LEO constellation augmented GPS RTK positioning for medium-to-long baselines

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Introduction

With the development of the GNSS and low earth orbit (LEO) satellites, the techniques of GNSS navigation and positioning are becoming increasingly important. In this poster, We design 54-, 162- and 324-satellite LEO constellations and simulate ground-based observations to investigate the medium-long baseline performances of LEO constellations augmented GPS Real-time kinematic (RTK) positioning from the perspectives of convergence time, time to first fix (TTFF), success rate of ambiguity fixing and position dilution of precision (PDOP) values. And the following discussions will be conducted from the aspects of constellation design, observation simulation, data processing strategy and RTK results.

Constellation Design

In order to investigate the influence of LEO satellite number on augmentation performance, a new system is designed by adding the LEO ranging satellite transmitting signals on the L1 and/or L2 band to the GPS. And three kinds of LEO constellations are designed using Satellite Tool Kit(STK) software, a sophisticated space-analysis platform.

Besides, we also simulate the GPS constellation based on its nominal parameter configuration. The nominal numbers of satellites for GPS is 24. For global coverage, these satellites are usually equally distributed over medium earth orbit (MEO). Detailed characteristics of GPS and designed LEO constellations are given in Table 1 .

Orbit	LEO	LEO	LEO	MEO(GPS)
Satellite Number	54	162	324	24
Altitude[km]	1100	1100	1100	20180
Constellations	6 planes	9 planes	18 planes	6 planes
Inclination[deg]	86	86	86	56

Tab. 1(left) : Detailed orbital configurations of GPS and designed LEO constellations

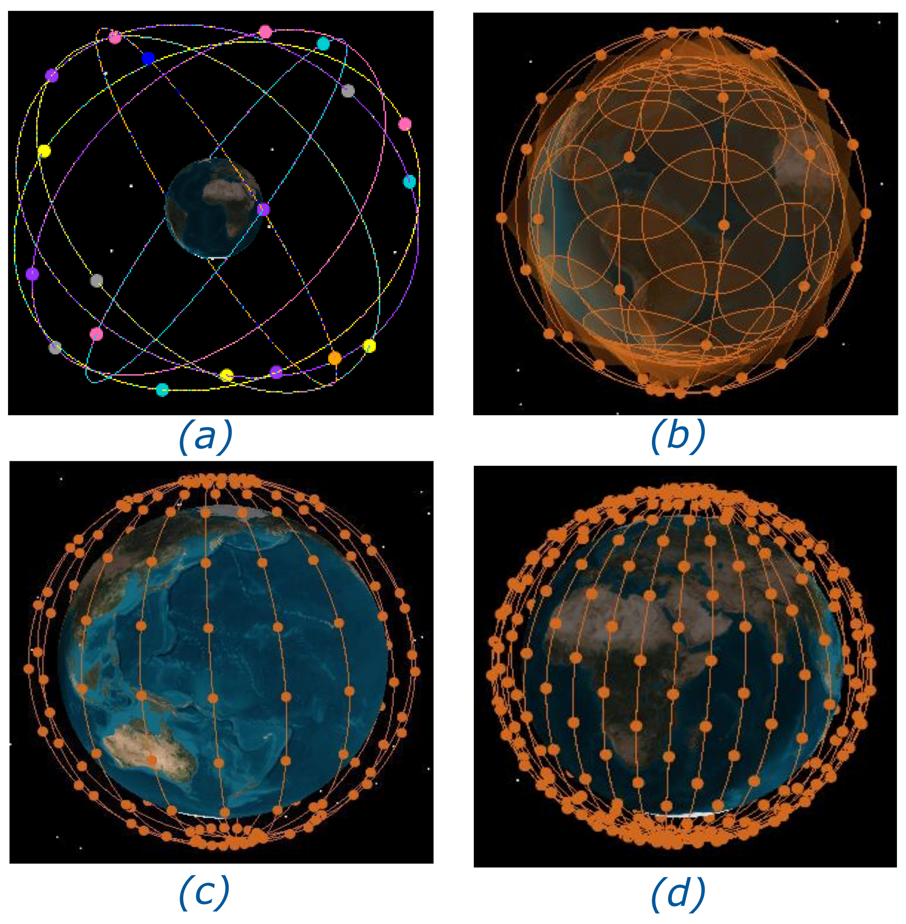

Fig. 1(left): GPS and designed LEO constellations
(a) GPS;
(b) 54 LEO;
(c) 162 LEO;
(d) 324 LEO,

Simulation and Data Processing Strategy

Atmospheric residuals should not be ignored for medium-to-long baselines. So in terms of the observation simulation, the ionospheric delay of GPS is calculated by real TEC grid from GIM, and the one of LEO needs to multiply by one coefficient on this basis. The tropospheric delay is computed by saastamoinen model and real GPS observation, the detail can be referred to (Li et al.2018)

Table 2 summarizes our data processing strategy, observation models and estimated parameters for LEO augmented GPS RTK positioning in details. Thanks to the simulated GPS and LEO observations, we can analyze the performance of GPS RTK without or with LEO satellites from the different perspective.

Tab. 2: Data processing strategy, observation models and estimated parameters for LEO augmented GPS RTK

Items	RTK Solution
Satellites	GPS(G);GPS+LEO(GL);
Estimator	Extended Kalman filter
Observations	pseudorange and carrier phase observations
Signal	G:L1/L2; L:L1/L2
Sample Interval	5s
Elevation mask	7.5°
Satellite/Receiver Clock	Eliminated or weekened by double differenced observation equations
Position parameters	Estimated in kinematic mode
Ionospheric delay	Estimated
Tropospheric delay	Estimated
Phase ambiguity	LAMBDA
Ratio	3.0

Results and Analyses

To get representative evaluation of different LEO constellations augmented GPS RTK, we simulate a 28km-baseline scenery in Hongkong to detailed analyze the augmented performance with 54-, 162- and 324- LEO satellites.

Figure 2 shows 1-hour sky plots of GPS satellites without or with the augmentation of different LEO satellites for 28km scheme. We can find that the LEO satellites streak much longer tracks than the GPS satellites during the same period, such a rapid geometric change is very critical to RTK convergence and ambiguity fixing.

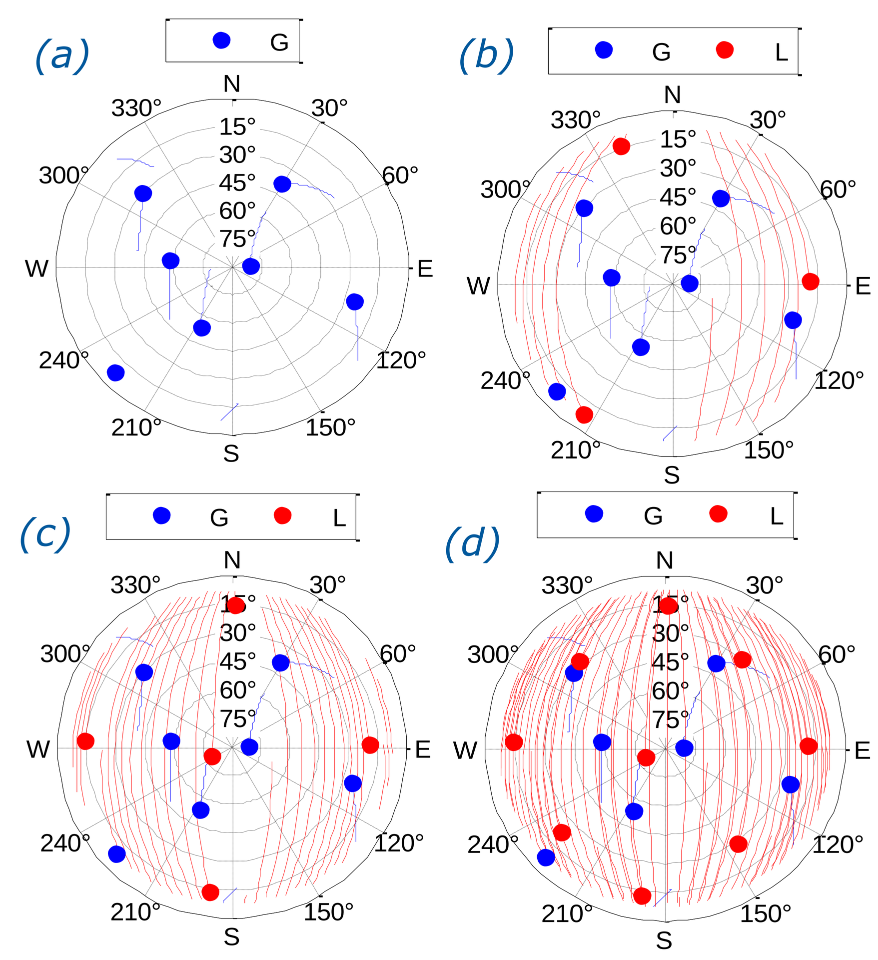

Fig. 2: 1-hour Sky plots of the GPS satellites without or with the augmentation of LEO satellites for 28km baseline, (a)GPS;(b)G+54L;(c)G+162L;(d)G+324L

Figure 3 shows GPS RTK 1-hour results with the augmentation of different numbers of LEO satellites for 28km scheme on January 1, 2017. Figure 4 shows specific statistic of convergence time ,TTFF and success rate of ambiguity fixing. It can be obviously found from Fig. 3a-c and Fig.4a that the inclusion of LEO satellites can significantly accelerate convergence and ambiguity fixing of RTK. Figure 3d, e show the corresponding total numbers of visible satellites and the position dilution of precision (PDOP) values, respectively. it is found that the PDOP values present more rapid variation after introducing LEO satellites, which is due to the fast movement of the LEO satellites.

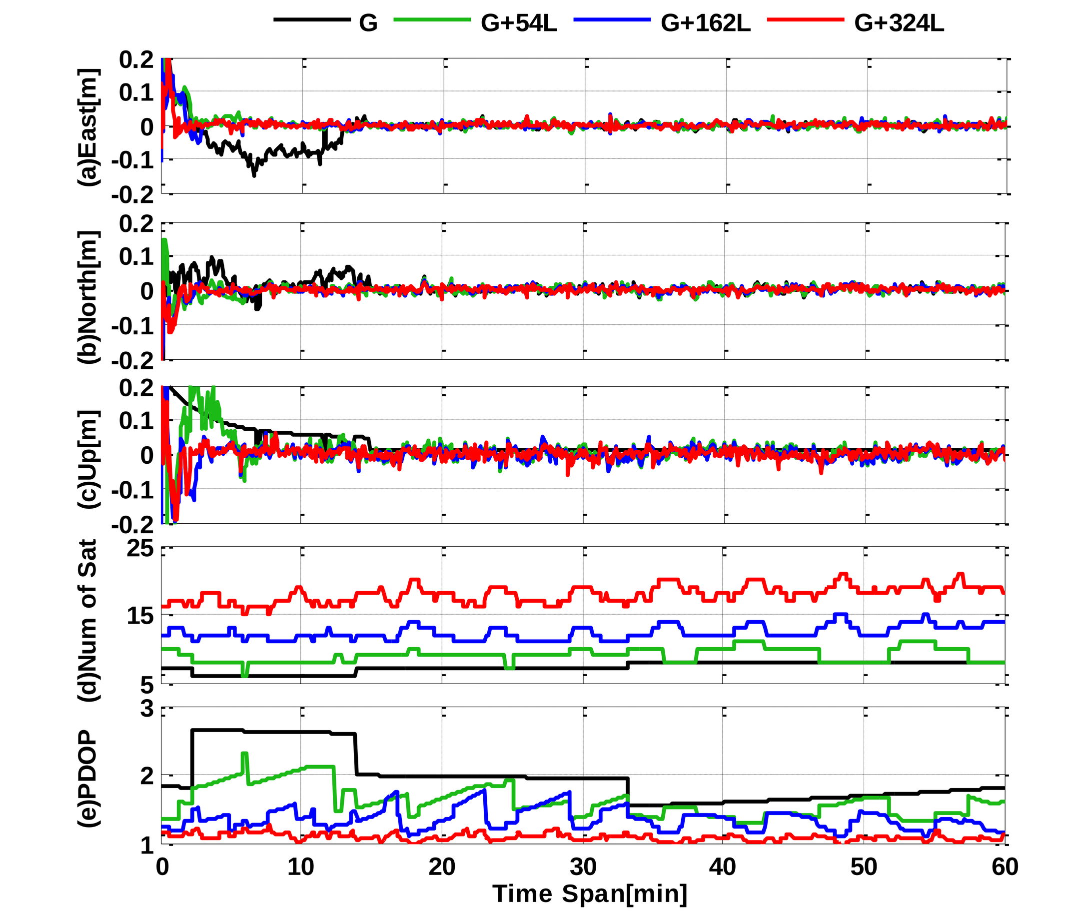

Fig. 3: Comparisons of different numbers of LEO satellites augmented GPS RTK solutions in east, north and up directions, respectively, for 28 km scheme. The corresponding satellite numbers and PDOP values are also shown.

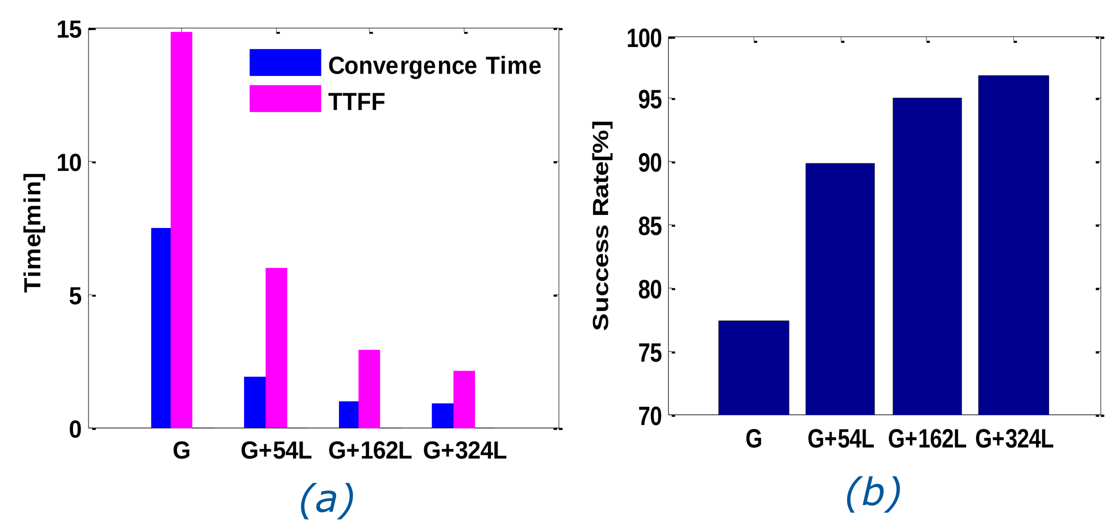

Fig. 4: Statistics of convergence time and TTFF(a), Success rate of ambiguity fixing(b), for 28 km scheme.

For better evaluating the effects of different LEO satellite solutions on the convergence time and TTFF of RTK, we select 5 different length baselines in Hongkong to get statistical average of 4 different periods.

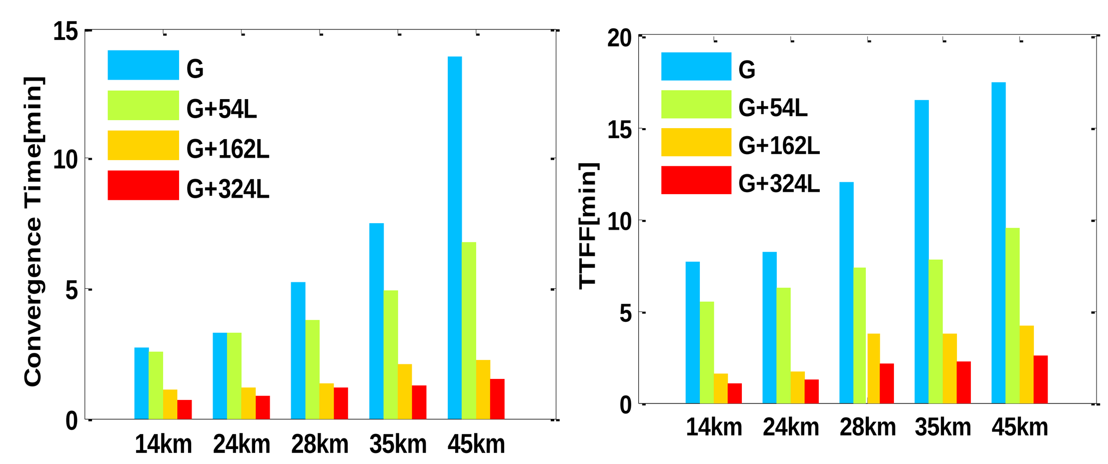

Fig. 5: Statistics of convergence time and TTFF with different length baselines

Conclusions

- With the increase of LEO satellite numbers, the convergences of East, North and Up components are much faster and more stable, and the baseline precisions are achieved at cm-mm level after ambiguity fixing.
- LEO satellites can significantly shorten convergence time and TTFF of GPS RTK, obviously for longer baselines.
- The success rate of ambiguity fixing can be improved by introducing LEO satellites, as well as geometric condition of stations.
- Observing more visible LEO satellites, yields shorter convergence time and TTFF .

References

Li,X., Ma,F., Li,X.et al. J Geod (2018). https://doi.org/10.1007/s00190-018-1195-2