A PPP-RTK Approach to Mass-Market Applications

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KEY WORDS: Precise Point Positioning, RTK

ABSTRACT:

PPP-RTK has been widely investigated to take the advantages of both real-time kinematic (RTK) and precise point positioning (PPP) techniques. Prior to PPP-RTK, the conventional RTK based on the use of a single base station, on the one hand, has been extended to work within a regional network of multiple base stations, known as network RTK (NRTK). The RTK and NRTK enable fast ambiguity resolution over a short baseline or a local region. PPP, on the other hand, eliminates the need to establish any local network like NRTK, which is able to work in a single receiver mode but it suffers long convergence time in ambiguity resolution. PPP-RTK therefore can provide fast ambiguity resolution capability like RTK and NRTK. Current PPP-RTK techniques however still face challenges in supporting mass-market applications such as mobile devices and autonomous vehicles. Although PPP-RTK system (a combination of RTK and PPP technologies) can help expand the coverage of RTK and speed up the ambiguity resolution in PPP, the deployment and maintenance of a dense network of permanent base stations and a central data processing infrastructure for generation of SSR corrections increases not only the system cost but also the system complexity. This is particularly an obstacle for mass-market applications. In this paper, a new RTK approach is described. First it is based on a single base station state-space-representation (SSR) correction generation strategy to support fast ambiguity resolved PPP. Further it presents a new peer-to-peer propagation strategy to form a real-time dynamically generated network of base stations to support mass-market application users with unbounded coverage. As a result, the new approach eliminates the need to deploy and maintain a dense network of permanent base stations and central data processing infrastructure as required in a conventional PP-RTK system.

1. INTRODUCTION

PPP-RTK has been widely investigated to take the advantages of both real-time kinematic (RTK) and precise point positioning (PPP) techniques. Prior to PPP-RTK, the conventional RTK based on the use of a single base station, on the one hand, has been extended to work within a regional network of multiple base stations, known as network RTK (NRTK). The RTK and NRTK enable fast ambiguity resolution over a short baseline or a local region. PPP, on the other hand, eliminates the need to establish any local network like NRTK, which is able to work in a single receiver mode but it suffers long convergence time in ambiguity resolution. PPP-RTK therefore can provide fast ambiguity resolution capability like RTK and NRTK (Wabbena et al. 2005; Teunissen et al. 2010).

Current PPP-RTK techniques however still face challenges in supporting mass-market applications such as mobile devices and autonomous vehicles. Although PPP-RTK system (a combination of RTK and PPP technologies) can help expand the coverage of RTK and speed up the ambiguity resolution in PPP, the deployment and maintenance of a dense network of permanent base stations and a central data processing infrastructure for generation of SSR corrections increases not only the system cost but also the system complexity. This is particularly an obstacle for mass-market applications (Lyu and Gao Y, 2022).

In this paper, a new RTK approach is described. First it is based on a single base station state-space-representation (SSR) correction generation strategy to support fast ambiguity resolved PPP. Further it presents a new peer-to-peer propagation strategy to form a real-time dynamically generated network of base stations to support mass-market application users with unbounded coverage. As a result, the new approach eliminates the need to deploy and maintain a dense network of permanent base stations and central data processing infrastructure as required in a conventional PP-RTK system.

2. APPROACH DESCRIPTION

The new PPP-RTK approach is based on an architecture with three major components as shown in Figure 1.

The function of each component is described in the following:

- **Single base station SSR correction generation:** The SSR corrections are generated using a single receiver station. This is different from the conventional PPP-RTK which generates SSR corrections using data from all network stations by a data processing center.
- **User station fast ambiguity resolved PPP:** A user station conducts fast ambiguity resolved PPP using single base station generated SSR corrections. This is different from the

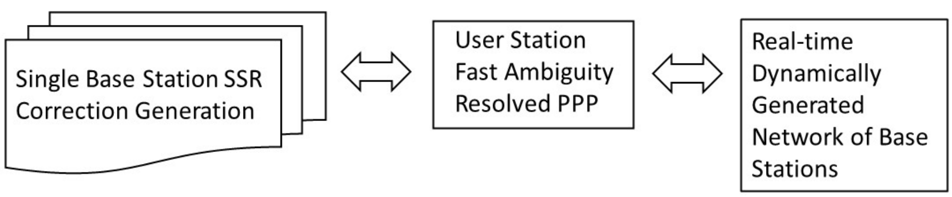

Figure 1: New PPP-RTK Architecture

https://doi.org/10.5194/isprs-archives-XLVIII-1-W1-2023-151-2023

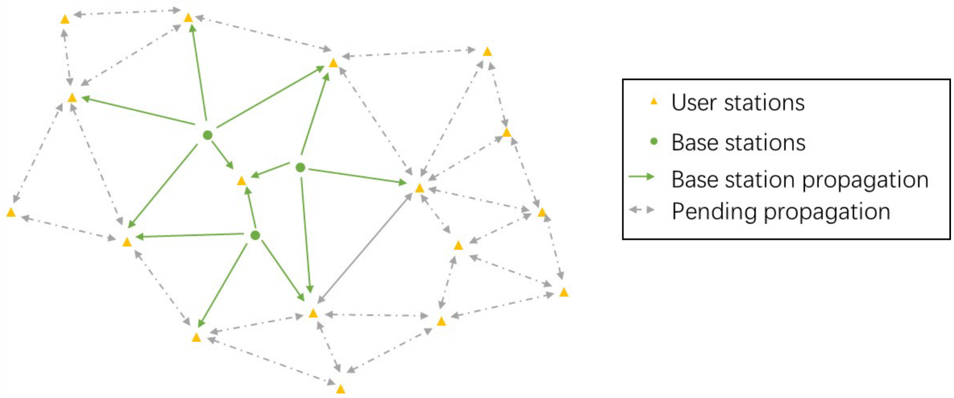

Figure 2: Real-time dynamically generated network of base stations via peer-to-peer propagation

Figure 3: UCENF, PRDS, BD982 and baseline length

conventional RTK which is based on baseline processing with double difference GNSS observations.

- **Real-time dynamically generated network of base stations:** A base station is a GNSS receiver with precisely known coordinates. Any user station can become a base station once ambiguity-resolved position solution has been obtained and contribute to a dynamically generated network of base stations with unbounded coverage via peer-to-peer propagation as shown in Figure 2. Unlike the base stations in the conventional PPP, NRTK and PPP-RTK which are permanently deployed static GNSS receiver stations, the real-time dynamically generated base stations in the new PPP-RTK approach can be static and moving stations.

3. INITIAL TEST RESULTS

To illustrate the proposed PPP-RTK approach, we have conducted a test with three receiver stations consisting of a station (UCENF, Trimble Net R9 receiver) on the roof of the Engineering Building at University of Calgary, an IGS station (PRDS, Javad Delta-3 receiver) and a vehicle with a Trimble BD982 receiver (see Figure 3).

The station UCENF is used as the first base station with precisely known coordinates to generate SSR corrections and the stations PRDS and DB982 whose positions are to be determined are used as two user stations. First we obtain ambiguity-resolved PPP solution at the user station PRDS (a static user in this case) using the SSR corrections from UCENF and then turn it into a new base station based on the concept of peer-to-peer propagation. Then, with PRDS becoming a newly generated base station, we can obtain ambiguity-resolved PPP solution at the user station BD982 using the SSR corrections from PRDS. BD982, initially also user station, now becomes another newly generated dynamic base station able to support fast ambiguity resolved PPP at other user stations. Together the three stations form a real-time dynamically generated network of base stations. Note that a user station can apply SSR corrections from multiple base stations and a fusion algorithm can be developed to further sped up ambiguity resolution, improve positioning accuracy and increase baseline length.

Figure 4 shows the positioning error and used satellite count of PRDS using SSR corrections from UCENF and BD982 using SSR corrections from PRDS (after it becomes a base station). The results indicates that instant convergence and ambiguity fix can be achieved at both stations. The positioning error RMS

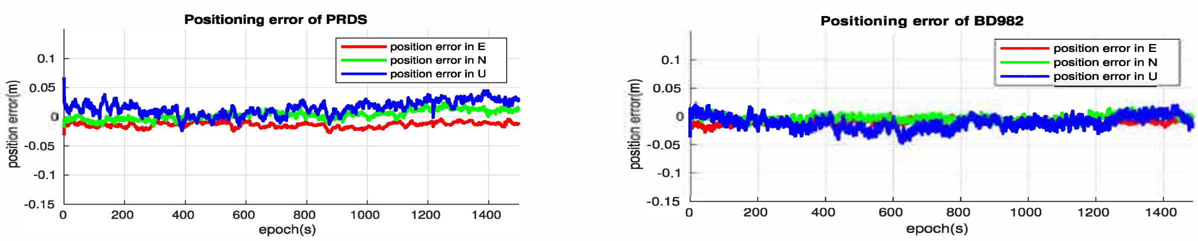

Figure 4: Positioning errors

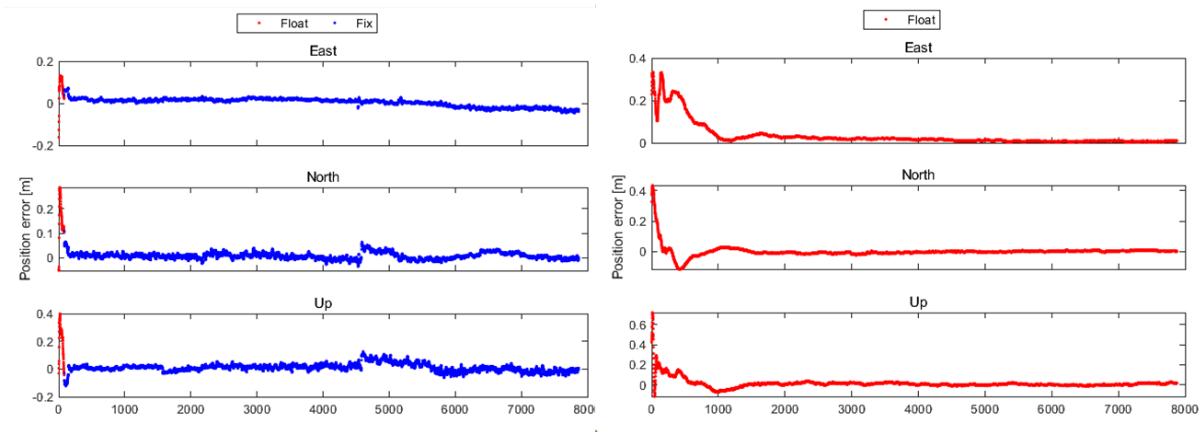

Figure 5: Performance of ambiguity fixing for long baseline (199 km)

values for the sttaic station PRDS are 1.44cm, 0.84cm, 1.92cm in the east, north and up directions respectively. The positioning error RMS values for the dynamic station BD982 are 0.98cm, 0.60cm, 1.55cm in the east, north and up directions respectively.

Shown in Figure 5 are the results from a recent test which show superior performance in terms of ambiguity fixing over long baseline for the new approach. The new approach (left plot) can provide ambiguity-resolved solutions while the conventional RTK (right plot) can provide only float solutions.

4. CONCLUSIONS

A new PPP-RTK approach is described for mass-market applications. It enables fast ambiguity resolved PPP using single base station generated SSR corrections and provides mass coverage by a real-time dynamically generated network of base stations via a peer-to-peer propagation strategy. The new approach therefore offers low-cost and reduced complexity in system implementation for mass-market applications. The initial test results have shown its promising performance.

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