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Trustworthy Positioning for Next Generation Intelligent Transport Systems

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Contents

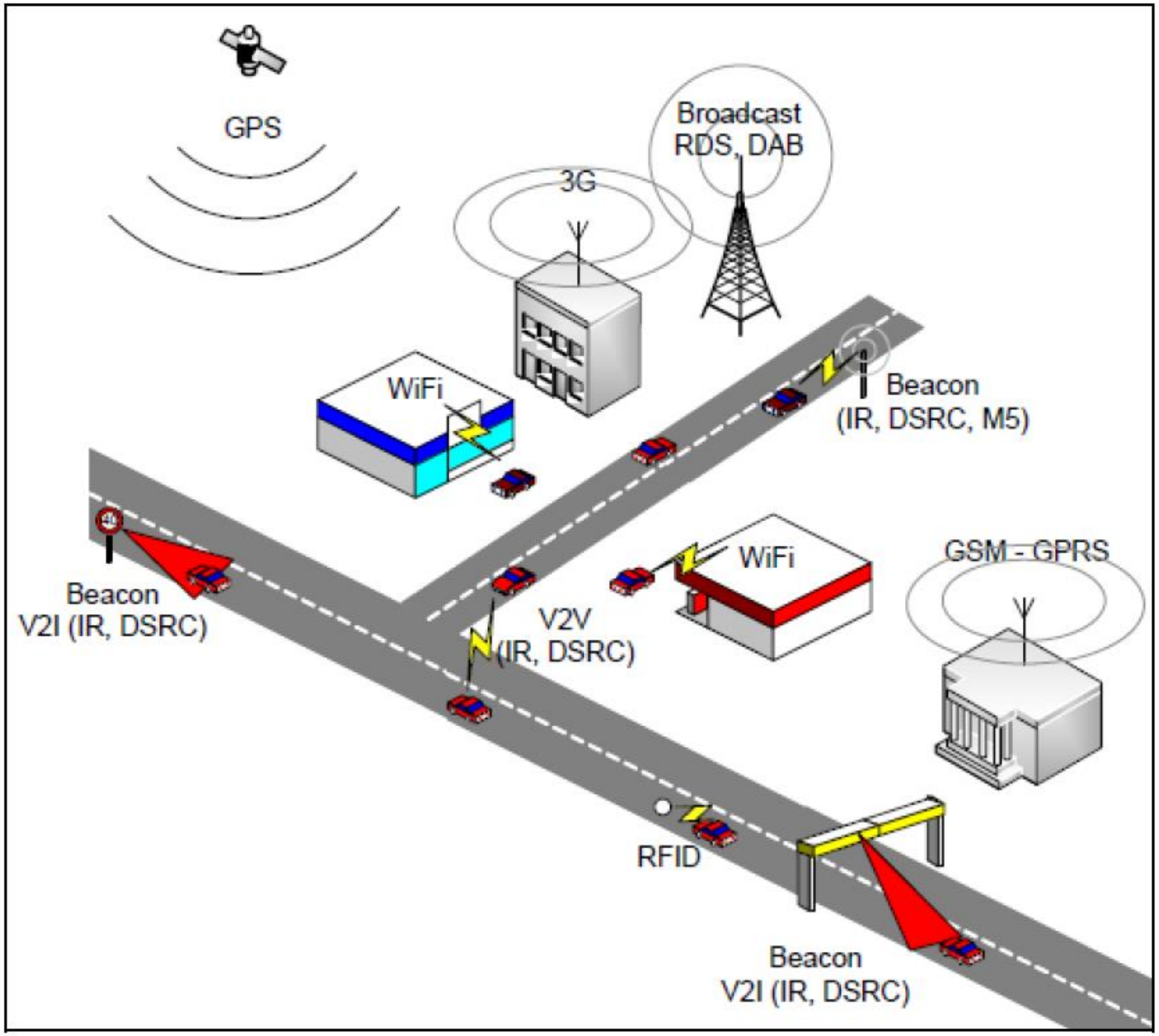
- Background on ITS and C-ITS
- Requirements
- Challenges
- RAIM
- Test and Results

ITS objectives

Make transportation safer, more efficient and reduce emissions

C-ITS

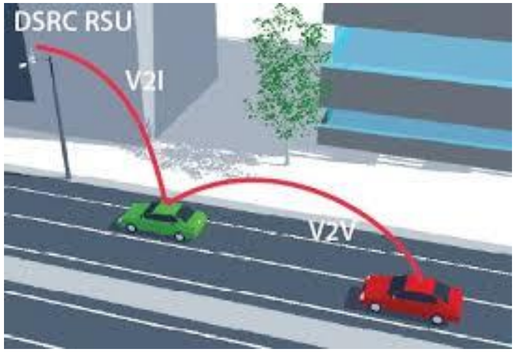
V2V and V2I



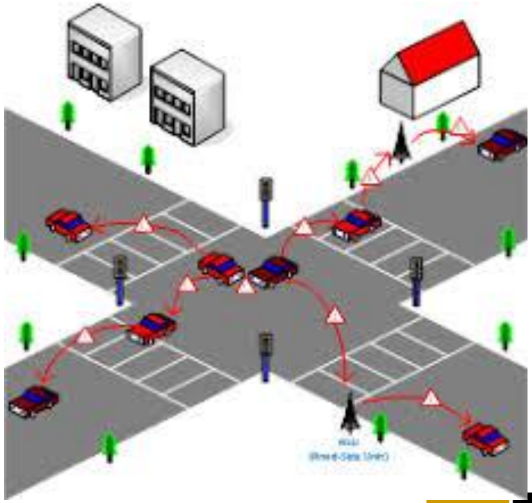
Source: Austroads, 2010

C-ITS

- Communication using DSRC. DSRC-based range-rating measurements can enable GNSS/DSRC cooperative positioning.



- VANET (Vehicular ad hoc network)



Source: Internet

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Satellite positioning accuracy requirements

- Road level (few m)
- Lane-level (< 1m)
- Where-in-lane level (sub-m)

More accuracy is needed

- Current systems mainly use SPS (Standard Positioning Service).
- SPS gives 1-5 m accuracy - not suitable for lane-level precision.
- Use of **augmentation** techniques, such as **SBAS** has the potential to offer the required accuracy.
- Most imported C-ITS uses SBAS technology.

But: Is it only accuracy we are interested in!

90s and early 2000s: Accuracy

- Positioning techniques
- DGPS, RTK
- Multipath mitigation

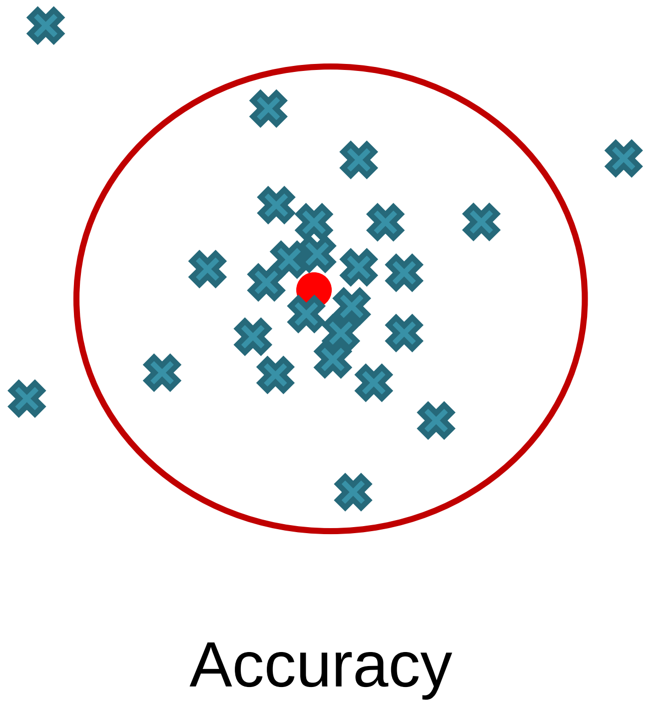
Now: Availability

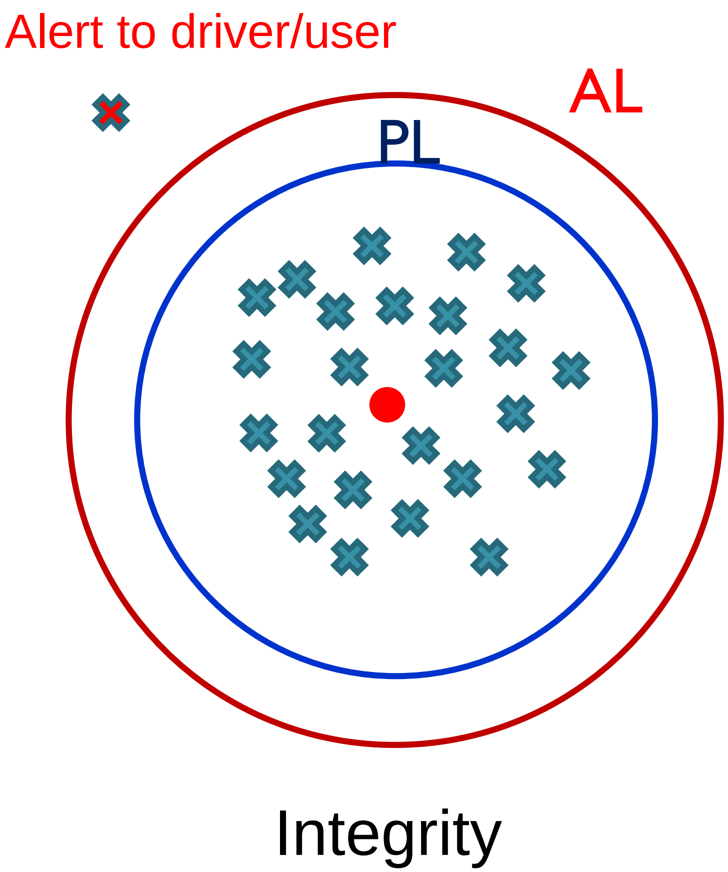
- Multi-constellation:
  GPS, GLONASS,
  Galileo, Beidou
- Sensor Fusion
- Position + orientation

Future: Safety & Reliability

- Safety of Life applications
- Functional Safety and Integrity
- Protection from spoofing/jamming

Accuracy VS Integrity





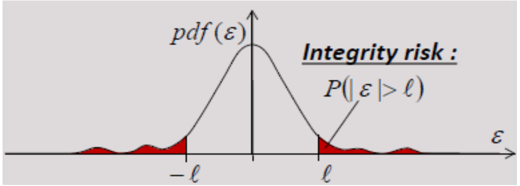
Challenges

Concepts

- Standards? need to be set based on performance requirements.
- Complete map of risks (e.g. collision types, faults, etc.)

  and vulnerabilities (system errors, interference, jamming spoofing, etc.)

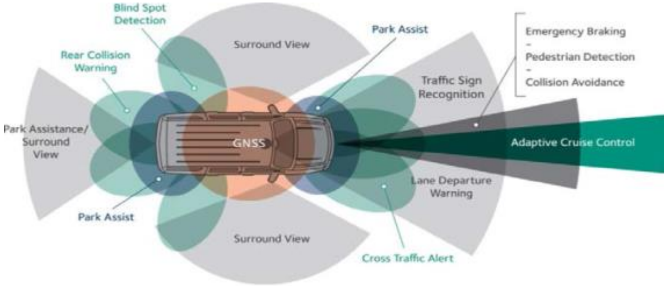
  and identify their probabilities.



- Application dependence.

Hardware

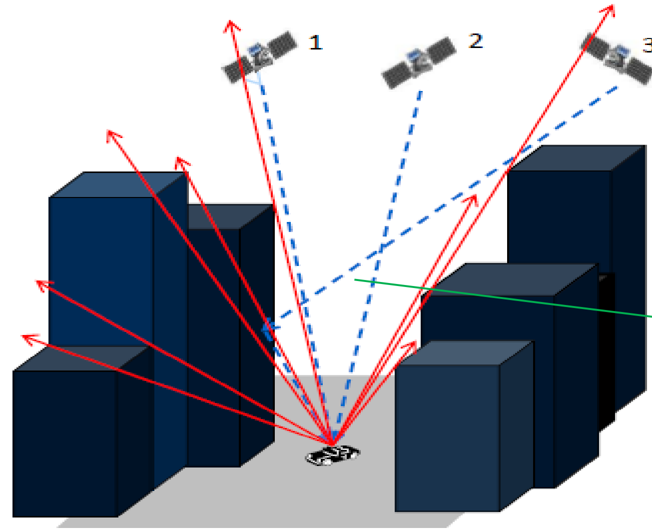
- Integration of sensors (GNSS is a main component but not alone)
- Cost
- Communications
- Technology.



Ex: Vulnerabilities due to the work environment

Urban environment:

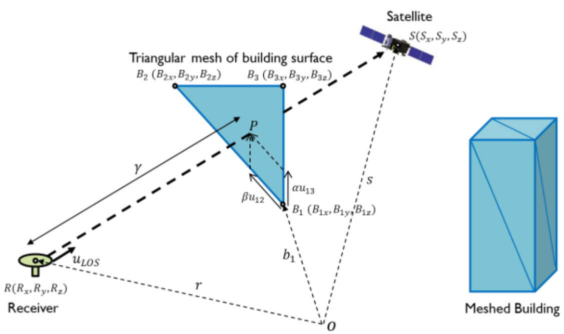
- Loss of lock
- Heavy multipath
- Non Line of Sight (NLOS)
- Frequent cycle-slips



Example of NLOS

Mitigations:

- Multipath mitigation at the antenna
- 3D city-models – ray-tracing algorithms
- SNR monitoring
- Non-Gaussian error models
- VANET CIM concept



Use 3D city-models

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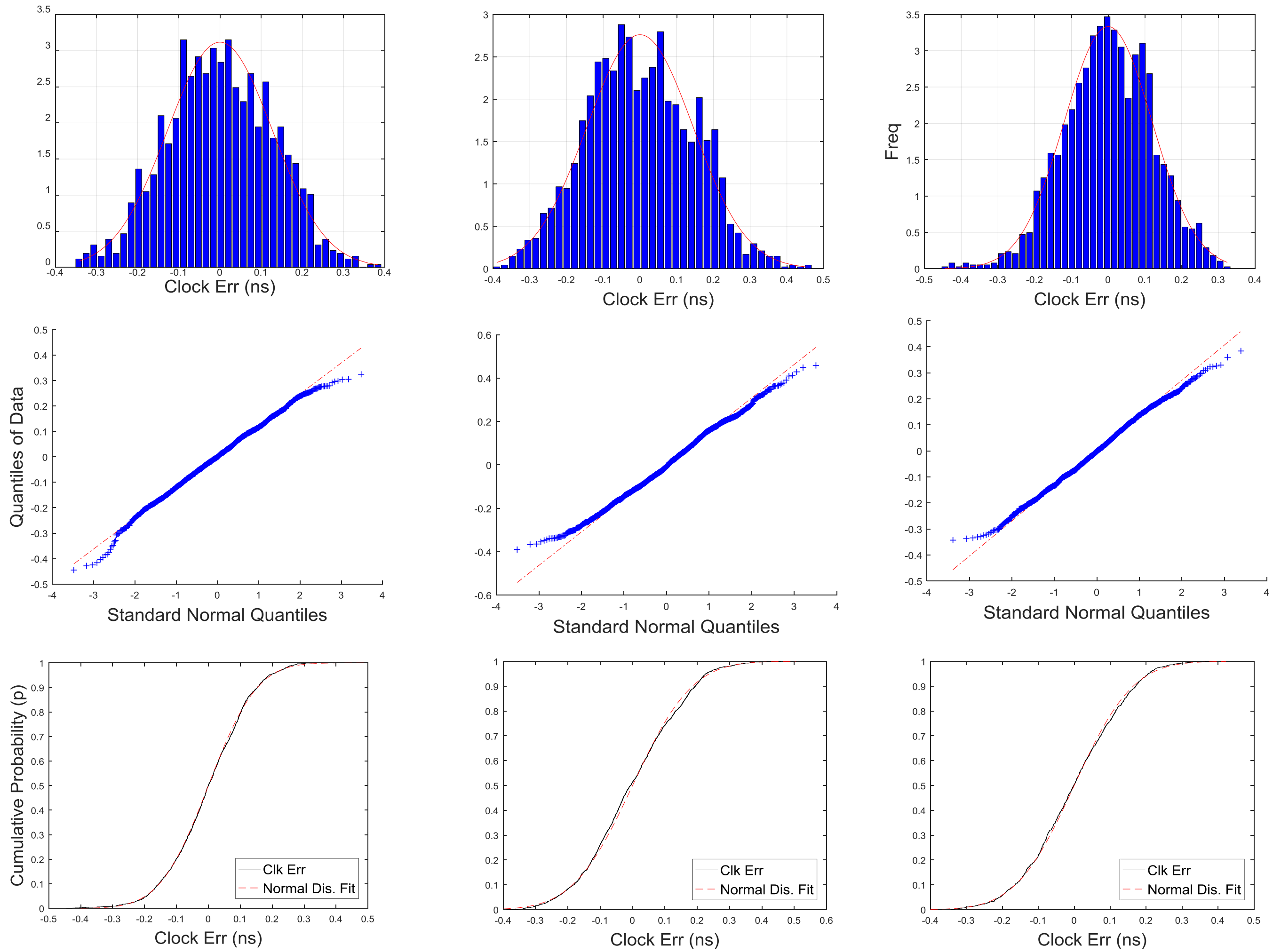
Characterisation of errors (ex: clock corrections)

Histograms

Q-Q

CDF



PRN16 PRN 29 PRN30

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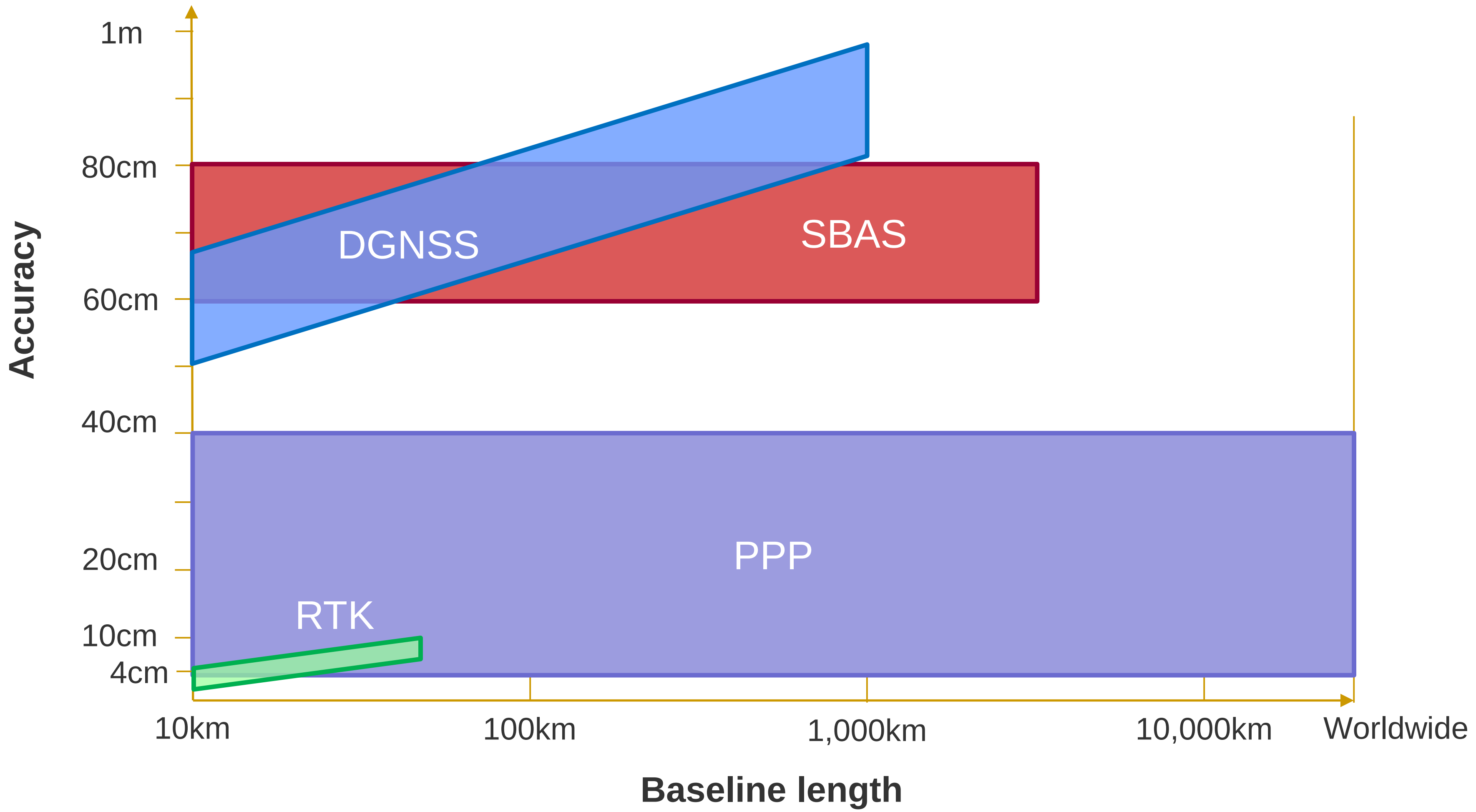
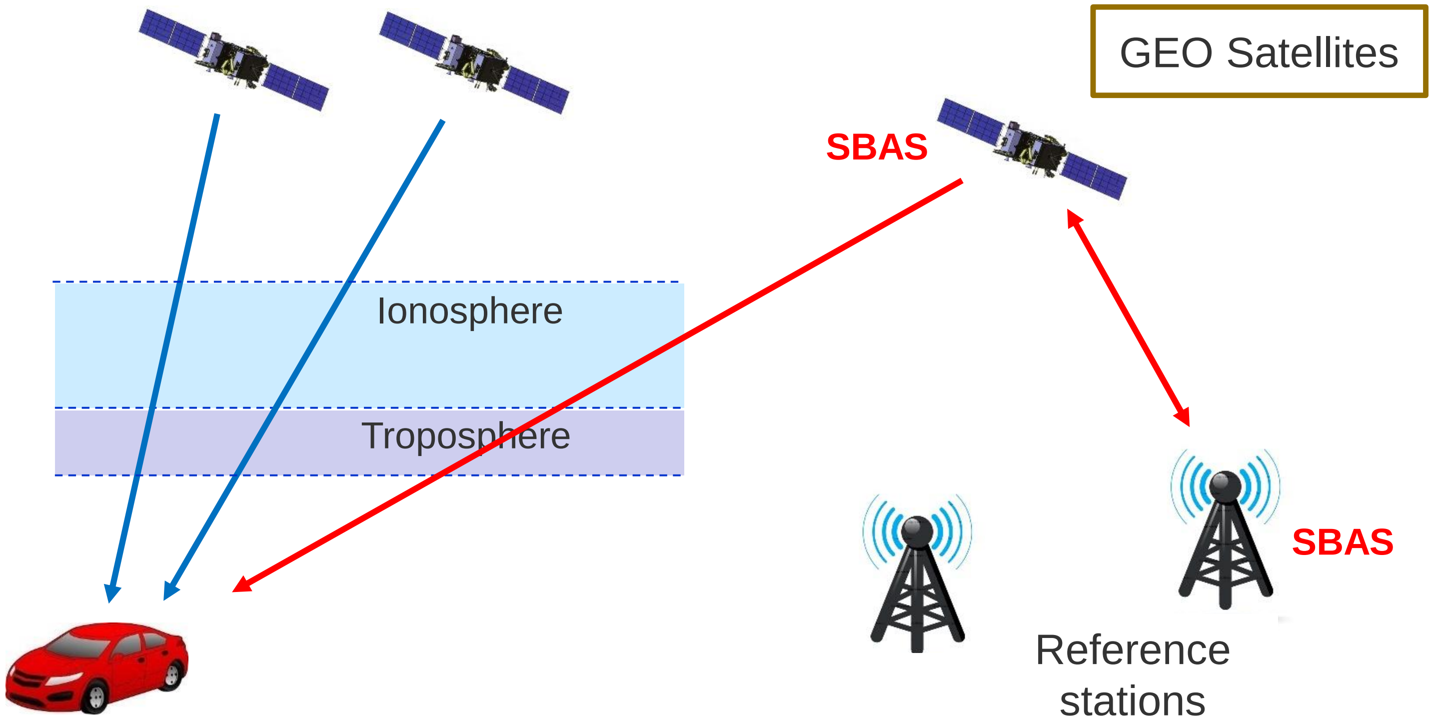
GNSS Positioning Methods



SBAS

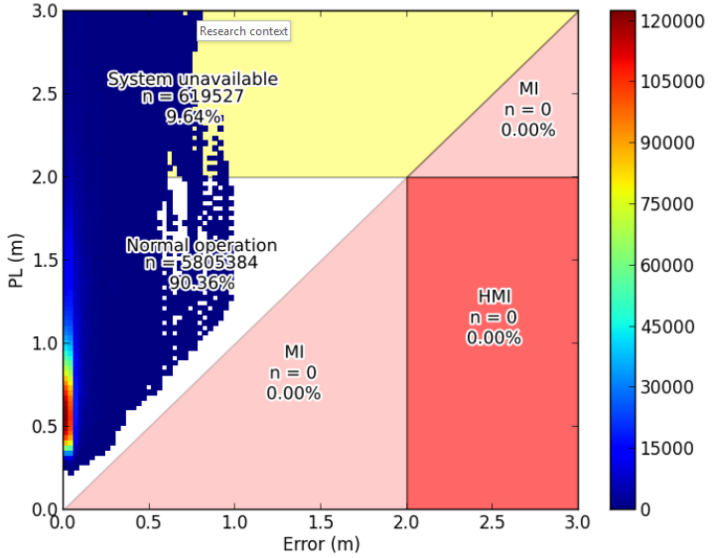
- Improved positioning:
  - sub-m (DGPS L1, L1/L5)
  - deci-metre (PPP)
- Integrity monitoring: error bounds for PL

Vulnerabilities linked to hardware, software and data link with the satellites

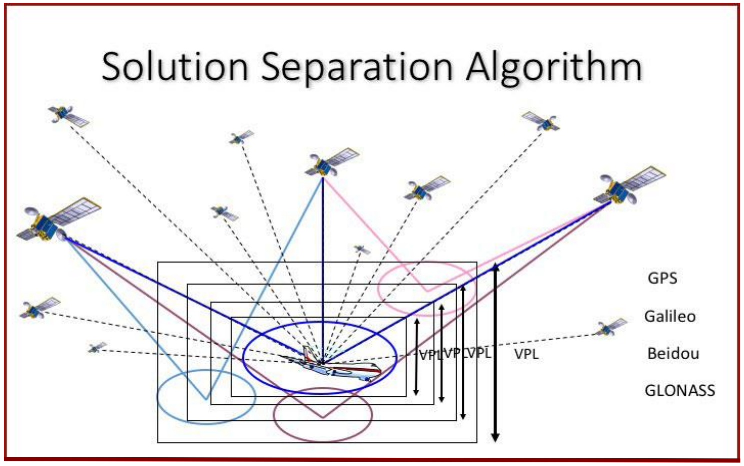


Integrity monitoring

- Advanced RAIM (ARAIM)
  - Fault Detection & Exclusion based on statistical hypothesis testing
  - PLs computation based on estimated impact of faults on position solution

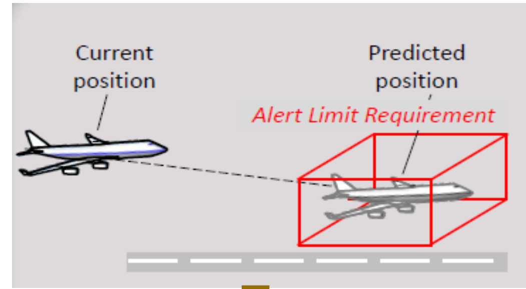


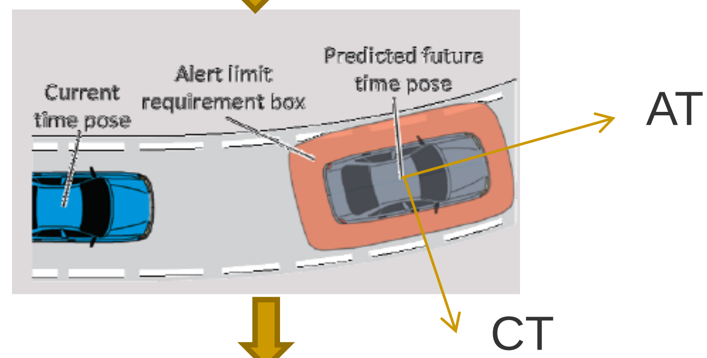
- Determine Protection Levels (PLs) as safety bounds to positioning errors
  - Take into account risk of anomalies/faults
  - PLs must be smaller than the Alert Limits (ALs) to guarantee availability

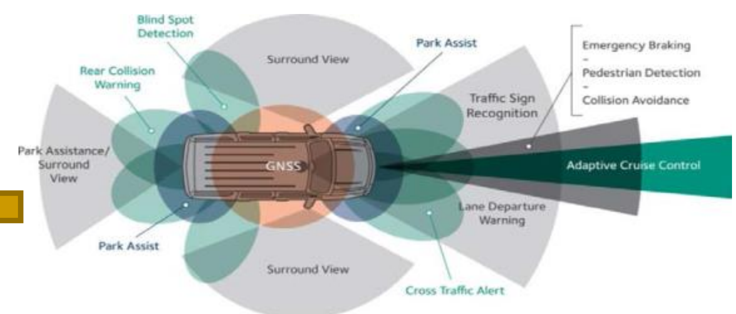


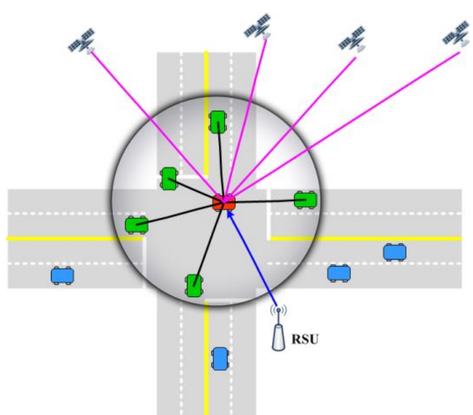
ARAIM

- For standalone vehicle
- Multi-sensor
- V2V and V2I .







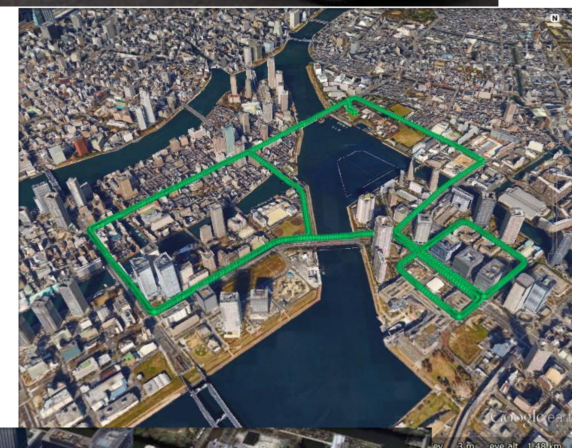


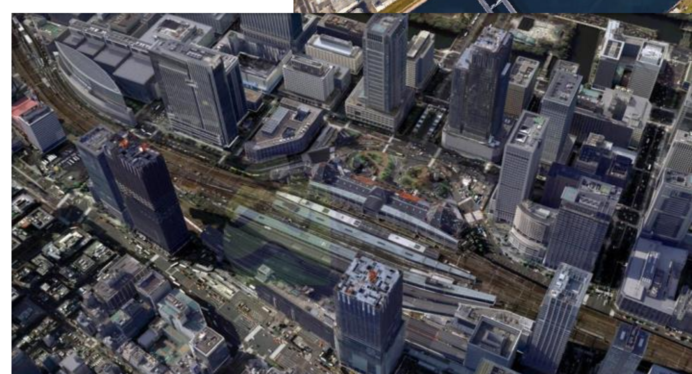
- Multi-sensor integration

Testing Ex.

- Kinematic test in Tokyo (with TUMSAT)
- Trimble RTK (10Hz)
- GPS, GLONASS and BeiDou
- a Bosch-consumer grade MEMS IMU

  The heading error of this IMU ranged from -2^o to 5^o, can accumulate to 10^o after 30 min if left uncalibrated.
- Speed sensor: σ = 5 cm/s
- GNSS-Doppler: σ = 10 cm/s.
- Reference : PPK & POS/LV

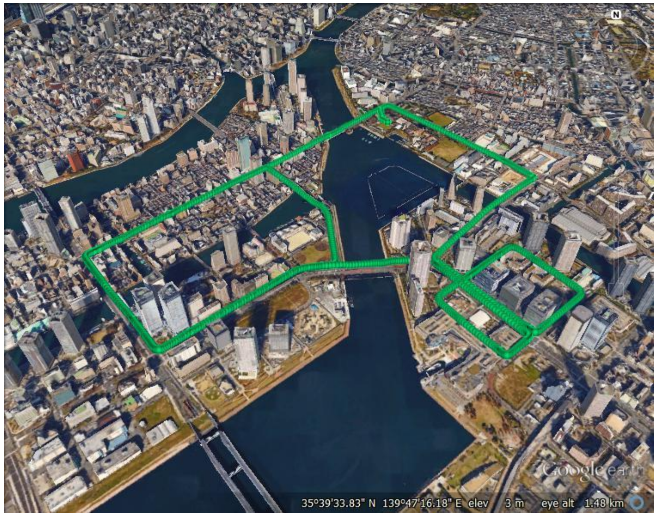


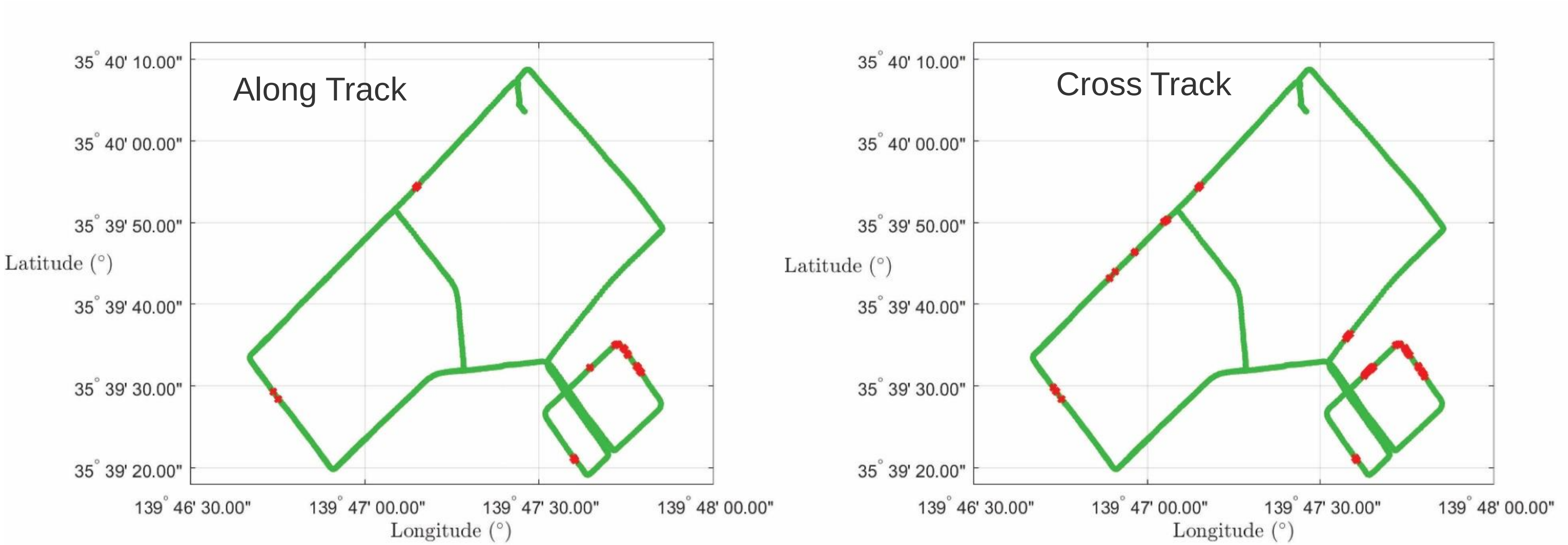


Testing: challenging environment

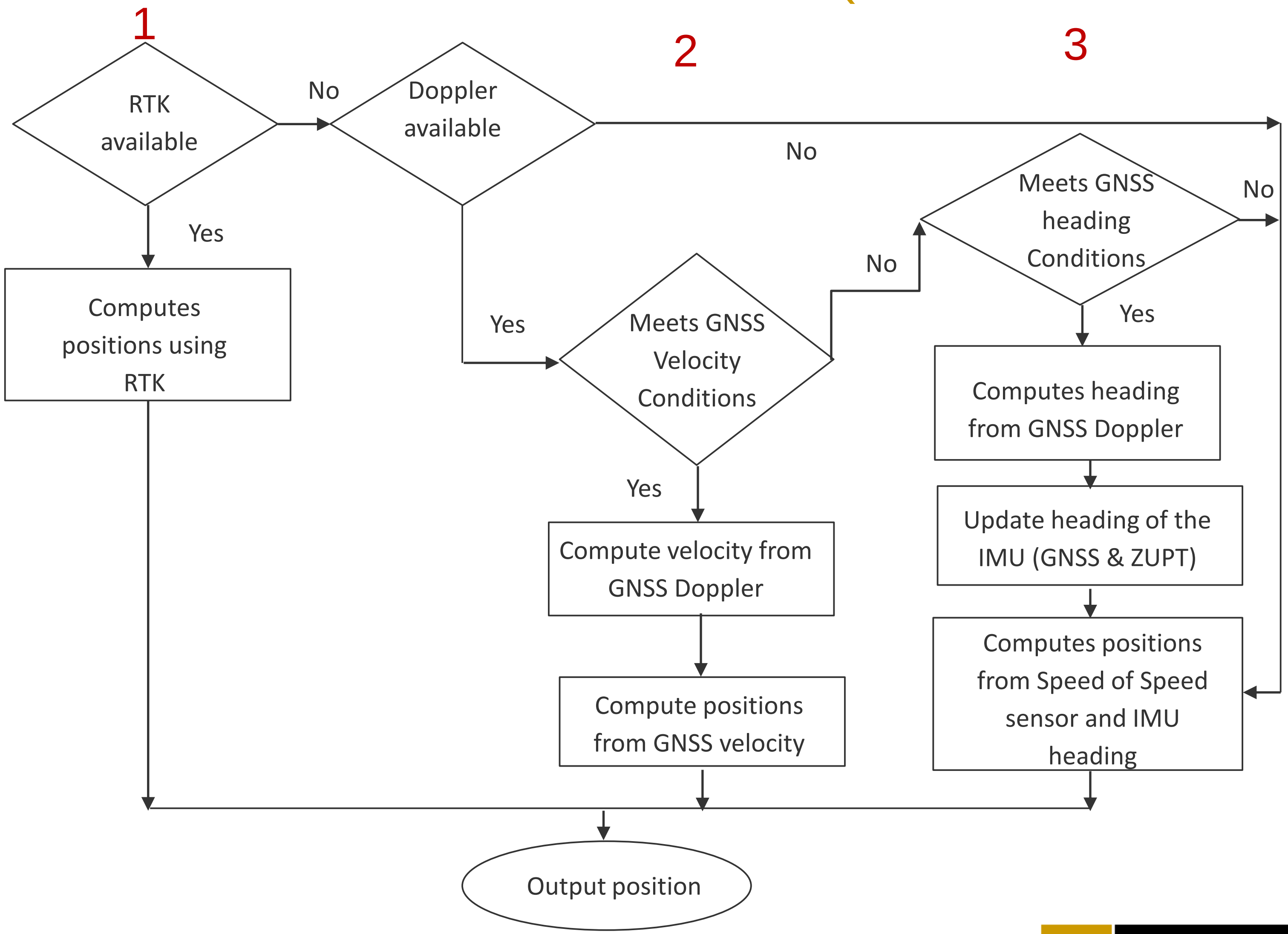
Integrity prediction

- Identify critical locations on the map, at different times of the day
- Integrity unavailable: red points (PL>AL)





Actual data: Flow chart of sensor fusion (RTK, IMU, odometer)



Protection levels

RTK

$$PL_{AT,i} = K_{fa,i}\ \sigma_{\delta AT,i} + K_{md,i}\ \sigma_{AT,i} + \sqrt{(\cos\theta\, a_1^T\, S_i \times\ b_o)^2 + (\sin\theta\, a_2^T\, S_i \times\ b_o)^2}$$

$$PL_{CT,i} = K_{fa,i}\ \sigma_{\delta CT,i} + K_{md,i}\ \sigma_{CT,i} + \sqrt{(\sin\theta\, a_1^T\, S_i \times\ b_o)^2 + (\cos\theta\, a_2^T\, S_i \times\ b_o)^2}$$

IMU+odometre

$$PL_{AT,i} = K_{md,i}\ \sigma_{AT,i} + \sqrt{(\cos\theta\, a_1^T\, S \begin{bmatrix} b_{\theta_{IMU}} \\ b_v \end{bmatrix})^2 + (\sin\theta\, a_2^T\, S \begin{bmatrix} b_{\theta_{IMU}} \\ b_v \end{bmatrix})^2}$$

biases

$$PL_{CT,i} = K_{md,i}\ \sigma_{CT,i} + \sqrt{(\sin\theta\, a_1^T\, S \begin{bmatrix} b_{\theta_{IMU}} \\ b_v \end{bmatrix})^2 + (\cos\theta\, a_2^T\, S \begin{bmatrix} b_{\theta_{IMU}} \\ b_v \end{bmatrix})^2}$$

Doppler

$$PL_{AT,i} = K_{md,i}\ \sigma_{AT,i} + \sqrt{(\cos\theta\, a_1^T\, S \begin{bmatrix} b_{v_E} \\ b_{v_N} \end{bmatrix})^2 + (\sin\theta\, a_2^T\, S \begin{bmatrix} b_{v_E} \\ b_{v_N} \end{bmatrix})^2}$$

$$PL_{CT,i} = K_{md,i}\ \sigma_{CT,i} + \sqrt{(\sin\theta\, a_1^T\, S \begin{bmatrix} b_{v_E} \\ b_{v_N} \end{bmatrix})^2 + (\cos\theta\, a_2^T\, S \begin{bmatrix} b_{v_E} \\ b_{v_N} \end{bmatrix})^2}$$

AT

CT

RTK Results

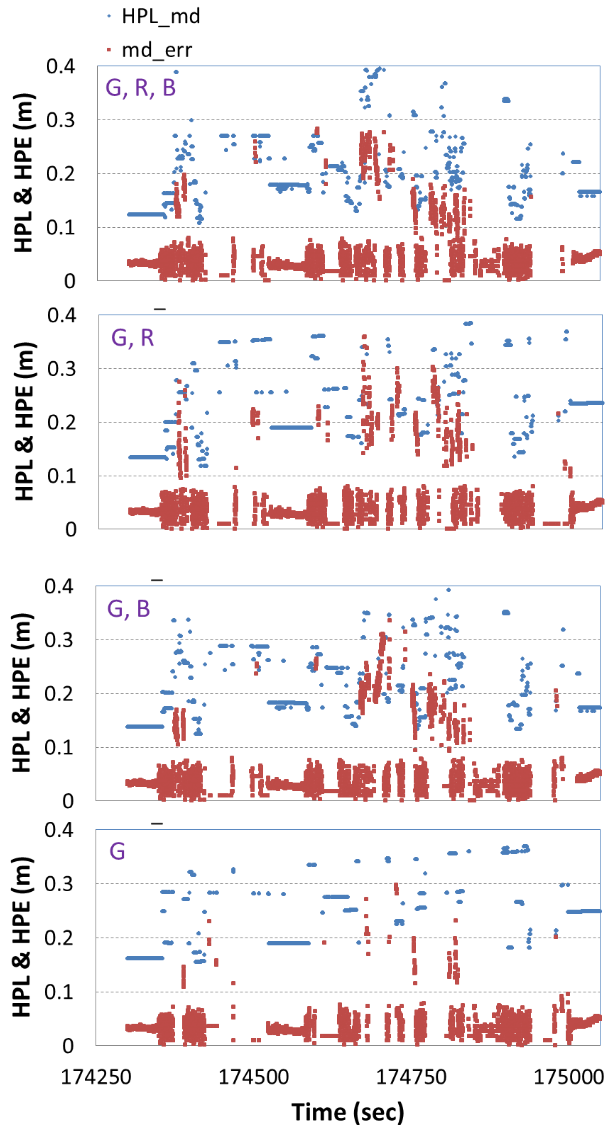
G+R+B

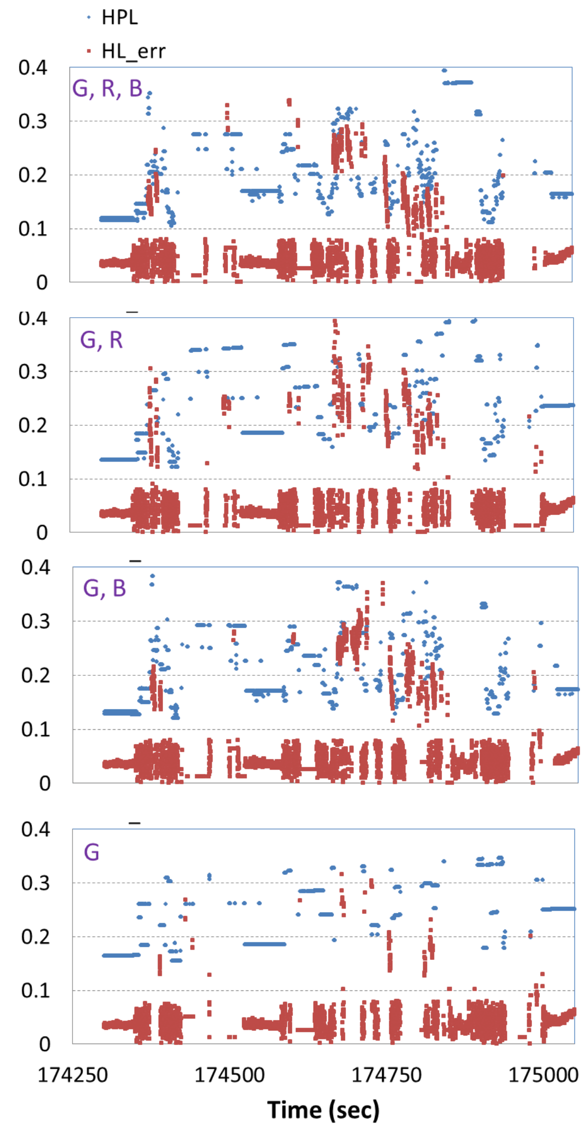
G+R

G+B

G

$* \beta = 1\times10^{-4}$





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AT CT

All sensors

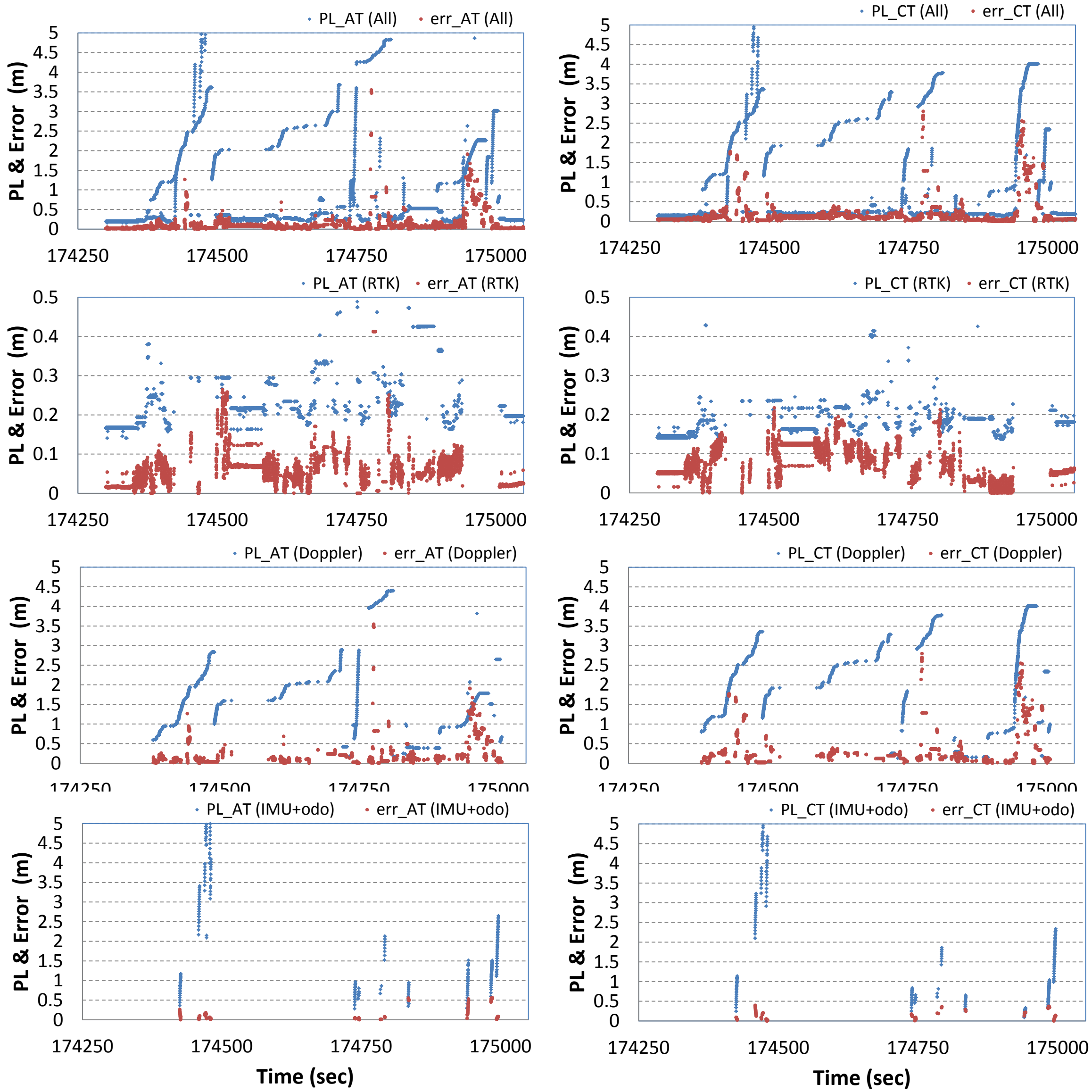
Combined

* $\beta = 1\times10^{-4}$

RTK

Doppler

IMU+odometer



Summary

- ITS / C-ITS might be the norm in the near future.
- Real-time safety related applications in ITS/C-ITS require highly trustworthy positioning: i.e. integrity monitoring.
- The technology might not be the problem: cost and interoperability might be.
- Integrity Monitoring (IM) is challenging
- IM can be achieved, but which standards? Applications?

Thank you

Questions