FIG Congress 2010
Facing the Challenges – Building the Capacity

TS 10C - GNSS Modernisation and Trends

PPP: Precise Point Positioning – Constraints and Opportunities

Presenting Author: Katrin Huber
Institute of Navigation and Satellite Geodesy
Graz University of Technology
katrin.huber@TUGraz.at

Authors: Florian Heuberger, Christoph Abart (Graz University of Technology)
Ana Karabatic, Robert Weber (Vienna University of Technology)
Philipp Berglez (TeleConsult Austria GmbH)

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Concept of Precise Point Positioning (PPP)

Enhanced single point positioning technique (SPP)

- Using code or phase measurements
- Enhanced SPP by using
  - precise orbits and clocks
  - ionosphere modeling for single-frequency data
  - ionosphere free combination for dual-frequency measurements
  - …

- PPP is a cost efficient technique for precise positioning with a single GNSS receiver
- No need for direct support of reference stations
- Globally valid corrections available

Static accuracies for dual-frequency measurements	
decimeter level	after 15 to 30 min
a few cm level	after 1 to 2 hours
almost no improvement	after 4 hours of observations

Concept of Precise Point Positioning (PPP)

Basic mathematical model underlying dual-frequency PPP

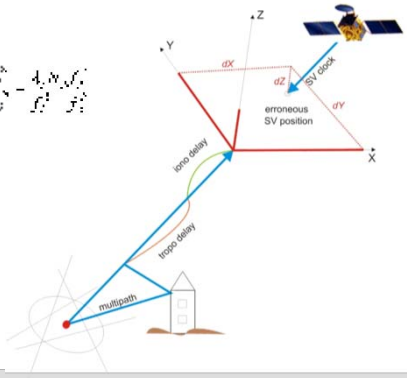
Ionosphere free (IF) combination for code pseudoranges

$$\frac{f_1^2}{f_1^2 - f_2^2} P_1 - \frac{f_2^2}{f_1^2 - f_2^2} P_2 = \rho + c\,dt_r + A_w$$

IF combination for phases

$$\frac{f_1^2}{f_1^2 - f_2^2} \lambda_1 \Phi_1 - \frac{f_1 f_2}{f_1^2 - f_2^2} \lambda_2 \Phi_2 = \rho + c\,dt_r + A_w - \frac{f_1 f_2}{f_1^2 - f_2^2} \lambda_1 N_1 + \frac{f_1 f_2}{f_1^2 - f_2^2} \lambda_2 N_2$$

- P_i ...Pseudorange on frequency f_i
- Φ_i ...Phase measurement on carrier i
- f_i ...Frequency of carrier i
- λ_i ...Wavelength of carrier i
- c ...Speed of light
- dt_r ...Receiver clock error
- A_w ...Troposphere delay
- N_i ...Ambiguity on frequency f_i



PPP Technique
RA-PPP
Tests of PPP services
Approaches for PPP enhancement
Conclusion and prospects

Constraints and Limitations

- PPP (Precise Point Positioning) is a relatively new technique
- Mainly used for post-processing applications because of long convergence times
- Ionosphere free linear combinations
  - combined code and phase noise is amplified compared to the noise of basic L1,L2 signals
  - Non- integer characteristics of the phase ambiguities, ambiguity fixing is prevented
- Account for instrumental biases (DCBs, Phase offsets)
- Real-time applications are in need of predictions of precise orbit and clock corrections (currently at the few dm accuracy level over a couple of hours)
  - need for supporting techniques based on regionally available real-time information
- Single-frequency users need ionosphere models
  - global and regional total electron content (TEC) models are currently at the ± 2-8 TEC-level with a time resolution of one hour (range errors in the order of 30 cm up to 1 m).

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RA-PPP

Innovative Algorithms for Rapid Precise Point Positioning (RA-PPP)

FFG

a research project financed by the Austrian Research Promotion Agency (FFG) in the course of the Austrian Space Applications Programme (ASAP)

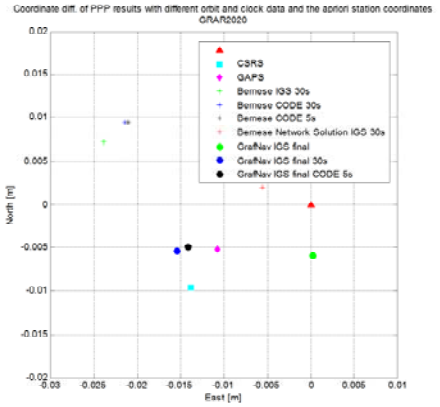
Project consortium:

- Institute for Navigation and Satellite Geodesy (Graz University of Technology)
- Institute of Geodesy and Geophysics (Vienna University of Technology)
- TeleConsult Austria GmbH
- Wienstrom GmbH

Project goals

- Development of improved algorithms for PPP
- New approaches based on
  - derivation of improved TEC models for single frequency users
    - due to increased spatial resolution of the models
    - enhanced position accuracy for single-frequency PPP
  - use of 'regional clock' corrections
    - improvement of convergence time
    - enhanced accuracy
  - use of new signals with reduced phase noise within iono-free linear combinations
    - reduced noise amplification compared to GPS L3 combination
    - combination might preserve integer character of ambiguities (tri-lane)
  - simulation to introduce a priori determined instrumental biases and to solve for ambiguities under special conditions
    - improved convergence times
- Development of a PPP user-client for single and dual-frequency processing

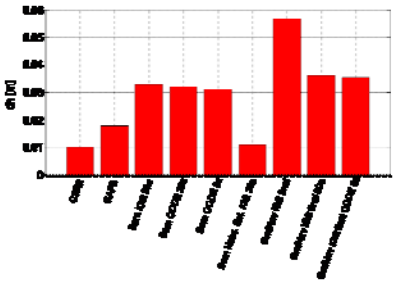
Tests of PPP services in run-up phase



Bernese PPP post-processing engine allows
- advanced PPP settings
- the use of modified routines

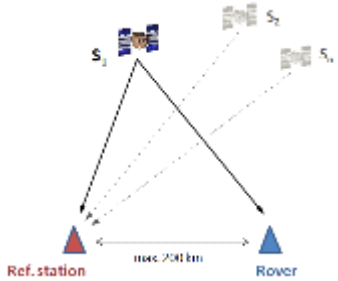
Use of 30 s clocks should be preferred to 5 min clocks

Results within a few cm compared to station coordinates



Regional Clocks

- Satellite clock corrections 'manipulated' to absorb regional effects
- Modified clock corrections used in PPP



Calculated from data of nearby master station – regional clocks capture:

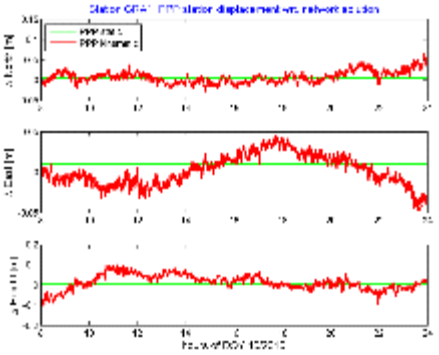
- Remaining troposphere delay
- Remaining satellite clock and orbit errors
- Ambiguity offset

Those correction terms are spatially and temporally correlated with measurements of the rover

Feed PPP with regional clocks
→ improvement of convergence time

Regional Clocks – test of concept 1 – post-processing

- Tested with Bernese software
- Data set recorded on February 9th, 2010 near Graz



PPP coordinate time series (precise orbit + clocks, estimated tropospheric delay)

- Static PPP solution
- Kinematic PPP solution (30 s)
- CODE precise orbits and clocks

Displacement from network solution:

Horizontal:	< 5 cm
Height:	<10 cm

Regional Clocks – test of concept 2 – post-processing

$$P_r = \rho + \boxed{\Delta\rho_{TROPO}} + \Delta\rho_{ORB} + c\Delta t_R - c\Delta t^s$$

$$L_r = \rho + \boxed{\Delta\rho_{TROPO}} + \Delta\rho_{ION} + c\Delta t_R - c\Delta t^s + b$$

Calculate ZWD at master station using precise products (orbit + clocks)

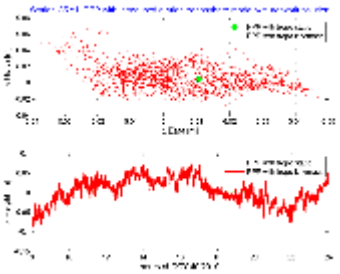
$$\delta t_{TROPO} = \delta\rho_{TROPO} / c$$

- Introduce δt_{TROPO} and forward to rover
- Solve for rover coordinates at rover site

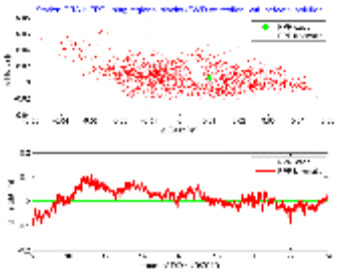
Regional Clocks – test of concept 3 – post-processing

Introduction of troposphere wet delay from network solution

Troposphere wet delay captured by 'regional clocks' and introduced in PPP solution



Introduced tropospheric delay from network solution



Introduced regional clocks (ZWD correction)

→ Tropospheric delays can be easily compensated by artificial corrections to the satellite clocks.
Remaining common range-differences are captured by the rover clock correction.

PPP Technique

RA-PPP

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Regional Clocks – test of concept 4 – post-processing

Account for imprecise orbit information at rover site (e.g. almanac)

$$P_r^s = \rho + \Delta\rho_{trop_r} + \Delta\rho_{orb_r^s} - c\Delta t_r + c\Delta t^s$$

$$L_r^s = \rho + \Delta\rho_{trop_r} + \Delta\rho_{orb_r^s} + c\Delta t_r - c\Delta t^s + b$$

Calculate ZWD at master station using precise products (orbit + clocks)

$\delta t_{trop_m} = \delta z_{trop_m} / c$

Calculate difference between precise and almanac orbits

$\delta t_{orb_r^s} = \Delta_{orb_r^s} / c$

$$\delta reg_{corr}^s = \delta t_{trop}^s + \delta t_{orb}^s$$

- Introduce δt_{reg} and forward to rover
- Solve for rover coordinates at rover site

PPP Technique

RA-PPP

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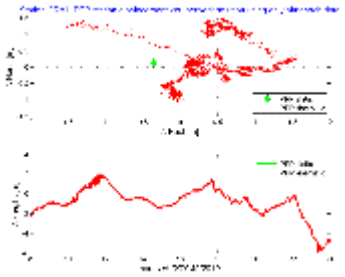
Regional Clocks – test of concept 5 – post-processing

Worst case scenario:

PPP solution with pure almanac data



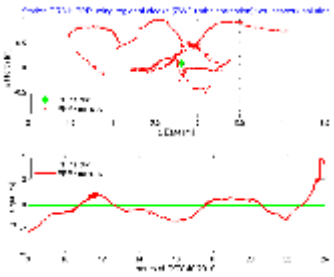
PPP distribution of plane coordinates plus height (raw almanac)

Displacement of static solution:
- Horizontal: < 4 dm
- Height: < 7 dm

Kinematic:
- some meters

'Regional clocks' solution:

PPP with almanac orbit information improved by 'regional clock' correction



Influence of regional clocks adapted for orbit corrections

Displacement of static solution:
- Horizontal: < 1-2 dm
- Height: < 1 dm

Horizontal displacements of the kinematic solutions are still huge due currently not accounting for along-track and cross-track orbital errors

Use of 'regional clock' corrections

- Real-Time (RT):
  Regional Clock corrections are calculated at the master station from
  - Code + Phase measurements and by means of
  - currently best available ZWD and
  - orbit information.

  RT - Regional Clock corrections are differences between satellite clock corrections and the master station clock offset.
- Alternative method to differential RTK- solution based on reference station network
  - if bandwidth for data communication is too low
  - or communication is too expensive to forward standard RTCM range and phase corrections.
- Validity span of Regional Clock corrections is quite long due to medium term variation of orbital errors and ZWD. Regional Clock corrections might therefore be interpolated and extrapolated (in case of stable satellite clocks). Spatial correlation of effects captured by Regional Clocks is up to 200km.
- Use of Regional Clocks will reduce convergence time of the PPP solution.
- PPP post-processing Services (PPP processing either at service center or at rover site) may take advantage of Regional Clocks due to limited need for data storage and data-transmission, short computation times and availability of a new service level aiming at sub-dm accuracy.

Conclusion and Prospect

- Project RA-PPP is running until end of July 2010
- Test execution of PPP client and evaluation of the new approaches will follow

Future aspects:

- Optimization of PPP algorithms towards real-time applications

→ Will be investigated in a possible follow-up project of RA-PPP

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Regional Clocks

Processing 1 - Rover Coordinates

Input:
- RINEX data of rover and 1 nearby reference station
- Almanac data
- IGU orbits and clocks
- A priori troposphere model
- Ionosphere model

- Accurate rover coord. over 24h using the reference station data with precise ephemerides
- PPP solutions under various scenarios (up to 24 hours)

Processing 2 - ZWD time series

Input:
- RINEX data of reference station used in 1 and surrounding stations
- IGS precise ephemerides
- A priori troposphere model

- ZWD time series with a temporal resolution of 30 min or 1 h from network solution
- ZWD time series from PPP with fixed coordinates

Processing 3 - 'regional clocks' correction

- **Post-processing:** Calculation of 'regional clocks' from

$$\Delta\rho^{s}_{reg} = \rho^{s}_{obs} + (\rho^{s}_{sat} - \rho^{s}_{geom})$$

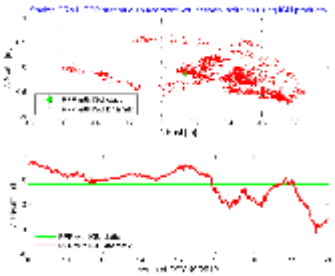
- **Real-Time:** Calculation of 'regional clocks' from range differences after correcting for the station clock.

$$\rho_{reg} = \frac{\rho_{obs} - \rho_{geom}}{c}$$

- 'Regional clock' corrections added to almanac clock model
- single- and dual-frequency PPP solutions for time intervals from 30 min – 6 h with clock correction

Regional clocks – test of concept 6 - postprocessing

PPP solution with IGU products



Displacement of static solution:

Horizontal:	< 2 dm
Height:	< 4 dm

Kinematic:

1-2 meters