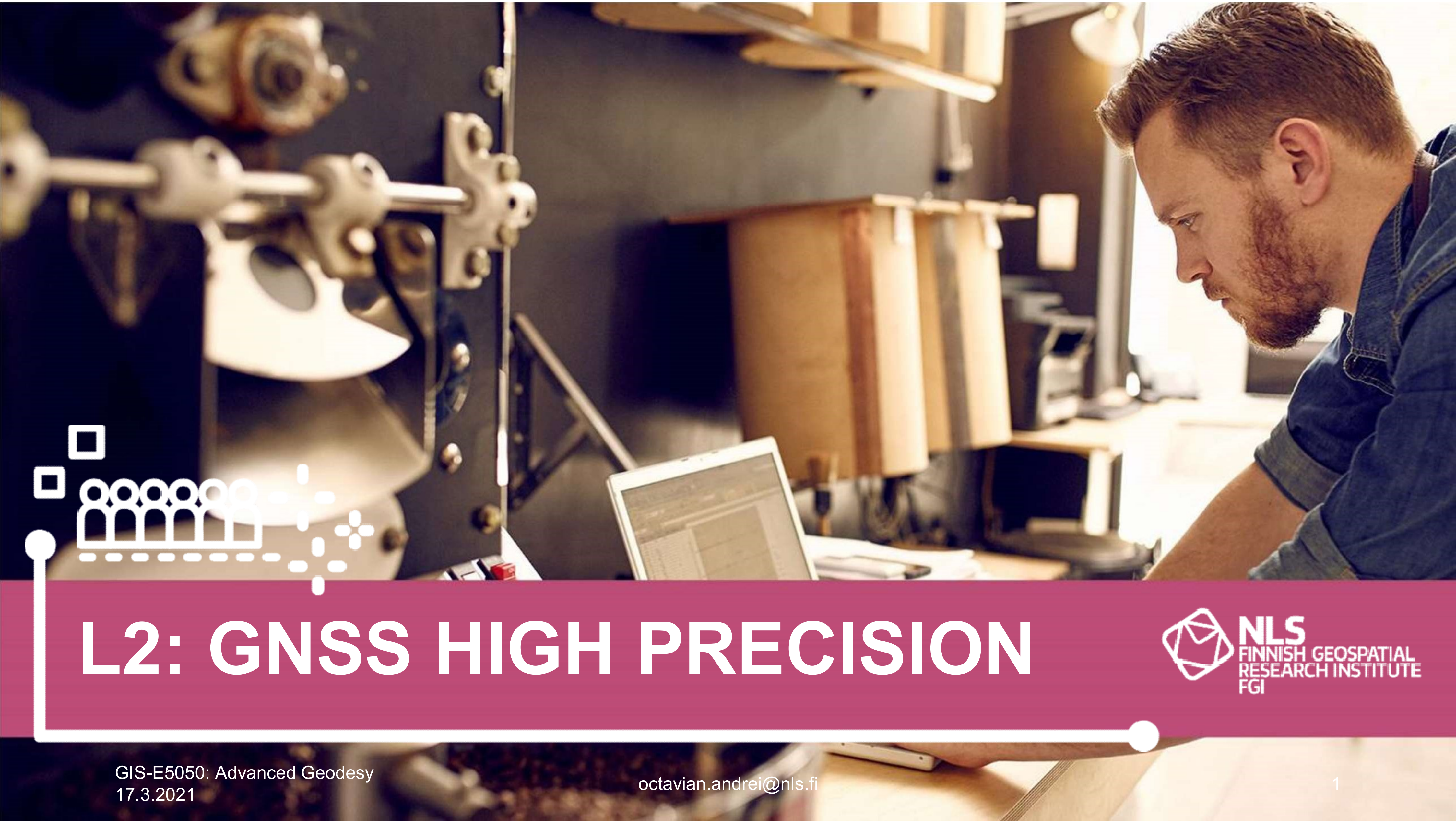

L2: GNSS HIGH PRECISION

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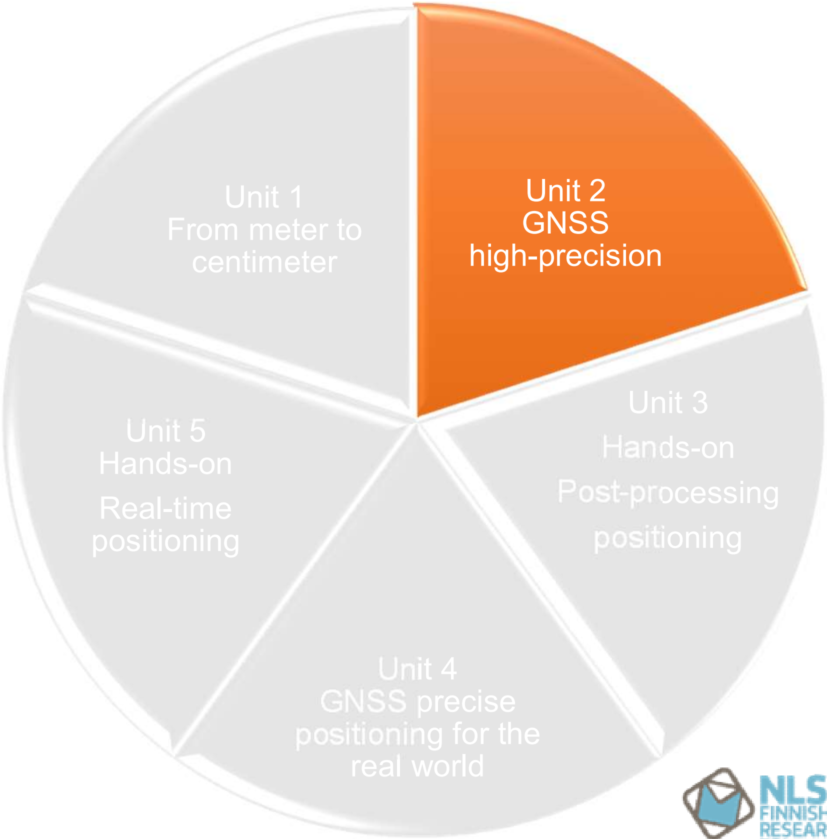
LECTURE STRUCTURE

- Lecture slides
- Reflection questions
- Demos

- Active student participation
- Questions on the chat
- Raise your hand



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GNSS HIGH PRECISION

- **Content**
  - ➢ Various techniques to obtain high-precision, high-accuracy positioning using GNSS technology

- After this lecture, the participant should be able:
  - ✓ **to explain** the principle of real-time kinematic and network-based positioning.
  - ✓ **to distinguish** between various network based implementations.

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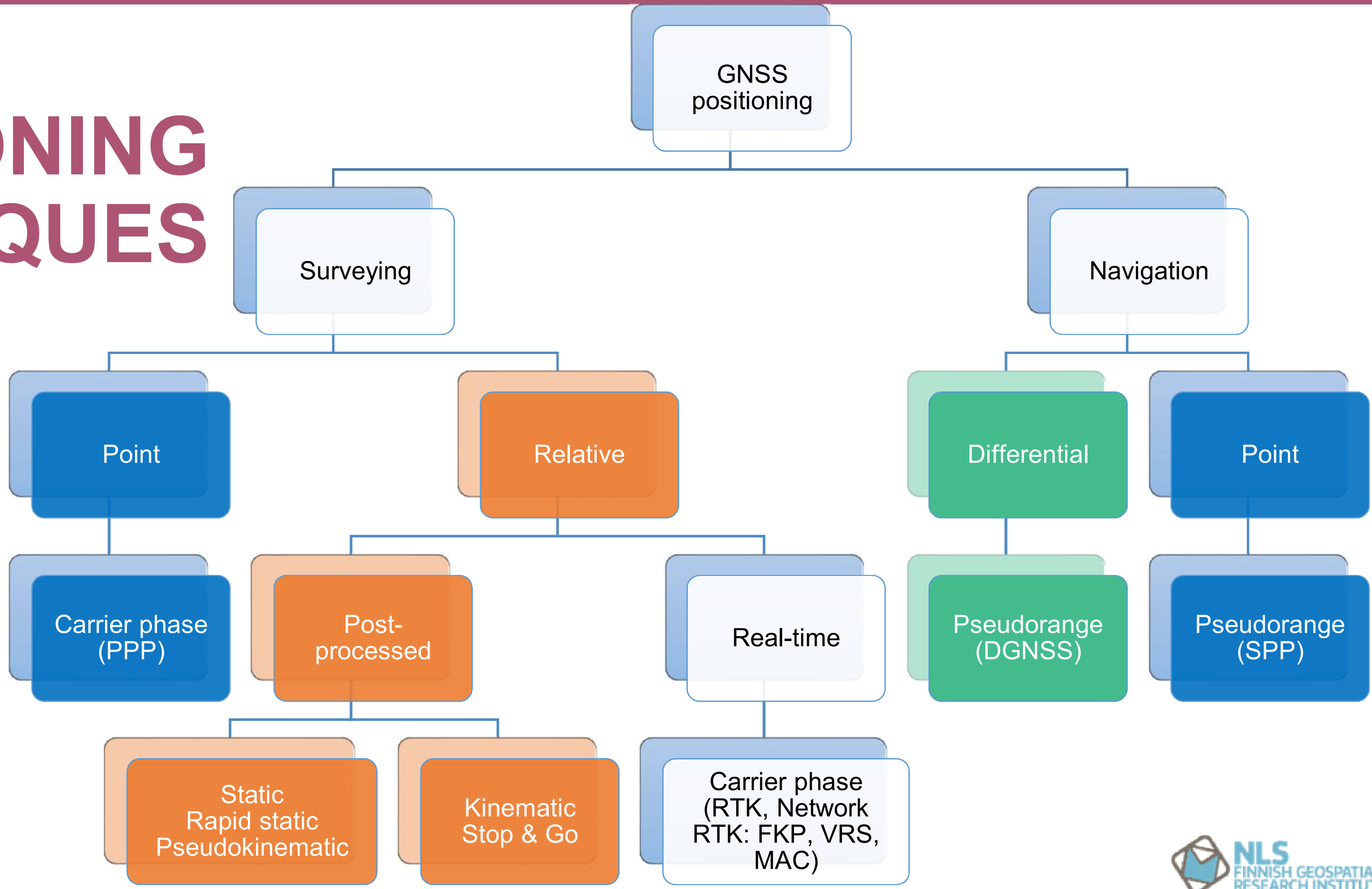
RECALL BEFORE CONTINUE

- Relative positioning mode
- Carrier phase based method
- Static vs. Kinematic
- Static
- Rapid static
- Re-occupation
- Stop & Go

GNSS POSITIONING TECHNIQUES



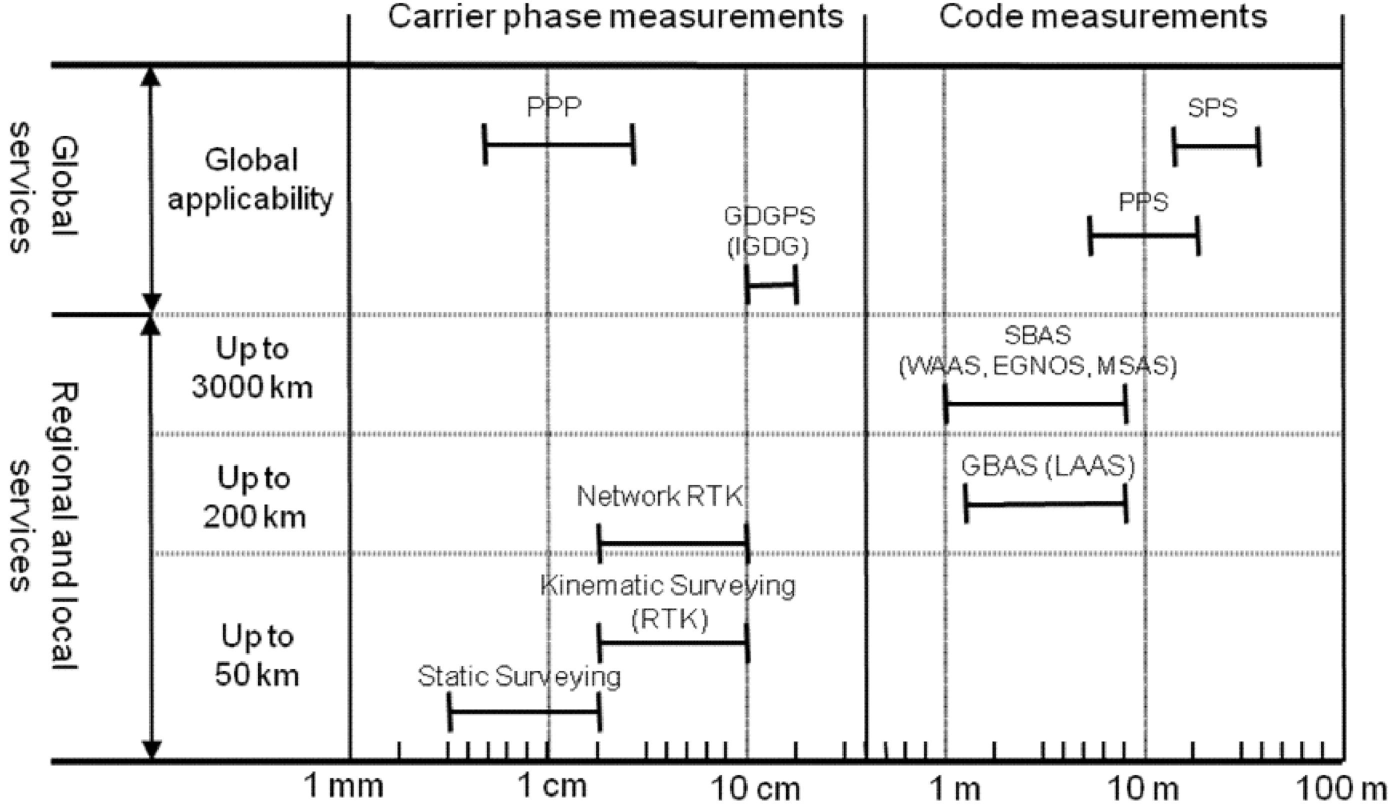
POST PROCESSING

- All necessary data are logged in files for **later processing**
- Software packages, multiple features, modular design
- Batch-processing, least-squares estimates, filtering, smoothing, etc
- Single station processing or network adjustments
- Trimble Business Center, Leica Geo Office, Topcon Magnet Office Tools, GravNav Waypoint, Spectrum Survey Pro, Javad Justin & Giodis, CHC Geomatics Office, etc
- Best workflow, integrity and compatibility
- Complex tasks, integration of heterogeneous data from various other surveying techniques (geometric levelling, photogrammetry, laser scanning)
- Cost involved (€100’s or €1000’s)

SOFTWARE TOOLS

Scientific Packages	Online Services	Open Source Libraries
• Bernese • GipsyX • GAMIT/GLOBK • PANDA • NAPEOS • GINS/DYNAMO	• CSRS-PPP • OPUS • GAPS • APPS (Gipsy) • SCOUT (Gamit) • AUSPOS (Bernese) • MagicGNSS • RTX	• RTKLIB (UoT) • GPSTk (ARL:UT) • BNC (BKG) • gLAB (gAGE/ESA) • PPP-Wizard (CNES)

COVERAGE VS. ACCURACY



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HOW ABOUT REAL-TIME?

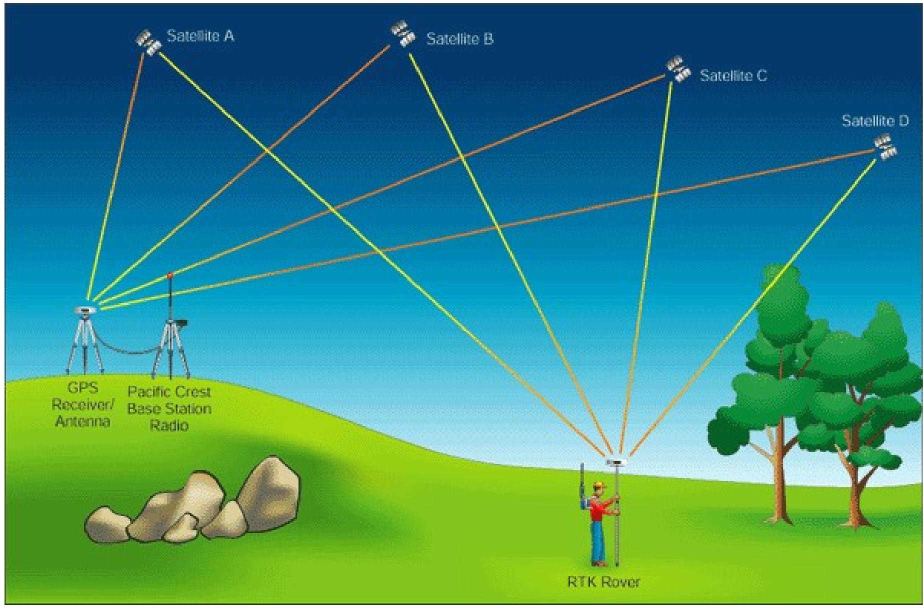
RT DEMO

REAL TIME POSITIONING: HOW?

- Reference Station (RS) collects observations from all satellites in view
- RS sends differential corrections (or raw data) to a rover receiver (stationary or mobile) via radio data link (UHF or VHF)
  - Raw data, RS coordinates, antenna types
  - Corrections for each SV-Rx pair
- Rover receiver performs DGNSS / RTK positioning using the corrections (or the raw data)

REAL TIME KINEMATIC (RTK)

- Golden standard in surveying & mapping
- Base station at a known location.
- Base station transmits **code and phase measurement** to rover (e.g., over a radio link).
- Rover combines own GNSS data with time-tagged measurements from base station.
- **Baseline vector and position are computed by the rover.**



L1/L2:
H: 1 cm + 1 ppm
V: 2 cm + 2 ppm

RTP ERROR SOURCES

- Real-time positions of cm-level accuracy are possible by effectively eliminating (by differencing) similar errors and biases in the carrier phase observations
  - Satellite clock error
  - Satellite orbit error
  - Ionosphere
  - Troposphere
  - Multipath
  - Antenna PCV
  - Receiver clock error
  - Code / phase bias

Not all these errors are **similar** at two ends of the baseline

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RTP DECORRELATION EFFECT

- Spatial correlated errors can be effectively cancelled out when the baseline length is not greater than about 10-30 km => **error de-correlation effect**

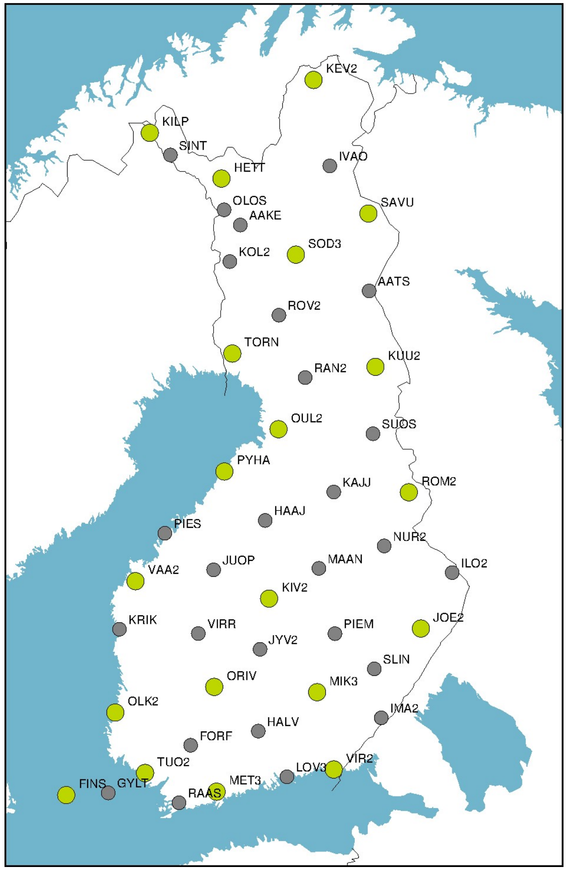
- As baseline length increases **Iono** and **Tropo errors** de-correlate causing a decrease in accuracy, reliability, and availability.

Solution: Network RTK

Main goal is to improve the rover performance

REAL TIME NETWORKS

- **Public networks**
  - International GNSS Service (IGS)
  - EUREF Permanent Network (EPN)
  - European Plate Observing System (EPOS)
- **Comercial networks**
  - Leica SmartNet
  - Trimble VRS Now
  - Topcon TopNET Plus
- **Finland**
  - FINREF (Finnish Geodetic Institute)
  - Trimnet (Geotrim Oy, Trimble)
  - SuomiNet (Leica Oy, Leica)



REFLECTION QUESTION

Is there any IGS/EPN station in your native country?

What kind of RTN may be found in your country?

Public? Commercial?

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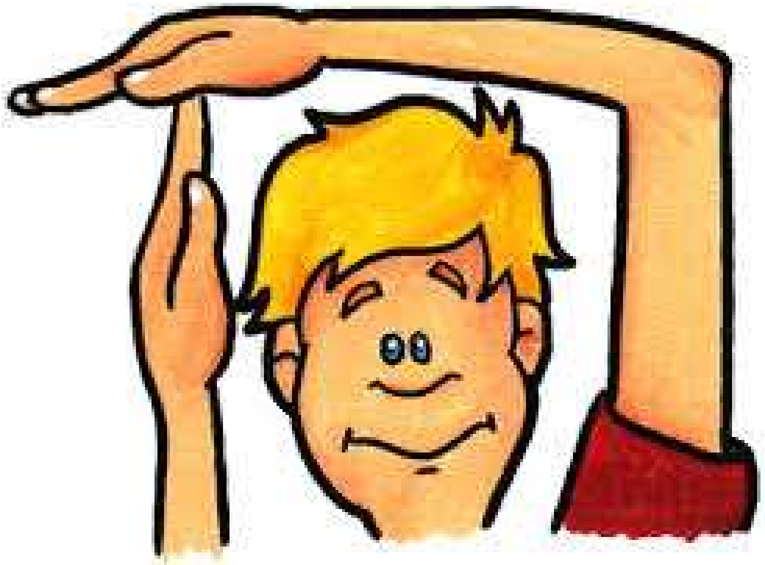
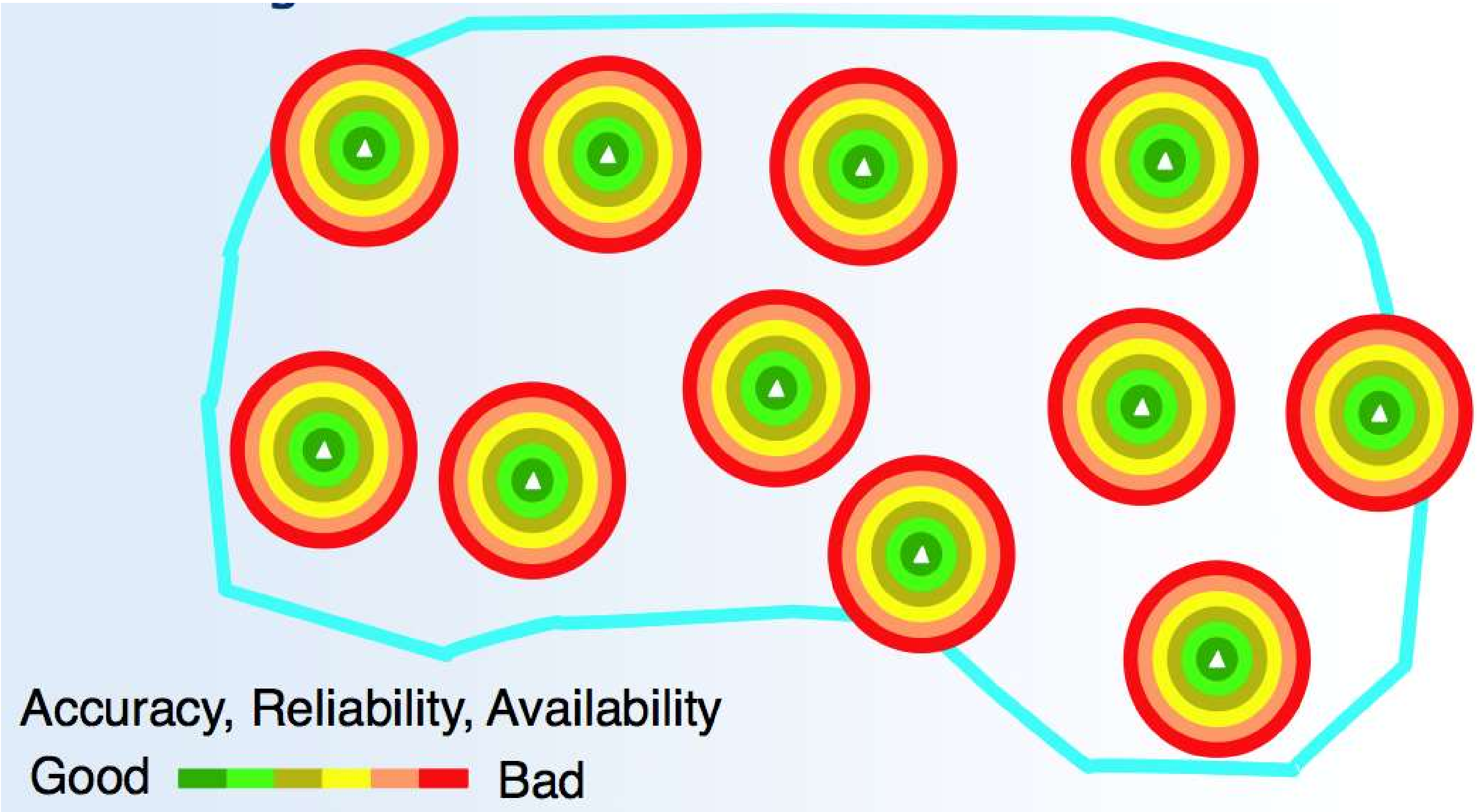
TIME FOR BREAK

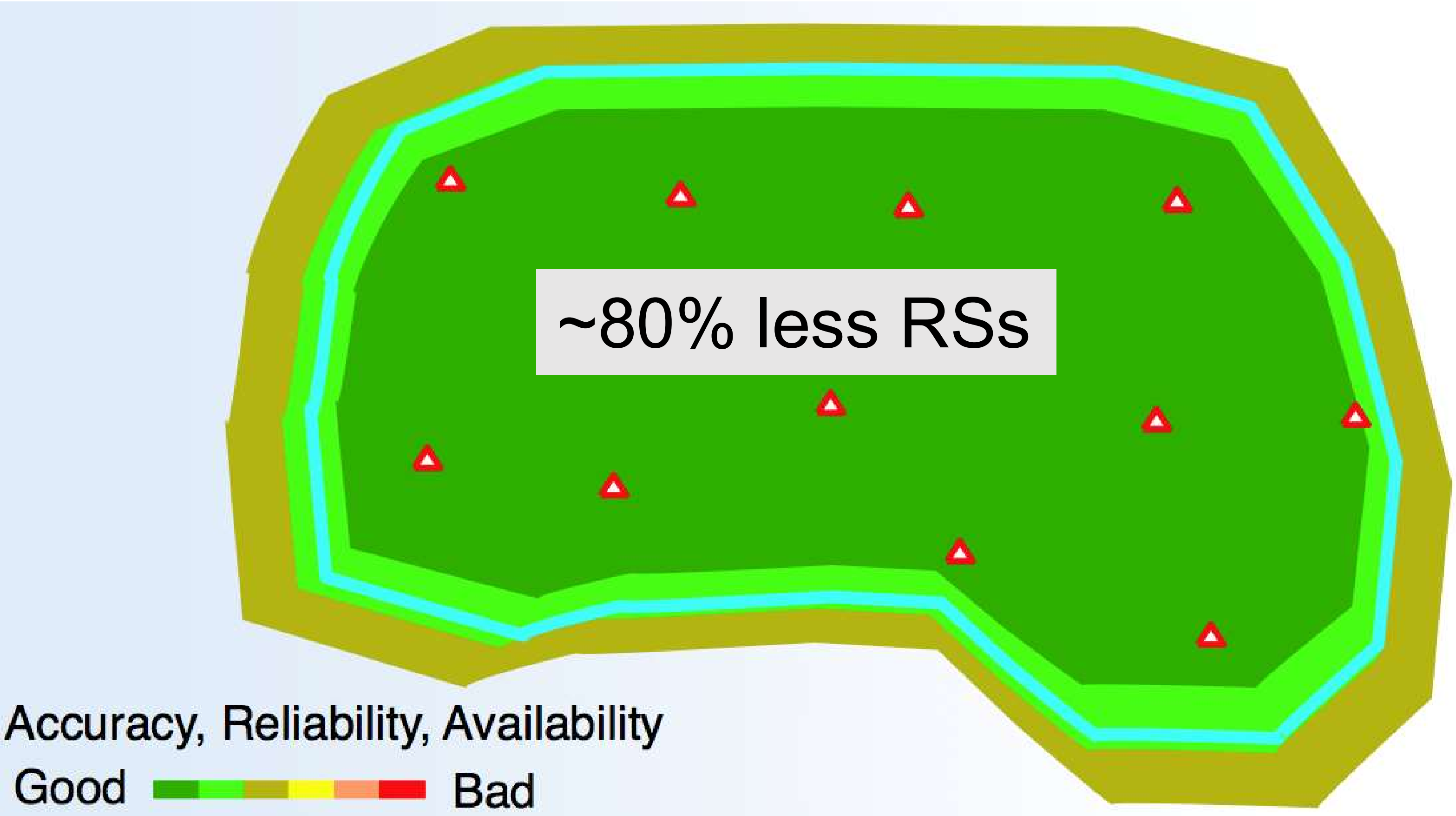


DECORRELATION DEMO

WHY NETWORK RTK?

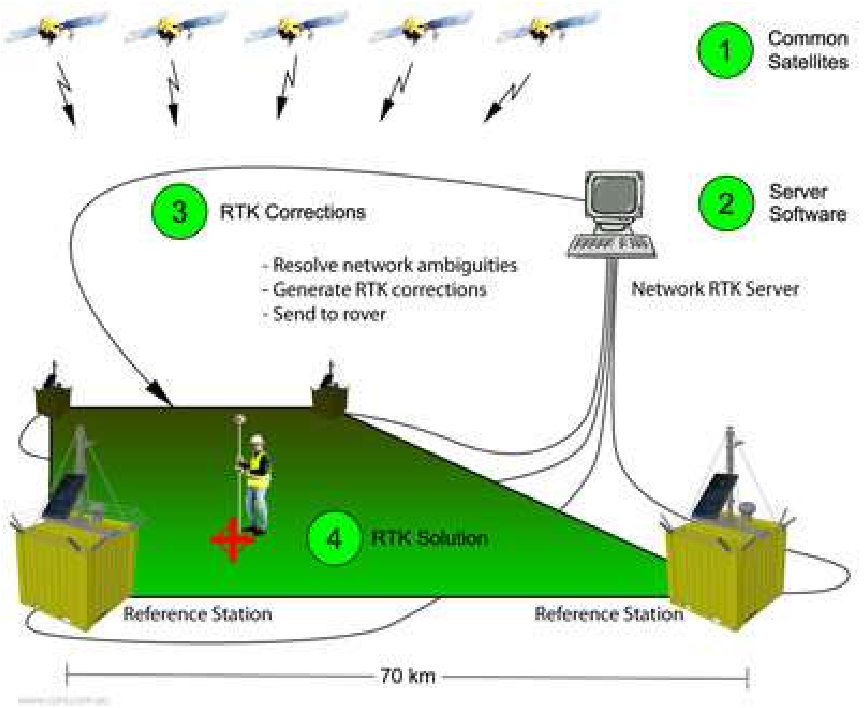


WHY NETWORK RTK?



NRTK CONCEPT

1. **Observe common satellites.**
   - @Rover & RSs
2. **Resolve Network Ambiguities**
   - The network server resolves the ambiguity of the network
3. **Generate RTK Corrections**
   - The network server generates and sends RTK corrections in standard (e.g., RTCM) or nonstandard (e.g., CMR) representation
4. **Produce RTK Solutions**
   - Rover computes an RTK solution



NTRK ADVANTAGES

- Models the GNSS errors over the entire network area
- Increases positioning robustness against RS failure
- Increases mobility and efficiency – no need for temporary RS => one person job!!!
- Offers quicker initialization times for rovers
- Extends the surveying range
- There are no restrictions on the network size (regional, national, global)
- Supports multiple users and apps

NTRK ADVANTAGES (CONT')

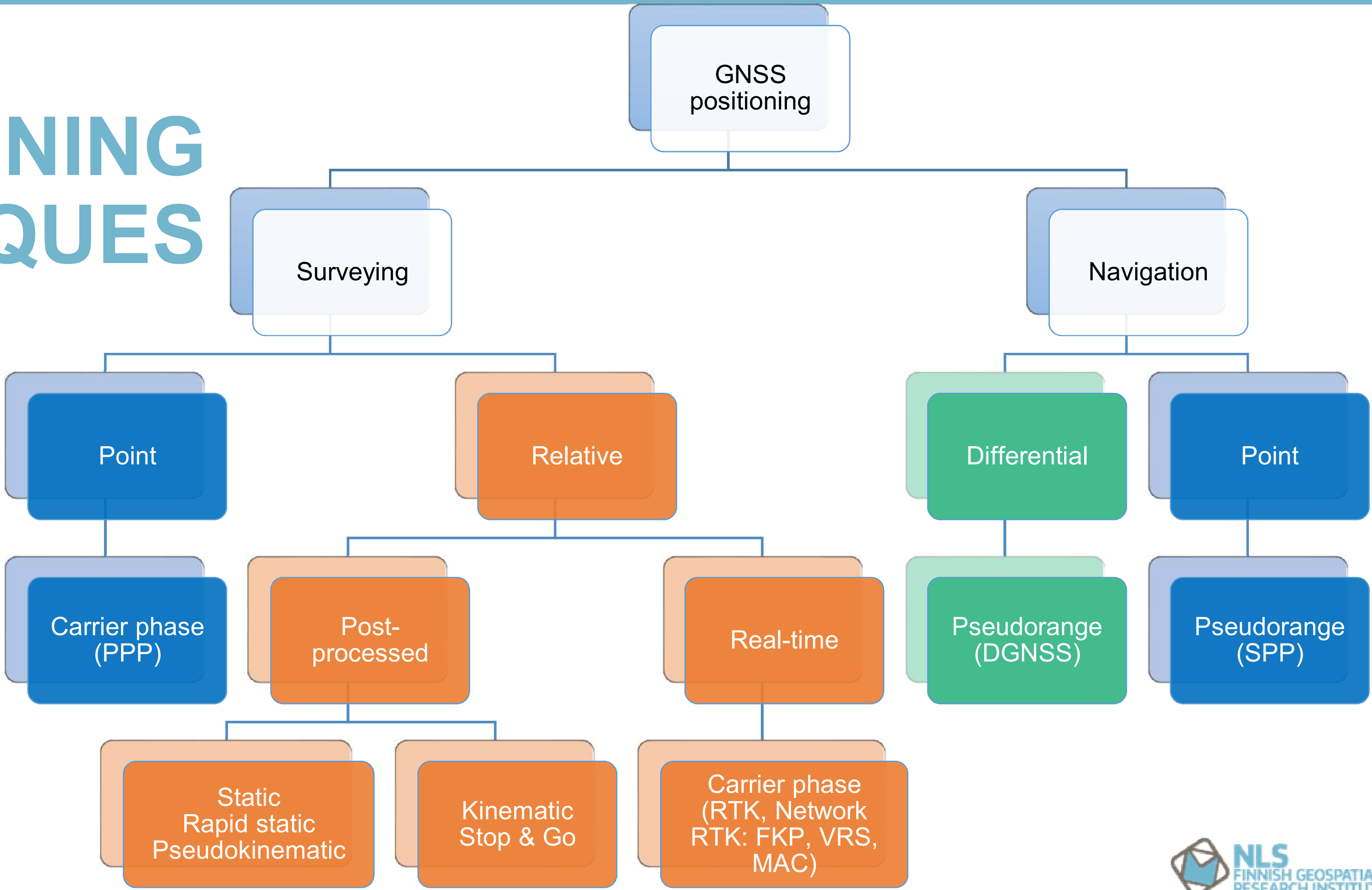
- Operates continuously 365/24/7
- Provides data & corrections in a consistent datum
- Provides other services apart from the real-time corrections
  - RINEX datasets for post-processing
  - GNSS corrections for DGNSS
  - Wide exploitation for geospatial, meteorological, transport, environmental and engineering applications.
- Allows central control monitoring of all stations / high integrity monitoring scheme.

NETWORK RTK: IMPLEMENTATIONS

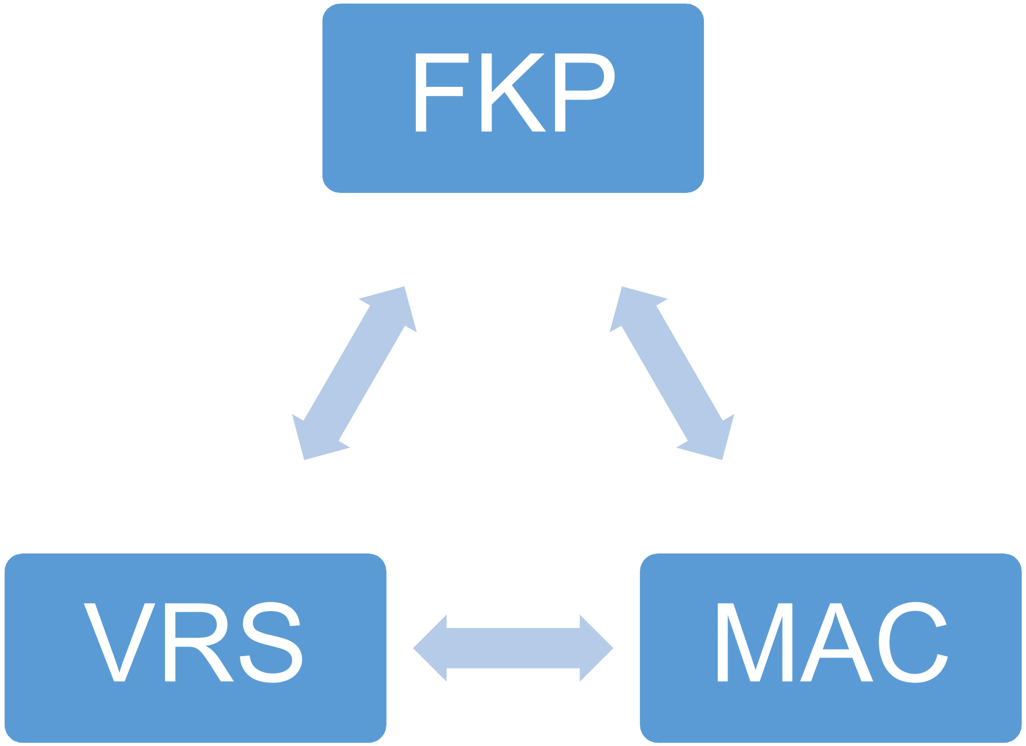
- **Area Correction Parameters (FKP)**
  - The Flächen-Korrektur Parameter (FKP) is the oldest Network RTK method and was developed by Geo++ in the mid 1990s
- **Virtual Reference Station (VRS)**
  - Developed by Terrasat in the late 1990's
  - Pseudo Reference Station (PRS)
- **Master Auxiliary Concept (MAC)**
  - Proposed by Leica and Geo++ in 2001
  - MAX
  - individualized-MAX

All approaches assume that a user will calculate **double differenced baseline** between one RS and the rover

GNSS POSITIONING TECHNIQUES

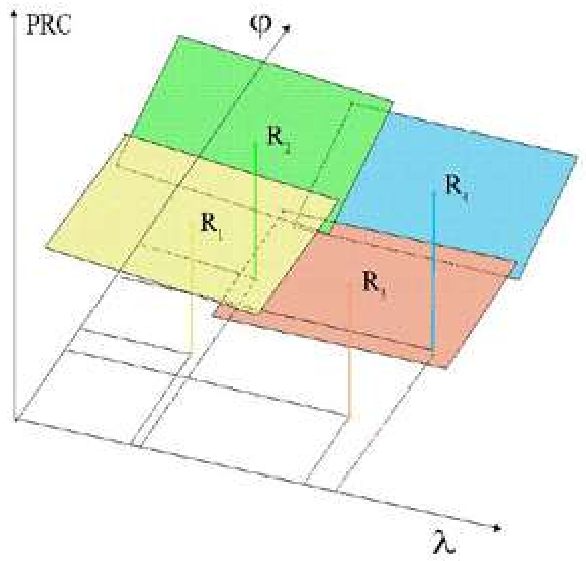


NRTK



AREA CORRECTION PARAMETER (FKP)

- The server models the distance-dependent errors (iono, tropo, orbit effects) for a specific area at certain time intervals
- Uncorrected RS measurements and network coefficients are sent for interpolation via **RTCM message type 59**
- Rover interpolates the messages in order to get its position
- Unidirectional technique
  - one-way comms



Wubenna G., Bagge A., Seeber G., Volker B., Hankemeier P. (1996). Reducing Distance Dependent Errors for Real Time Precise DGPS Applications by Establishing Reference Station Networks. In Proc. Institute of Navigation National GPS 1996 Kansas, 17-20 September, Vol 2, 1845-1852.

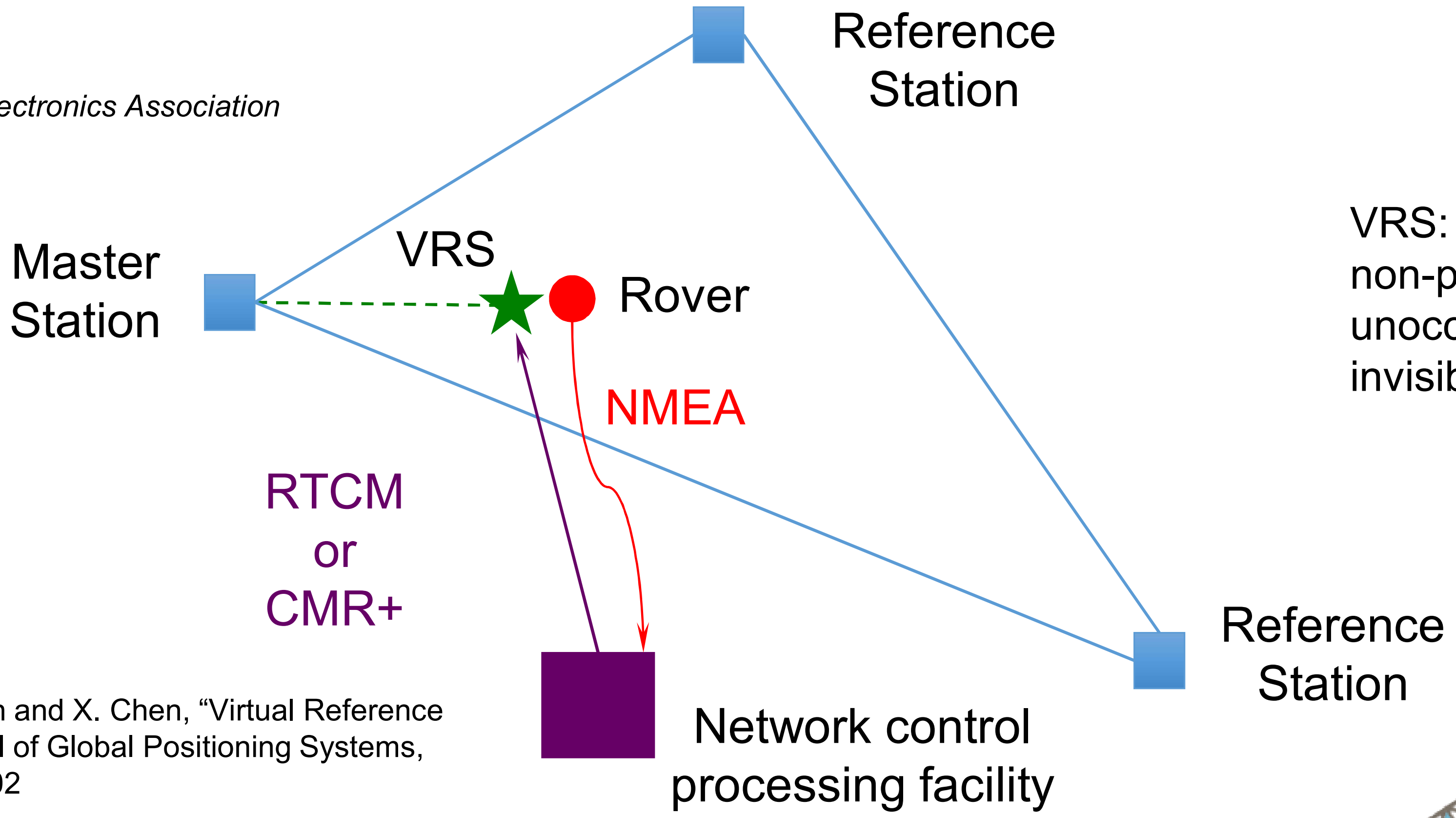
FKP: PROS & CONS

- Unidirectional method
- Low load on server because no complex models
- No restriction on the number of users
- Correction parameters cover a determined area, thus, no force re-initialization required for kinematic apps

- RTCM type 59 is a proprietary message type that may lead to compatibility problems
- **FKP is not fully compatible with the RTCM standard**
- FKP has very limited possibilities to model the residual ionospheric effect
  - Inconsistencies at the edge of the planes

VIRTUAL REFERENCE STATION (VRS)

NMEA: National Marine Electronics Association



VRS:
non-physical,
unoccupied,
invisible

Landau H., and U. Vollath and X. Chen, "Virtual Reference Station Systems", Journal of Global Positioning Systems, Vol. 1, No 2:137-143, 2002

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VRS: BENEFITS

- **Support for RTCM 2/3**
  - no need to update firmware in old receiver
- The server models ionospheric and tropospheric effects using **full network information**
- Data processing at the rover **same as conventional RTK**
  - no need of additional computation
- **Continuous optimization** of the corrections according to each rover position
- **Simplicitiy**

VRS: LIMITATIONS

- **Bi-directional comms links**
  - Costly, high computational burden on the server side, limited number of simultaneous users
- **Re-initialisation**
  - Required at a certain distance from VRS initial position
- **Arbitrary number of reference stations (typically three)**
  - No network corrections are available if one of the reference station is unable to provide data
- **Not a true network solution**
  - Single-baseline method, albeit shorter baseline length

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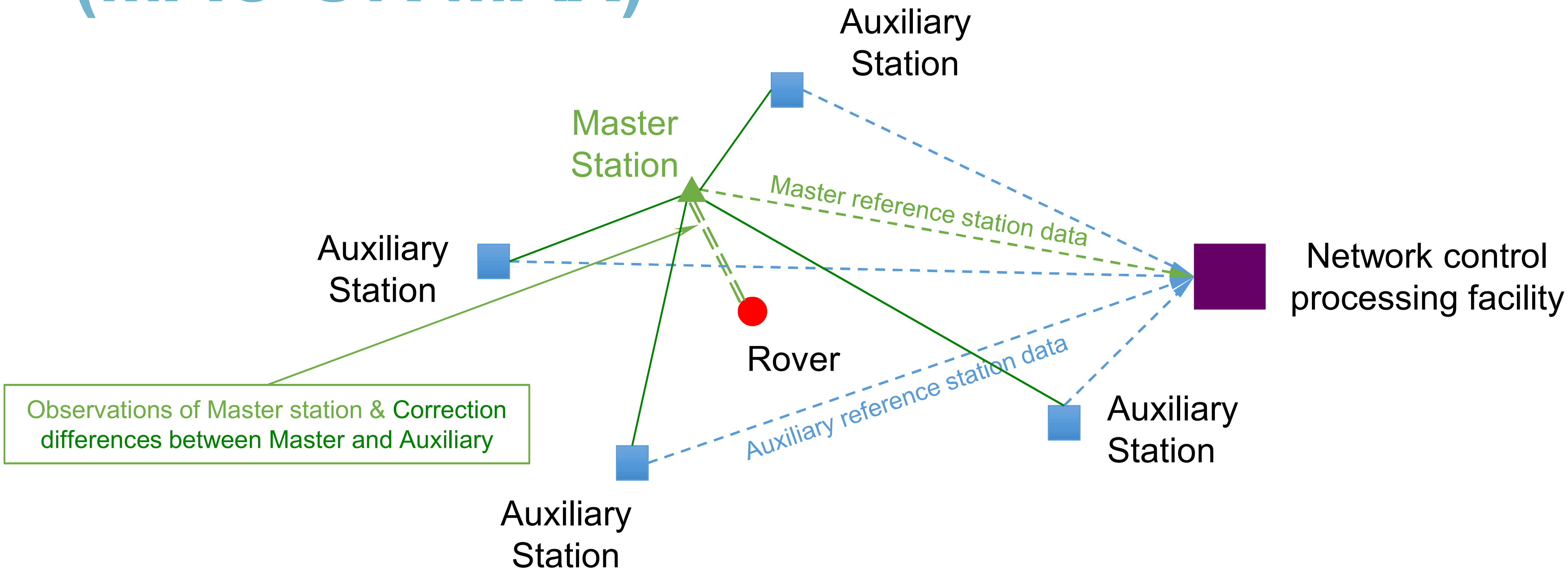
MASTER AUXILIARY CORRECTION (MAC OR MAX)



Euler, H-J., Keenan, C.R., Zebhauser, B.E. and Wuebbena, G. (2001) "Study of a Simplified Approach in Utilizing Information from Permanent Reference Station Arrays", ION GPS 2001, September 11-14, 2001, Salt Lake City, UT.

COMMON AMBIGUITY

- A fundamental requirement of MAC is that the phase ranges from the RS are reduced to a common ambiguity level (the integer ambiguities for each phase range have been removed or adjusted so that when double differences are formed the integer ambiguities cancel)

Ambiguity = CP – P/λ, λ_{L1} *= 0,19 cm*

PRN	Pseudorange (m)	Carrier phase (cycles)	Ambiguity	Corrected carrier	Levelled Ambiguity
19	21256078,787	-20020396,085	-131721844	111701447,915	-0,033
7	20921769,067	-18479457,049	-128424096	109944638,951	0,439
26	20548986,646	-24915615,597	-132901269	107985653,403	-0,265
8	23975564,652	-2831829,561	-128824272	125992442,439	-0,186
19	21267605,587	-19959825,123	-131721847	111762021,877	0,186
7	20907843,148	-18552641,781	-128424099	109871457,219	-0,095
26	20547293,779	-24924512,158	-132901270	107976757,842	0,250
8	23978902,451	-2814288,203	-128824271	126009982,797	-0,081

TIER SYST

- **Network**
- **Cluster**
  - sub-network
- **Cell**
  - Several RS
- **Rover**

MAC: PROS & CONS

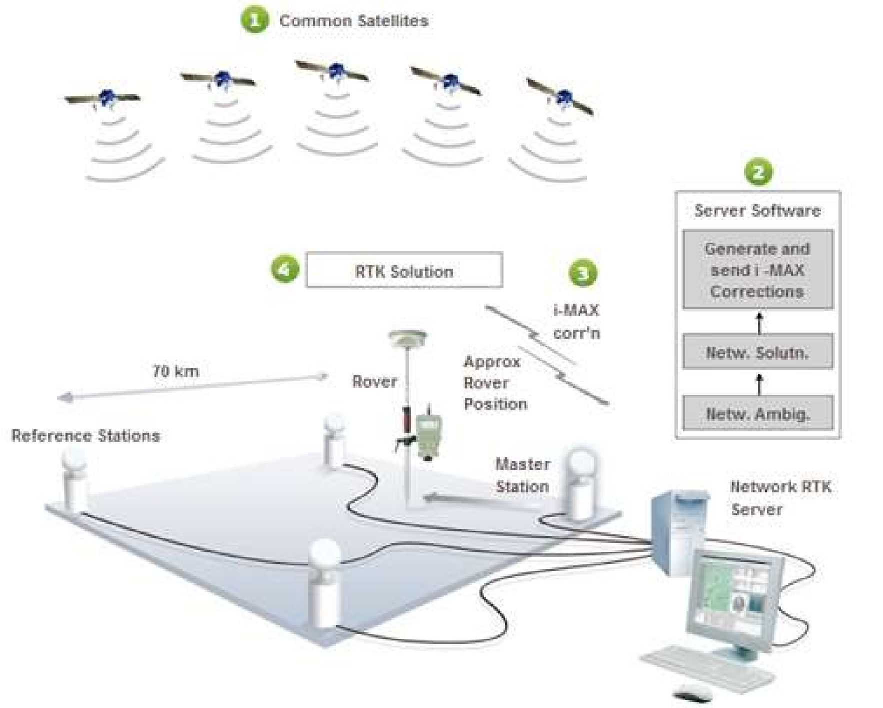
- Latest recommended standard
- Works unidirectional
- No complex models are performed on the server side, making the computational load very low
- The rover is not restricted moving within a determined area within the network

- Only provides a snapshot of the distance dependent errors for a given time
- Only transmits observation differences
- MAC can be setup to work at a lower correction update rate but compromise the results due to increased Age of Correction

INDIVIDUALIZED MAX (I-MAX)

- i-Max generates corrections for a real RS
- i-Max corrections are dynamically updated to follow the rover movement
- Traceable & repeatable

- Non-standardized
- Server controlled solution
- Simulates a single-reference RTK



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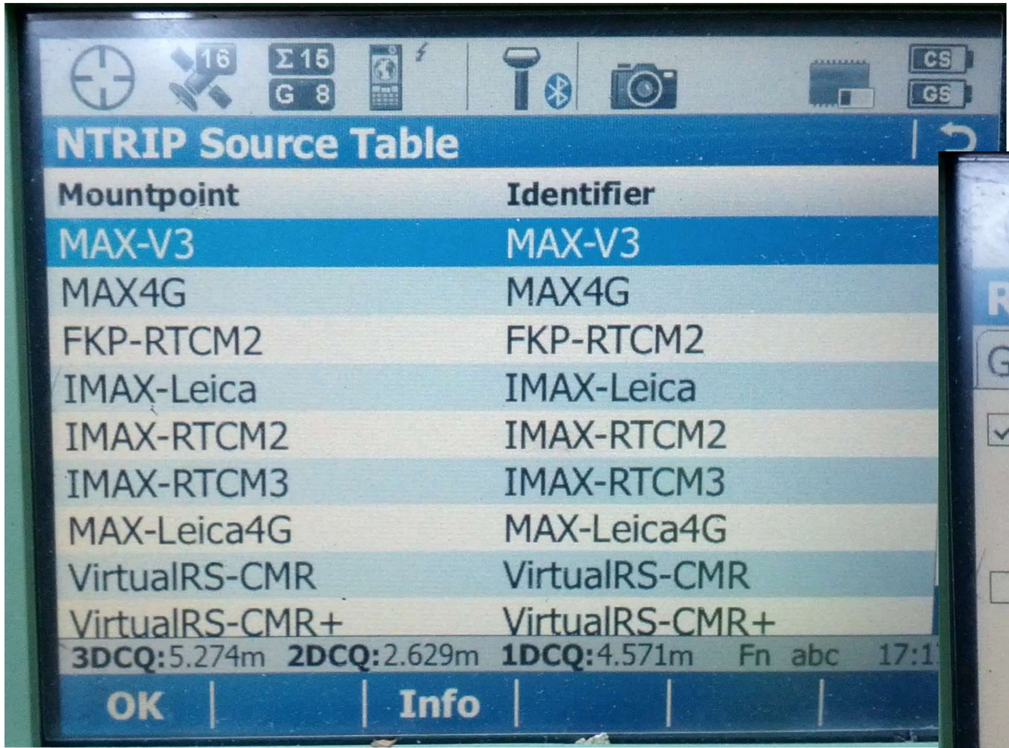
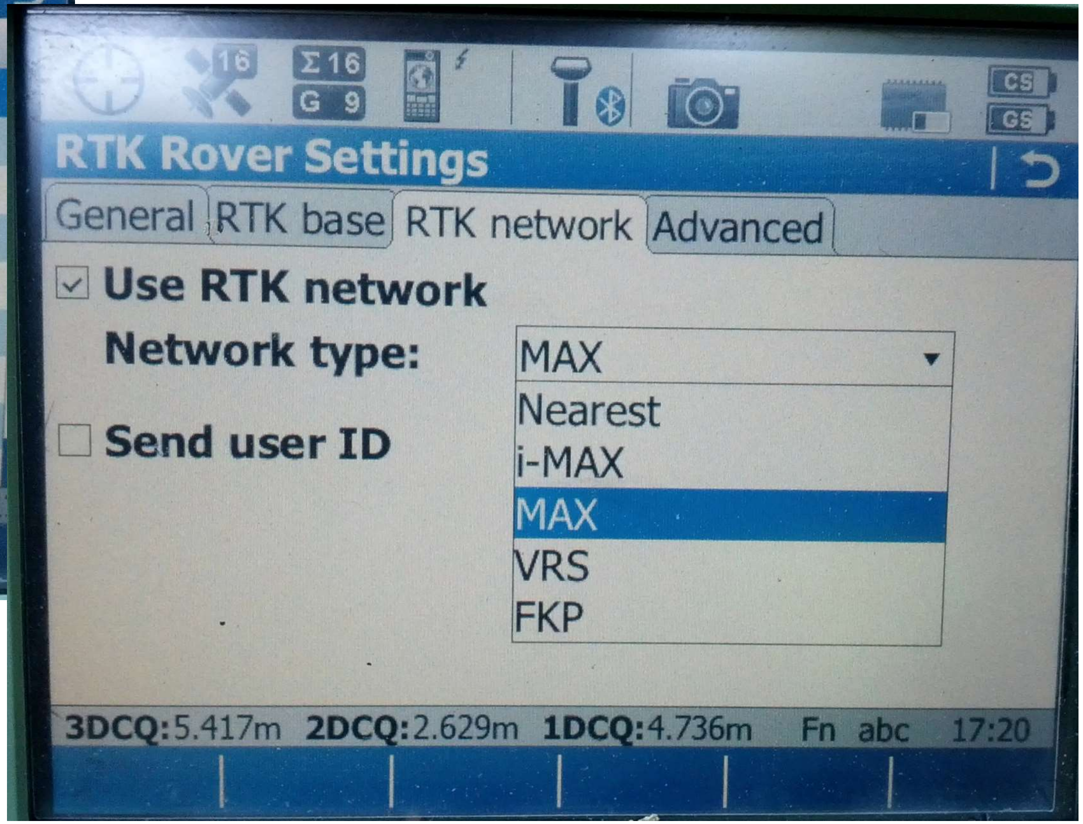


NTRIP Source Table
Mountpoint
Identifier
MAX-V3 MAX-V3
MAX4G MAX4G
FKP-RTCM2 FKP-RTCM2
IMAX-Leica IMAX-Leica
IMAX-RTCM2 IMAX-RTCM2
IMAX-RTCM3 IMAX-RTCM3
MAX-Leica4G MAX-Leica4G
VirtualRS-CMR VirtualRS-CMR
VirtualRS-CMR+ VirtualRS-CMR+
3DCQ:5.274m 2DCQ:2.629m 1DCQ:4.571m Fn abc
OK
Info



RTK Rover Settings
General
RTK base
RTK network
Advanced
Use RTK network
Network type:
MAX
Nearest
i-MAX
MAX
VRS
FKP
Send user ID
3DCQ:5.417m 2DCQ:2.629m 1DCQ:4.736m Fn abc 17:20

REFLECTION QUESTION

Explain the differences in the correction data streams available in the previous slide:

Nearest

i-MAX

MAX

VRS

FKP

NTRK: SUMMARY

	FKP
Network side	Generates area correction parameters Sends the corrections together with a (real) raw master data.
Rover side	Interpolates corrections Applies them to master data Computes DD baseline with corrected data.

NTRK: SUMMARY

	FKP	VRS
Network side	Generates area correction parameters Sends the corrections together with a (real) raw master data.	Generates corrected RS data for a point near the user that includes effect of the error models.
Rover side	Interpolates corrections Applies them to master data Computes DD baseline with corrected data.	Computes DD baseline between two close receivers containing the same (or similar) errors.

NTRK: SUMMARY

	FKP	VRS	MAX
Network side	Generates area correction parameters Sends the corrections together with a (real) raw master data.	Generates corrected RS data for a point near the user that includes effect of the error models.	Sends raw master data and „correction differences" for auxiliaries.
Rover side	Interpolates corrections Applies them to master data Computes DD baseline with corrected data.	Computes DD baseline between two close receivers containing the same (or similar) errors.	Interpolates correction differences to user location, Applies them to raw master observations, Computes DD baseline between master and rover

NTRK: SUMMARY

	FKP	VRS	MAX	i-MAX
Network side	Generates area correction parameters Sends the corrections together with a (real) raw master data.	Generates corrected RS data for a point near the user that includes effect of the error models.	Sends raw master data and „correction differences" for auxiliaries.	Sends master data which is individually adjusted to contain the errors modelled at the user's location.
Rover side	Interpolates corrections Applies them to master data Computes **DD baseline** with corrected data.	Computes **DD baseline** between two close receivers containing the same (or similar) errors.	Interpolates correction differences to user location, Applies them to raw master observations, Computes **DD baseline** between master and rover	Computes **DD baseline** using data containing the same (or similar) errors.

SUMMARY

- **Content**
  - ➢ Various positioning modes: point, differential, relative.
  - ➢ Various positioning techniques: SPP, PPP, DGNSS, Static baseline, RTK

- Are you able?
  - ✓ **to list** different potential error sources in GNSS operation and how they are mitigated
  - ✓ **to explain** how to remove or mitigate the errors

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