ARAIM Milestone III Report

EU-U.S. Cooperation on Satellite Navigation Working Group-C on Next Generation GNSS

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Advanced Receiver Autonomous Integrity Monitoring (ARAIM) Progress

- Conducted by ARAIM Technical Working Group under EU-US agreement to cooperate on GNSS modernization (identified as WG-C in the agreement)
- Three phases completed

Phase 1:

- Identified performance requirements
- Defined a reference user algorithm
- Performed initial evaluation of achievable performance, and
- Provided initial identification and characterization of ARAIM threats

ARAIM Progress (continued)

Phase 2: Focused on ARAIM service architectures:

- Ground infrastructure,
- ARAIM threat allocation and mitigation,
- Integrity Support Message contents (ISM), and
- potential ISM broadcast means and risks

Phase 3:

- Addressed stakeholder feedback
- Added implementation roadmap and user algorithm updates
- Assessed resulting performance

- Milestone 3 report completed Feb 2016 and available at:
  http://www.gps.gov/policy/cooperation/europe/2016/working-group-c
  and
  http://ec.europa.eu/growth/tools-databases/newsroom/cf/itemdetail.cfm?item_id=8690

Milestone III Report

Milestone III Report structured as Follows:

1. Introduction
2. Roadmap
3. Institutional Issues
4. ARAIM Complements SBAS
5. Availability Results
6. Message Types
7. Conclusions and Follow on Activities

Appendix A: Updated User Algorithm

Appendix B: Definitions and Assertions

Roadmap

- ARAIM is a natural evolution of RAIM intended to support:
  - Multiple constellations
  - Two frequencies
  - Operations with more stringent integrity (vertical guidance)
  - Updatable parameters for evolving GNSS capability
- Enables higher performance than today's RAIM
- ARAIM development will take an evolutionary path
  - Horizontal ARAIM (H-ARAIM) developed first since Horizontal operations are already supported with today's RAIM and have simpler requirements
  - Vertical ARAIM (V-ARAIM) developed later against more demanding integrity requirements

ARAIM and SBAS

- Single-frequency single-constellation (SFSC) SBAS already provides horizontal and vertical guidance to specific regions: WAAS, MSAS, EGNOS, GAGAN
- RAIM already provides worldwide horizontal guidance
- Both systems co-exist in today's receivers
- Dual-frequency multi-constellation (DFMC) SBAS intends to improve horizontal and vertical guidance
- ARAIM also intends to provide global horizontal and vertical guidance
- While they may be perceived to be in competition with each other, they are also quite complementary
  - Expected to co-exist in future receivers

Institutional Issues

- Sovereignty
  - Many non-constellation provider States were either slow to accept use of GPS or still have not approved its use
  - States hesitant to accept dependence on foreign State
  - Combination of multiple providers and terrestrial back ups should be sufficient to address sovereignty concerns
- Liability
  - Aircraft Operator is primary liable party in case of accident
  - Airline may attempt to pass responsibility to third party
  - Responsible system design should limit liability considerations

Single Global vs. Multiple ISM

- Consequences of Multiple ISM
  - Non-uniform safety level
  - Receiver Impacts:
    - Geo database and update mechanism
    - Switching between ISM regions
    - Risk of availability loss due to incorrect or missing ISM
  - However, likely easier for many States to approve
- Preference is to develop ARAIM with a single, global ISM
  - Need mechanism for mutual recognition of constellation-specific ISM similar to mutual recognition of certifications
  - Maximizes airspace user benefits
  - Encourages equipage

H-ARAIM Availability

L1 - L5 Dual-Frequency Capability

Constellation/P_{const}	GPS 10^{-4} Gal 10^{-4}	GPS 10^{-8} Gal 10^{-4}	GPS 10^{-8} Gal 10^{-8}
GPS 23 – Gal 23	RNP 0.1	RNP 0.1	HAL < 40 m
GPS 24 – Gal 24	HAL < 40 m	HAL < 40 m	HAL < 40 m
GPS 27 – Gal 27	HAL < 40 m	HAL < 40 m	HAL < 40 m

L5 Only Reversionary Capability

Constellation/P_{const}	GPS 10^{-4} Gal 10^{-4}	GPS 10^{-8} Gal 10^{-4}	GPS 10^{-8} Gal 10^{-8}
GPS 23 – Gal 23	RNP 0.3	RNP 0.3	RNP 0.1
GPS 24 – Gal 24	RNP 0.3	RNP 0.3	RNP 0.1
GPS 27 – Gal 27	RNP 0.3	RNP 0.3	RNP 0.1

Service criterion used: 90% coverage of 99.5%-availability quantile (Ref. Milestone II report)

Vertical ARAIM (H-ARAIM) Availability

Expected V-ARAIM (Offline Architecture)

With Airborne Constellation Cross-check: $P_{sat} = 10^{-5}$, $P_{const} = 10^{-4}$					
Constellation/URA	.5 m	.75 m	1 m	1.5 m	2 m
Depleted (GPS 23 – GAL 23)	LPV-250	LPV-250			
Baseline (GPS 24 – GAL 24)	LPV-200	LPV-200	LPV-200	LPV-250	
Optimistic (GPS 27 – GAL 27)	LPV-200	LPV-200	LPV-200	LPV-250	LPV-250

Expected V-ARAIM (Online Architecture)

Without Airborne Constellation Cross-check: $P_{sat} = 10^{-5}$, $P_{const} = 10^{-8}$					
Constellation/URA	.5 m	.75 m	1 m	1.5 m	2 m
Depleted (GPS 23 – GAL 23)	LPV-200	LPV-200	LPV-200	LPV-250	LPV-250
Baseline (GPS 24 – GAL 24)	LPV-200	LPV-200	LPV-200	LPV-200	LPV-250
Optimistic (GPS 27 – GAL 27)	LPV-200	LPV-200	LPV-200	LPV-200	LPV-250

Service criterion used: 90% coverage of 99.5%-availability quantile (Ref. Milestone II report)

Next Tasks

- Working Group C proposed future ARAIM work in two primary areas:

1) **ARAIM research and development (R&D) for aviation as well as other user communities**
   - Continue R&D activities initiated in the ARAIM TSG for the Aviation community
   - Initiate R&D activities related to extension of the ARAIM concept to other user communities (especially Maritime and Rail applications)

Next Tasks (cont.)

2) Contribute to preparation of ARAIM Standards for the Aviation community

- Provide inputs to assist in preparation of ARAIM standards for the Aviation community.
- Roadmap for ARAIM Service implementation (as proposed in MS 3 Report) foresees preparation of Horizontal ARAIM standards to support 2023 services
- Standards organizations (ICAO, and Avionics Standards bodies) require final inputs in 2020 timeframe
  - Including inputs/comments on iterations of draft standards until final version is completed

Next Tasks (cont.)

Milestone 3 Report identifies three main areas of work where WG-C can contribute in 2016-2018 including:

- Contributions to standards development (see prior slide)
- Launch prototype development and testing for ground and airborne algorithms
- Determine potential Constellation Service Providers' commitments, and compatibility coordination
  - Build upon 2016 Munich outreach to various entities to establish dedicated exchanges on ARAIM concepts with the Constellation Service Providers and identify potential incompatibilities
    - Data was provided to Russia and others at the Munich 2016 event and feedback is requested
  - Future interactions will follow development of potential CSP commitments needed for ARAIM

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- U.S./EU Working Group C ARAIM Technical Subgroup is responsible for the Technical content
  - Participants are experienced in development and/or certification of RAIM, WAAS, EGNOS, GBAS and Galileo

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Thank you

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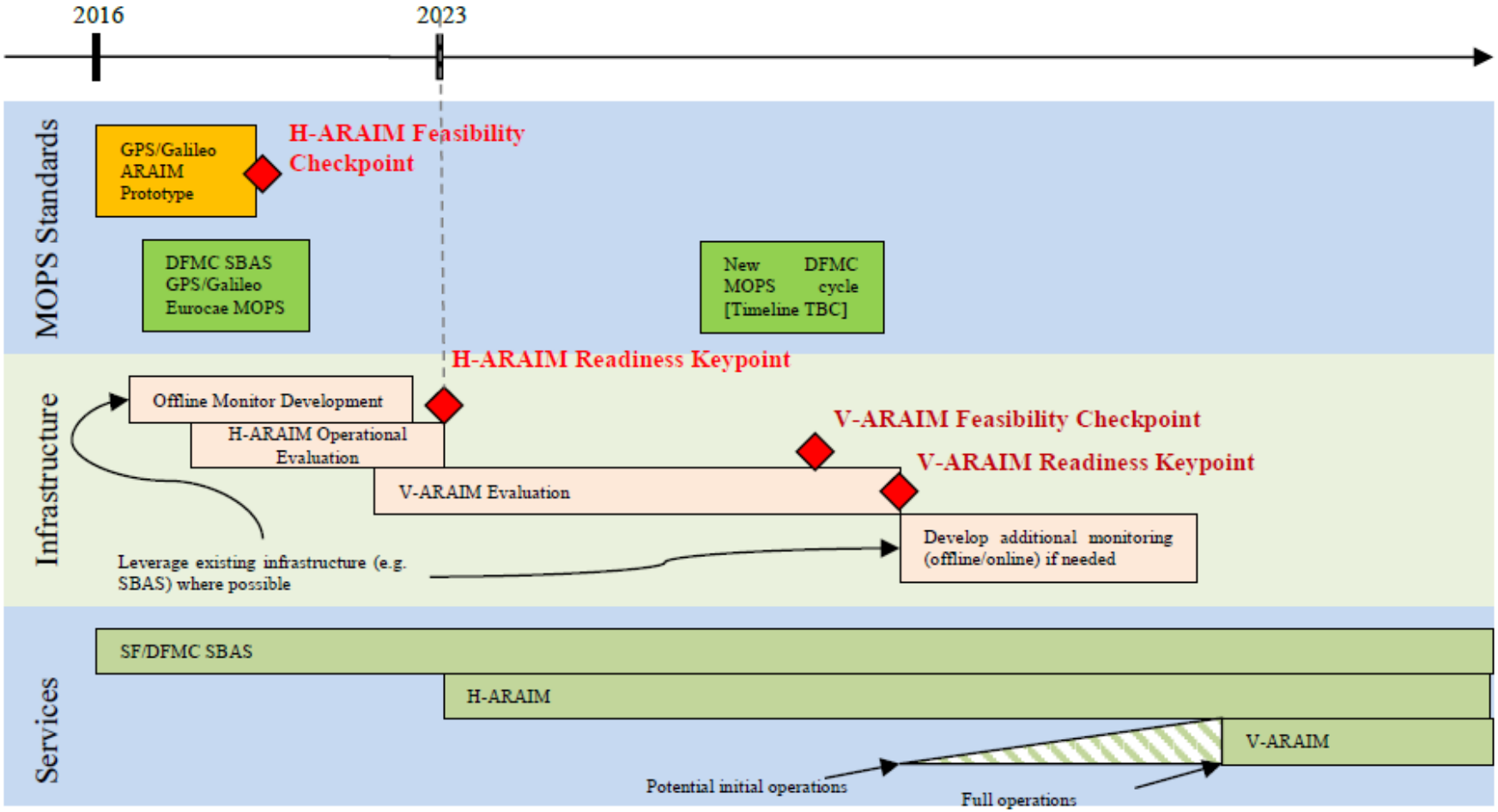
This briefing summarizes the current assumptions and progress of Working Group-C. The Working Group will continue to investigate ARAIM assumptions, algorithms, and candidate architecture implementations in order to mature the concept.

BACKUPS

Timeline


2016
2023
MOPS Standards
GPS/Galileo ARAIM Prototype
H-ARAIM Feasibility Checkpoint
DFMC SBAS GPS/Galileo Eurocae MOPS
New DFMC MOPS cycle [Timeline TBC]
H-ARAIM Readiness Keypoint
Infrastructure
Offline Monitor Development
H-ARAIM Operational Evaluation
V-ARAIM Feasibility Checkpoint
V-ARAIM Readiness Keypoint
V-ARAIM Evaluation
Develop additional monitoring (offline/online) if needed
Leverage existing infrastructure (e.g. SBAS) where possible
Services
SF/DFMC SBAS
H-ARAIM
V-ARAIM
Potential initial operations
Full operations

ARAIM Benefits Complement SBAS

Horizontal ARAIM in Near Term Based on Single Frequency
- Before dual frequency GPS + dual frequency Galileo
- e.g. single frequency GPS + single frequency GLONASS
- Two constellations with different P_{sat} & P_{const}

ARAIM to Support Artic Navigation with High Integrity
- Energy exploration, eco-tourism & shipping
- Ship speed is doubled in ice cracks
- SBAS GEOs do not cover the poles

Vertical ARAIM Worldwide Without GEOs

Multi-Constellation to Harden GNSS Receivers
- Does not need GEOs
- Does not need low SVs

Train navigation (e.g. Railway High Integrity Navigation Overlay System, RHINOS)

Offline Message

	Parameter	Description	Value	Size (bits)
Data Header	ISM_WN	ISM Week Number	[0, 1, … 1023]	10
	ISM_TOW	ISM Time of Week (hours)	[0, 1, … 167]	8
	ANSP ID	Service Provider Identification	[0, 1, … 255]	8
	Criticality	Usable for Precise/Vertical?	[0, 1]	1
	Total Header = 27 bits			
Per Constellation Parameters	$Mask_i$	32 bits indicating whether an SV is valid for ARAIM (1) or not (0)	$[m_1, m_2, \ldots m_{32}]$	32
	$P_{const,i}$	Probability of constellation fault at a given time	$[10^{-8}, 10^{-5}, 10^{-4}, 10^{-3}]$	2
	$P_{sat,j}$	Probability of satellite fault at a given time	$[10^{-6}, 10^{-5}, 10^{-4}, 10^{-3}]$	2
	$\alpha_{URA,j}$	Multiplier of the URA for integrity	[1, 1.25, 1.5, 2, 2.5, 3, 5, 10]	3
	$\alpha_{URE,j}$	Multiplier of the URA for continuity & accuracy	[0.25, 0.5, 0.75, 1, 1.25, 1.5, 2, 4]	3
	$b_{nom,j}$	Nominal bias term in meters	[0.0, 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, 2, 2.25, 2.5, 3, 4, 5, 7.5, 10]	4
	Total Core = 46 bits x 4 Constellations = 184 bits			

Online Message

Type=16	ISM Header				ISM Core				Eph/Clock Correction (at SoA)				Eph/Clock Correction Rate (at SoA)			
	SAT-ID	Message IOD	ISM SoA	Const-ID	P_sat	Sigma_int	Sigma_cont	Bias_int	Along Track	Across Track	Common Error	Distance Error	Along Track Error	Across track Error	Common Error	Distance Error
6	6	10	11	2	3	3	3	3	9	8	12	5	6	5	11	3

Total [bits]
100