BDS/GNSS instantaneous centimeter-level Precise Point Positioning (PPP): method and applications

Zhao Qile

GNSS Research Center，Wuhan University

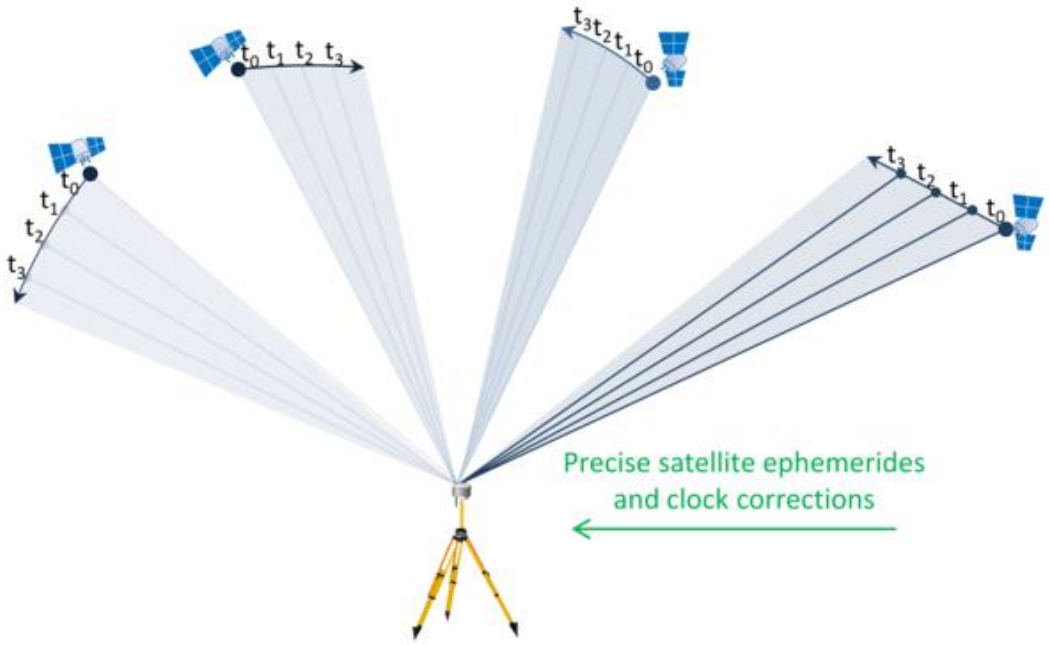
December，2022

Outline

- ☐ The challenges and opportunities of PPP
- ☐ Instantaneous cm-level PPP: technology and system
- ☐ Applications of Instantaneous cm-level PPP
- ☐ Summary and outlook

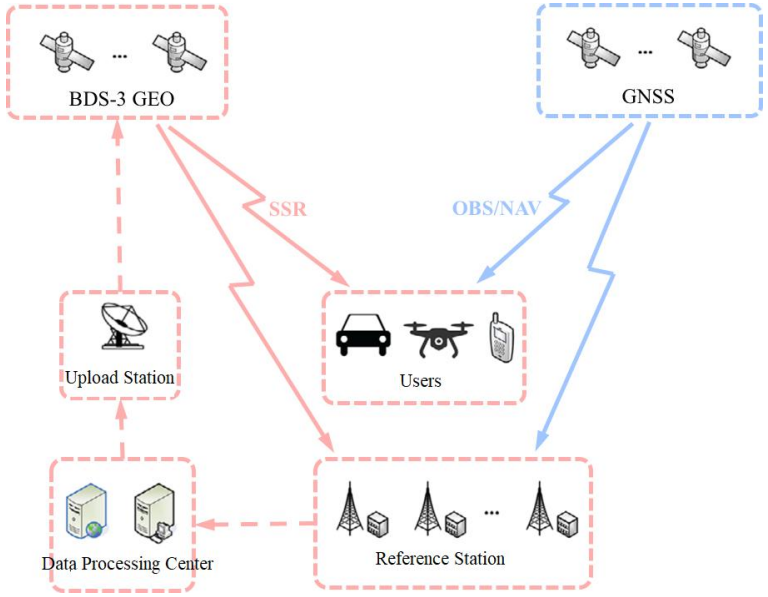
PPP and its challenges

- PPP (Precise Point Positioning)
  - undifferenced pseudorange and carrier-phase observations
  - precise satellite orbit and clock products
  - standalone static or kinematic point positioning with centimeter precision
- Benefit and challenges of PPP
  - \+ Global solution, single station, low cost
  - − Ambiguity float solution, < 10 cm anywhere
  - − **Initialisation ~20-30 minutes**
  - − Requires full re-initialisation after loss of data

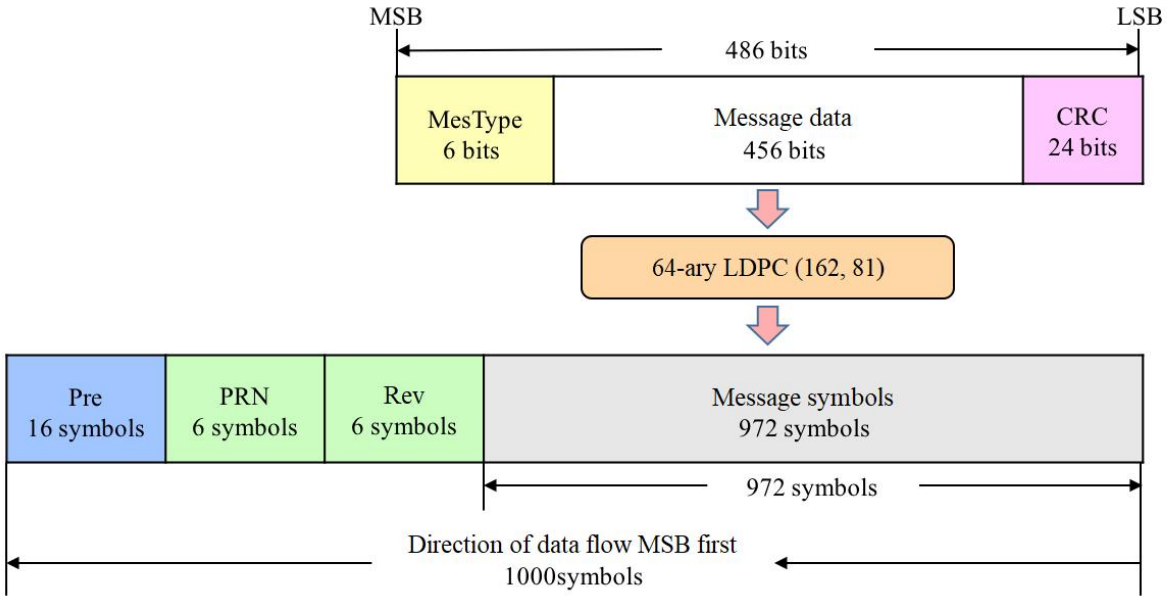


BDS PPP service

- High-accuracy PPP service on BDS-3 broadcasted via three GEO satellites
  - PPP-B2b I-component signal
  - Special designed navigation message with orbit, clock, and more corrections
  - Real-time corrections for BDS and GPS system in BDCS and BDT
  - Decimeter-level positioning around China and surrounding areas



BDS-3 PPP-B2b service system

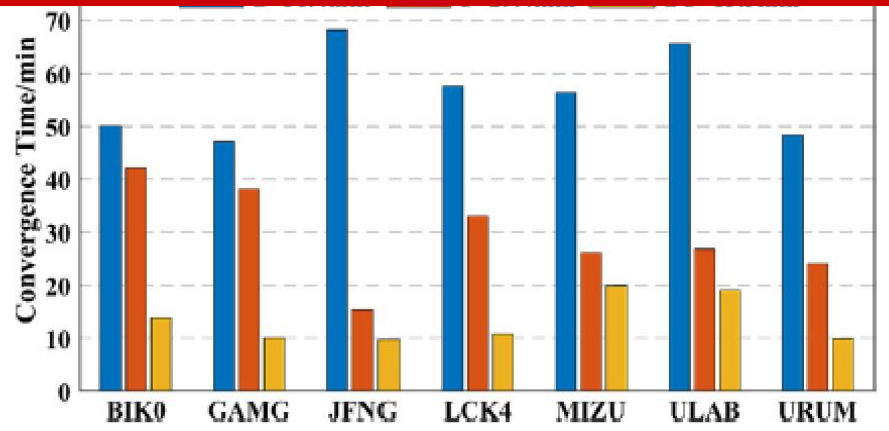


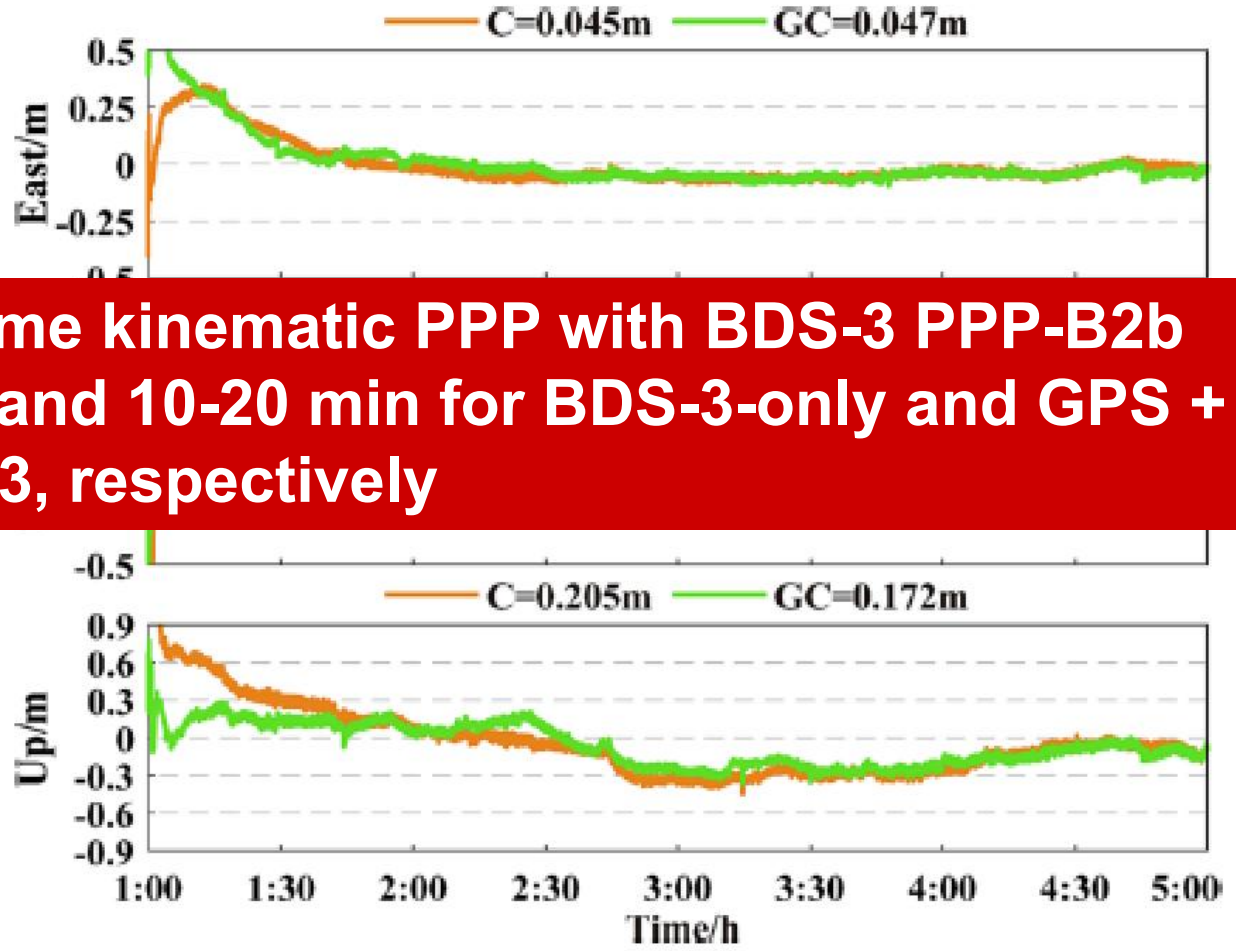
The PPP-B2b navigation message frame structure

Assessment of BDS PPP-B2b

- 7 IGS static stations in China and 1 shipborne kinematic experiment in Guangdong for performance assessment of BDS PPP-B2b

The convergent time of real-time kinematic PPP with BDS-3 PPP-B2b corrections is about 20-30 min and 10-20 min for BDS-3-only and GPS + BDS-3, respectively

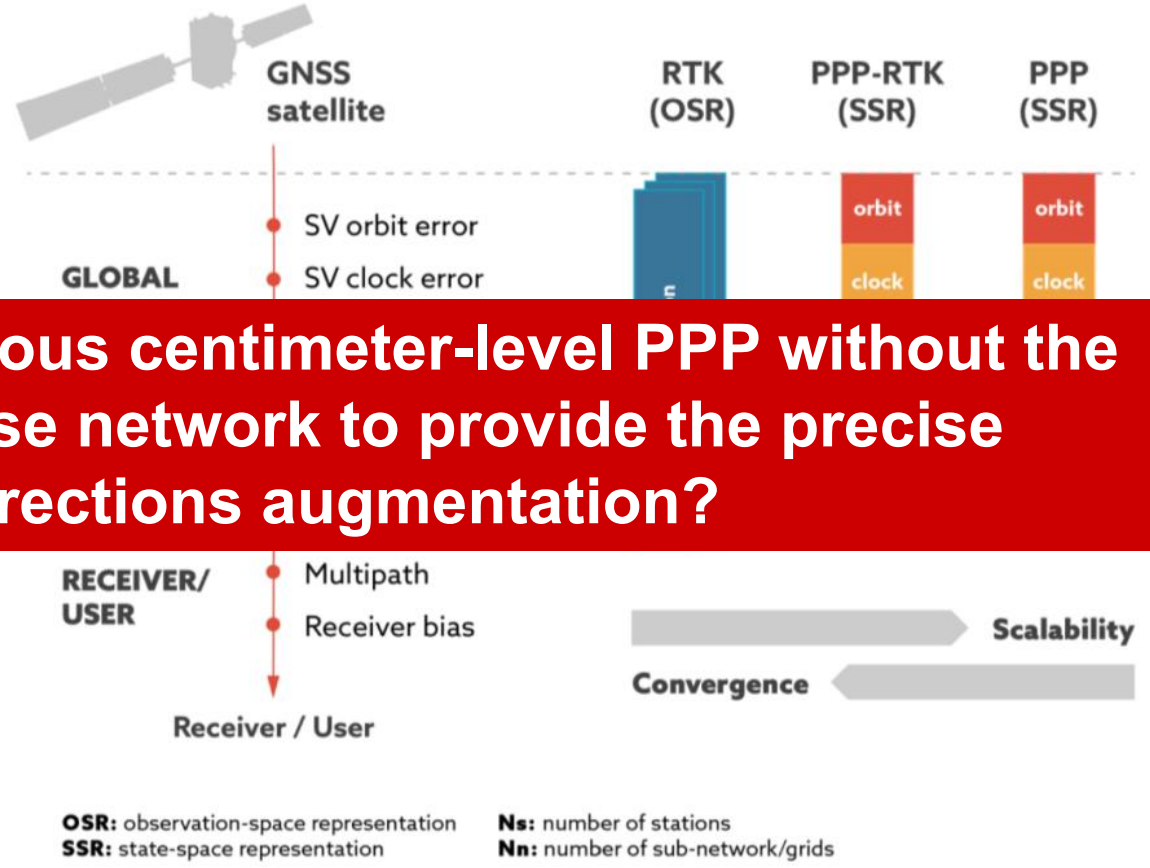




PPP-RTK

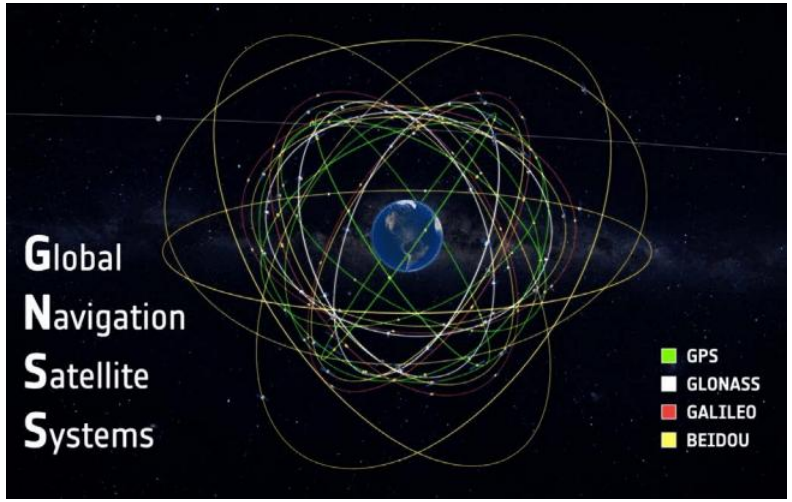
- PPP-RTK is proposed to accelerate PPP convergence
  - + Global solution, single station
  - + Integer Ambiguity solution
  - + Initialisation in a few minutes (<2 min)
  - − Large bandwidth is required for broadcasting the corrections

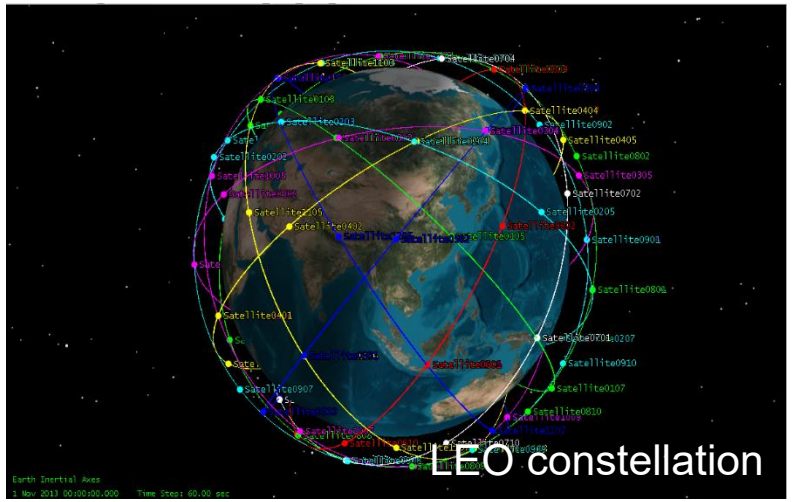
Can we implement instantaneous centimeter-level PPP without the wide-area or regional dense network to provide the precise atmospheric corrections augmentation?

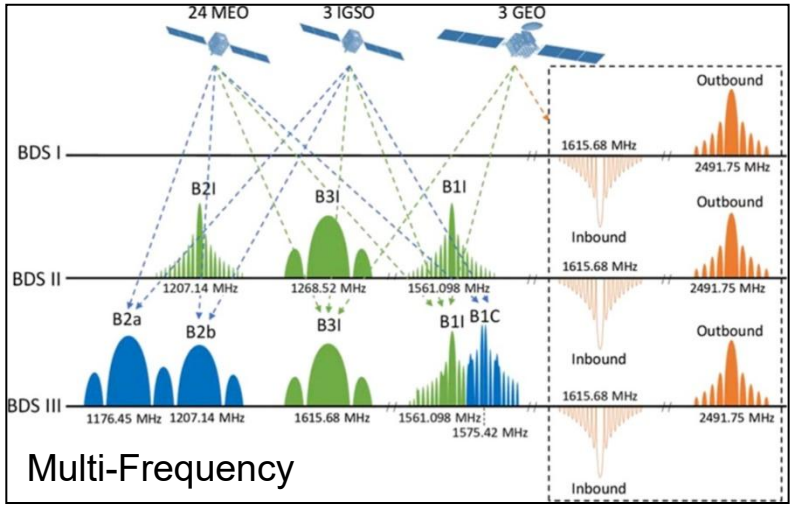


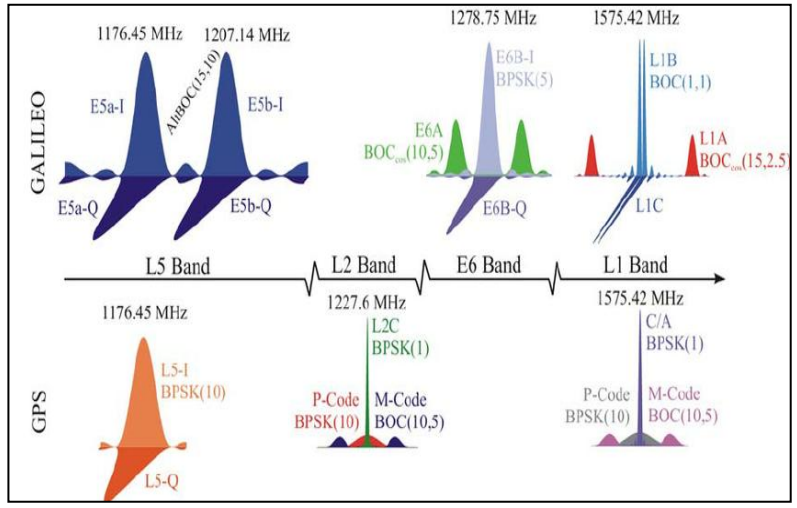
Opportunities for PPP

- Multi-GNSS
  - GPS, GLONSS
  - Galileo, BDS
  - QZSS, NAVIC
  - more
- Multi-Frequency
  - L1/L2/L5
  - E1/E5a/E5b/E6…
  - B1I/B2a/B2b/B3I…
- LEO constellation







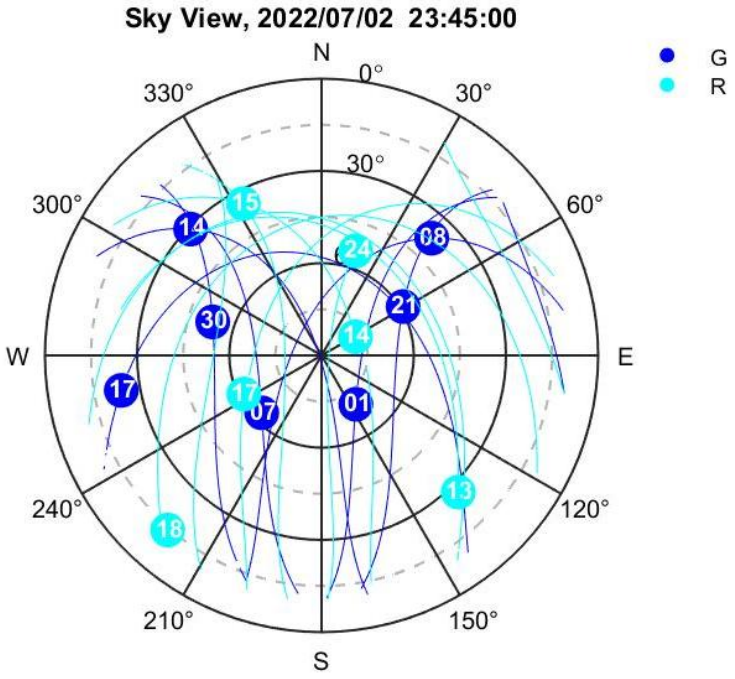


Outline

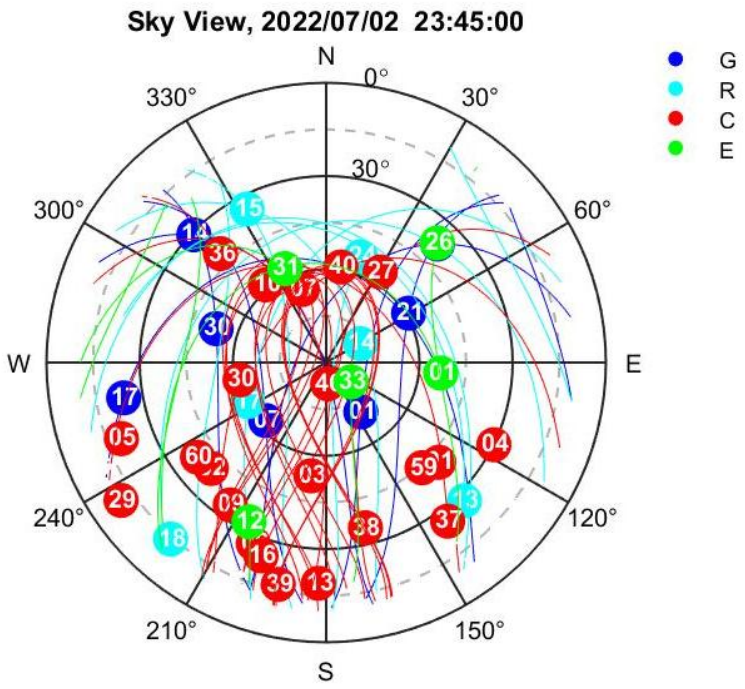
- The challenges and opportunities of PPP
- Instantaneous cm-level PPP: technology and system
- Applications of Instantaneous cm-level PPP
- Summary and outlook

Instantaneous cm-level PPP: observations

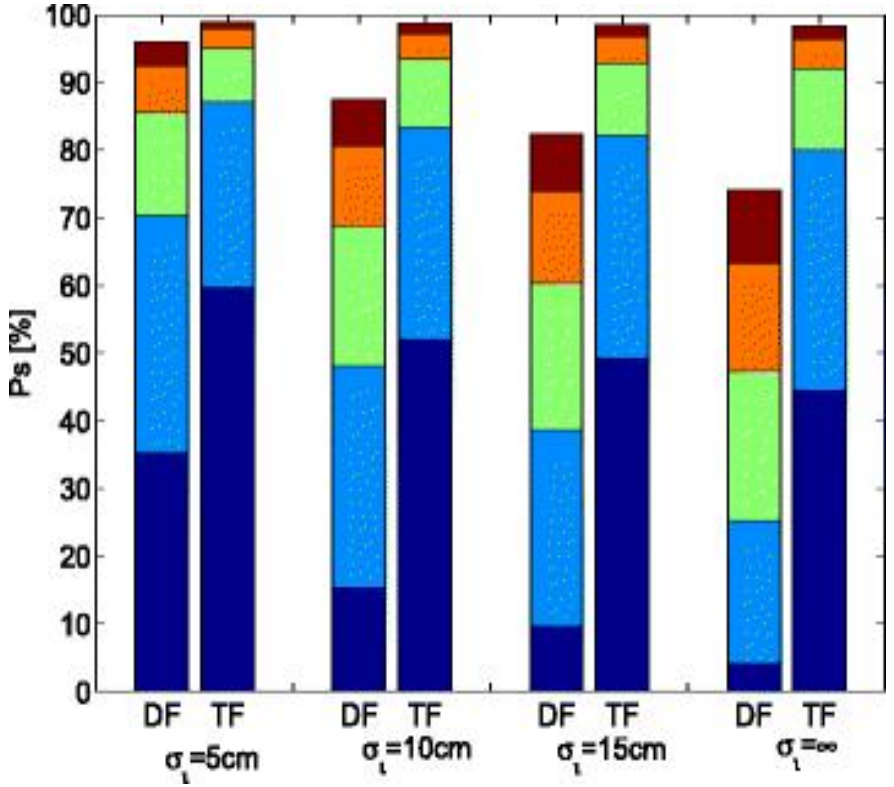
- Multi-GNSS obs. to improve the observation geometry and convergence
- Multi-frequency obs. to accelerate the convergence and ambiguity resolution



GPS+GLONASS



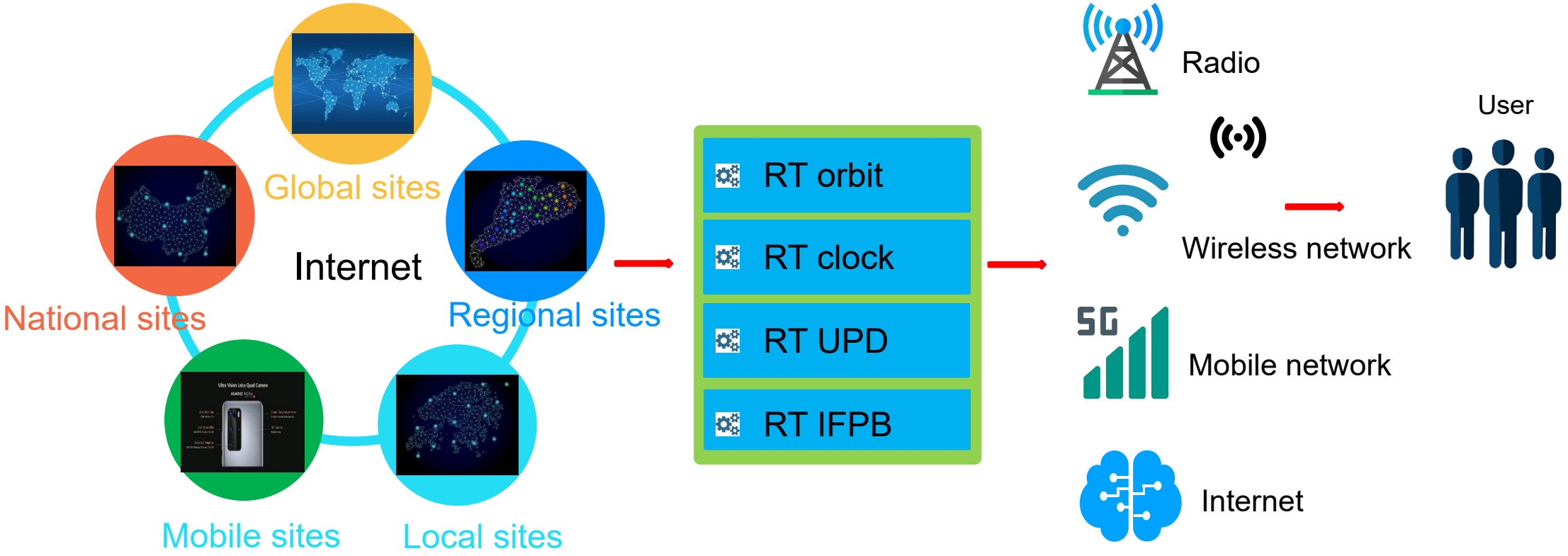
GPS+GLONASS+BDS+Galileo



The success rate of AR for dual- and tripe-frequency during 1 to 5 seconds

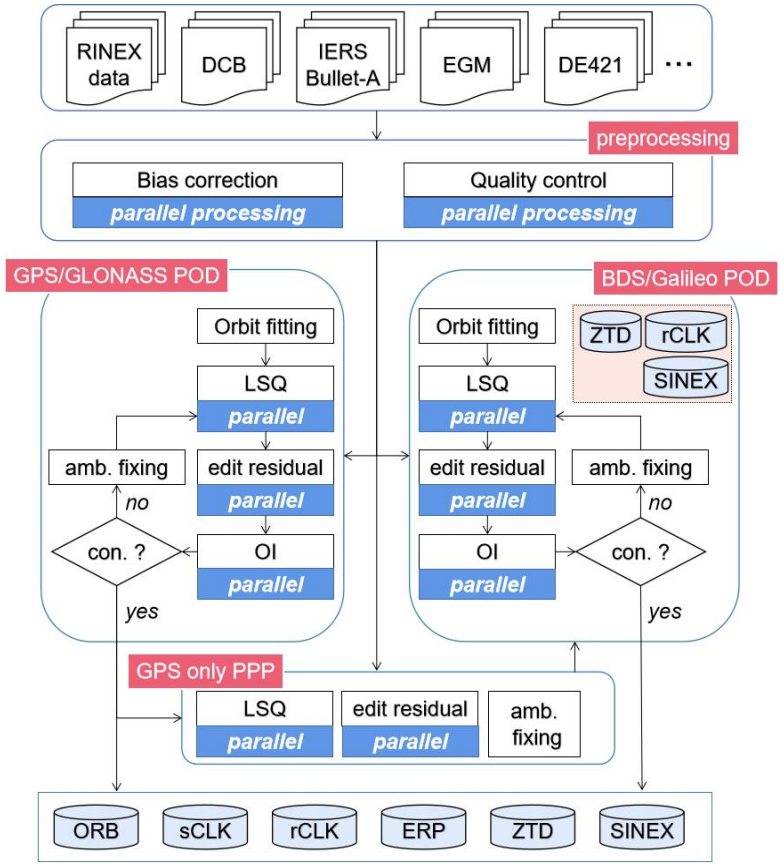
Instantaneous cm-level PPP: corrections and system

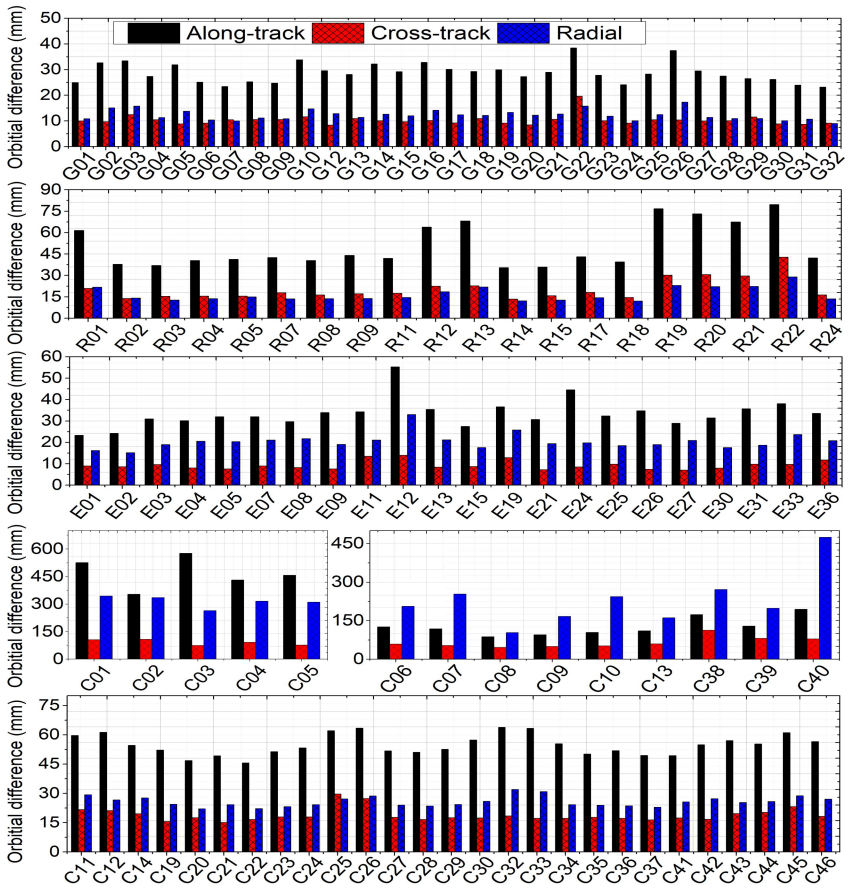
- Using space-state representative (SSR) to modeling each GNSS errors
  - Precise orbit and clock products
  - Uncalibrated Phase Delay (UPD) for ambiguity resolution
  - Inter-frequency phase bias (IFPB)



Real-time orbit

- Hourly updated ultra-rapid products with 1 hour latency
- The 1-2 h predicted orbits are used as the real-time orbit

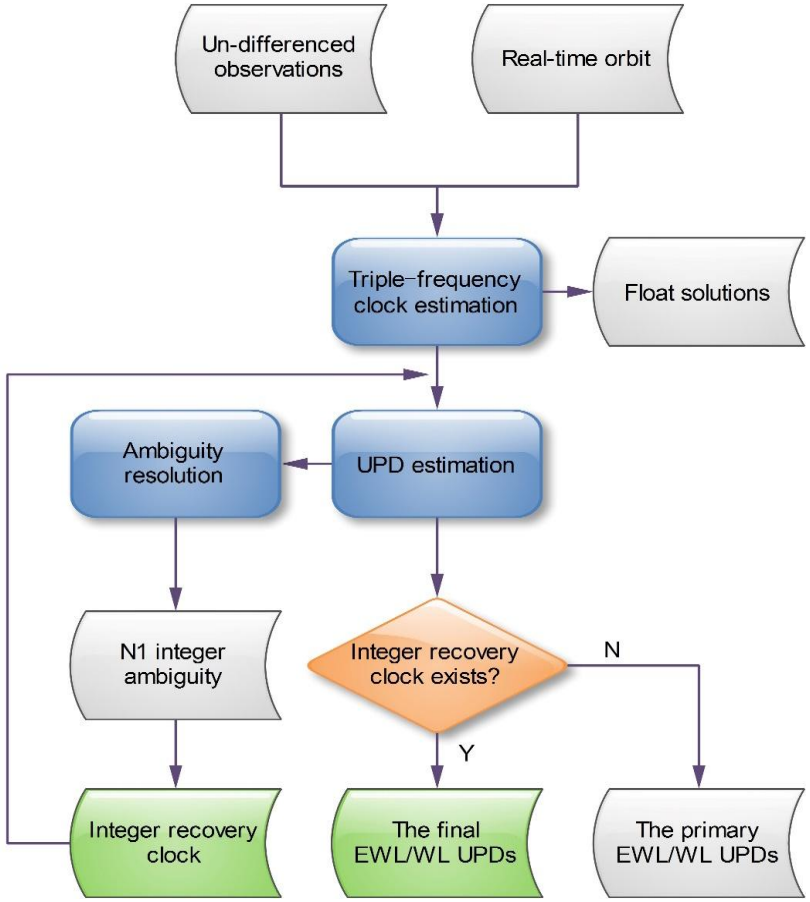


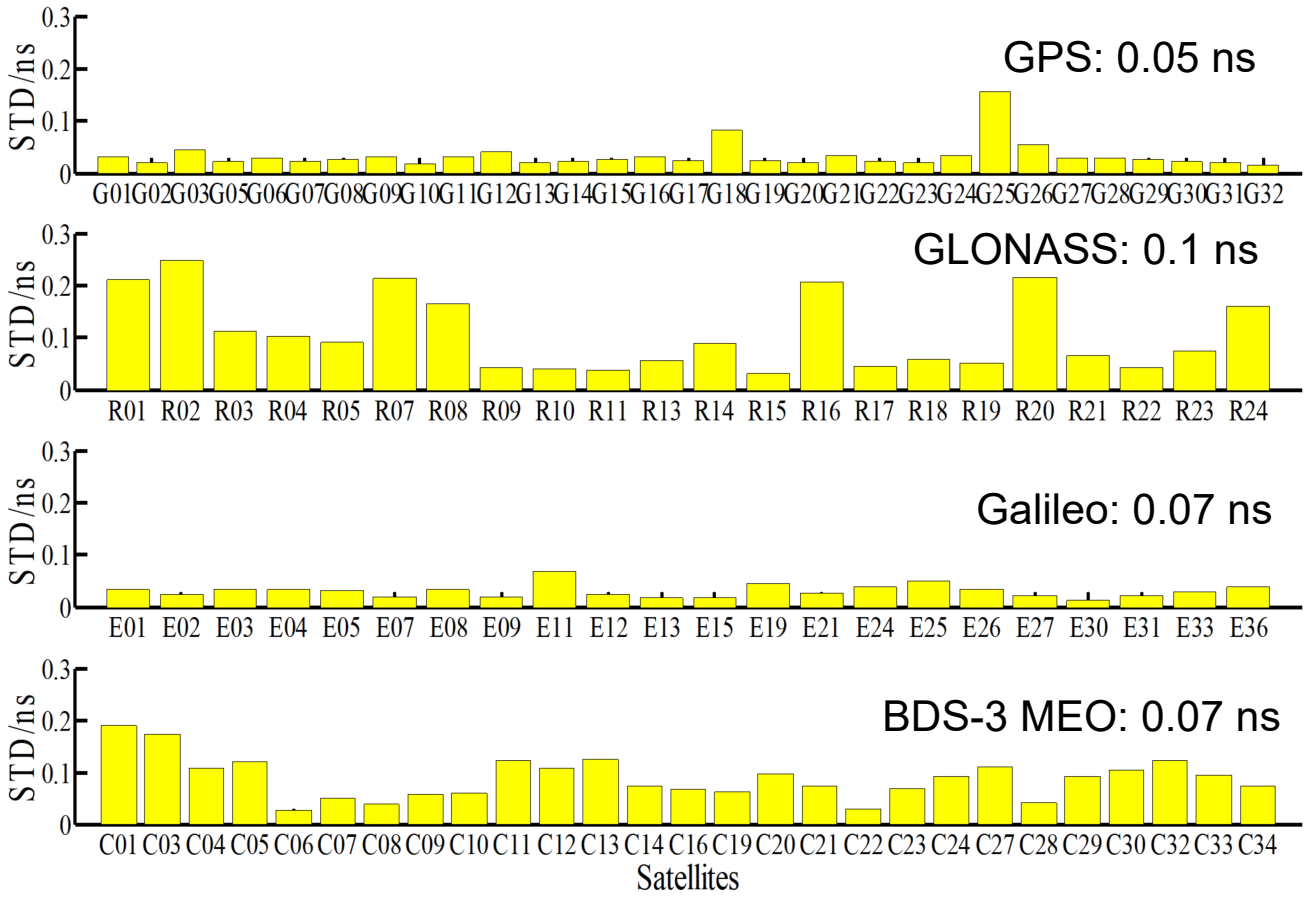


Constellation	Overlap w.r.t. IGS or GFZ (mm)			
	A	C	R	3D
GPS	25.0	13.0	13.2	31.2
GLONASS	64.7	46.7	24.8	83.9
Galileo	36.7	16.8	23.6	47.0
BDS-GEO	901.1	91.1	477.7	1041.8
BDS-IGSO	98.8	87.6	156.4	206.9
BDS-MEO	64.2	38.8	30.8	82.0

Real-time clock

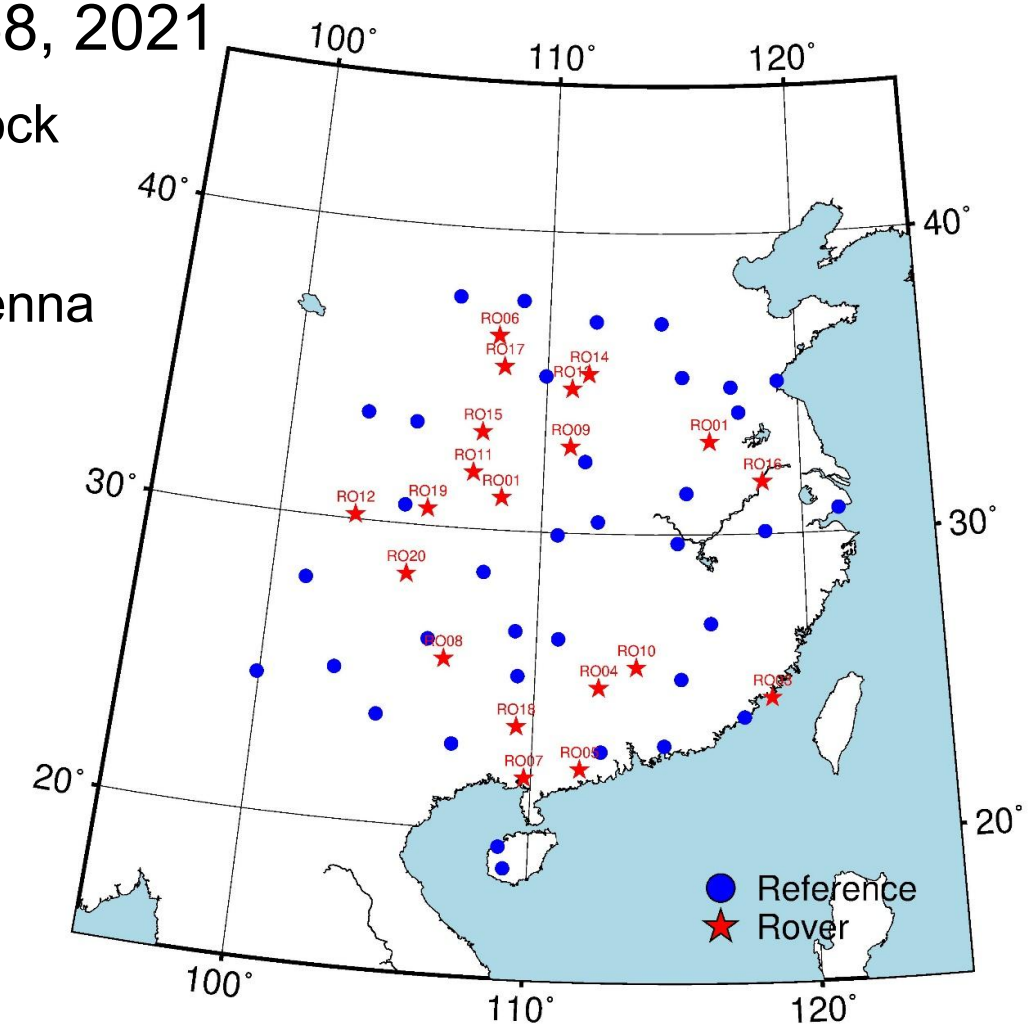
- Integer recovery clock based on global/regional tracking stations
- Better than 0.1 ns accuracy for the real-time clock





Experiment : data and strategy

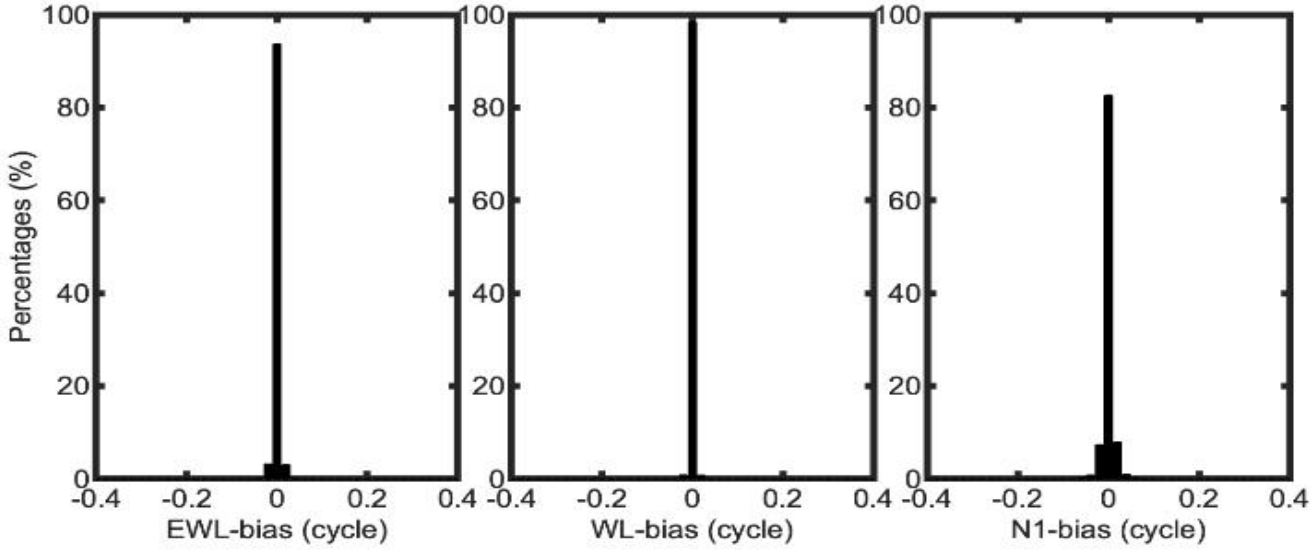
- Data from 45 sites in **China** of DOY 352~358, 2021
  - 25 stations (blue) used for estimating UPD and clock
  - 20 stations (red) for PPP validation
  - All with identical UB4B0 receivers and Dywell antenna
- Frequency
  - GPS L1/L2/L5, Galileo E1/E5a/E5b
  - BDS-2 B1I/B3I/B2I, BDS-3 B1I/B3I/B2a
- Real-time orbit, clock, and DCB



Real-time UPD

- Residual distribution
  - EWL: 90% residuals in -0.02 and 0.02 cycles
  - WL: 96% residuals in -0.02 and 0.02 cycles, as EWL constraint
  - L1: 80% residuals in -0.02 and 0.02 cycles
  - All within -0.2 and 0.2
- The highly concentrated residual distributions with zero are benefited from the unified receiver type

The residual distribution

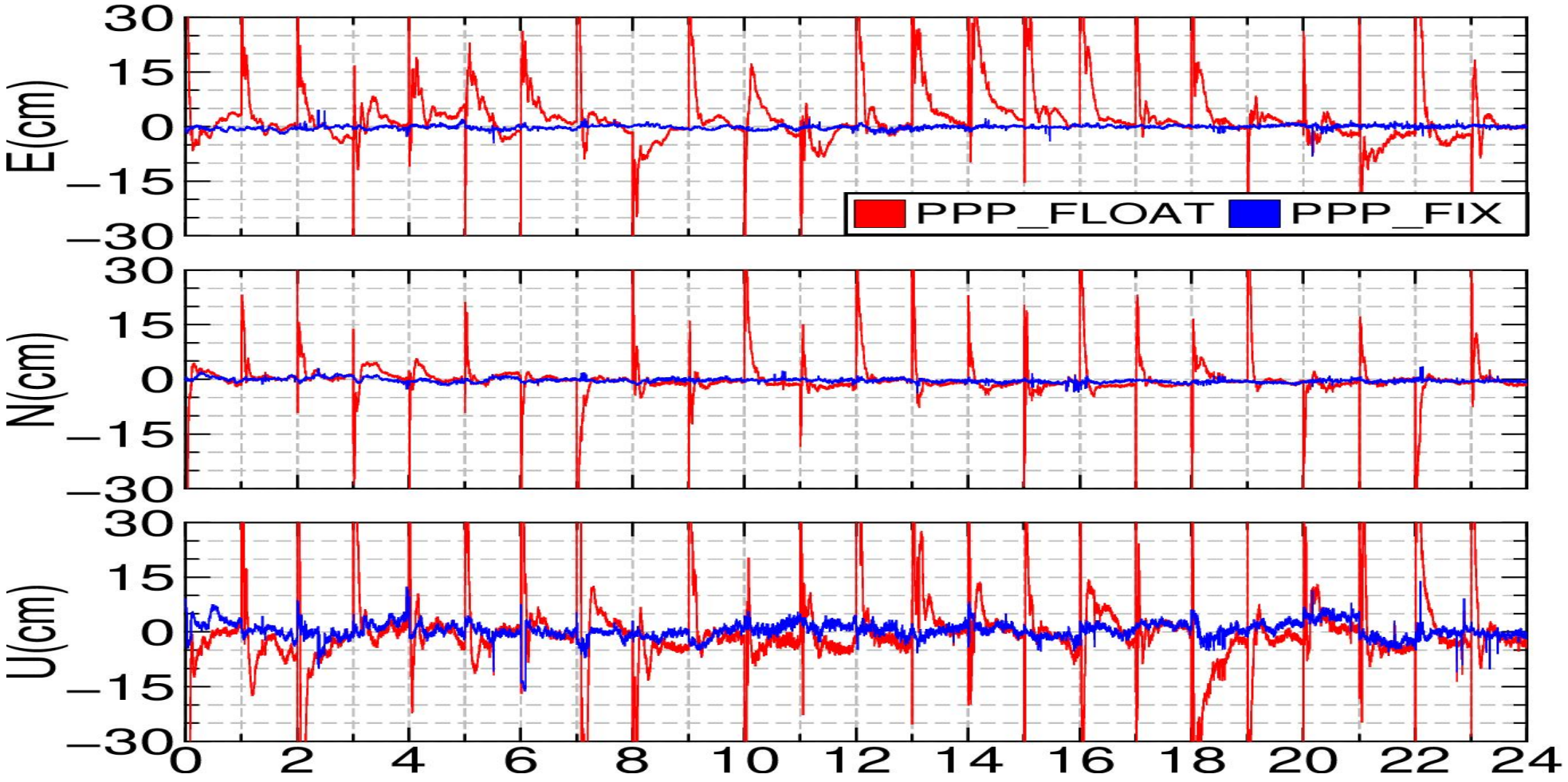


Constellation	EWL (%)	WL (%)	N1 (%)
GPS	100.0	99.3	98.4
GAL	100.0	99.8	98.6
BDS-2	99.9	99.9	99.1
BDS-3	100.0	99.9	98.6

Fixing

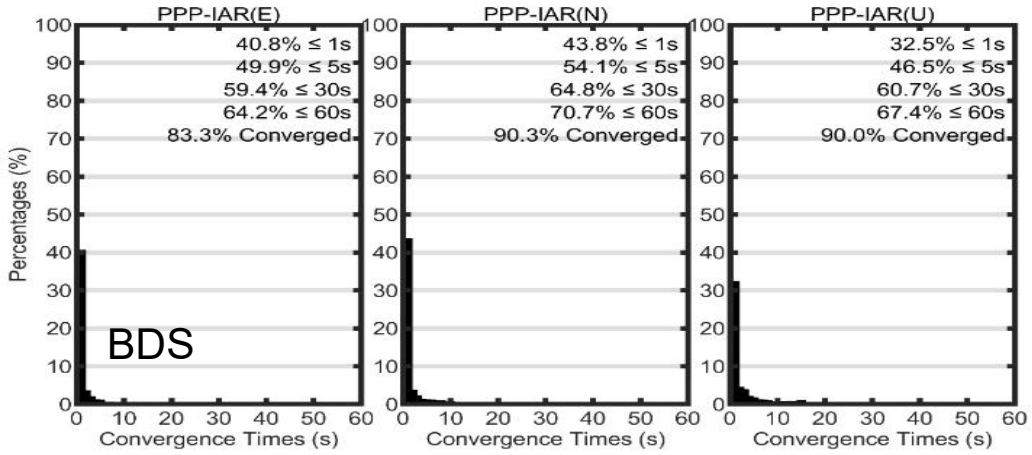
Experiment #1: Real-time PPP validation

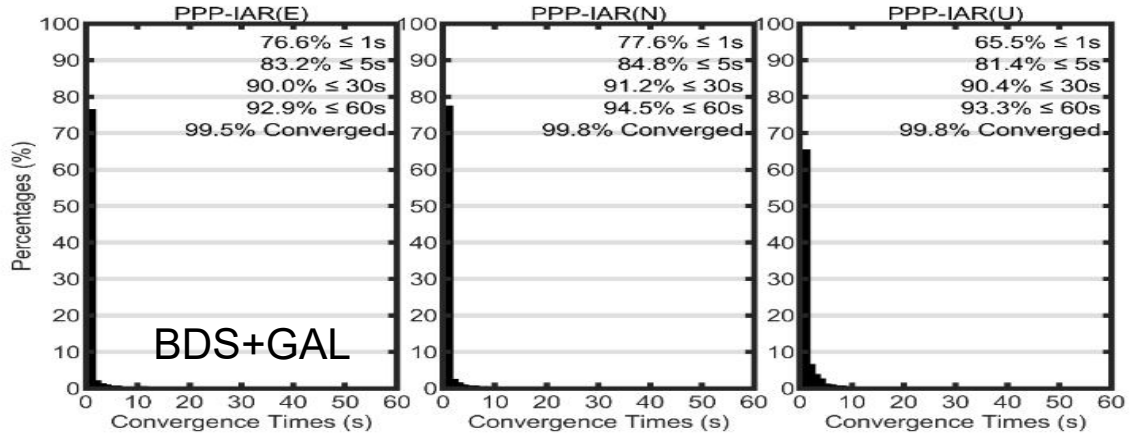
- Instantaneous PPP ambiguity resolution is possible in the real-time service

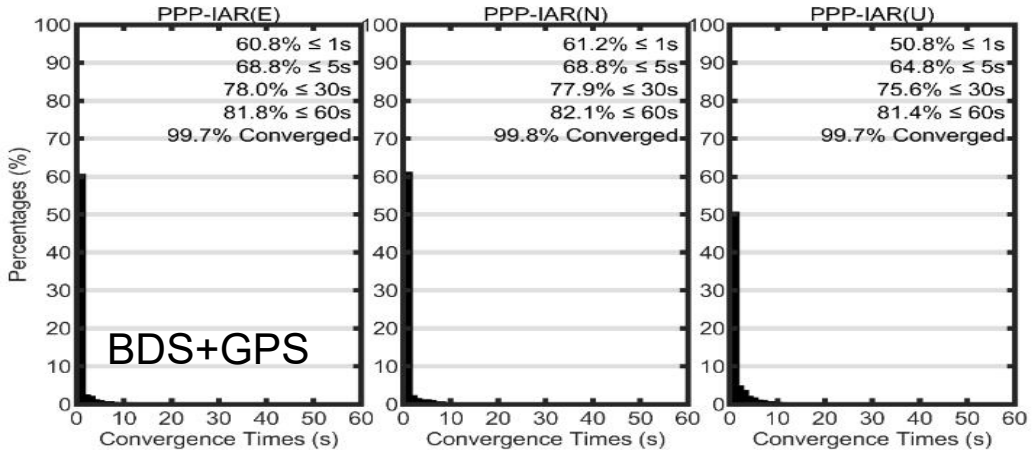


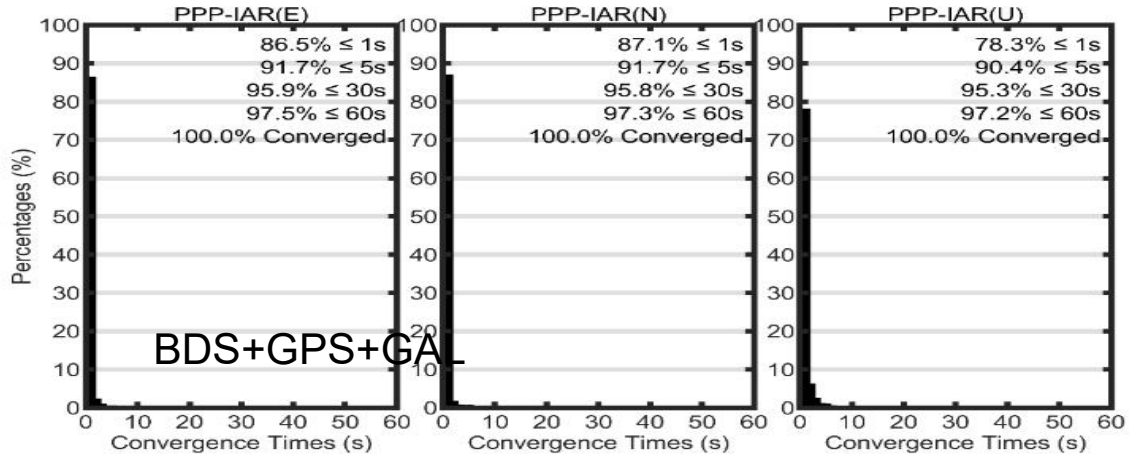
Experiment #1: Real-time PPP validation

- 86% of cases can converge within 1 s for the horizontal components. The percentage increase to 95% and 97% after 30 s and 60 s









Outline

- The challenges and opportunities of PPP
- Instantaneous cm-level PPP: technology and system
- Applications of Instantaneous cm-level PPP
- Summary and outlook

Equipment requirements to support Inst. PPP

- Multi-frequency and Multi-GNSS
  - GPS: L1, L2, L5
  - Galileo: E1, E5a, E5b/E6, and more
  - BDS: B1I, B1c, B2a, and more
- High quality measurements, particularly the pseudorange
  - Better than 30 cm

Applications: Surveying and mapping

- A practical and low cost alternative to RTK for surveying and mapping

Applications	Cadastral & Construction	Infrastructure monitoring	Mine surveying	Mapping and GIS	Marine surveying
Key GNSS requirements	Accuracy (down to mm), Availability, Continuity, Time To First accurate Fix (TTFaF)	Accuracy (down to mm), Availability, Continuity, TTFaF	Accuracy (down to cm), Availability, Continuity, TTFaF	Accuracy (down to cm) Availability Continuity	Accuracy (down to cm) Continuity Integrity
Other requirements		Connectivity Interoperability		Connectivity, Size, Weight	Interoperability Resilience

GSA, GNSS Market Report 2019

Applications: Precise Agriculture

- An integral part of smart, connected and integrated farm management solutions and a key driver for precision farming across the whole crop cycle

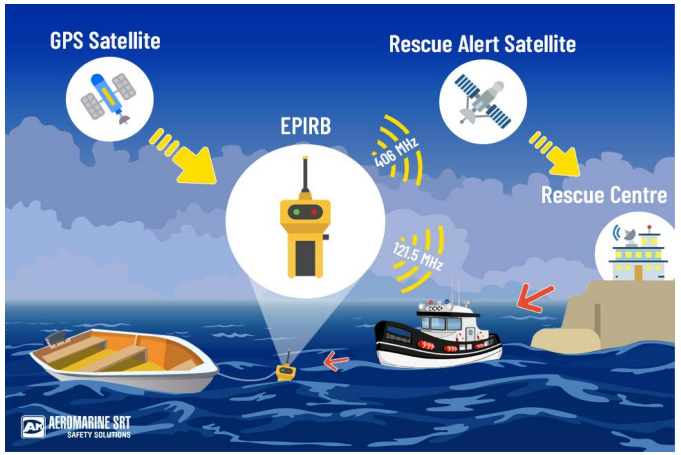
	Operations		Monitoring	Other applications
Applications	**Farm Machinery Guidance**	**Automatic Steering, Variable Rate Application**	**Harvest/Yield Monitoring, Biomass Monitoring, Soil Sampling**	**Livestock Tracking, Virtual Fencing, Geo-traceability, Machinery Monitoring, Field Boundary Measurements**
Key GNSS requirements[1]	Accuracy (decimetre-level) Availibility Continuity	Accuracy (centimetre-level) Availibility Continuity	Accuracy (centimetre-level) Availibility	Accuracy (centimetre-level) Availibility Authentication
Other requirements	Connectivity	Connectivity Interoperability	Connectivity Interoperability	Connectivity Interoperability Traceability

[1] Please note that:
- for 'operations' horizontal, pass-to-pass accuracy is stated. However, certain in-field operations that involve coming back to exact locations at different times require in addition high-repeatability;
- for 'monitoring' and 'other applications' horizontal, absolute accuracy is stated.

GSA, GNSS Market Report 2019

Applications: Maritime

- Cost-effective maritime operations and enhanced safety at sea
  - Search and Rescue
  - Port operations
  - Marine engineering



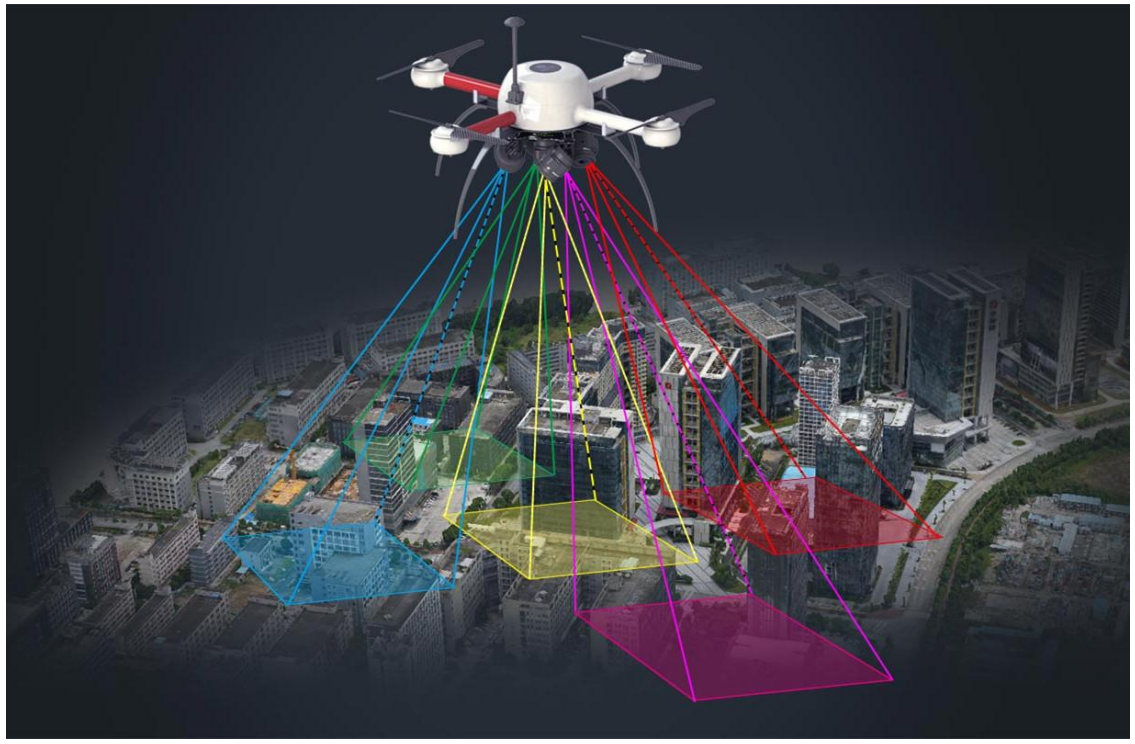
Applications	Navigation[1]	Ship Operations	Traffic Management & Tracking	Search & Rescue	Port Operations	Engineering & Offshore
Key GNSS requirements	Accuracy (from metre to 10 metres) Availability Integrity	Accuracy (from sub-metre to 10 metres) Availability Integrity	Availability Continuity	Accuracy (final approach 5 metres) Availability	Accuracy (sub-metre) Availability Integrity	Accuracy (sub-metre) Availability Integrity TTFF
Other requirements	Interoperability	Interoperability	Connectivity	Connectivity (incl. return link) Power consumption Resiliency	Inter-operability	Inter-operability

[1] The GNSS requirements for general navigation vary with the given maritime environment.

GSA, GNSS Market Report 2019

Applications: Unmanned Aerial Vehicle

- Fast and high accurate positioning empower drone users
  - to enhance drone functionality: precision, surveying and mapping, etc.
  - to brings increased freedom of airspace access



Applications: Automotive smart cockpit

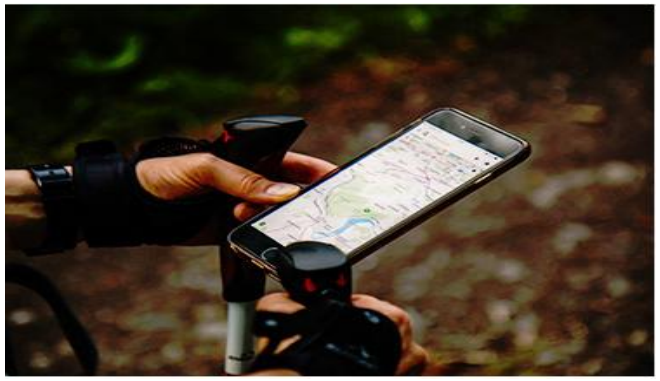
- Smarter vehicles become platforms for innovative services and applications
- Better GNSS performance required by more demanding applications
  - Connected and Automated Driving, Road User Charging, Insurance telematics, and more

Applications	Safety related automatic actions in V2X, Autonomous driving, eCall, Tracking & tracing of dangerous goods		Liability: RUC, Pay-as-you-drive, Taxi meter, Smart tachograph		Smart mobility: Road navigation, Automated parking, Dynamic ride sharing
Key GNSS requirements	Accuracy (decimetre-level) Authentication Availability (>99.5%)	Integrity Robustness TTFF	Accuracy (decimetre-level) Authentication Availability (-99.5%)	Integrity Robustness TTFF	Authentication Integrity
Other requirements	Connectivity (mainly short range) Interoperability		Connectivity (short range and long range)		Connectivity (long range)

GSA, GNSS Market Report 2019

Applications: Customer devices

- Smarter connectivity requires high accuracy and low power consumption of GNSS positioning, Inst. PPP GNSS benefits connectivity and automation



Applications	**Traditional applications:** Navigation, Sports, Tracking, Social networking, Enterprise applications, Infotainment, Games	**Innovative applications:** Augmented Reality, Robotics, mHealth, Geo marketing and advertising, Fraud management and billing, Safety and emergency
Key GNSS requirements	Availability (in all environments) TTFF	Accuracy (high) Authentication Availability (in all environments) TTFF
Other requirements	Connectivity (including short range) Interoperability Power consumption	Connectivity (including short range) Interoperability Power consumption

GSA, GNSS Market Report 2019

Outline

- The challenges and opportunities of PPP
- Instantaneous cm-level PPP: technology and system
- Applications of Instantaneous cm-level PPP
- Summary and outlook

Summary and outlook

- PPP surfers slow convergence with low cost and global availability
- PPP-RTK can reduce the convergence time
  - wide/regional facilities are need, resulting in relatively higher cost
- Multi-frequency and Multi-GNSS constellations provide opportunities
  - instantaneous centimeter-level PPP without the wide-area or regional network
- Orbit, clock, UPD and bias products needed
- Instantaneous cm-level PPP validated in real-time
  - data from a wide area network equipped identical receiver and antenna
  - BDS is the key constellation for instantaneous ambiguity resolutions
  - 95% epoch can be fixed within 30 s in real-time

Summary and outlook

- In kinematic mode, centimeter-level accuracy achieved within 5 s
- This approach has numerous potential as high-accuracy, low convergence and cost, as well as small bandwidth for satellite broadcasting
- It can be used as a practical and low cost alternative to RTK globally to meets the requirements of many applications in accuracy, availability, connectivity, and low latency

感谢聆听！

Thanks for your attention!