Preliminary analysis of ionosphere-corrected PPP-RTK user performance

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1. Introduction
The realization of the integer ambiguity resolution (IAR) enabled precise point positioning (PPP) method, the so-called PPP-RTK, is enabled by providing single-receiver PPP users with satellite phase biases to recover the integerness of the user ambiguities. Successful IAR can greatly reduce the solution convergence time. However, the unknown ionospheric delay parameters that are estimated by the PPP-RTK user (ionosphere-floating model) do not allow for fast (or instantaneous) convergence to the centimeter level.

In this paper, we present a preliminary analysis on the improvement of PPP-RTK GPS dual-frequency user positioning performance using precise ionospheric corrections, which are expected to greatly reduce the convergence time. The ionospheric corrections used at the user level are determined by modeling PPP-RTK ionospheric slant delays computed from receivers of a regional network. The improvement of the PPP-IAR user performance is analyzed in terms of the required time to fix the integer ambiguities (TTFs) and the achieved convergence time to the 1 cm level.

2. PPP-RTK network system
The basis of the PPP-RTK network system is the uncombined GNSS code and carrier-phase observation equations:

\[ E(p^*_j + d_t^*) = p^*_j + d_t^* + m^*_j + \mu \nu_j + \delta \lambda + \delta \theta_j + \delta \phi_j \]

Since not all the unknown parameters are unbiasedly estimable, we apply the S-system theory to eliminate the rank-deficiencies [1]. Assuming that precise orbits and clocks are used, the estimable parameters are:

\[ d_t^* = (d_t + d_t^*) + (d_t + d_t^*) - (d_t + d_t^*) \]

\[ \delta \lambda = (\delta \lambda - \delta \lambda) + (\delta \lambda - \delta \lambda) \]

\[ \delta \theta_j = (\delta \theta_j - \delta \theta_j) + (\delta \theta_j - \delta \theta_j) \]

\[ \delta \phi_j = (\delta \phi_j - \delta \phi_j) + (\delta \phi_j - \delta \phi_j) \]

3. PPP-RTK user system
The definition and estimability of the ionosphere-floating PPP-RTK user parameters are the same as in the network component:

\[ E(p^*_j + d_t^*) = p^*_j + d_t^* + m^*_j + \mu \nu_j + \delta \lambda + \delta \theta_j + \delta \phi_j \]

The user phase ambiguities are now double-differenced and therefore integer.

If ionospheric corrections are provided to the user, the receiver code bias parameter of the user becomes estimable.

4. Data – Processing strategy
For the network and user processing, a network in US with the largest inter-station distance being ~370 km was processed for 24 hours on February 15, 2014. Dual-frequency GPS-only 30 s data are used for the processing with an elevation mask of 50 degrees.

- Meas. noise at zenith: 30cm / 3mm for code / phase
- Parameter estimation using Kalman filter
- Full integer ambiguity resolution using LAMBDA [3]
- User-specific ionospheric slant delays determined using the least-squares collocation [3] and the best linear unbiased prediction model [4].

5. Results
- When precise ionospheric corrections are provided to the user, the model becomes stronger than before leading to more precise phase ambiguities and, therefore, to higher ambiguity success rates and shorter TTFAs, see (a) and (b).

- The quite stable satellite phase biases, see (c), allow for realizing PPP-RTK. When ionospheric corrections are further used, the convergence time drops to only 9 minutes, see (d).

- The estimable receiver code bias shows a stability over time, with its daily variation not exceeding 20 cm, see (e).

6. Conclusions
- The ionosphere-floating model is weak in terms of IAR due to the increased number of unknown parameters.
- Precise ionospheric corrections can significantly reduce the convergence time.

Outlook: A large number of sample data will be processed to infer the distribution of the achieved convergence times, due to the random nature of the GNSS data.

References
[1] Khodabandeh, M., Skłodowska, K., Delft University of Technology, The Netherlands
[4] Skłodowska, K., Ph.D., Faculty of Geosciences, University of Twente, The Netherlands

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