Performance enhancement in BeiDou system - Integrity and Accuracy

Yongchao GENG [1], Rui LI [2], Hongliang XU [3], Xingqun ZHAN [3]

1. CETC-20 Institute
2. Beihang University
3. Shanghai Jiao Tong University

Presented by Prof. Xingqun ZHAN

Contents

- Introduction
- Part I: Research on GNSS Integrity
- Part II: Autonomous precise ephemeris determination

Background

- Future trend of PNT service
  - GNSS: Interoperable Multi-constellation
  - Objective: Ubiquitous positioning and seamless navigation
  - Techniques: Fusion of GNSS and other positioning techniques
    - Indoor positioning
    - Mobile communication technology
  - Extended application: LBS, GIS, etc.
- GNSS provider's obligation
  - GNSS performance enhancement

Our views on Performance enhancement

- GNSS service performance
  - Accuracy: ➢Differential positioning
  - Availability: ➢Constellation design
  - Continuity: ➢System operation
  - Integrity: ➢Integrity monitoring
  - Health: ➢Ground monitoring and health indicator
  - etc.

Part I : Research on GNSS Integrity

- **The Definition of Integrity：**

  The Alarming Ability Under the Occurrence of fault

- **The Component of Integrity：**
  - Integrity risk: Related to the Fault Probability and the Monitoring Method
  - Alert Threshold: Related to the Application
  - Time to alarm: Related to the User Dynamic and the Surrounding Scenario

Necessity of Integrity

- **Requirement of Integrity**
  - **SOL Service:** Civil Aviation, Railway …..
  - **Reliability Service:** ITS, Fishing, Disaster Alarm…..

To 2012, in China, forecasted amount of automobiles is over 200 millions, while that of cell phone is over 800 millions. Most mass- market users also require integrity.

The Status of SBAS

- **Satellite Based Augmentation System**
  - **WAAS (US)**
  - **EGNOS (EU)**
  - **MSAS (JAPAN)**
  - **GAGAN(INDIA)**
  - **……**

Necessity of Integrity

- Developing Trend

The modernization of GPS:

- Use URA to broadcast the integrity information;
- The development of WAAS;

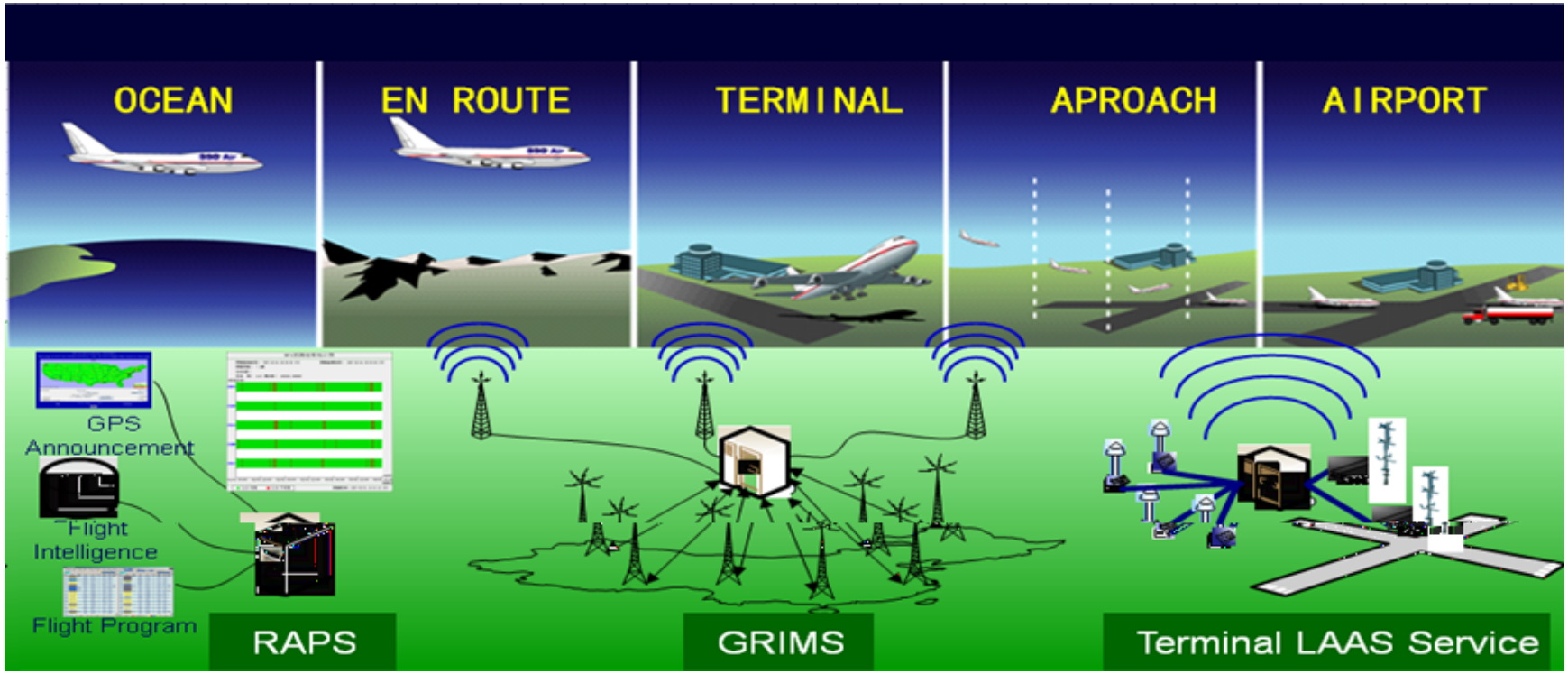
The Construction of GALILEO:

- Providing SOL Service;
- Providing Augmentation Service of the European Users;

Considering The Integrity Issue In the design of BeiDou

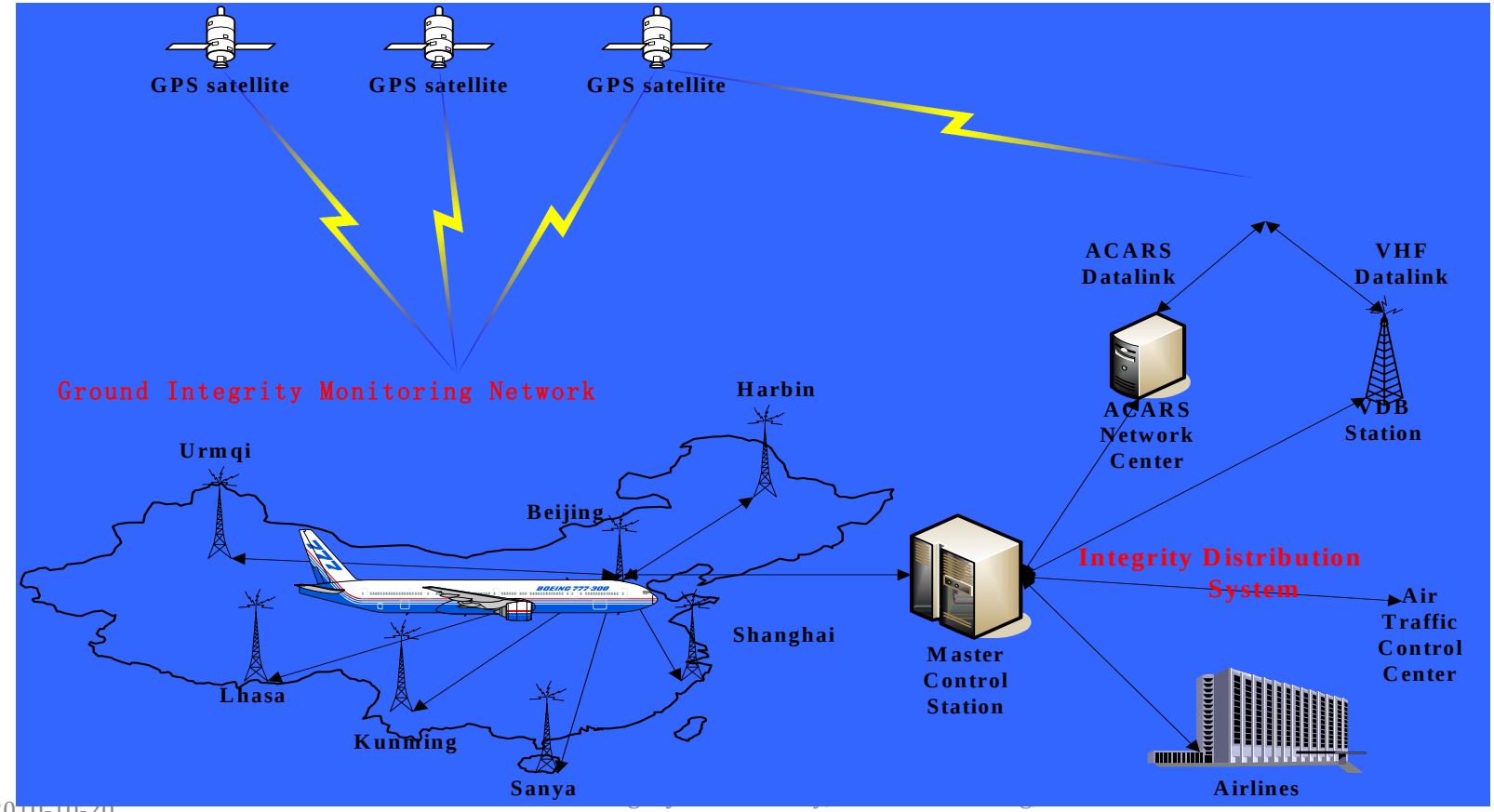
Integrity Solution of CAAC

- CAAC Integrity Monitoring System Solutions



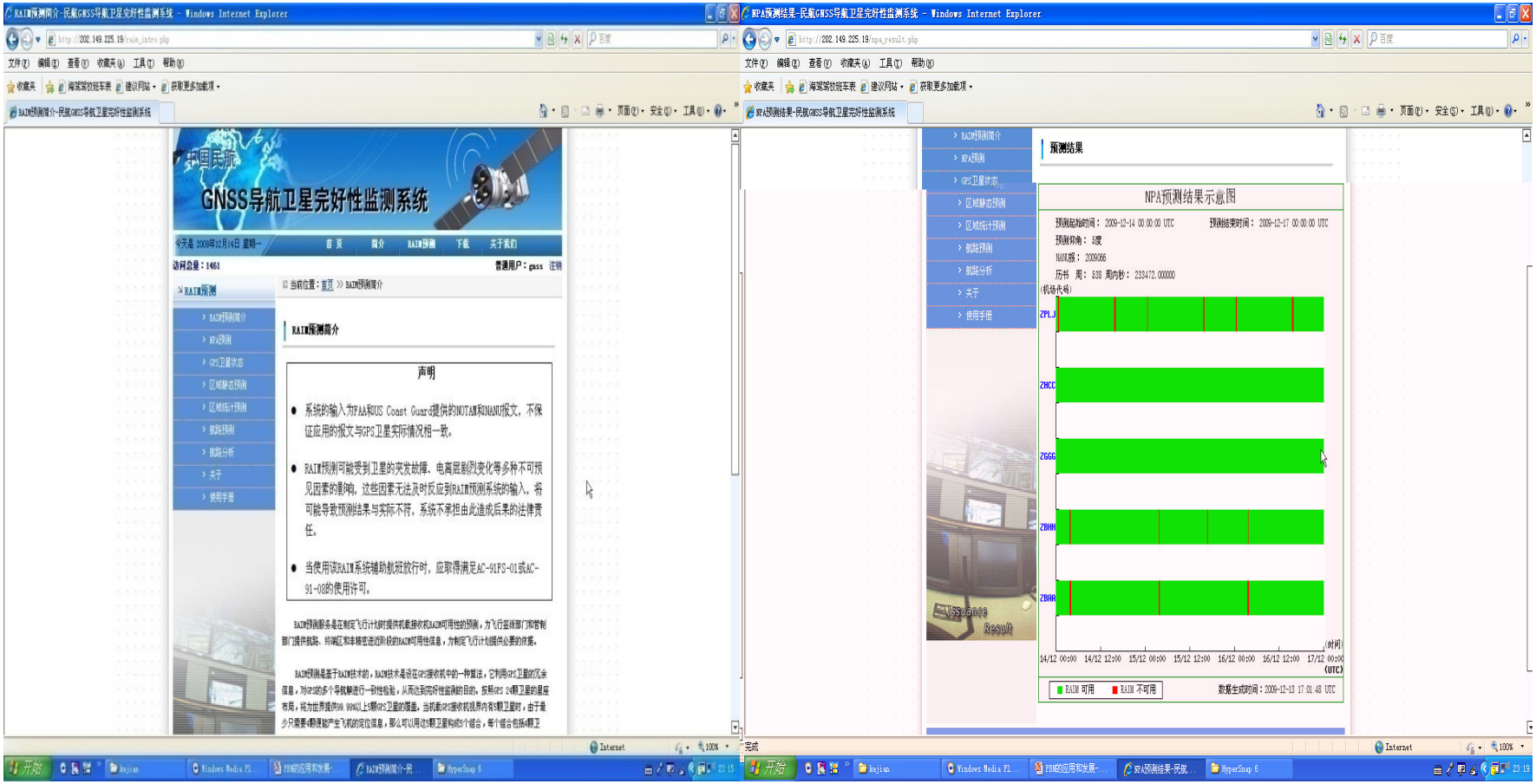
Integrity Solutions of CAAC

- Ground based Regional Integrity Monitoring System-GRIMS



Integrity Solutions of CAAC

- RAIM Availability Prediction System-RAPS



Integrity Solutions of CAAC

- Ground Based Augmentation System-GBAS

Research on the Integrity concept of BeiDou

- Integrity Monitoring and Processing On the System Level
  - The Global and Multi-frequency Broadcasted Integrity Information;
  - Providing Satellite-Based Augmentation Service in China;
  - Conforming to the Standard of ICAO;

Research on the Integrity concept of BeiDou

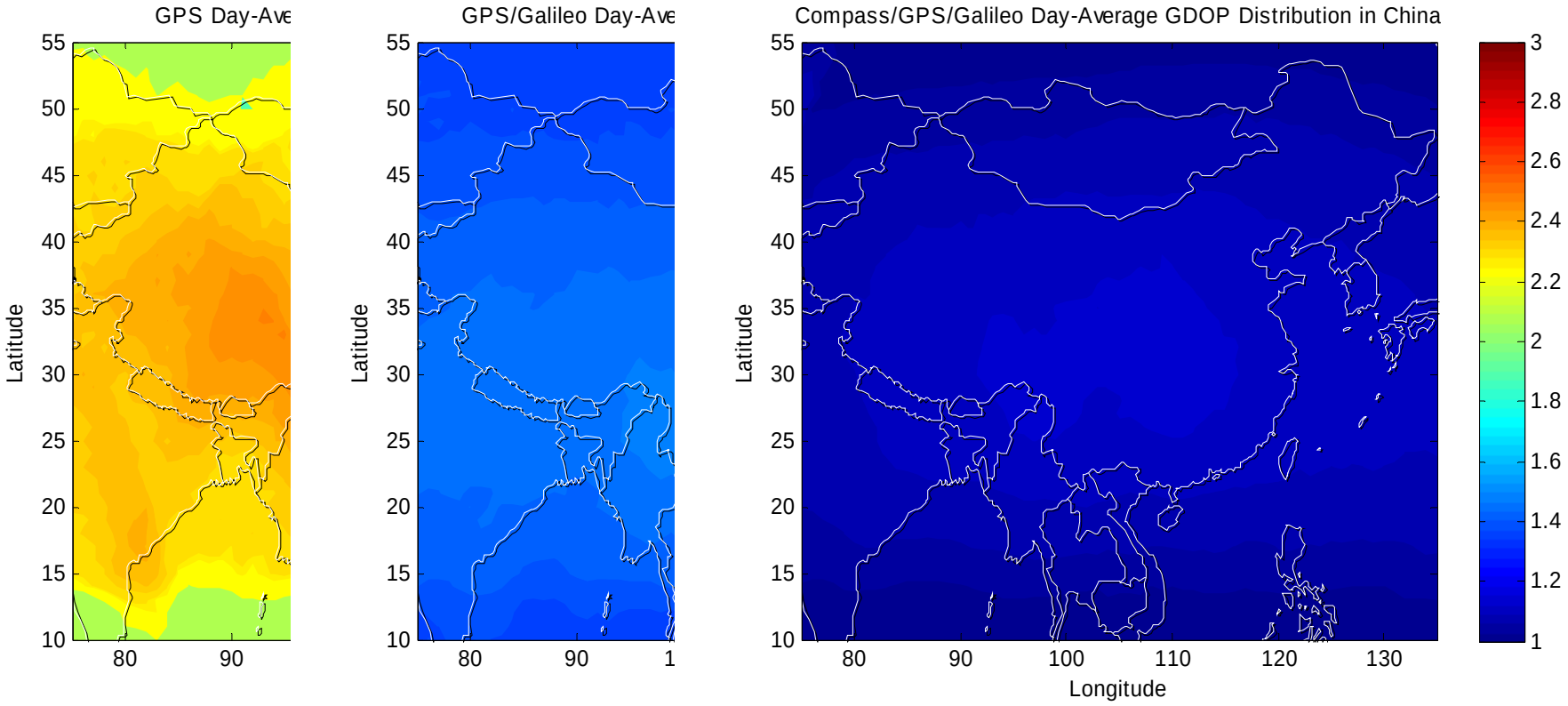
- Global Integrity Concept of the BeiDou
  - Capability of Global Broadcasting;
  - Open Service;
  - The Feasibility of Disposing Reference Station Beyond China Region;
  - The interoperability with GPS and GALILEO;
  - Global Integrity Performance Expectation - NPA

Research on the Integrity concept of BeiDou

- SBAS Performance Expectation
  - Capability of Wide Area Augmentation in China
  - Supporting Both Single and Multi-frequency Users
  - Capability of Compass, GPS and Galileo Compatible Augmentation Service
  - Taking Full Advantage of Compass GSO and IGSO Communication Link
  - Discussing the possibility of the Interoperability with EGNOS and WAAS
  - Performance-CAT I

Influence of BeiDou on Multi-constellation Interoperability

- **Contribution:**
  - Smaller and More Uniform GDOP ;
  - More Redundancy;



Influence of BeiDou on Multi-constellation Interoperability

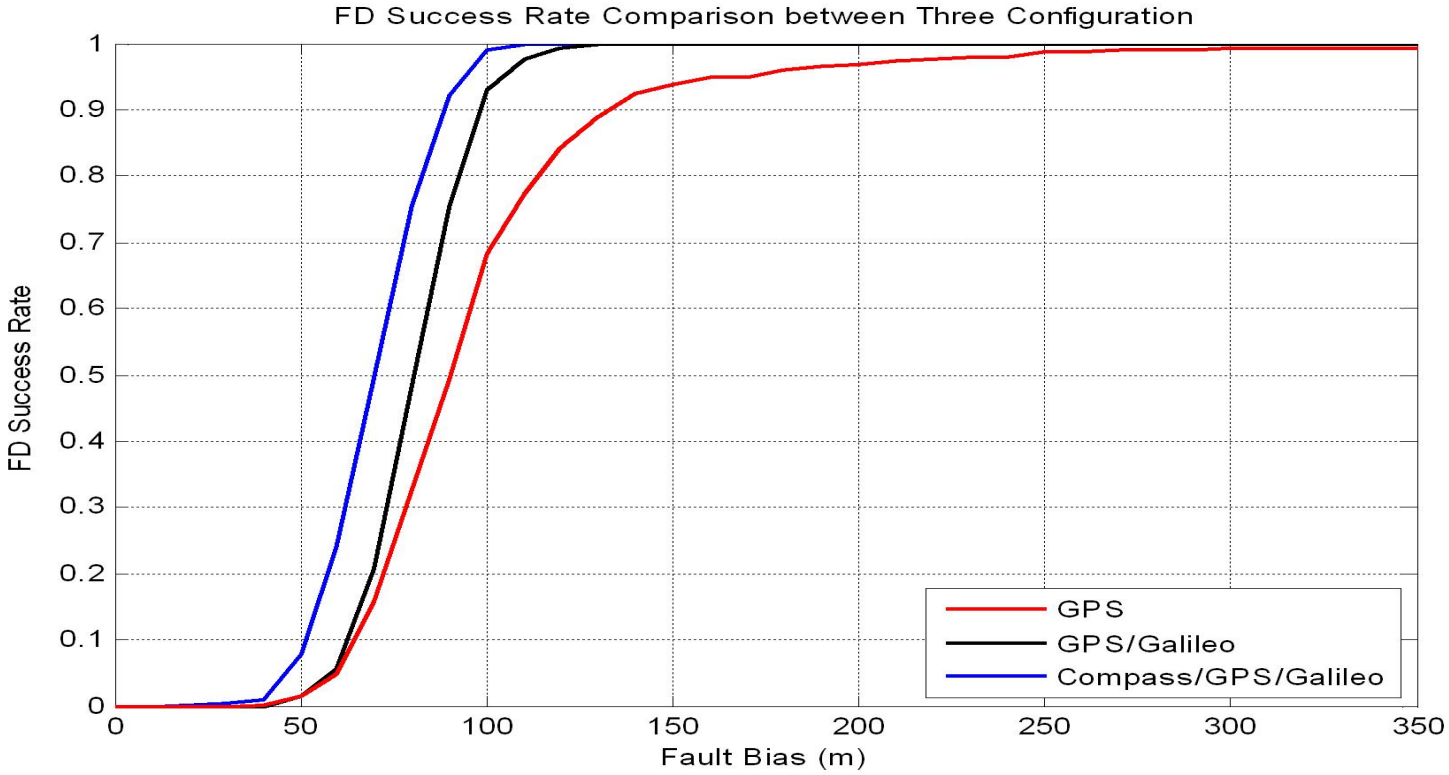
- **Challenges:**
  - More Probability of the Multi-constellation System;
  - Current RAIM Methods Only Monitoring Single Fault

$$P_{\text{failure}}^{n} = C_{m}^{n} \times \left(P_{\text{failure}} \right)^{n} \times \left(1 - P_{\text{failure}} \right)^{(m-n)}$$

Influence of BeiDou on Multi-constellation Interoperability

➢ Solution:

➢Analyze the Fault's Num by observing HMI;
Research the New Monitoring Methods;



Summary (Part I)

- Integrity is an essential part of future GNSS
- BeiDou has taken integrity as a critical design objective
- Global service: broadcasting, open service, interoperability, NPA
- Regional service: CAT-I

Part II : Autonomous precise ephemeris determination

- Most GNSSs have Inter-satellite ranging ability, primarily designed for autonomous ephemeris determination (autonomous navigation).
- The capability is not fully exploited
  - Ground monitor stations are available on most of the times
  - Observability problem in ephemeris determination
- A new application
  - Generate precise ephemeris (ephemeris corrections) using inter-satellite ranging (ISR)

Principle

- Concept
  - Calculate satellite clock and orbit errors for user correction using ISR only.
  - Provide higher User Ranging Accuracy (URA)
  - Provide system-level autonomous integrity monitoring (SAIM) as well.
- Prerequisite
  - Ranging: between visible satellites
  - Communication: within constellation
- Process
  - Measurement
  - Decoupling
  - Estimation

Simulation

- Ephemeris improvement

	RMS Error (before correction)	RMS Error (after correction)
Radial	1.0300	0.2623
Along-track	1.1236	0.6167
Cross-track	0.6956	0.5597
Clock	0.2378	0.1662
URE	1.0533	0.3276

  - Orbit: ~1m to 0.5m
  - Clock: 0.24m to 0.17m
  - URE: 1m to 0.3m

Comparison

	Broadcast ephemeris	IGS product Ultra-Rapid (predicted half)	SBAS(WAAS)	GDGPS (JPL 2010)	Proposed method
Origins of Measurements	Monitoring Stations	Ground reference stations	Ground reference stations	Ground reference stations	Inter-satellite ranging
Accuracy (orbit)	~100cm	~5cm	>0.75m (UDRE)	<20 cm RMS	~20cm RMS (radial) ~50cm RMS (otherwise)
Accuracy (clock)	~150 cm RMS ~75 cm SDev	~90cm RMS ~45cm SDev	-	<20 cm RMS	~20cm RMS
Coverage	Global	Global	Regional	Global	Global
Update rate	4~6h	6h		1Hz	15min
Sample interval	daily	15 min		30s (orbit) / 1s (clock)	15 min
Latency	Real time	Real time	<15 seconds	4-6 seconds	~3 min
Accessibility	broadcast	Internet	SBAS GEO satellites	Network / GEO sat. (TDRSS)	broadcast
Receiver compatibility	Y	N	Y	N	Y

Summary (Part II)

- Significant User Ranging Accuracy improvement: 1m to 0.3m
- Satellite autonomous integrity monitoring is possible with this technique.
- Fully autonomously operated within constellation
- Ideal for developing navigation system.

Conclusions

- Performance enhancement involves every aspects of the GNSS
- From the system provider's point of view, the most important parameters include: accuracy, availability, continuity, integrity and health.
- Presentation talks about the accuracy and integrity.

谢 谢！

Thanks for your attention!