Architectural Optimization of Extensible Ground-based GNSS Augmentation System

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- The views expressed in this article are those of the authors and do not reflect the official policy or position of CAAC.

Outline

- Background
- Extensible ground-based GNSS augmentation system architecture
- Simulations

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Background

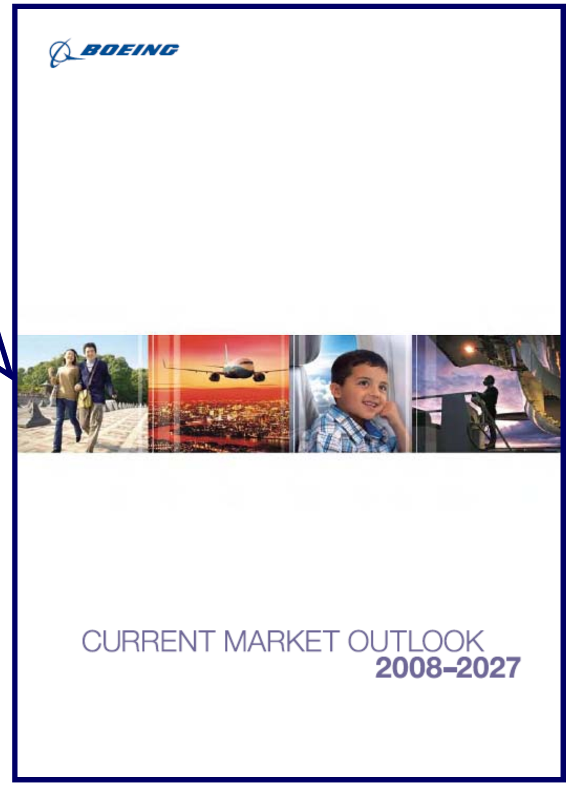
- Rapid growth of China air traffic
  - 2006: 2nd largest aviation market in the world
  - 2007 – 2027

Airplane fleet		Rank
2007	1,300	4
2027	4,560	3

Triple

Domestic traffic will grow at an average annual rate of 8.9%

Cargo traffic will grow at an average annual rate of 7.1%



Background

- Evolution of ATM system

1st Gen.	2nd Gen.	3rd Gen.	Next Gen.

Visual Flight | Instrument Flight | Instrument Landing

Free Flight

Next generation ATM system is the only solution to China.

⇩

GNSS is key enabler

Light & Flag | Procedure Control | Radar Control

NextGen
SESAR

Background

ICAO requirements of GNSS

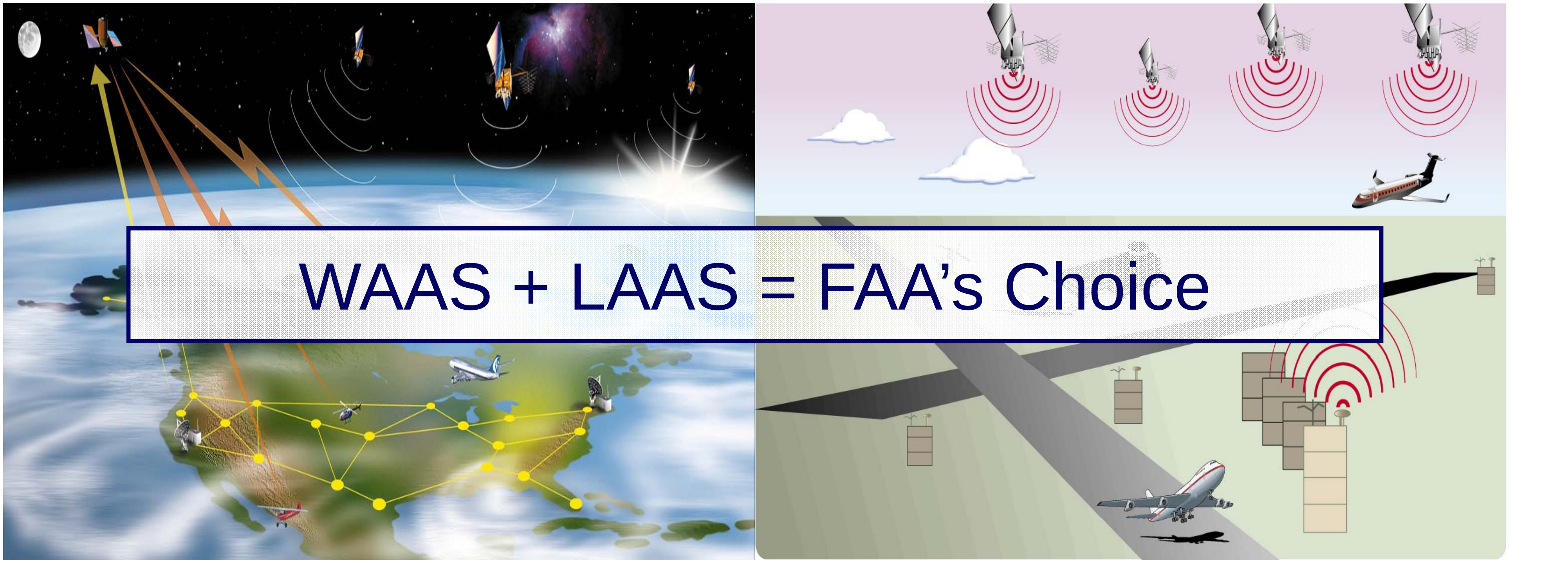
Typical operation	Accuracy horizontal 95%	Accuracy vertical 95%	Integrity	Time-to-alert	Continuity	Availability
En-route	3.7 km (2.0 NM) (Note 6)	N/A	$1-1\times10^{-7}$/h	5 min	$1-1\times10^{-4}$/h to $1-1\times10^{-8}$/h	0.99 to 0.99999
En-route, Terminal	0.74 km (0.4 NM)	N/A	$1-1\times10^{-7}$/h	15 s	$1-1\times10^{-4}$/h to $1-1\times10^{-8}$/h	0.99 to 0.99999
Initial approach, Intermediate approach, Non-precision approach (NPA), Departure	220 m (720 ft)	N/A	$1-1\times10^{-7}$/h	10 s	$1-1\times10^{-4}$/h to $1-1\times10^{-8}$/h	0.99 to 0.99999
Approach operations with vertical guidance (APV-I)	16.0 m (52 ft)	20 m (66 ft)	$1-2\times10^{-7}$ per approach	10 s	$1-8\times10^{-6}$ in any 15 s	0.99 to 0.99999
Approach operations with vertical guidance (APV-II)	16.0 m (52 ft)	8.0 m (26 ft)	$1-2\times10^{-7}$ per approach	6 s	$1-8\times10^{-6}$ in any 15 s	0.99 to 0.99999
Category I precision approach	16.0 m (52 ft)	6.0 m to 4.0 m (20 ft to 13 ft)	$1-2\times10^{-7}$ per approach	6 s	$1-8\times10^{-6}$ in any 15 s	0.99 to 0.99999

Could NOT be satisfied by GPS alone

ICAO GNSS SARPs

Background

- An integrity monitor system independent to GPS is essential for CAAC in order to implement GPS applications in China airspace.



http://gps.faa.gov

Background

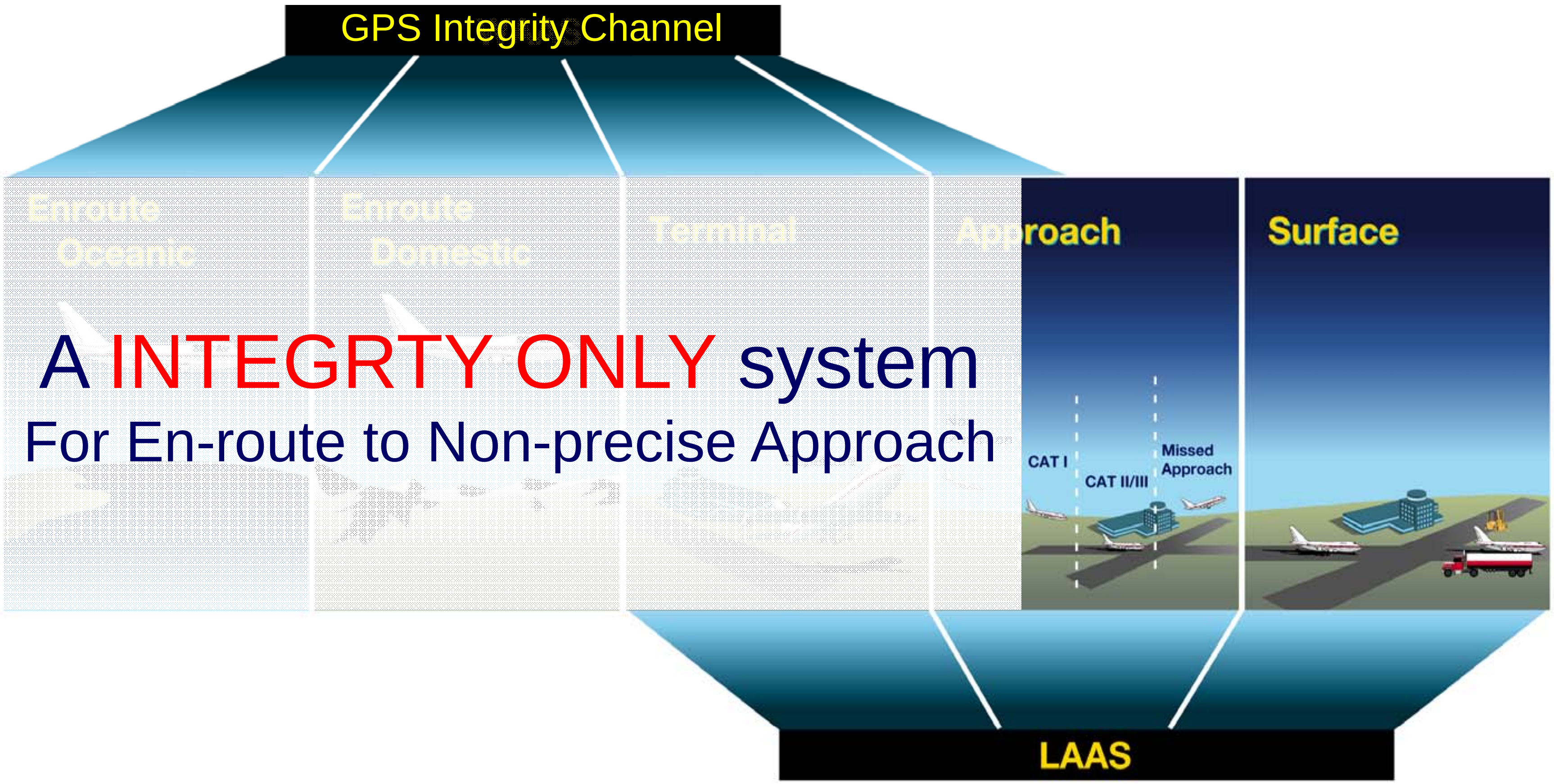
- FAA's Choice

CAAC needs a more cost-efficient solution

http://gps.faa.gov

Background

- CAAC solution: GPS Integrity Channel (GIC)



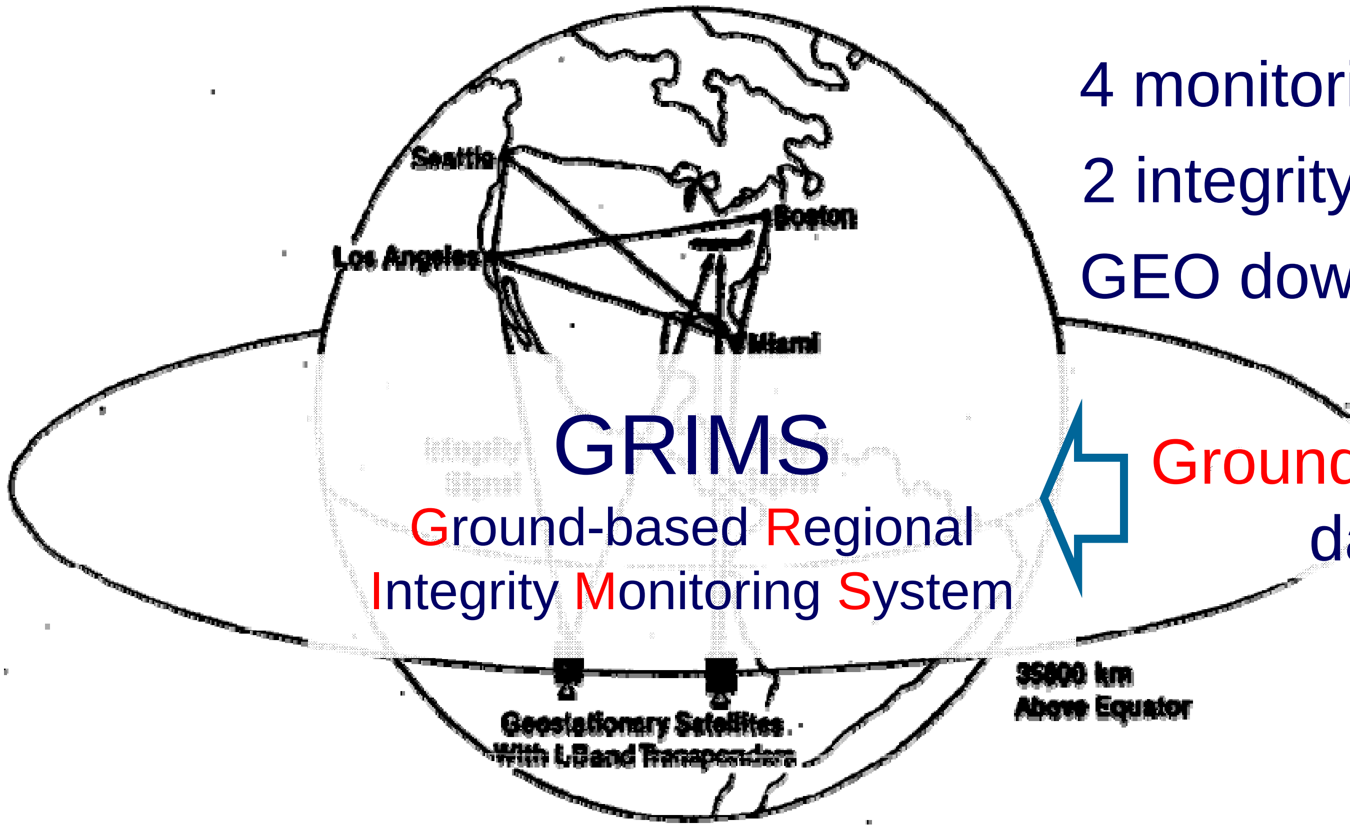
A INTEGRTY ONLY system

For En-route to Non-precise Approach

http://gps.faa.gov

Background

- Original GIC Concept



4 monitoring stations

2 integrity control nodes

GEO downlink

Ground-based VHF data link

Ronald Braff, Curtis Shively, 1985, GPS Integrity Channel, Navigation: 32(4), The Institute of Navigation, pp. 334-350.

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Extensible ground-based GNSS augmentation system architecture

Extensible ground-based GNSS augmentation system architecture

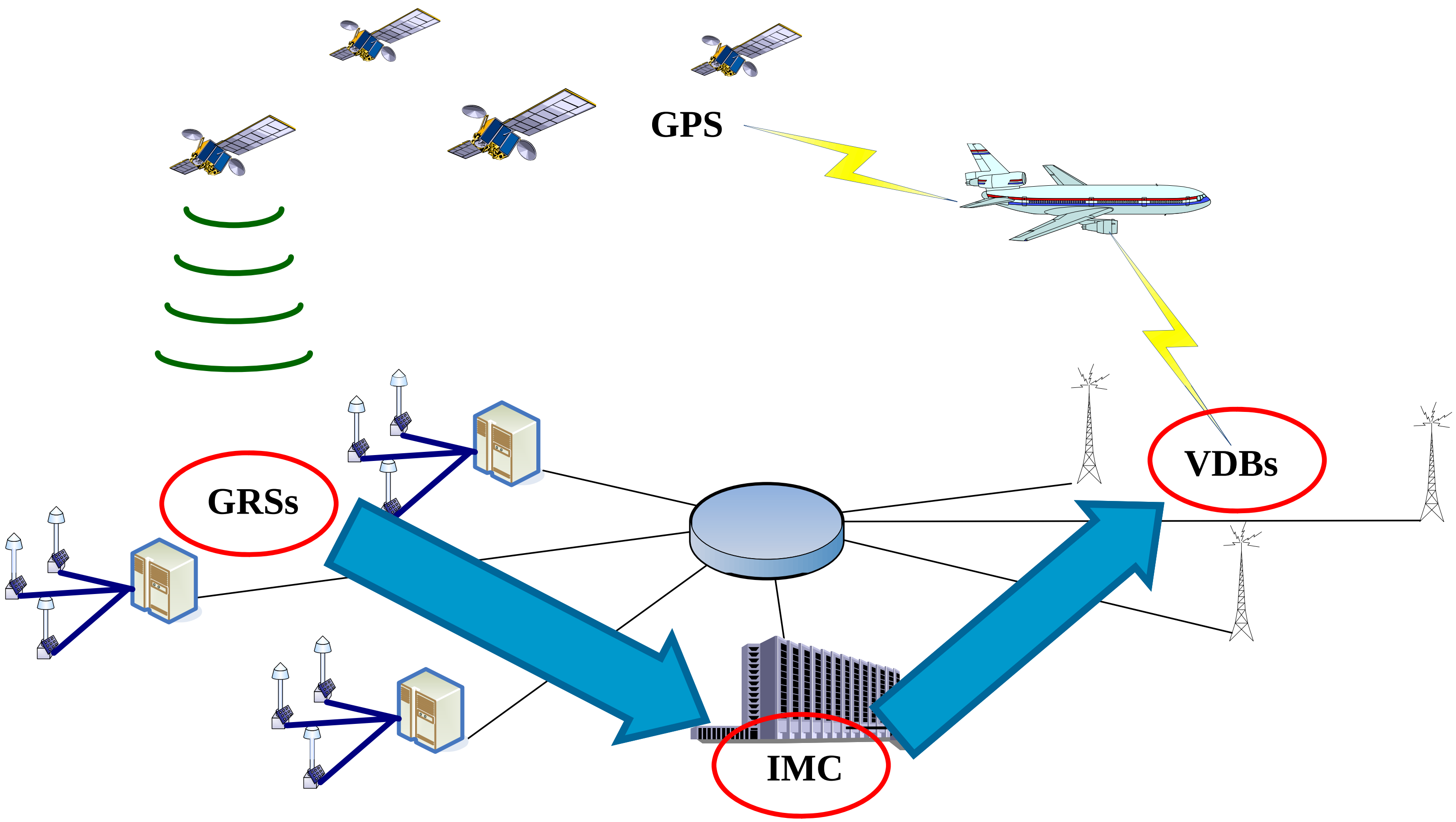
GRIMS	GBAS
Ground-based Regional Integrity Monitoring System	Ground Based Augmentation System

Extensible ground-based GNSS augmentation system architecture

- GRIMS
  - Purpose
    - augment GNSS to be used as primary navigation mean for en-route, terminal and NPA operations
  - A network of Ground Reference Stations (GRSs)
    - measure accuracy of each GPS ranging sources in view
  - A Integrity Monitoring Center (IMC)
    - uses information gathered from all GRSs to make a final decision of integrity of each GPS satellite
  - VHF Data Broadcasting sites (VDBs) covering China
    - format and broadcasted integrity information to all airplanes inside effective communication range.

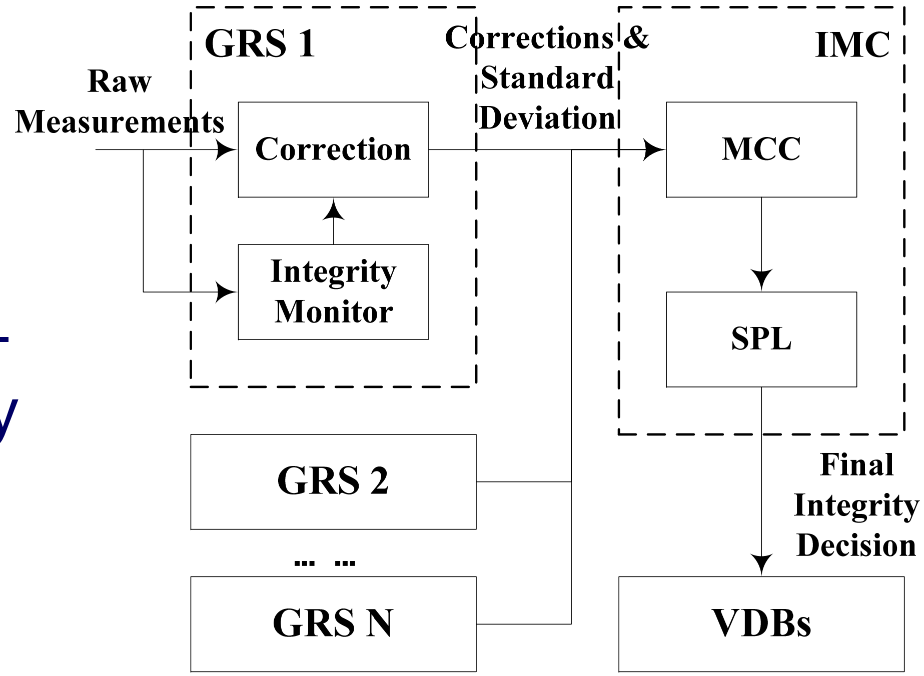
Extensible ground-based GNSS augmentation system architecture

- GRIMS architecture



Extensible ground-based GNSS augmentation system architecture

- GRS
  - 3 independent reference receivers
  - calculate correction and standard deviation of pseudo-range error for every satellite in view
  - A set of integrity monitors detect and exclude faults in all measurements

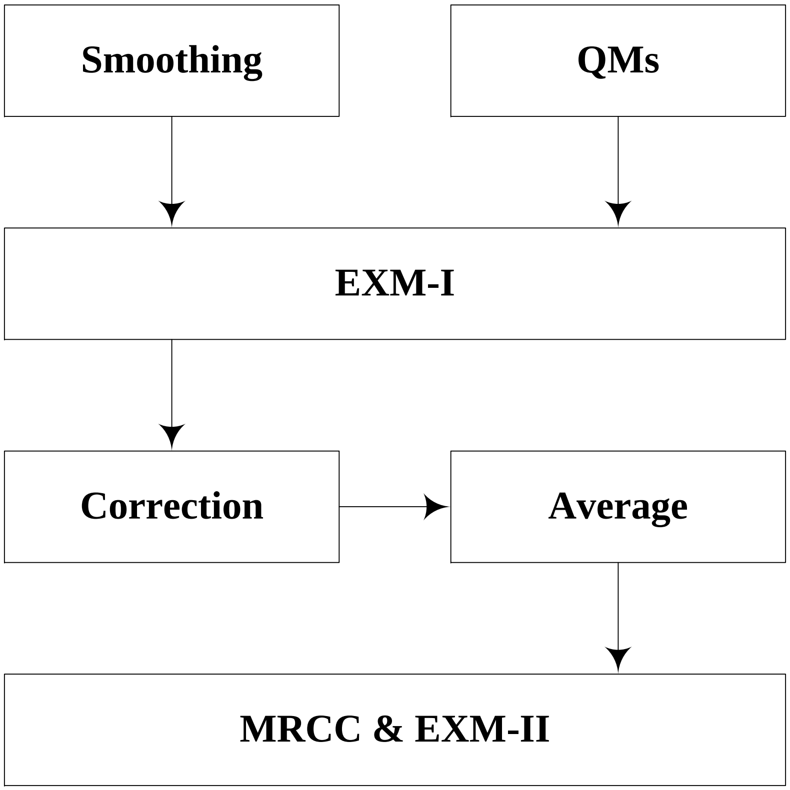


GRSs and IMC processes

Extensible ground-based GNSS augmentation system architecture

- GRS
  - incorporates a simplified version of algorithms implemented in Stanford GPS Lab LAAS Integrity Monitor Testbed

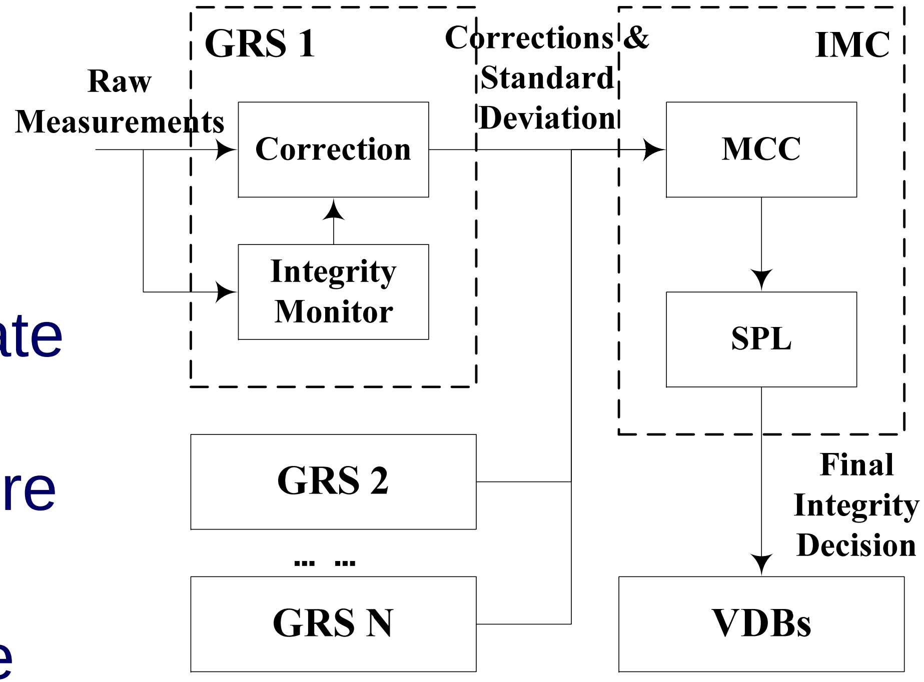
M. Luo, S. Pullen, J. Zhang, S. Gleason, G. Xie, J. Yang, D. Akos, P. Enge, B. Pervan, 2000, Development and Testing of the Stanford LAAS Ground Facility Prototype, Proceedings of the ION 2000 National Technical Meeting, pp. 210-219.



GRSs process

Extensible ground-based GNSS augmentation system architecture

- IMC
  - detect and exclude errors in data from GRSs
  - Multi-GRSs Cross Check (MCC) - isolate single GRS or communication failure
  - Synthetic Process Logic (SPL) - decide whether each satellite is good for use



GRSs and IMC processes

Extensible ground-based GNSS augmentation system architecture

- VDB
  - use identical Interface Control Document as GBAS
  - type 5 message - ranging source availability
  - message could be resolved by LAAS-capable MMR automatically

RTCA SC-159, 2008, GNSS-Based Precision Approach Local Area Augmentation System (LAAS) Signal-in-Space Interface Control Document (ICD), Washington, DC, RTCA, pp. 54-56.

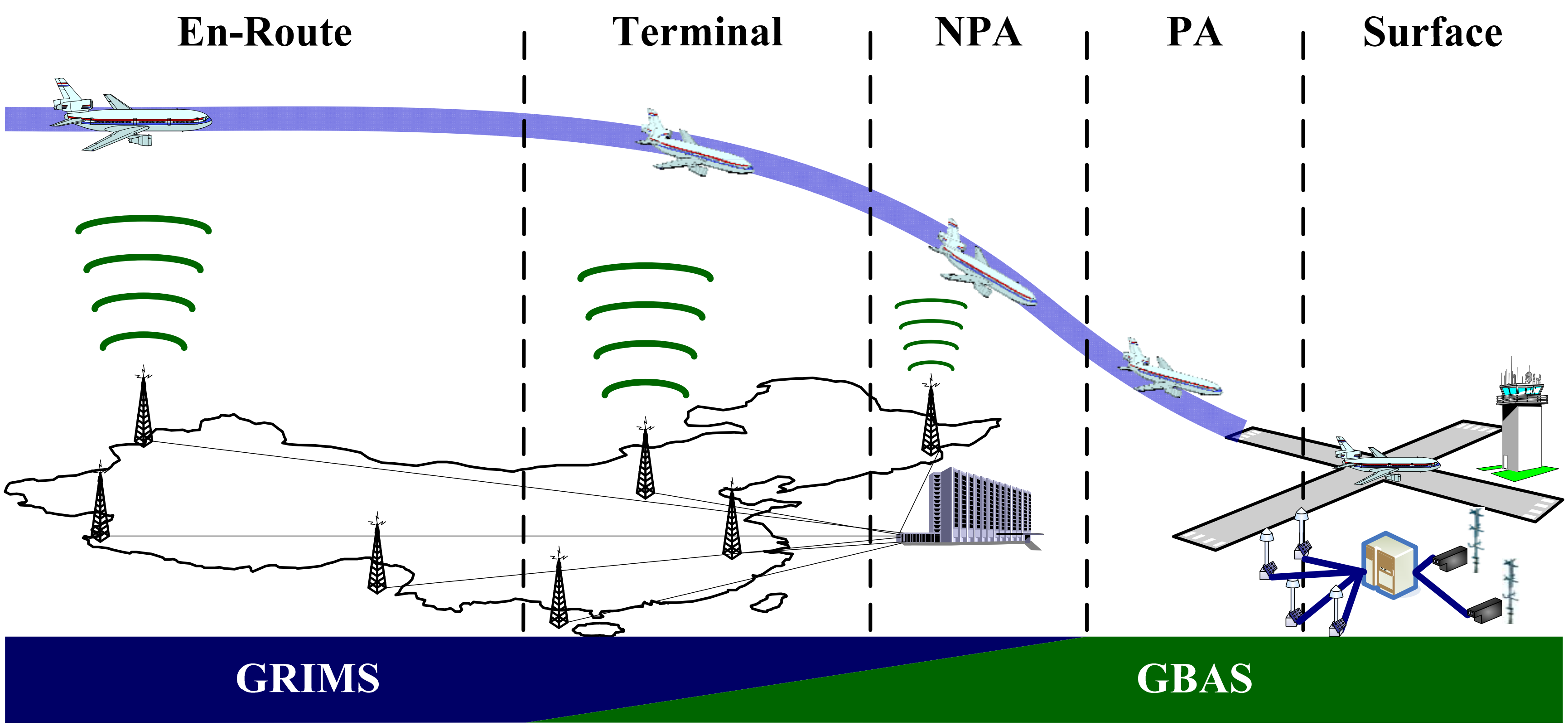
Extensible ground-based GNSS augmentation system architecture

- Incorporate GBAS into GRIMS
  - GRSs adopt GBAS algorithms and calculate pseudorange correction and standard deviation just as GBAS does
  - IMC combines outputs of all GRSs into a wide area integrity solution

GRIMS can easily accommodate GBAS ground station output at IMC and treat it just like one GRS without any specific processing

Extensible ground-based GNSS augmentation system architecture

- Concept of Operations



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Simulation

- Scenario
  - Three different GPS constellations
    - Constellation 1. Standard GPS constellation containing 24 satellites as defined in the GPS Standard Positioning Service (SPS) standard published by DoD.
    - Constellation 2. Standard GPS constellation plus 3 hot spare satellites.
    - Constellation 3. A constellation of 31 satellites, which represents a maximum constellation we could see currently

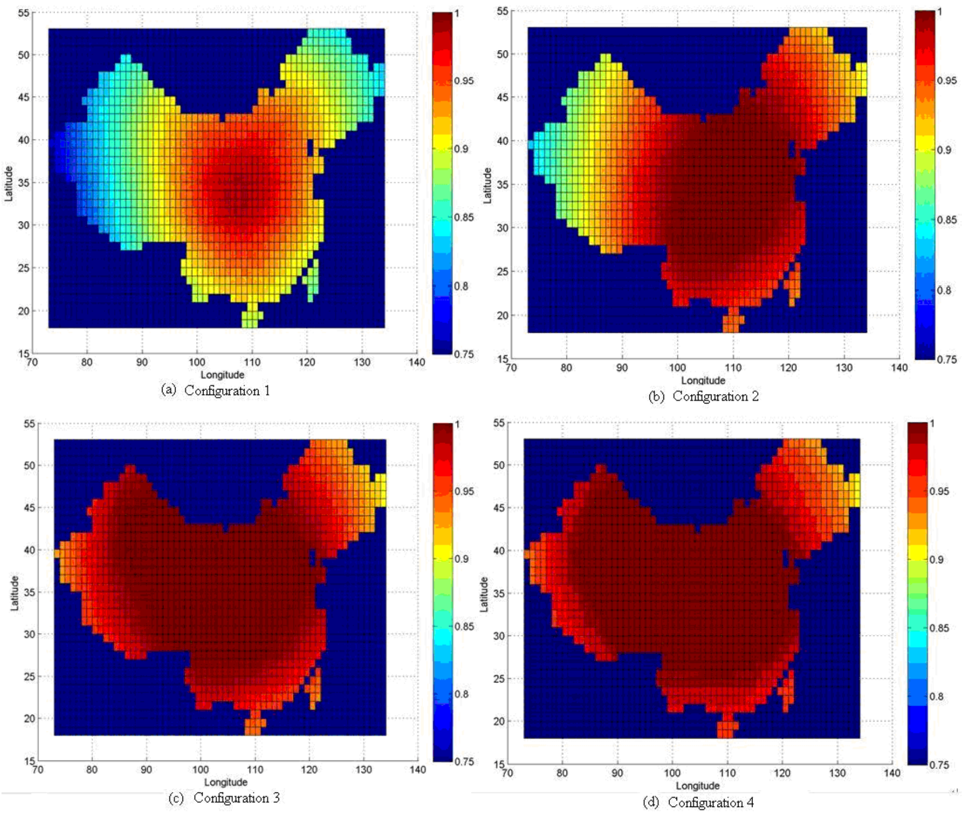
DoD, 2001, Global Positioning System Standard Positioning Service Performance Standard. Washington, DC, DoD

Simulation

- Scenario
  - Four different GRSs configurations
    - Configuration 1: 7 GRSs, including: Harbin, Beijing, Shanghai, Sanya, Kunming, Lhasa and Urumchi.
    - Configuration 2: 10 GRSs, including: all GRSs in 1 plus Mohe, Xiamen and Ali.
    - Configuration 3: 16 GRSs, including all GRSs in 2 plus Kashi, Germu, Aletai, Baotou, Xi’an and Jiayuguan.
    - Configuration 4: 22 GRSs, including all GRSs in 3 plus Qiemo, Chengdu, Wuhan, Zhangjiajie, Jinan and Lanzhou.

Simulation

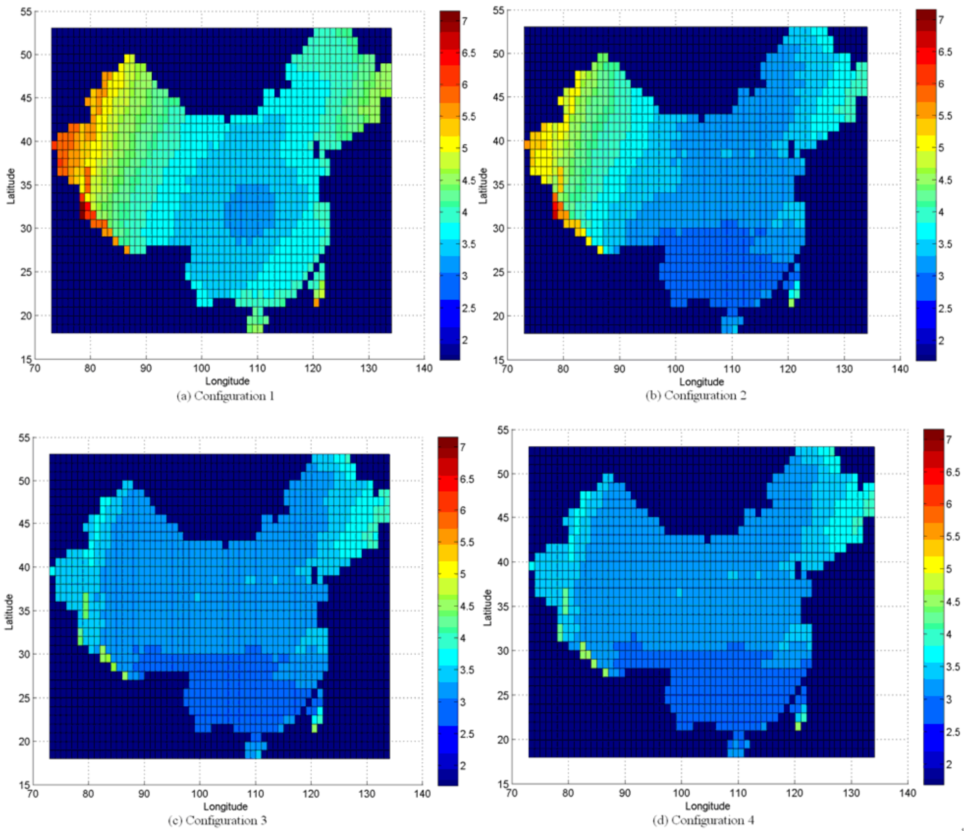
- Simulation Results
  - depth-4-coverage:
    - satellite be seen by four GRSs simultaneously
  - configuration 3 and 4 is enough for China



Depth 4 coverage using standard GPS constellation

Simulation

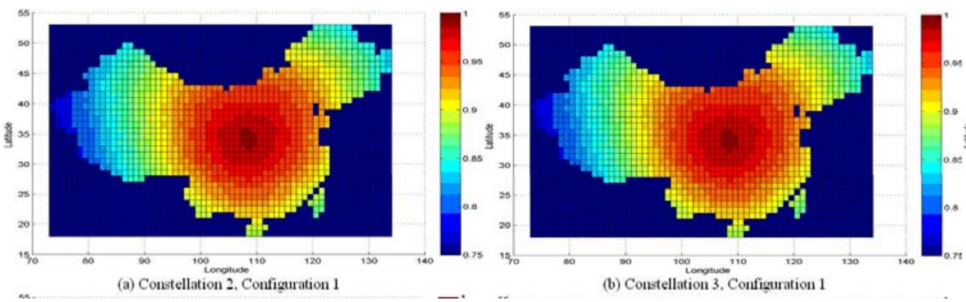
- Simulation Results
  - configuration 3 and 4: HDOP is less than 4 at 99% of all China territory



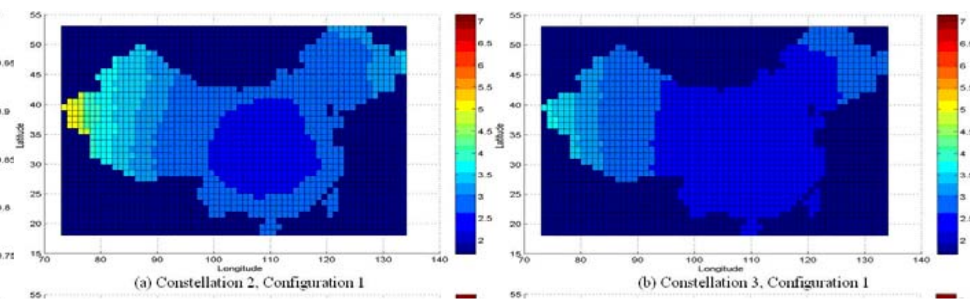
HDOP of monitored satellites using standard GPS constellation

Simulation

- Conclusion
  - For a standard GPS constellation with 24 satellites, 16 GRSs are enough to provide reliable integrity monitoring service to all users inside China
  - when number of satellites increase to 31, only 7 GRSs are needed.



Depth-4-coverage using GPS constellation 2 and 3 and GRSs configuration 1



HDOP of monitored satellites using GPS constellation 2 and 3 and GRSs configuration 1

Thank you !

For ANY questions, please email:

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