



Performance enhancement in BeiDou system - Integrity and Accuracy

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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;

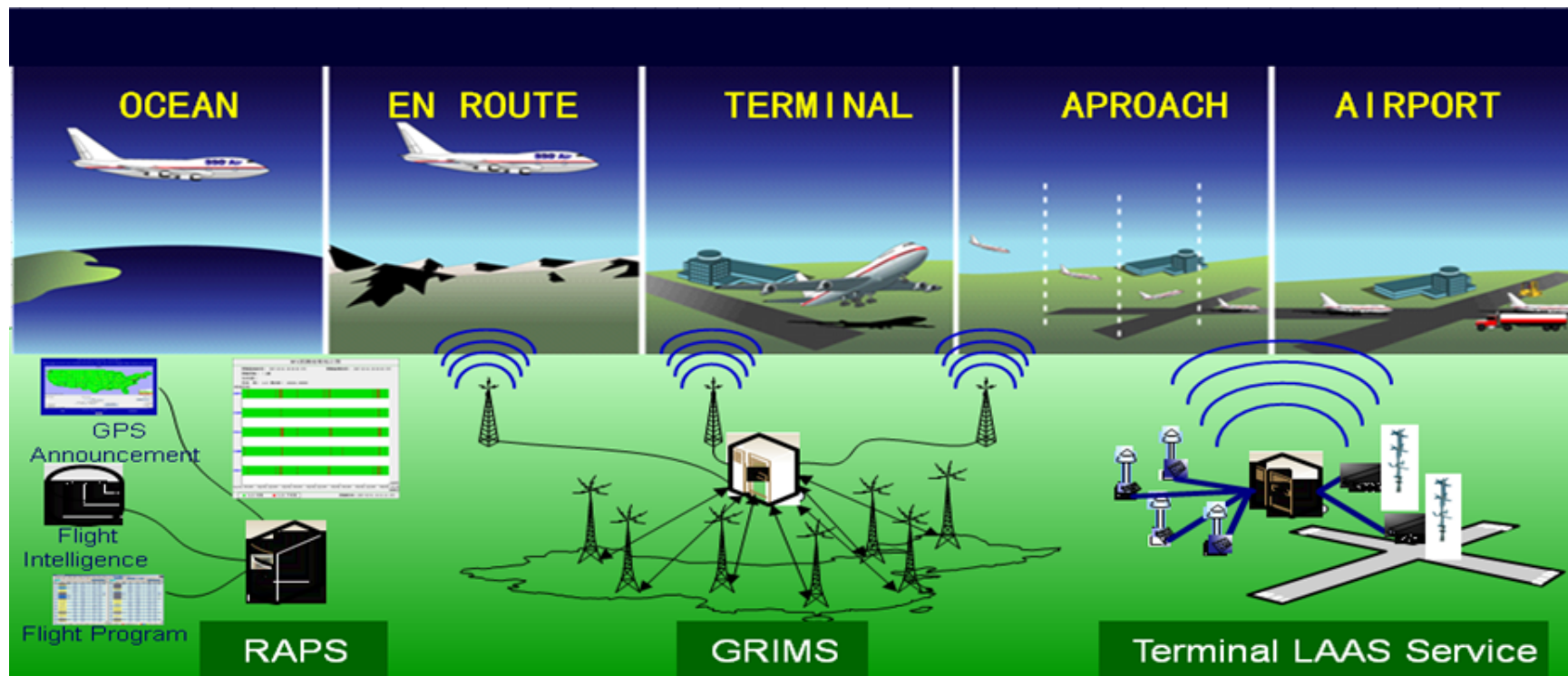
Considering The Integrity Issue In the design of BeiDou



Integrity Solution of CAAC



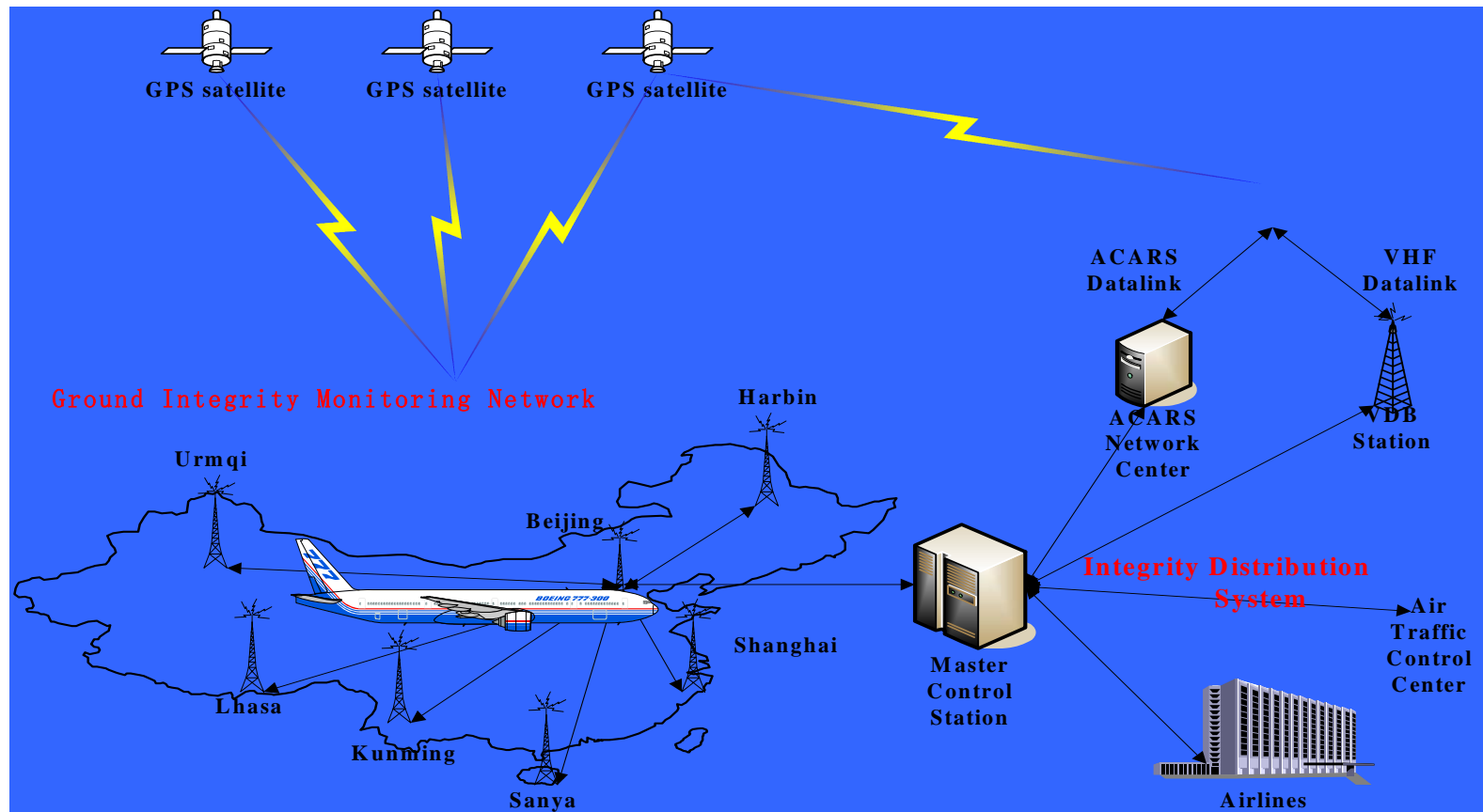
CAAC Integrity Monitoring System Solutions





Integrity Solutions of CAAC

Ground based Regional Integrity Monitoring System-GRIMS





Integrity Solutions of CAAC



RAIM Availability Prediction System-RAPS

RAIM预测简介-民航GNSS导航卫星完好性监测系统

今天: 2009年12月14日 星期一

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RAIM预测简介

声明

- 系统的输入为FAA和US Coast Guard提供的NOTAM和NANU报文, 不保证应用的报文与GPS卫星实际情况相一致。
- RAIM预测可能受到卫星的突发故障、电离层剧烈变化等多种不可预见因素的影响, 这些因素无法及时反应到RAIM预测系统的输入, 将可能导致预测结果与实际不符, 系统不承担由此造成后果的法律責任。
- 当使用该RAIM系统辅助航班放行时, 应取得满足AC-91FS-01或AC-91-08的使用许可。

RAIM预测服务是在制定飞行计划时提供机载接收机RAIM可用性的预测, 为飞行签派部门和管制部门提供航班、终端区和非终端区航路的RAIM可用性信息, 为制定飞行计划提供必要的依据。

RAIM预测是基于RAIM技术的, RAIM技术是精密进近中的一种方法, 它利用GPS卫星的冗余信息, 对GPS的多个导航解进行一致性检验, 从而达到完好性监测的目的。按照GPS卫星星座的分布, 能为世界提供约 99% 以上 GPS 卫星的覆盖。当机载 GPS 接收机视界内有 4 颗卫星时, 由于至少只需要 3 颗卫星产生飞机的定位信息, 那么可以用过这颗卫星构成一个组合包括 4 颗卫

预测结果

NPA预测结果示意图

预测起始时间: 2009-12-14 00:00:00 UTC 预测结束时间: 2009-12-17 00:00:00 UTC

预测精度: 4米

NUM: 200806

历书 周: 538 周内秒: 233472.000000

(机场代码)

ZPLA

ZHCC

ZG66

ZBNA

ZBNA

时间 (UTC)

14/12 00:00 14/12 12:00 15/12 00:00 15/12 12:00 16/12 00:00 16/12 12:00 17/12 00:00

■ RAIM 可用 ■ RAIM 不可用

数据生成时间: 2009-12-13 17:01:48 UTC

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

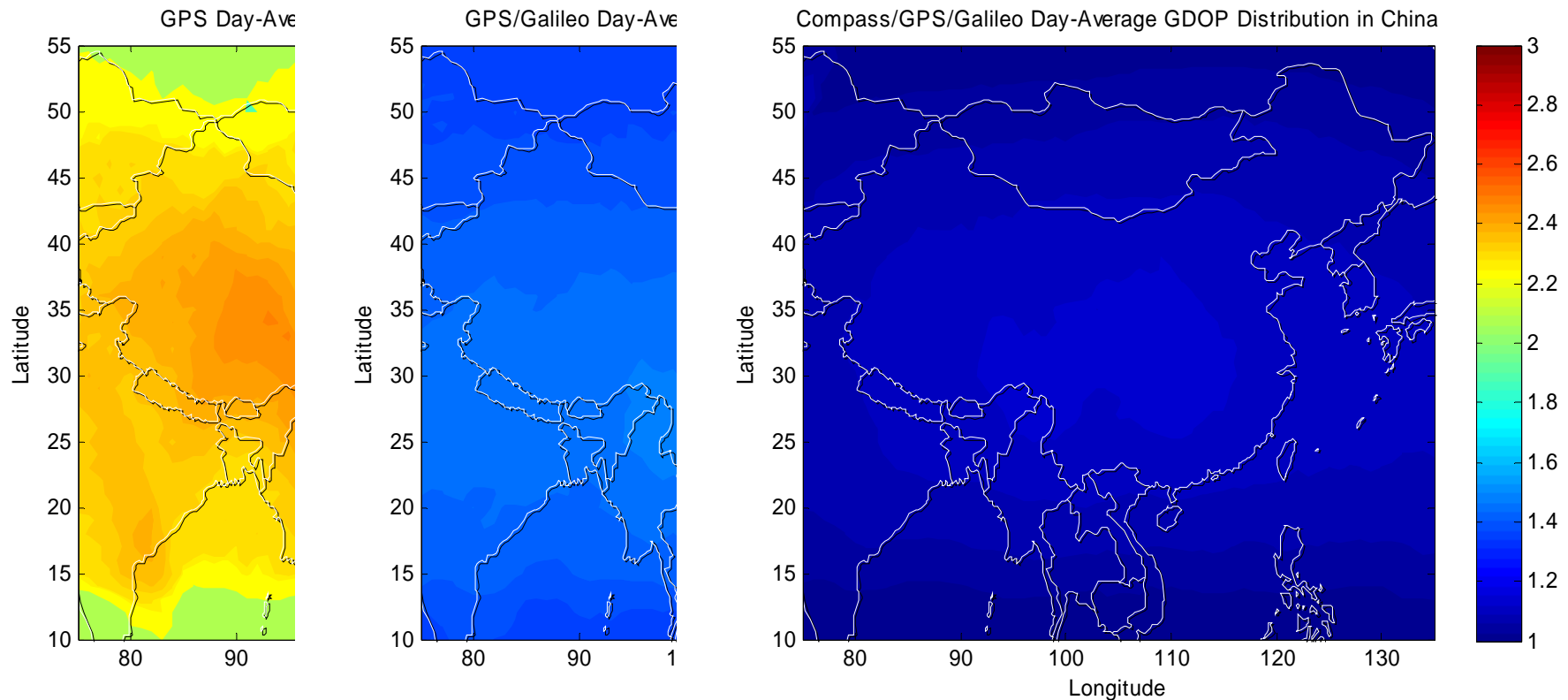


Influence of BeiDou on Multi-constellation Interoperability



➤ 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

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

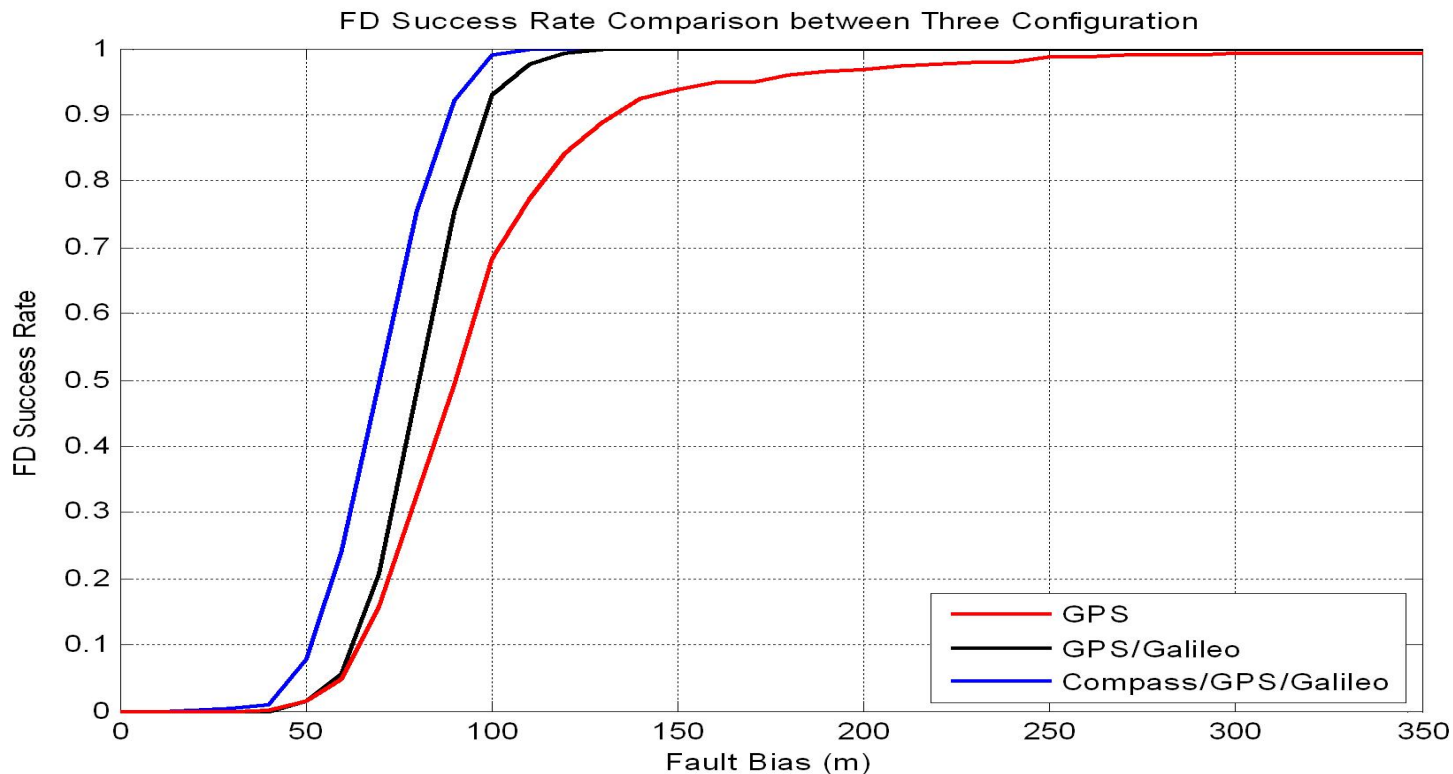


Influence of BeiDou on Multi-constellation Interoperability



➤ 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 (TDRSS) sat.	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!