Standards and Technologies in Modern GNSS

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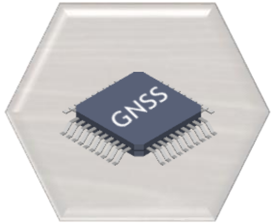
The Market Evolution

Geodetic grade GNSS receivers and the classic applications

Geodetic high-precision GNSS technology has been used over several decades in professional applications

Low-cost GNSS chips



- ✓ Multi-frequency support
- ✓ Flexibility with optimized size and power consumption
- ✓ Measurements with high performance

Low-cost GNSS receiver chips have become capable enough to provide high accuracy

New range of applications

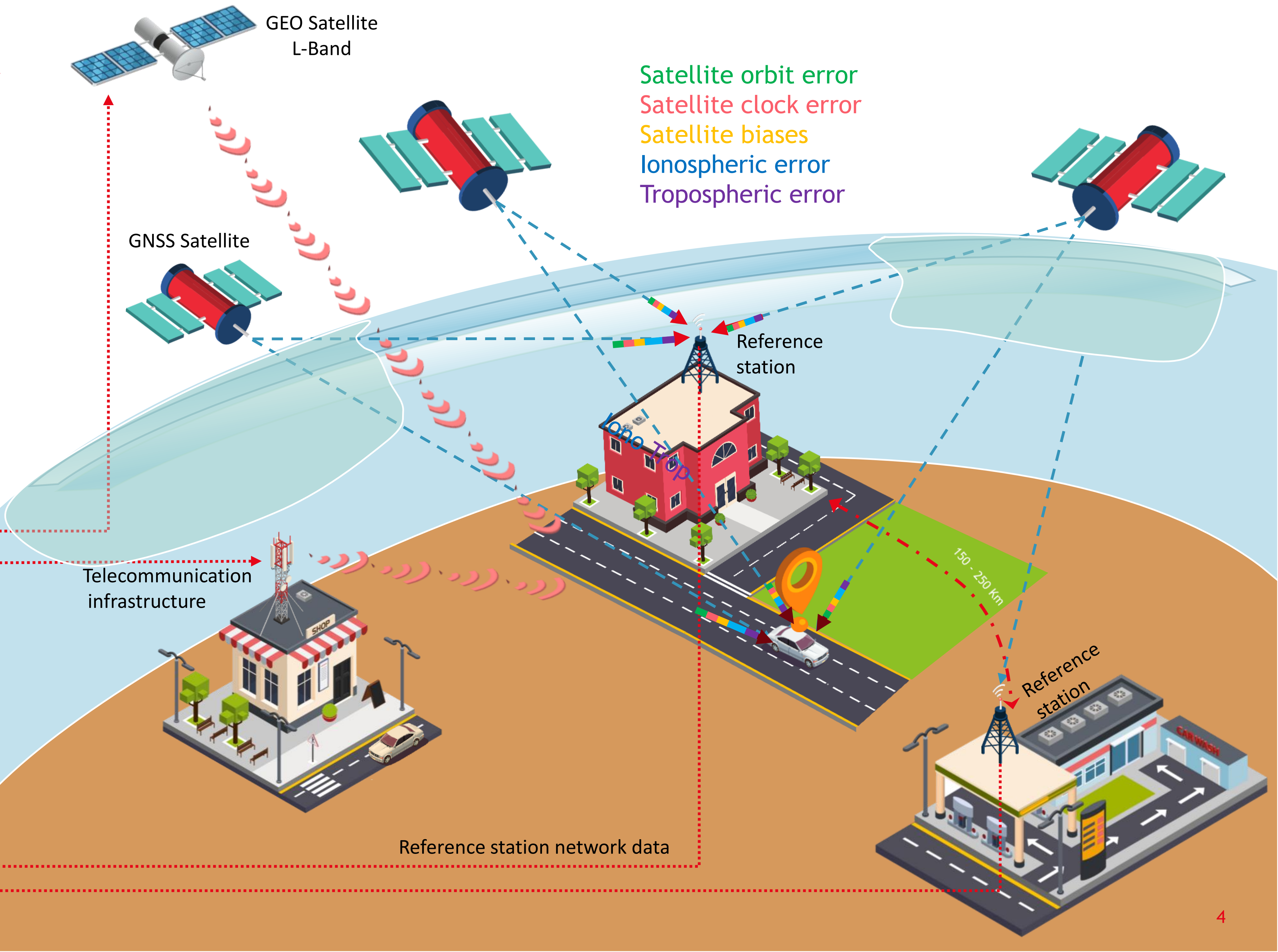
High-precision GNSS is becoming an essential tool for a wide range of consumer applications

What Modern GNSS Correction Services Look Like

- High accuracy and precision, e.g. less than 10 cm
- 24/7/365 availability in continental scale with homogenous coverage
- Compatible with high precision receiver (including low-cost)
- Fast convergence, within seconds
- Cost efficient and affordable pricing
- Robust solution with high stability in case of minor system disturbances
- Integrity and functional safety

Correctios workflow

- Observation data is acquired by ref. stations and sent to data centers
- Data center calculates correction components for each source of error over coverage area
- Corrections are broadcast via IP or geostationary satellite (L-Band)
- Corrections are received by rover and applied to all satellites in view



GNSS processing technologies evolution

Technology

- **Single-base RTK:**
  - Line-of-sight modelling

- **Network RTK:**
  - Line-of-sight modelling for OCB
  - Atmosphere interpolation
  - Geophysical models (sparse networks)

- **PPP:**
  - Components modelling for OCB
  - Atmosphere interpolation (or none)
  - Geophysical models

Data representation

OSR

OSR+SSR

SSR

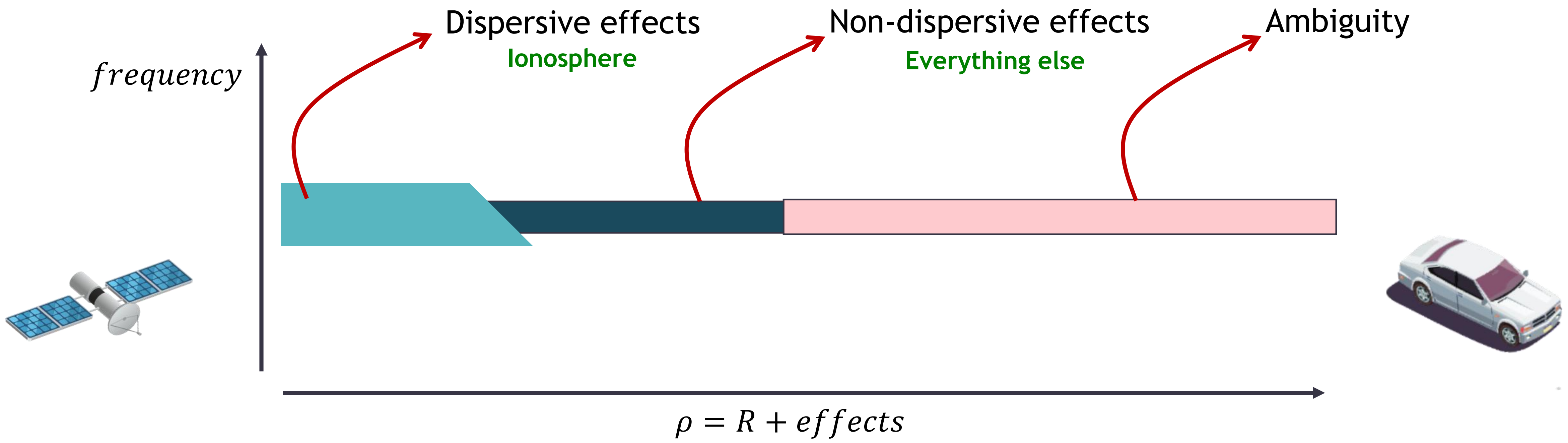
Key events in component-based correction technology research

- 1995 – Heroux and Kouba (NRCan) – First use of global precise orbits and clocks as correction data for positioning
- 1997 – Zumberge et. al (JPL/NASA) – Mass positioning using precise products
- 2001 – Kouba and Heroux (NRCan) – Phase-based positioning using precise products – first cm-level positioning in global scale
- 2002 – Gabor and Nerem (USSC) – Calibration of measurement biases for ambiguity resolution with precise products

Challenges of traditional technologies

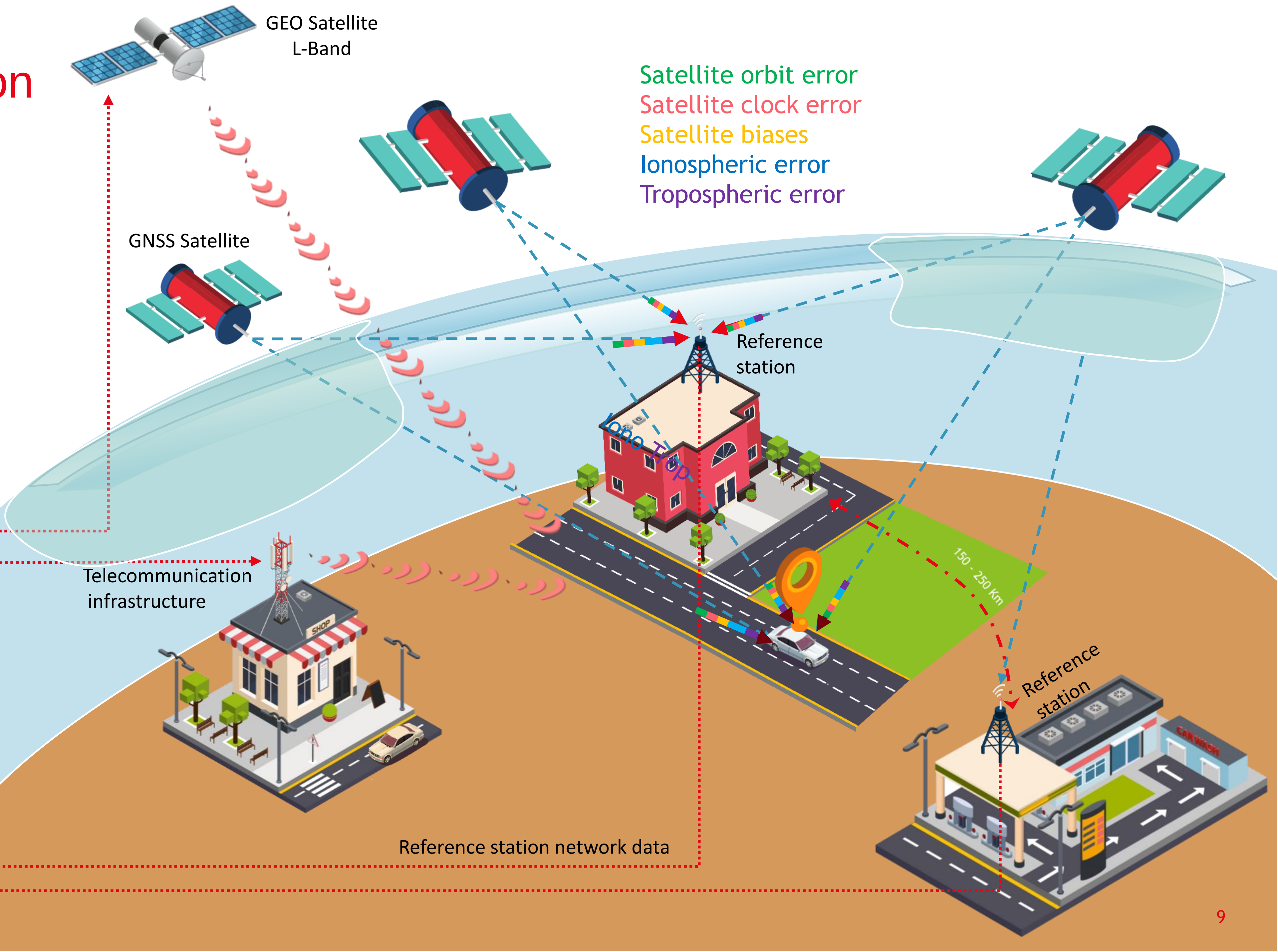
- RTK:
    - High dependency on the closest reference station
    - Requiring Bi-directional communication (in most cases)
    - High bandwidth and data consumption
    - Scalability challenges
- PPP:
    - High convergence time due to un-modeled atmospheric errors

Overcoming the ionosphere



Sapcorda solution

- Observation data is acquired by ref. stations and sent to data centers
- Data center calculates correction components for each source of error over coverage area
- Corrections are continuously broadcast with optimized data bandwidth via IP or geostationary satellite (L-Band)
- Corrections are received by rover and applied to all satellites in view

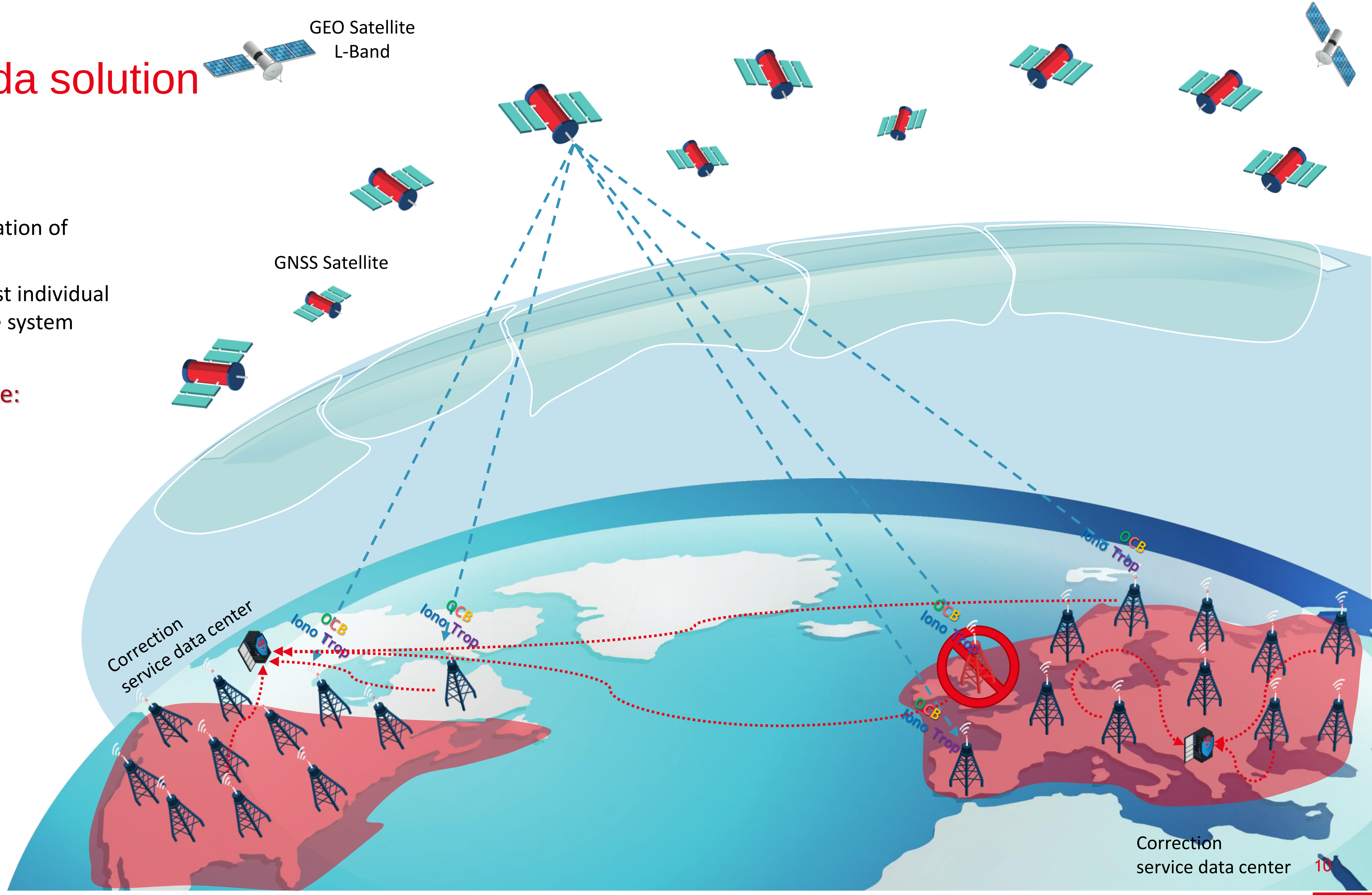


Sapcorda solution

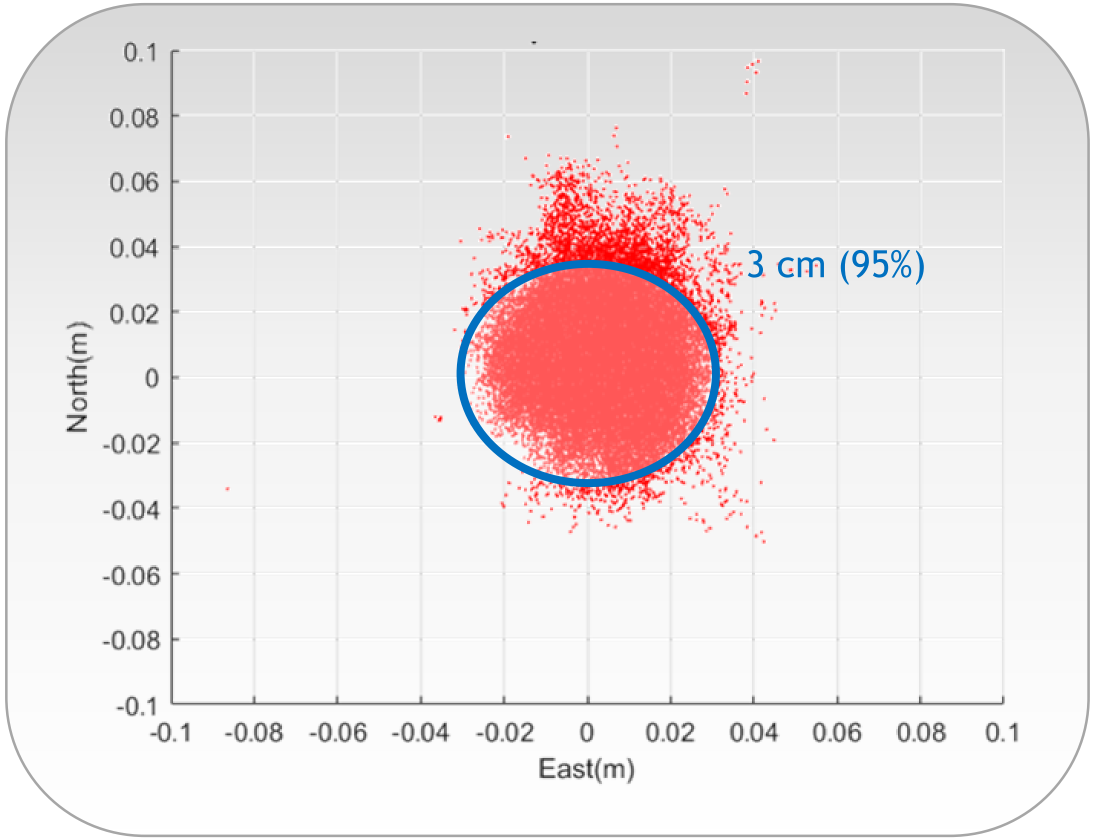
- Redundant calculation of corrections
- Robustness against individual failures across the system

Sapcorda coverage:

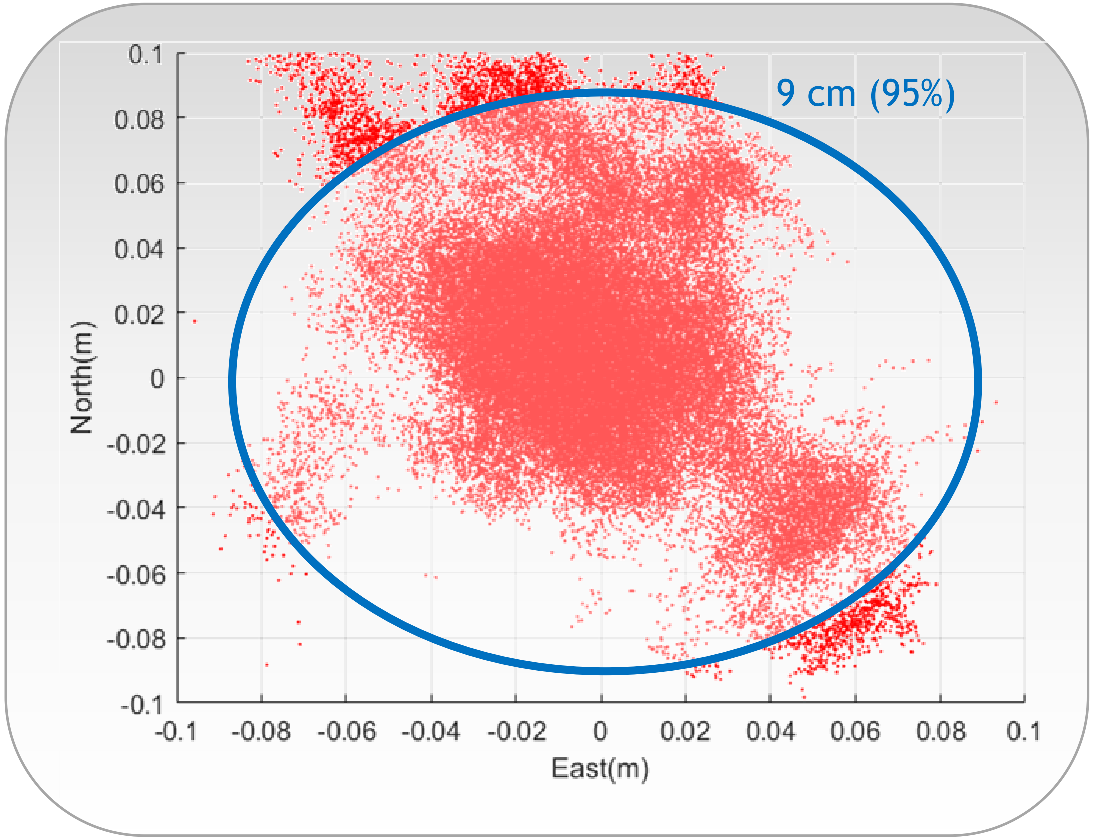
- Europe
- United States



Scatter plot



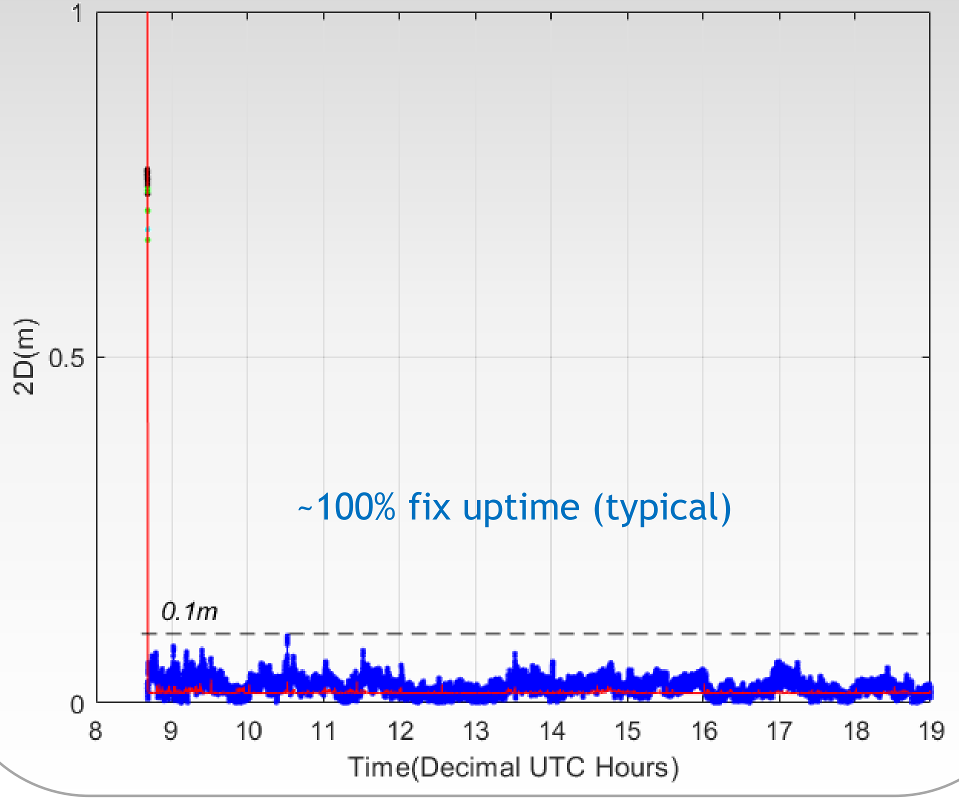
Using geodetic receiver and antenna

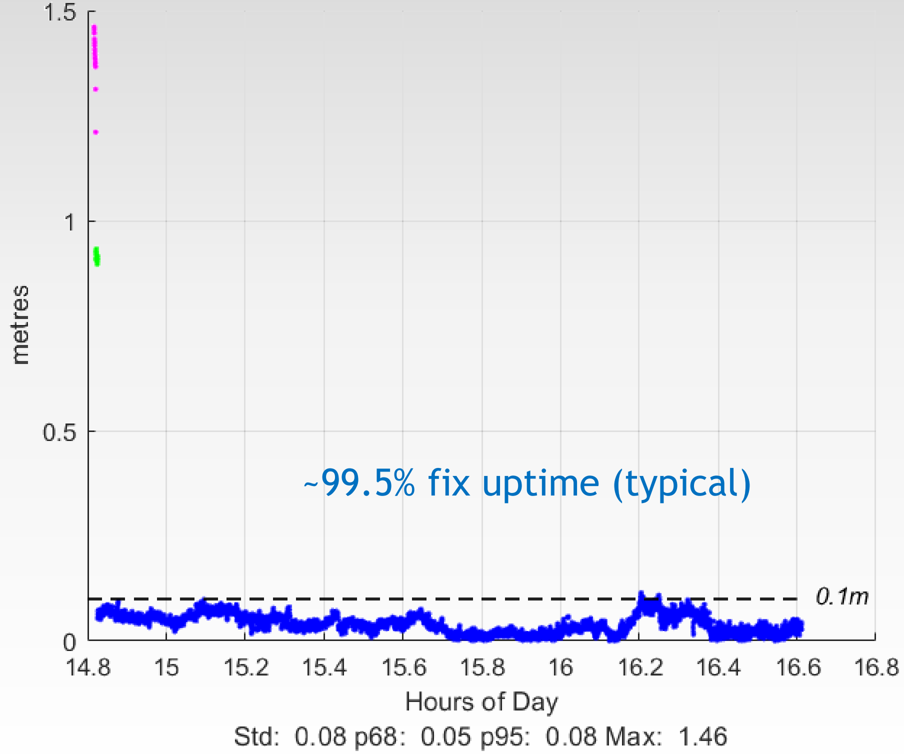


Using low-cost receiver and patch antenna

Test had performed in urban environment.

Performance over time





Using geodetic Antenna - *In this specific case exactly 7 sec*

Using patch Antenna - *In this specific case exactly 20 sec*

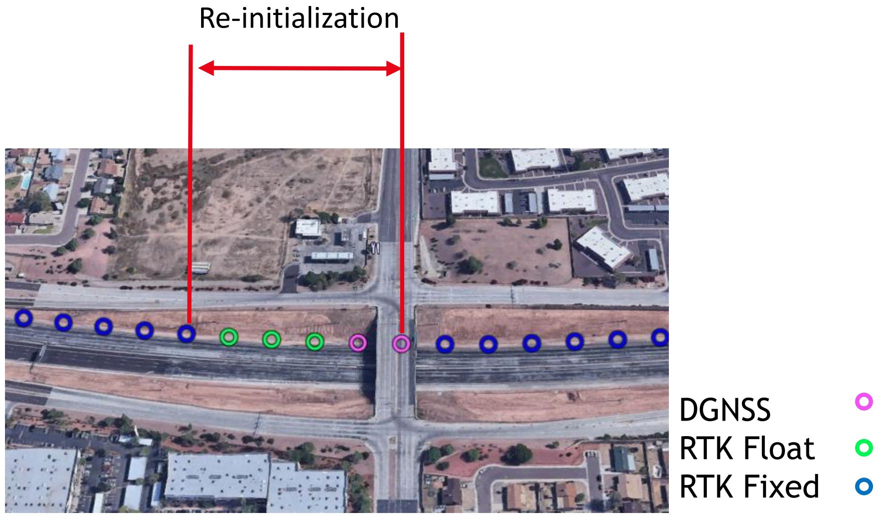
Test had performed in static mode in urban environment.

Convergence time analysis

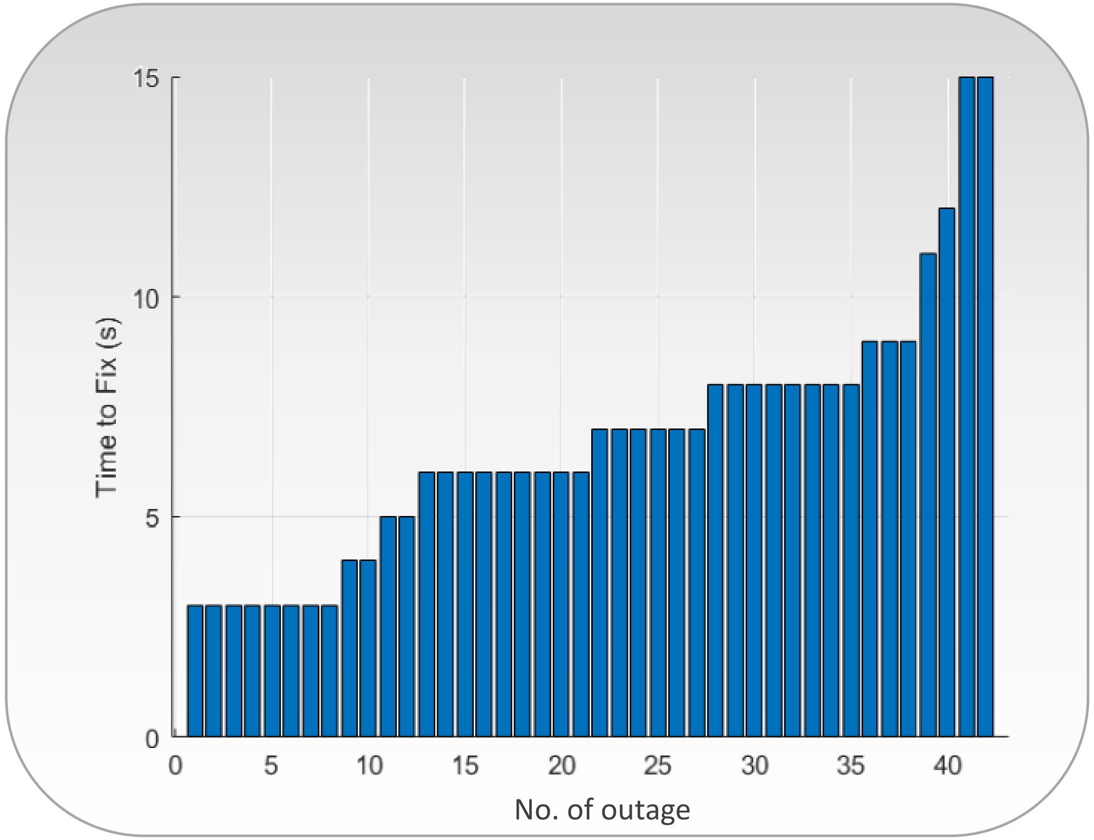
Time to First Fix (TFF)

Drive test with several environment variations, including 42 re-initialization situations (e.g. bridges)

In nearly all the 42 occurrences the time to re-initialize is less than 15 seconds.



Re-initialization time is computed as the time it takes to return to nominal system accuracy (RTK Fixed quality) after an outage. In this definition, the time of the outage is included in the overall re-initialization time.



What makes correction services dependable?

Accuracy is not enough

- ✓ Must comply with known quality standards
- ✓ Performance quality must be assured with comprehensive testing and validation
- ✓ Independent real-time verification of data product must assure integrity of service
- ✓ Must be developed according to appropriate safety goals and standards
- ✓ Must be protected from external interference

Compliance

with quality standards at organization, project, and product level

Quality

assurance via continuous testing, verification, and qualification of service performance

Integrity

of the correction data with on-the-fly verification against independent data sources and algorithms

Safety

achieved by employing technology developed according to stringent industry-recognized safety standards

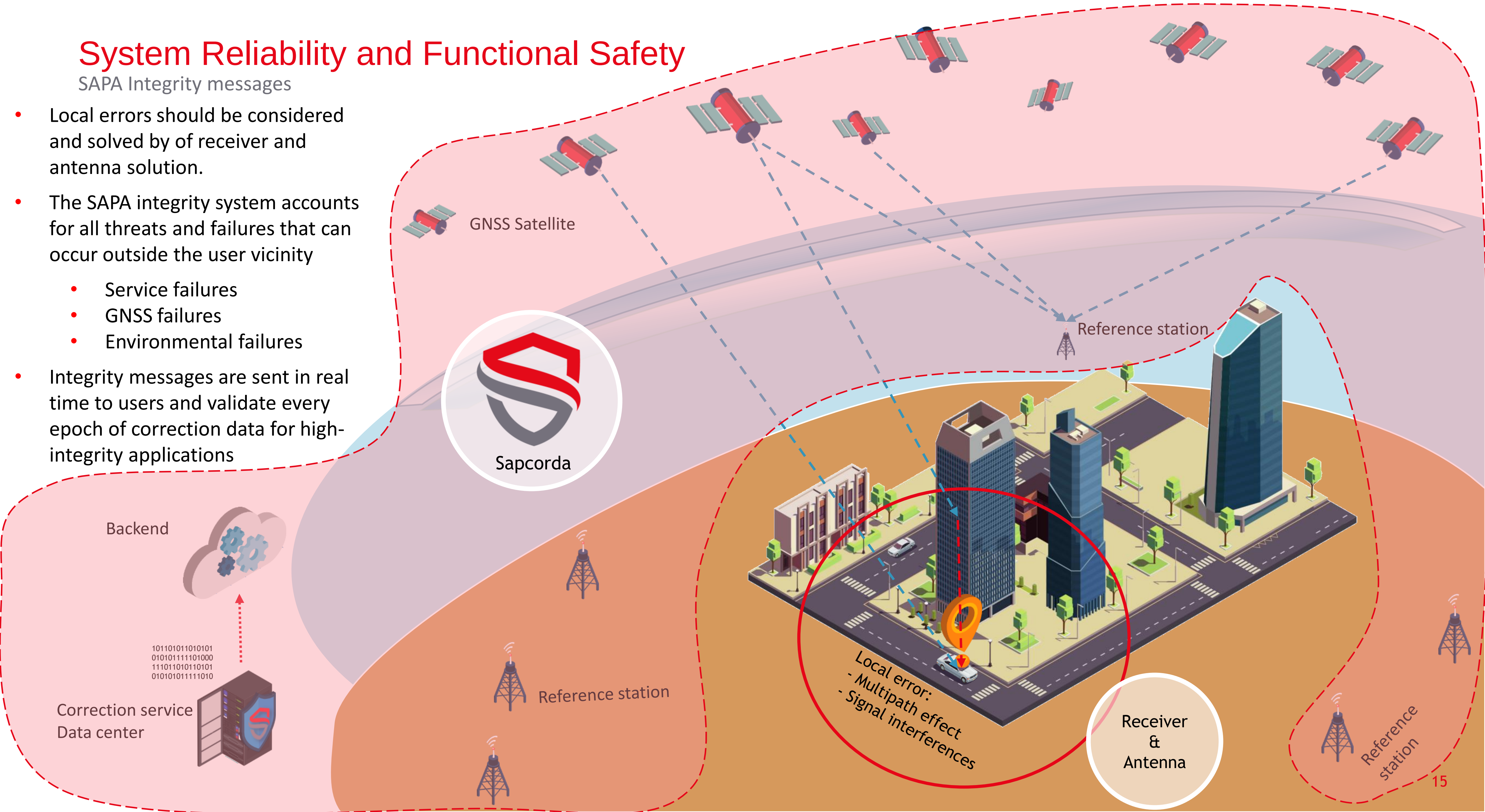
Security

with extreme protection of ground infrastructure, processing centers, and data communication

System Reliability and Functional Safety

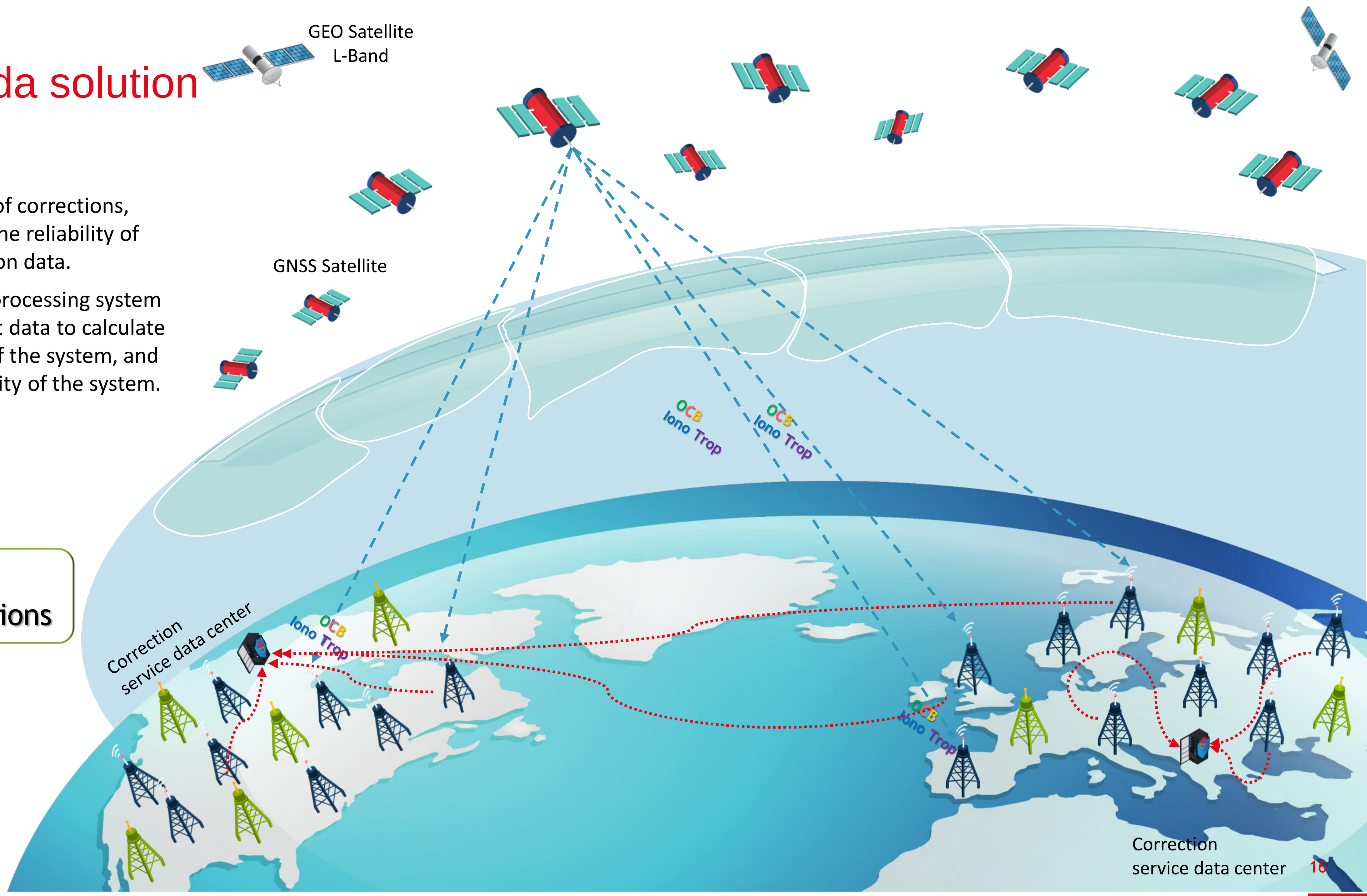
SAPA Integrity messages

- Local errors should be considered and solved by of receiver and antenna solution.
- The SAPA integrity system accounts for all threats and failures that can occur outside the user vicinity
  - Service failures
  - GNSS failures
  - Environmental failures
- Integrity messages are sent in real time to users and validate every epoch of correction data for high-integrity applications

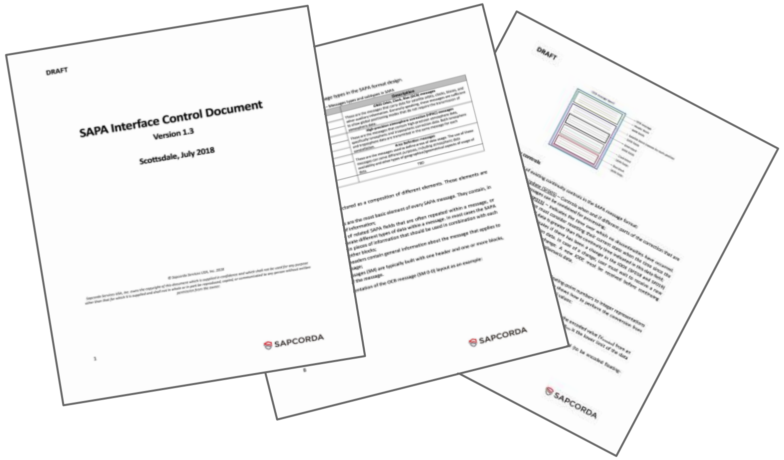


Sapcorda solution

- After calculation of corrections, system evaluate the reliability of provided correction data.
- An independent processing system used independent data to calculate the actual error of the system, and define the reliability of the system.



SARTN Format Overview



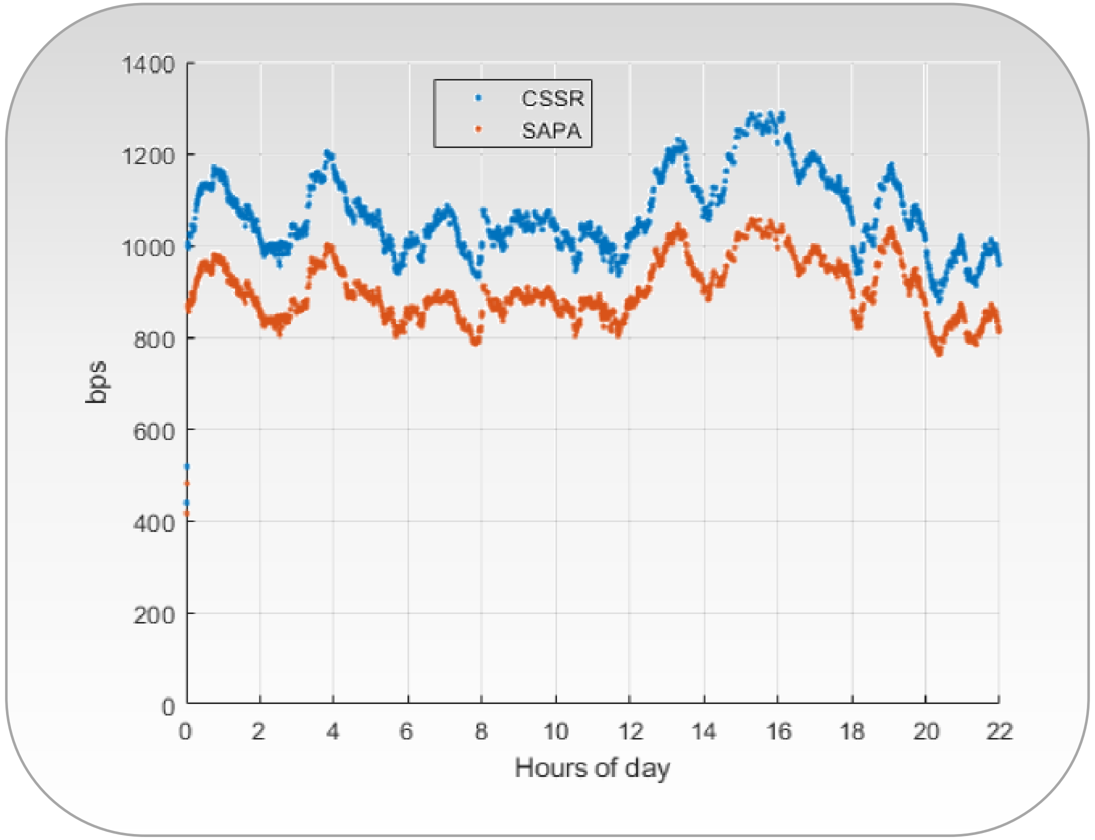
- SPARTN - Safe And Precise Augmentation for Real Time Navigation
- New format developed in collaboration with major GNSS automotive players

Type	Message Type	Description
0	Orbit, Clock, Bias	• Contain data for satellite orbits, clocks, biases, and other auxiliary information. • Generally speaking, these messages are sufficient to allow global PPP
1	High Precision Atmosphere Corrections	• Contain high-precision atmosphere data for the ionosphere and troposphere • Ionosphere modelled as slant delay on a per satellite basis • Flexible configuration to allow optimization for low and high bandwidth systems
2	Geo Area Definition	• Define geographic areas of data usage. • Serve various purposes, including atmospheric data, and other types of geographic specific data such.
3	System Functional Safety	• Identifies the current state of the system including fault modes for constellations, satellites and regions. • Indicates when the system is in a nominal or faulted state.

Area Definition Implementations

- Area definitions in GAD message (SM-2) are used for computing the high-precision atmosphere correction messages using (SM-1)
- Tile based approach to atmosphere modelling
- Can be optimized for very efficient bandwidth if users send approximate location to server
- Can change on the fly (as noted by the AIOU) but typically would be quite static

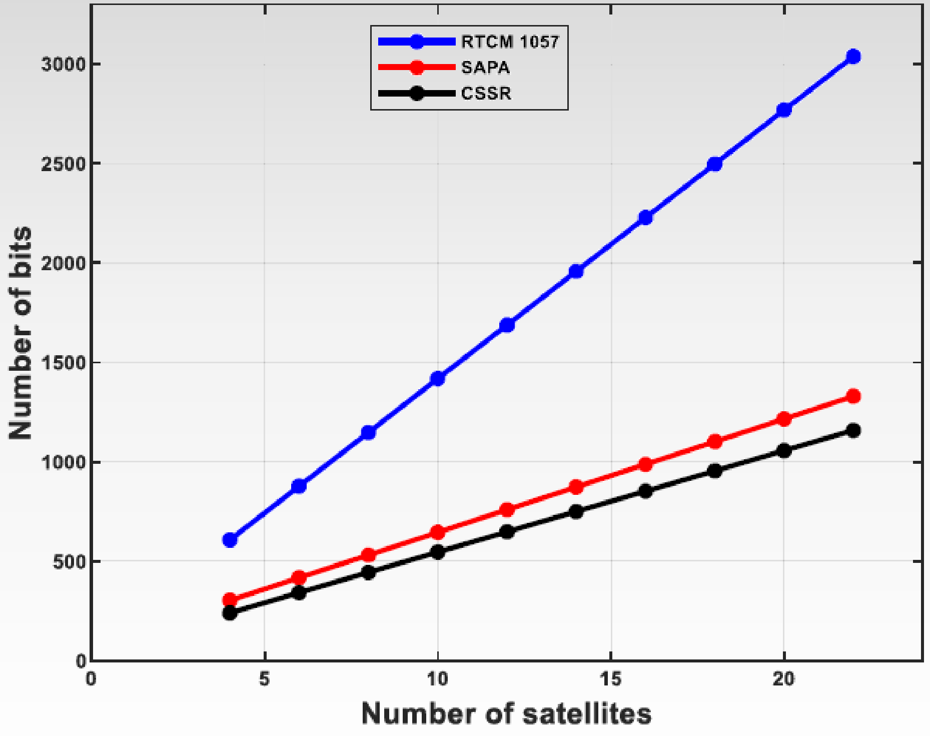
Bandwidth analysis



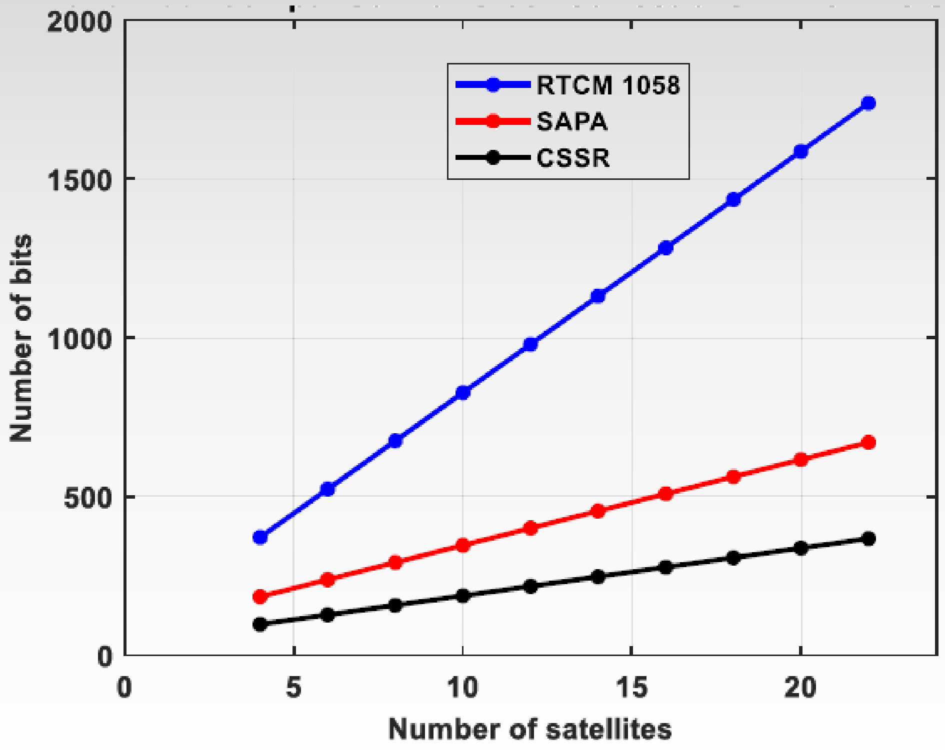
Atmosphere bandwidth (bps) for the SPARTN and CSSR

Vana, S, Aggrey, J, Bisnath, S, Leandro, R, Urquhart, L, Gonzalez, P. Analysis of GNSS correction data standards for the automotive market. *NAVIGATION*. 2019; 66: 577–592. https://doi.org/10.1002/navi.323

Bandwidth analysis



Bandwidth comparison - ***orbit correction*** *message*



Bandwidth comparison - ***clock corrections*** *message*

Vana, S, Aggrey, J, Bisnath, S, Leandro, R, Urquhart, L, Gonzalez, P. Analysis of GNSS correction data standards for the automotive market. *NAVIGATION*. 2019; 66: 577–592. https://doi.org/10.1002/navi.323

Thank you

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