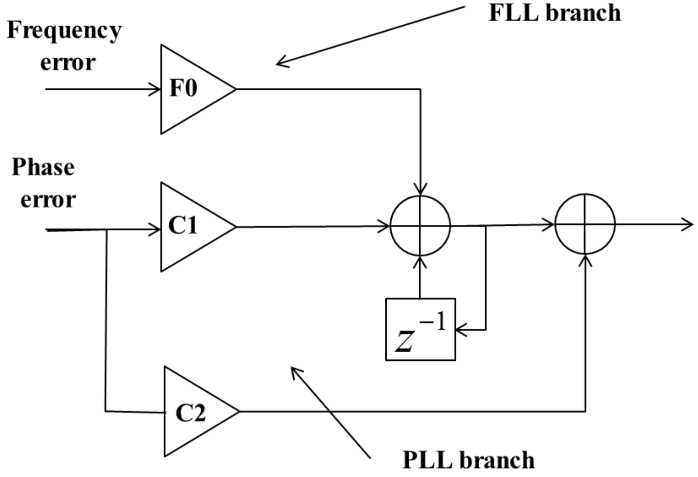
SDR implementation of a Loop Filter

$$F(z) = C1 + \frac{C_2}{1-z^{-1}} = \frac{(C_1 + C_2) - C_1 z^{-1}}{1-z^{-1}}$$

$$N(z) = \frac{k_0 z^{-1}}{1-z^{-1}}$$

C++ Filter implementation

```
PLL_OMEGA0 = (double)((8*parameters.pllNoiseBw*parameters.pllDamp)/(4*pow(parameters.pllDamp, 2)+1));
PLL_TAU1 = (double)((parameters.pllK0*parameters.pllKd)/pow(PLL_OMEGA0, 2));
PLL_TAU2 = (double)((2*parameters.pllDamp)/PLL_OMEGA0);

PLL_COST1 = (double)(PLL_TAU2/PLL_TAU1);
PLL_COST2 = (double)(parameters.integrationTime/PLL_TAU1);
FLL_COST1 = (double)(4*parameters.fllNoiseBw*parameters.integrationTime);

pll = outPLL;
fll = outFLL;

yo1 = pll * PLL_COST2;
yo2 = pll * PLL_COST1;
yo3 = fll * FLL_COST1;

yo4 = yo1 + yo3 + carrierLoopDelay1[channel];

output = (double)(yo4 + yo2);

carrierLoopDelay1[channel] = yo4;
```



PVT Module

- Unscented Kalman Filter State vector:

Clock offset → b, Clock drift → $\dot{b}$

$$x = \begin{bmatrix} x & y & z & | & \dot{x} & \dot{y} & \dot{z} & | & b & \dot{b} \end{bmatrix}^T$$

$$y = g(x) = \begin{bmatrix} PR \\ D \end{bmatrix}$$

Pseudorange

Doppler

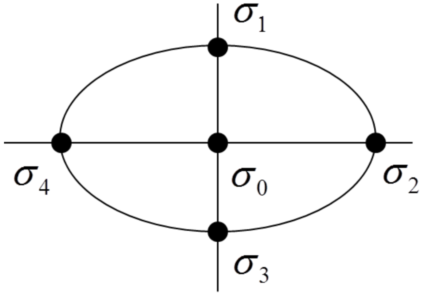
- Carrier Phase measurements through Integrated Doppler

- UKF (Unscented Kalman Filtering) processing:
  - **No linearisation and Jacobian calculation** needed
  - **Covariance matrix propagation by points** (2n+1)
  - Relaxed initial conditions constraints (no Bancroft needed)
  - Kalman Update phase as in EKF

Propagation by points: the centrality of the Covariance

"*It is easier to approximate a Gaussian distribution, than a non-linear function*"

- Assuming a Gaussian distribution with mean $\overline{x}$ and Covariance σ
- We approximate the continuous distribution by a set of 2n+1 points (*Sigma-Points*):



$$\chi_i = \overline{x} + \sigma_i$$

Initialization

$$M = \sqrt{(n+k)\cdot P_0^-}$$

$$S = \big\| 0 \,|\, -M \quad | +M \big\|$$

$$\sigma_i = i^{th}\ column \quad of \quad S$$

$$\chi_0(i) = \hat{x}_0^- + \sigma_i$$

Prediction

State

$$w_m^0 = \frac{\overline{k}}{n+\overline{k}}$$

$$w_m^i = \frac{1}{2(n+\overline{k})}$$

$$\overline{k} = \alpha^2 \cdot (n+\widetilde{k}) - n$$

$$\chi_{k+1}(i) = f(\chi_k(i), u(k))$$

$$\hat{x}_{k+1}^- = \sum_{i=0}^{2n} w_m^i \cdot \chi_k(i)$$

Measurements

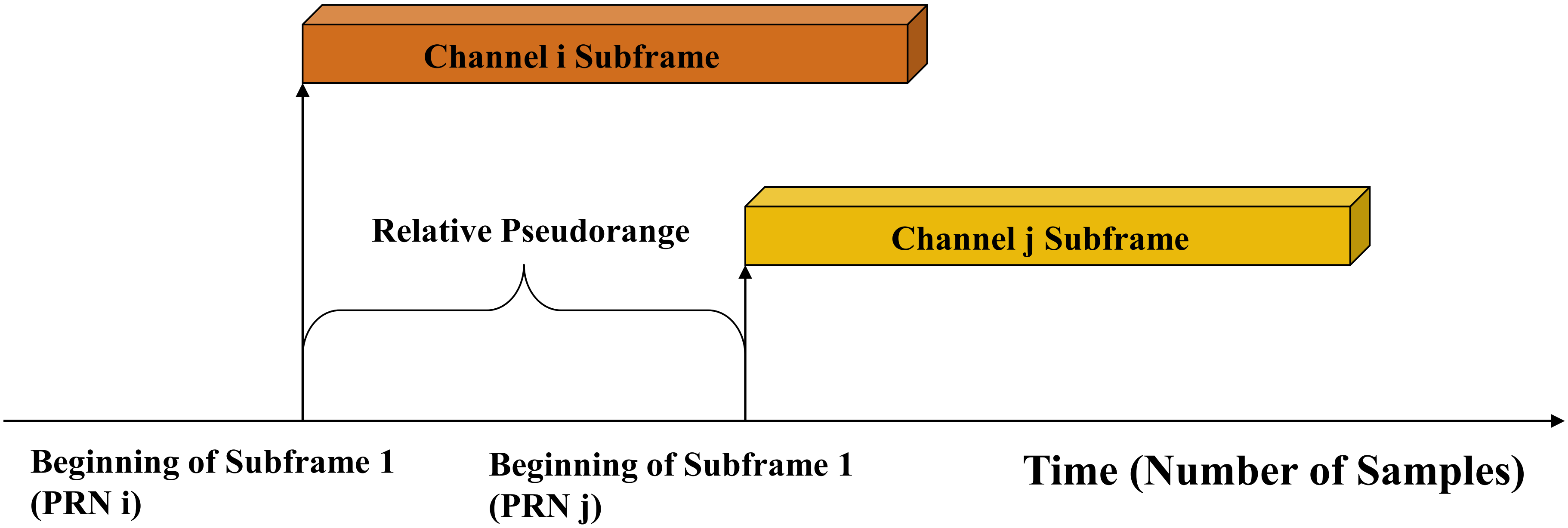
$$Z_{k+1}(i) = h(\underline{\chi}_k(i), \underline{u}_k, t_k)$$

$$\hat{z}_{k+1}^- = \sum_{i=0}^{2n} w_m^i \cdot Z_k(i)$$

The basic SDR Measurements challenge

- In a Software Receiver sample data have **no absolute time reference**
- The only timing is the progressing **number of samples count**
- Message are transmitted at the same time and received at different times due to different propagation times (satellite-user distances)

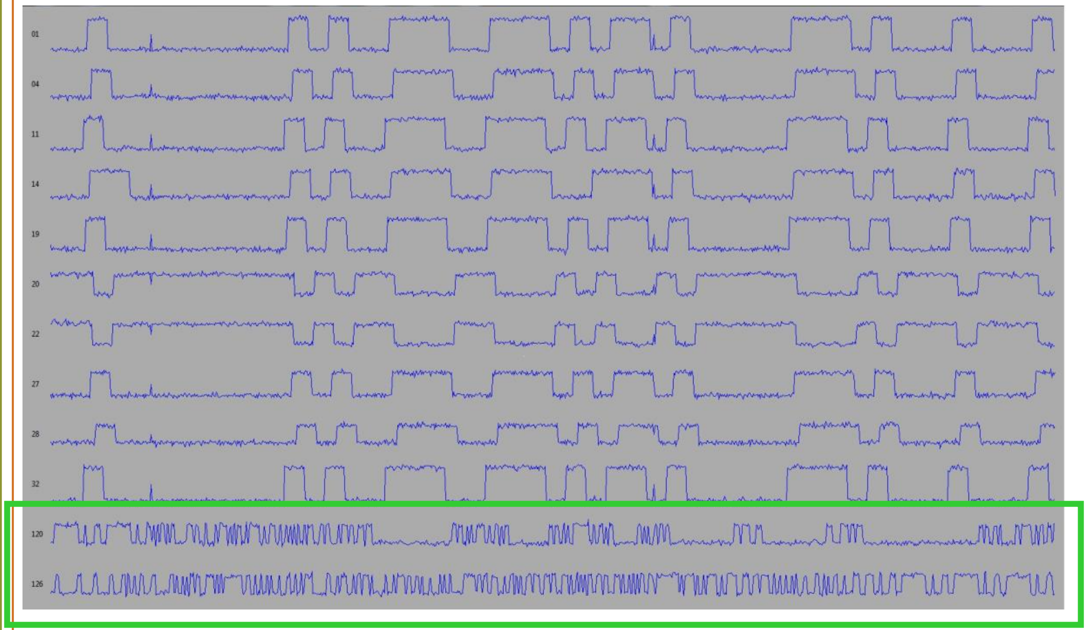
- Pseudorange has to be calculated in a relative way from Subframe 1 starts (supposed to be transmitted at the same time by each satellite)



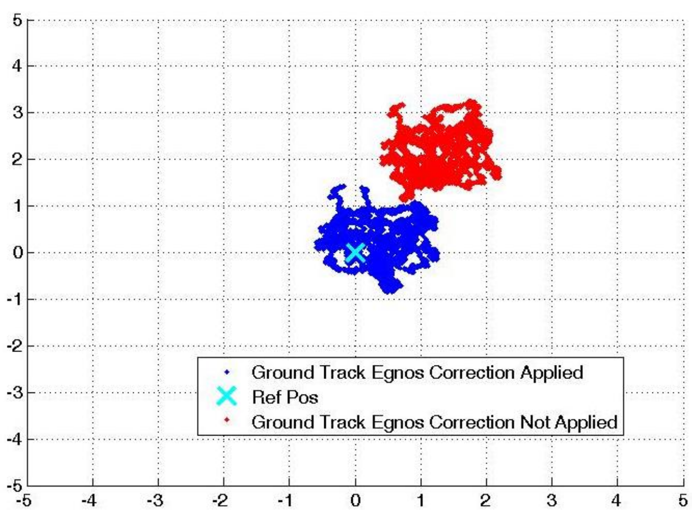
PVT SDR implementation issues

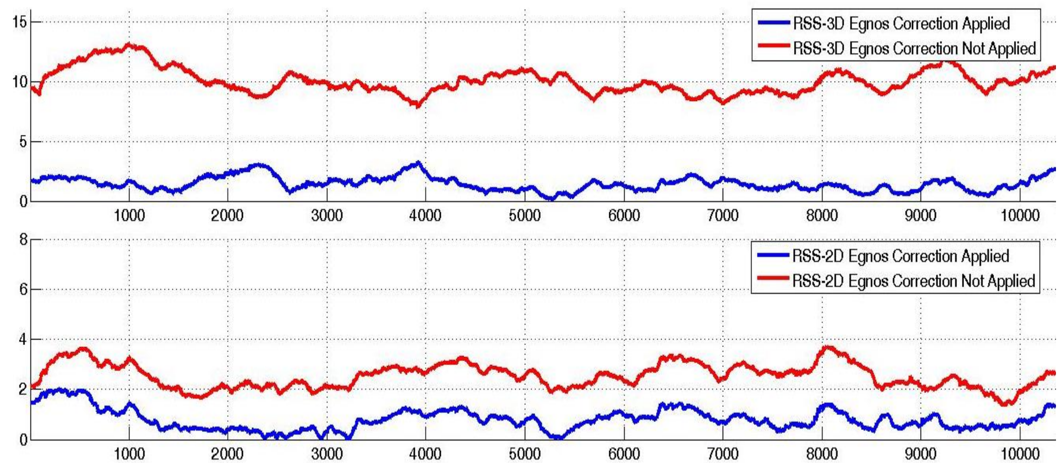
- Data exchange:
  - Tracking results to be packed in blocks (e.g. 500 ms)
  - Check communication failure among components (e.g. Acquisition, Tracking, PVT)
- Pseudorange computation:
  - Avoid overflows of counters with proper resetting
- Real-Time constraints
  - Acquisition to be performed at a low rate (e.g. 30 s step) or after loss of lock

EGNOS on the GNSS SDR



SBAS Tracking Channels



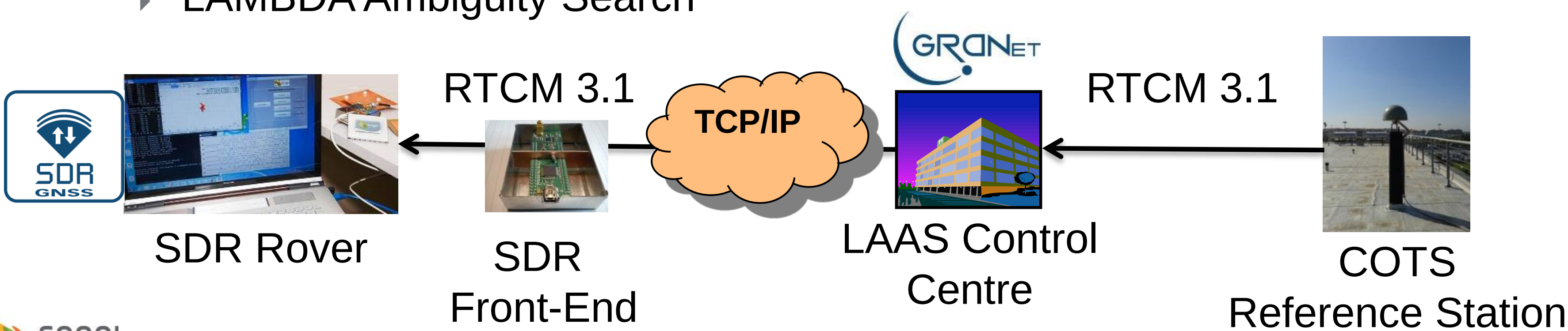


GNSS SDR Criticalities and Constraints for RTK Processing

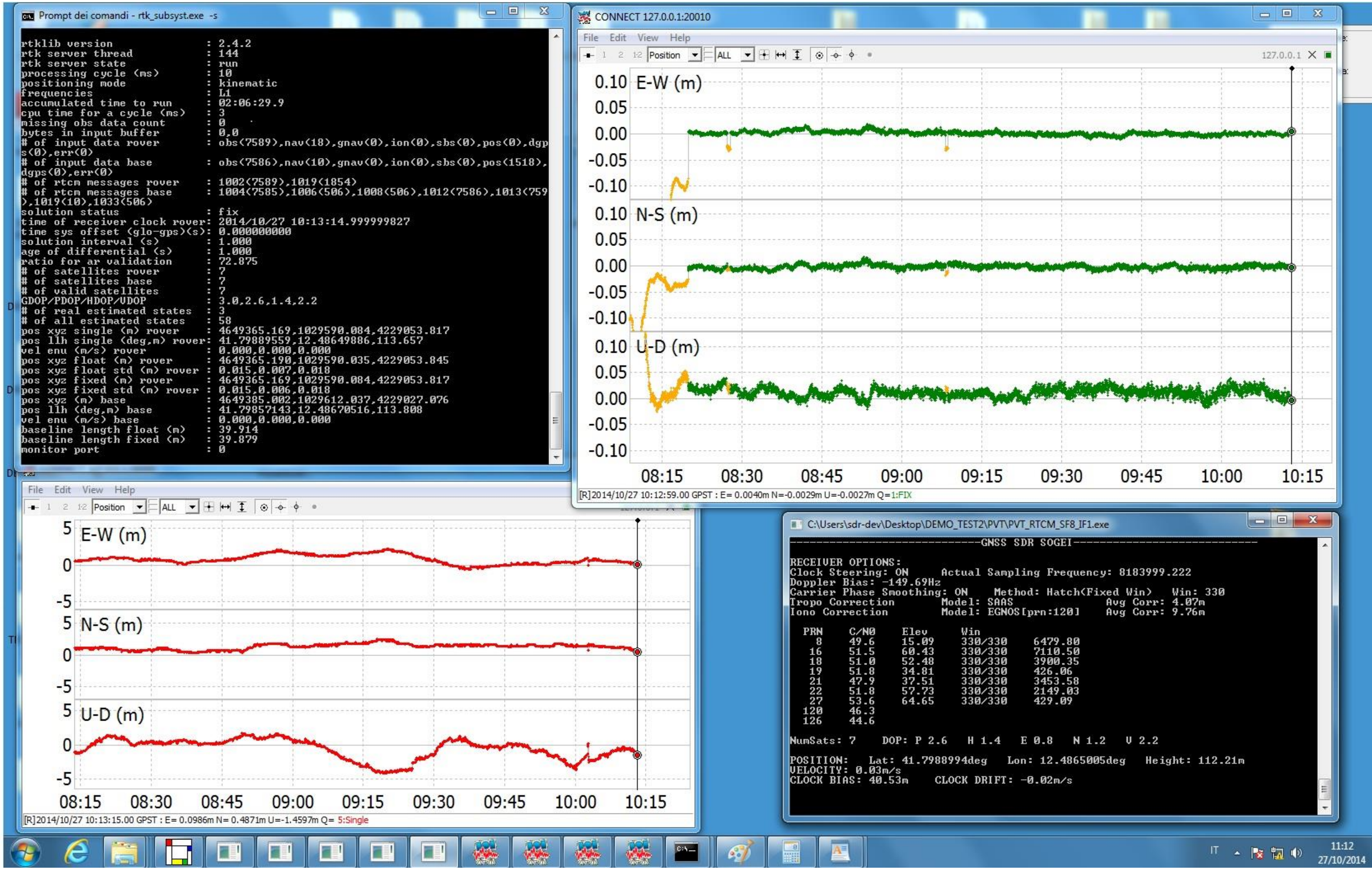
- **Computational Load**: GNSS SDR, fully working on a Notebook, provides measurements affected by quantization errors due to the maximum applicable sampling frequency
- **Receiver Clock error Compensation**: clock steering has to be applied in order to compensate receiver clock errors and generate the needed high quality phase measurements
- **Pseudorange Carrier Smoothing**: to be applied for reducing the impact of quantization errors
- **Initial Carrier Phase determination**: complex due to absence of time tagged measurements (only sequences of samples) and clock steering application
- **Mixed Hardware and SDR measurements for double differencing**: SDR Measurements Alignement and Synchronization wrt time tagged Reference Station ones
- **Measurements errors modelling**: as accurate as possible in order to limit feedbacks from clock steering (SBAS corrections, Tropo)

RTK Processing and Test Case

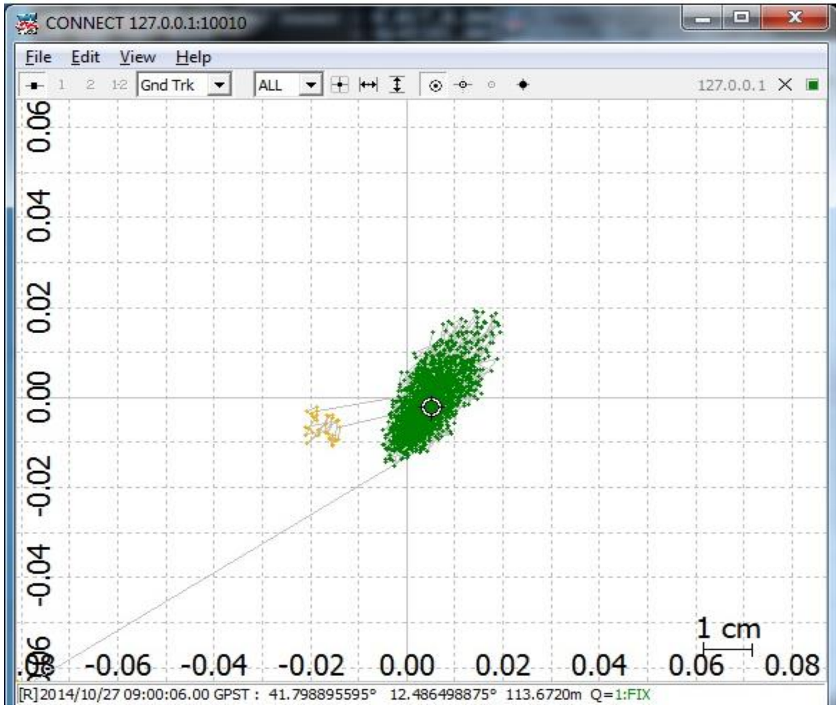
- Sampling frequency: 8.184 MHz
- Geodetic Reference Station data from a Local Augmentation Network
- GNSS SDR Rover with COTS surveying antenna
- Communication Interfaces toward the LAAS Service Centre:
  - Mobile Communication or internal LAN
  - NTRIP protocol
  - RTCM 3.1 1004 and 1006 messages
- RTK implementation:
  - Carrier-smoothed PR with SBAS corrections applied
  - Double Differences determination
  - LAMBDA Ambiguity Search



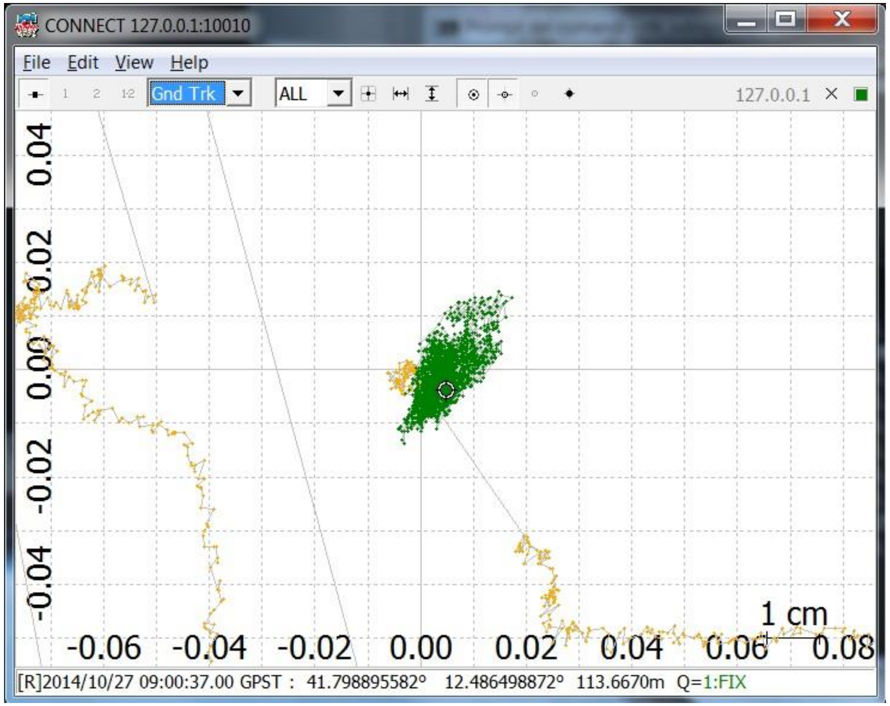
SDR RTK Test Results



SDR vs. Hardware Geodetic Receiver performances – Ground Track



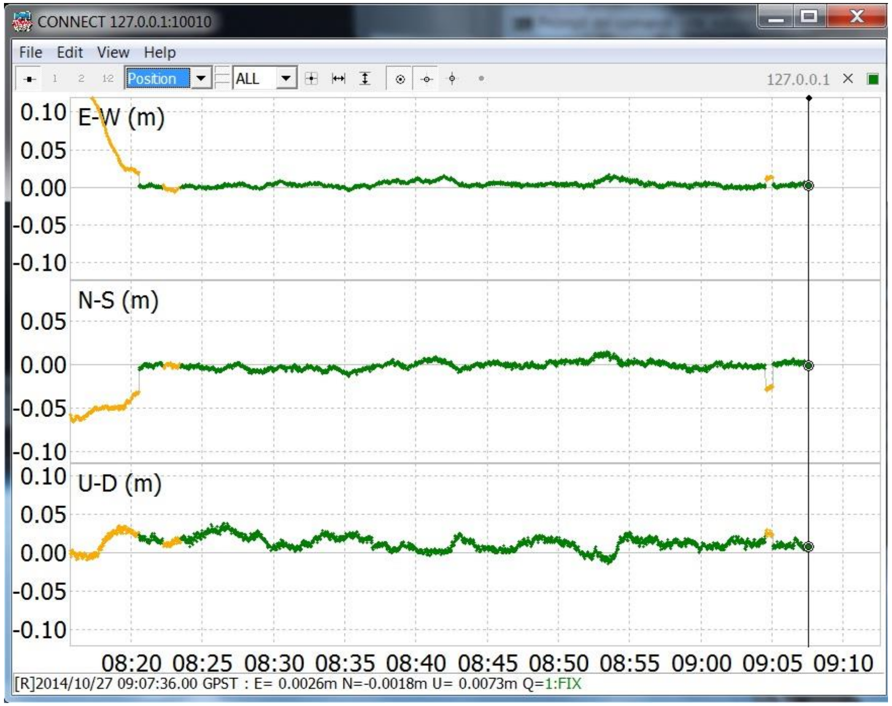
GNSS SDR Rover



Commercial Hardware Rover

SDR vs. Hardware Geodetic Receiver performances - ENU

GNSS SDR Rover



Commercial Hardware Rover

Conclusions and Remarks

- Public Administrations need reconfigurable, reliable, low cost and open equipments
- Developed a GNSS SDR based, with internally designed Front-End, working in Real-Time on a Notebook without FPGA/DSP preprocessing/processing
- Pseudorange and Carrier Phase Measurements to be coherently dealth with
- RTK Test in a mixed environment:
  - GNSS SDR Rover
  - Geodetic Hardware Reference Station
  - Standard Interfaces: NTRIP/RTCM 3.1
- Test Results:
  - 3 cm 3D accuracy
  - Perfectly matching Commercial Geodetic receiver performances

Sogei S.p.A

Via M. Carucci n. 99

00143 Roma

Italy

Roberto Capua

e-mail: rcapua@sogei.it