Progress on Working Group-C Activities on Advanced RAIM

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ABSTRACT

Advanced Receiver Autonomous Integrity Monitoring (ARAIM) is a concept that extends RAIM to other constellations beyond GPS. ARAIM will enable the integration in the position solution of the newer GNSS core constellations that may have different properties (in particular with higher failure rates than GPS). This inclusion will provide better levels of performance of horizontal guidance than RAIM with GPS alone. In addition, when sufficient satellites have dual frequency (L1-L5) signals, ARAIM could enable aviation safety of life operations, including approaches with vertical guidance.

The European Union (EU) and the United States (US) have an agreement establishing cooperation between GPS and Europe's Galileo system. As part of this cooperative agreement a technical subgroup was formed to investigate the benefits of Advanced Receiver Autonomous Integrity Monitoring (ARAIM) [1]. This EU-US ARAIM subgroup has developed a reference airborne algorithm [2] and two potential ARAIM architectures [3, 4, 5]:

- **Offline ARAIM** to support horizontal and vertical navigation based on a low latency (days to months) ISM.

- **Online ARAIM** to support horizontal and vertical navigation based on an hourly ISM from the ground, which would include clock and ephemeris corrections.

We will describe the current status of ARAIM as a concept. We will start by discussing the relationships between SBAS and ARAIM, and among the different architectures. This is important, as ARAIM aims to provide globally the services that SBAS already provides regionally. Then, we will present preliminary Integrity Support Message formats adapted for a GNSS broadcast, both for the offline architecture (which are the same for horizontal and vertical), and the online architecture (which include clock and ephemeris corrections). Finally, we will describe a notional ARAIM roadmap for the deployment of a global ARAIM service.

INTRODUCTION

The US-EU Agreement on GPS-Galileo Cooperation signed in 2004 established the principles for the cooperation activities between the United States of America and the European Union in the field of satellite navigation. The Agreement foresaw *a working group to promote cooperation on the design and development of the next generation of civil satellite-based navigation and timing systems*. This work became the focus of Working Group C (WG-C).

One of the objectives of WG-C is to develop GPS-Galileo based applications for Safety-of-Life services. To this end, WG-C established the ARAIM Technical Subgroup (ARAIM TSG) on July 1, 2010. The objective of the ARAIM TSG is to investigate ARAIM (Advanced Receiver Autonomous Integrity Monitoring) on a bilateral basis. The further goal is to establish whether ARAIM can be the basis for a multi-constellation concept to support air navigation worldwide. Specifically, ARAIM should support enroute and terminal area flight; it should also support lateral and vertical guidance during approach operations.

Amongst these, global vertical guidance for aviation is the most ambitious goal. These aircraft operations are called localizer precision vertical or LPV. LPV-200 indicates that this guidance should support approach operations down to 200-foot height (above runway threshold), and the ARAIM TSG focuses on ARAIM architectures to support LPV-200 or LPV-250 globally.

The ARAIM TSG has produced two publically available reports. The first one [3] described the progress made on the analysis of the relevant Performance Requirements, the definition of an ARAIM reference user algorithm, a first evaluation of the achievable Performance, as well as the identification and first characterization of the ARAIM Threats. The second report [5] focused on the description of the architectures for the implementation of the ARAIM service (ground infrastructure, ARAIM threat allocation and mitigation, Integrity Support Message contents and potential ISM broadcast means and risks). Two potential ARAIM architectures were developed [3, 4, 5]:

- **Offline ARAIM** to support horizontal and vertical navigation based on a low latency (days to months) ISM.
- **Online ARAIM** to support horizontal and vertical navigation based on an hourly ISM from the ground, which would include clock and ephemeris corrections.

After the publication of the second report, the ARAIM TSG sought feedback from stakeholders in standardization forums (RTCA and EUROCAE). Some common themes have emerged from the responses received so far. First, the main interest in ARAIM is for global vertical guidance, which confirms that this is the appropriate goal for the ARAIM TSG. There is however a definite interest in a (sooner) horizontal guidance service. For the architectures, the offline is seen as more achievable due to lower infrastructure costs, but it is recognized that there is an availability risk associated to it. The responses also suggested that if the integrity support information must be updated regularly, then GNSS is the preferred broadcast channel. It has also appeared that it is necessary to clarify the relationship between ARAIM and SBAS.

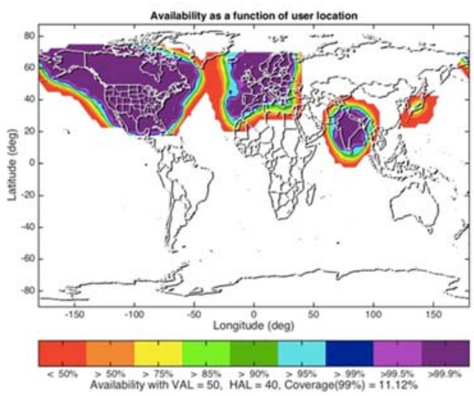
In this paper, after discussing the relationship between SBAS and ARAIM, we will present message structures for both the offline and the online architectures that demonstrate that the ISM could be broadcast through GNSS. Then, we will discuss how ARAIM services could be incrementally deployed.

ARAIM AS A COMPLEMENT FOR SBAS

Today, the Satellite Based Augmentation Systems (SBAS) are serving an increasing number of aircraft. Figure 1 shows the coverage of SBAS in 2015; it shows four separate SBAS. The Wide Area Augmentation System (WAAS) covers North America, providing approach guidance to over 3000 runways with avionics carried by more than 100,000 aircraft. The European Geostationary Navigation Overlay Service (EGNOS) covers Europe; the GPS-Aided Geo-Augmented Navigation (GAGAN) system serves India, and the MTSAT Satellite Augmented System (MSAS) is used over the Japanese Islands.

Figure 1 coverage assumes that the aircraft carries SBAS receivers that only use the GPS civil signal at the L1 frequency of 1575.42 MHz. In other words, the Figure 1 coverage is for single-frequency single-constellation (SFSC) operation of SBAS. The Figure 2 coverage is based on air receivers that process signals at 1575.42 MHz and 1176.45 MHz. These are dual-frequency (DF) systems, and the DF operation eliminates the troublesome ionospheric error.

Figure 1: SBAS Coverage for LPV-200 in 2015

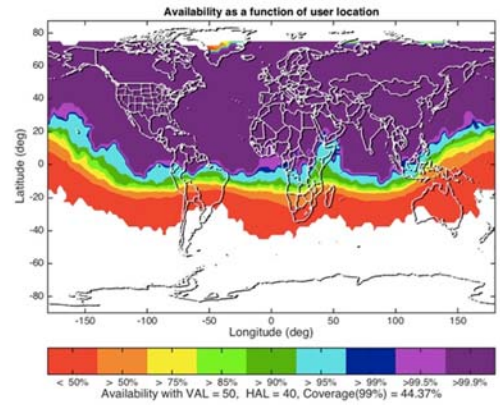


WAAS will continue to serve avionics that use the L1 frequency alone, but it will also support SBAS avionics that process the GPS signals at 1575.42 and 1176.45 MHz. As such, WAAS will become a dual-frequency single constellation (DFSC) system. EGNOS will expand to support GPS and Galileo at these two frequencies. As such, it will become a dual-frequency multi-constellation (DFMC) system. With dual frequencies, SBAS coverage will expand from Figure 1 to Figure 2, because the air receivers will eliminate the ionospheric error that is the largest error source for single-frequency operation.

The DF coverage of SBAS shown in Figure 2 will support approach operations down to an altitude of 200 feet for all of the airports within the coverage area. This DF SBAS capability has some important advantages. Specifically:

- DF operation can be based on a single healthy constellation (e.g. GPS or Galileo only), and the capability will become available when the GPS L5 and Galileo E5A signals are operational.

Figure 2: SBAS Coverage for LPV-200 in 2026



- The DF ground systems will be able to reuse much of the single-frequency software.
- A strong cadre of existing SBAS receiver manufacturers will be able to readily make the step from single-frequency to dual-frequency avionics. Thus the technical risk associated with the new receivers should be reasonably low.
- No dramatically new safety proofs are needed to support DF operation. Unlike ARAIM, SBAS supports the time-to-alarm from the ground system directly.
- LPV-200 approach operations can be approved based on the now familiar error distribution associated with SBAS, while ARAIM will present a new error distribution.
- Sovereign control of SBAS seems feasible on a regional basis.

Even so, ARAIM does offer important capabilities that complement SBAS, and Table 1 lists these applications in a rough chronological order. Please know that these applications are only predictions. They may not come to pass, and unexpected applications may arise and be more important than the ones that we anticipate today.

Horizontal ARAIM in the Near Term Based on One Frequency: ARAIM may find near-term application before dual frequency GPS and dual frequency Galileo are operational. Specifically, ARAIM could enable dual or multiple constellation navigation based on one frequency. After all, single frequency GPS is already operational; single frequency GLONASS is already operational; and single frequency Galileo will be operational in 2020. ARAIM would enable the

integration of these early constellations even if they differ sharply in P_{sat} and P_{const}. In the near term, ARAIM could store the ISM in the receiver's non-volatile memory or disseminate the ISM via an existing communications link or database.
ARAIM to Support Arctic Navigation: The Arctic Ocean requires navigation with integrity for energy exploration, eco-tourism and shipping. Importantly, ARAIM could enable the ship to travel in existing ice cracks or tracks from previous ships. Thus guided, the ship could double its speed. ARAIM supplants SBAS in the Arctic, because the needed ISM could be broadcast by the GNSS satellites or through the use of databases, while SBAS GEOs do not cover the Arctic.
Vertical ARAIM Worldwide Without Needing Geostationary Satellites: In time, ARAIM could obviate or reduce the need for the geostationary satellites used by SBAS. As such, it would reduce a significant part of the SBAS operational budget.
ARAIM to Provide GNSS Resilience: As mentioned above, ARAIM does not need the SBAS geostationary satellites. The needed ISM will be broadcast over the GNSS satellites, stored in the receivers or disseminated through aviation databases. As such, ARAIM does not suffer from the signal outages associated with geostationary satellites that frequently appear low in the sky. These outages can be due to blockage by terrain or buildings, or they can be due to intentional or non-intentional radio frequency interference.

Table 1. ARAIM Applications that Complement SBAS

GNSS BROADCAST OF THE ISM: MESSAGES FOR OFFLINE ARAIM

The offline ARAIM architecture is an extension of today's RAIM architecture [5]. It adds four elements: multiple constellations, dual-frequency, a deeper threat analysis, and the possibility to update the ISM. The ISM parameters are based upon CSP commitments and observational history. An updatable ISM allows the performance to adapt to the changing GNSS environment. In particular, it will allow ANSPs to include new constellations as they become available, and to improve the ISM parameters as they establish a history of good performance.

The ISM elements described in this section are common to both the horizontal-only architecture and to the offline architecture to support vertical guidance. **Error! Reference source not found.** 2 describes the full set of the offline ISM data content. A reference algorithm [3], [4] was developed to show how the ISM content must be used by the airborne receiver. The same reference algorithm used for H-ARAIM is applicable to offline V-ARAIM. There are some differences in the allocation of the integrity budget between horizontal and vertical modes, but otherwise the same algorithms may be used for each.

Parameter	Description
Time of applicability	The time of applicability includes a week number and a time of week. This value indicates a start time for when the information may be used. It will likely be set to the approximate time of creation for the ISM or for the time that the data was disseminated. Later time tags should pre-empt any earlier information, and any earlier ISM data should be discarded. A variant that may be considered is that ISM data have a finite window of effectivity and that any data older than a certain threshold can also be discarded. This would ensure that the user maintains the most current information.
ANSP ID	There is an identification number for the specific ANSP, which may be national, regional, or global. This number could be matched to the air-route or approach and gives the ANSP the ability to decide which ISM is used in its airspace.
Criticality	This flag indicates whether these parameters may be used for more precise or vertical guidance. If this bit is set to 0 then the parameters may only be used to support horizontal guidance. If the bit is set to 1 then the data may be used to support either horizontal-only guidance or horizontal and vertical guidance. Because there is a difference in the risk level for these operations, it is possible that horizontal-only operations may be supported with somewhat less conservative ISM parameters. It is still to be decided whether ARAIM should support simultaneous but separate horizontal and vertical ISMs or whether a

	single ISM with criticality set to 1 is sufficient for all operations.
$Mask_i$	The satellite mask is similar in format to the SBAS Message Type 1 satellite mask [6], but updated to include all constellations. Each bit corresponds to a specific PRN number in a specific constellation. Setting a bit to 1 indicates that the satellite will have parameters included in the core of the ISM message. If a bit is set to 0, then there is no information provided for that satellite and it should not be used for ARAIM in that ANSP's airspace.
$P_{const,i}$	For each constellation included in the satellite mask, there is a parameter specifying the value for P_{const}.
$P_{sat,j}$	For each satellite included in the satellite mask, there is a parameter specifying the value for P_{sat}.
$\alpha_{URA,j}$	This value multiplies the broadcast *URA*/SISA value from the satellite to determine the ovbounding integrity sigma to be input to the user algorithm. α_{URA} allows the ANSP to increase the overbounding sigma term used in the protection level computation, σ_{URA}.
$\alpha_{URE,j}$	This value multiplies the broadcast *URA*/SISA value from the satellite to determine the accuracy/continuity sigma to be input to the user algorithm. α_{URE} allows the ANSP to set the sigma term used to describe the expected accuracy of the ranging signal, α_{URE}.
$b_{nom,j}$	This parameter allows the ANSP to specify the overbounding nominal bias term used in the protection level computation.

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We present two offline messaging approaches: one where all of the ISM content is contained in a single message, and another where each message contains only the ISM content for one constellation. The former is more compact and requires lower bandwidth. The latter provides more flexibility if there is a need to have different values apply to different satellites within each constellation.

The V-ARAIM message structure is deliberately kept identical to the H-ARAIM message structure. This approach is to permit a smooth transition from H-ARAIM-only operation to the inclusion of V-ARAIM. The user algorithm and ISM parameters are the same for both although the specific parameter values will likely change due to the higher criticality of the impact of loss of integrity for vertically guided operations.

The proposed range of values is preliminary. Only GPS has been well-characterized so the range of values needed for the other constellations may not be well represented by the tentative values proposed here. The specific values may need to be updated, but the overall message format should still be valid.

Offline ARAIM ISM in a single message

First we look at putting all ISM values in a single 250 - 300 bit message. For example, an SBAS message has either 212 data bits available for L1 or 214 available for L5. Our proposed message requires 211 data bits. A specific SBAS message type could be designated for the ARAIM ISM. This message would then use 27 header bytes to specify the time the message was either created or should start being used. Users should then use the latest version that is before the current time. There is also information to specify the specific ANSP. Each country would have its own unique ID number and there could be numbers to specify regions or the entire globe. Finally, the header includes a criticality indicator, which would let the user know if the values may be used for horizontal guidance only (0) or may be used for both horizontal and vertical guidance. An ANSP may send two ISMs one optimized for horizontal only and one optimized for vertical (and that would also support horizontal). The user can elect which one to use when not in a precision flight mode.

The rest of the message contains specific values for each of four constellations. The ISM parameters are contained in a set of 46 bits specific to each constellation. The first set of 46 bits is for GPS, the next set for GLONASS, then Galileo, and finally for Beidou. Within the constellation specific set is a mask used to indicate whether a satellite may be used (1) or not (0). The mask contains 32 bits and may therefore indicate usage of up to 32 satellites per constellation. If an ANSP does not wish aircraft to use a specific constellation, all mask bits for that constellation would be set to zero.

The remaining 12 bits are used to indicate the values for P_{const}, P_{sat}, α_{URA}, α_{URE}, and b_{nom} for the constellation. The same set of values applies to all allowed satellites within a constellation. However, different values may be used for different constellations.

	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, … 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			

Table 3. Offline ISM Parameters for single Message

Offline ARAIM ISM in one message per constellation

Instead of trying to describe all satellites within a single constellation by the same set of parameters, satellites may be grouped and different sets of parameters would apply to different sets of satellites within a constellation. For example, satellites could be grouped by Block, by age, by clock type, or by some combination of all of those characteristics. This message allows up to six different groupings to be defined. These are specified by a three bit grouping indicator with values between 0 and 6 (0 indicates not to use the satellite at all).

	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
	Constellation	Specify constellation described	[GPS, GLONASS, Galileo, Beidou]	2
	$Mask_i$	3 bits for each of 32 SVs indicating SV grouping (0 is do not use, otherwise m_i provides the group number that the SV belongs to)	[m_1, m_2, … m_{32}]	3 x 32
	Total Header = 125 bits			
Per Satellite Group Parameters	$P_{const,i}$	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 = 14 bits x 6 Groups = 84 bits			

Table 4. Offline ISM Parameters for one SBAS Message per Constellation

These data formats can easily also be broadcast through GPS CNAV messages. CNAV messages are 300 bits each and have 238 bits of usable data for the ISM. The addition 26 bits could be put to use to expand the range of some of the described variables or they could be left as reserved to keep the formats identical to other data channels.

Determining the content of the ISM

Legacy RAIM provides default ISM values for L1 GPS. Table 5 shows the values that RAIM assumes currently for GPS, and that are expected to be valid in the future. Other constellations have yet to publish performance commitments and establish a similar history of operation. It is anticipated that, at least initially, larger values may be needed for at least P_{const}, P_{sat}, and α.

Criticalit	$P_{const,G}$ PS	$P_{sat,G}$ PS	$\alpha_{URA,G}$ PS	$\alpha_{URE,G}$ PS	$b_{nom,G}$ PS
0	0	10^{-5}	1	1	0

Table 5. Default message content for H-ARAIM

Unlike for H-ARAIM, it is not yet possible to specify any default values for the V-ARAIM parameter values. Extensive evaluation of the iono-free ranging performance of the two constellations needs to take place [5]. Further, the civil aviation authorities need to determine acceptable methodologies for determining and setting these parameters. Larger values for α, P_{sat}, and P_{const} are possible or even likely.

GNSS BROADCAST OF THE ISM: MESSAGES FOR ONLINE ARAIM

The goal in this section is to show that it is possible to include the online ISM data in both Galileo I/NAV and GPS CNAV from a message structure point of view, therefore mitigating part of the connectivity risk identified in [5]. At this point, other relevant system level analysis, in particular latency aspects, are not yet addressed.

It is important to point out that the work presented in this section is the result of R&D level work and does not preclude any implementation decisions regarding the ARAIM concept, nor does it address wider system relevant aspects.

Correction	Bit-Size	LSB	Coded Range
Orbit Along Track Error	09	0.2496 m	[-63.89 m, +63.64 m]
Orbit Across Track Error	09	0.2496 m	[-63.89 m, +63.64 m]
Orbit Radial Track Error	10	0.0312 m	[-15.97 m, +15.94 m]
Clock Error	12	0.0312 m	[-63.89 m, +63.86 m]
Orbit Along Track Error Rate	06	0.000346666 m/s	[-0.0111 m/s … +0.0107 m/s]
Orbit Across Track Error Rate	06	0.000346666 m/s	[-0.0111 m/s … +0.0107 m/s]
Orbit Radial Track Error Rate	07	0.000043333 m/s	[-0.0028 m/s … +0.0027 m/s]
Clock Error Rate	11	0.000043333 m/s	[-0.0444 m/s … +0.0443 m/s]
Sum	**70**		

Table 6. ECD data in the online ARAIM message (Courtesy ESA).

As in SBAS, Ephemeris and Clock Data would be sent as corrections to the broadcast GNSS navigation message. Preliminary analysis of the GPS error characteristics suggest that one set of corrections every 12 minute per satellite will be sufficient. Table 6 shows a possible structure for the corrections.

The header and integrity data are given in Table 7. The ISM header includes a field for GNSS IOD Reference, allowing to link the correction data unambiguously to the reference ephemeris and clock correction data provided by the core constellation. As opposed to the integrity data in the offline ARAIM, this data characterizes the errors after applying the ECD corrections.

	Bit-Size	**Scaling Factor**	**Coded Range**
Constellation ID	3	N/A	[0 … 7]
Satellite ID	6	N/A	[0 … 63]
GNSS IOD Reference	10	N/A	[0 … 1023]
ISM ToA	11	60 sec	[0 … 1 day]
Sum	**30**		
Data	**Bit-Size**	**Scaling Factor**	**Coded Range (TBC)**
SAT_Health_Flag	1		[Use, Do Not Use]
Psat	4		[10-6 … 10-3] log-equidistant.
Pconst	4		[10-8 … 10-3] log-equidistant
Sigma_int	3	N/A. [Index=Value]	[0.30:0.10:0.70; 0.90; 1.10; 1.50] m
Bias_int	4	N/A. [Index=Value]	[0.30:0.05:.90, 1.10 1.30, 1.50, 1.70] m
Sigma_cont	3	N/A. [Index=Value]	[0.20; 0.25; 0.35; 0.40; 0.50, 0.60; 0.75; 1.00] m
Bias_cont	4	N/A. [Index=Value]	[0.30:0.05:.90, 1.10 1.30, 1.50, 1.70] m
Sum	**22**		

Table 7. Integrity data in the online ARAIM message (Courtesy ESA).

The structure of the integrity data of the online ARAIM message is very similar to the offline ARAIM message. One of the main differences is that the clock and ephemeris nominal bounding information (Sigma_cont and Sigma_int) is an absolute value, whereas in the offline ARAIM message it is a scaling factor.

ARAIM ISM Data in Galileo I/NAV

One nominal page of the I/NAV Galileo message structure has 128 bits available, of which 6 are intended for the message identifier. The message described above has a length of 122 bits, and would therefore fit in one nominal page. Assuming that one nominal page per subframe (which contains 15 pages) could be allocated to ARAIM data, up to 24 satellites could be covered within the duration of one I/NAV frame (12 minutes) (Figure 3). By exploiting all satellites within Galileo, it can be shown that two constellations of 30 satellites can be covered.

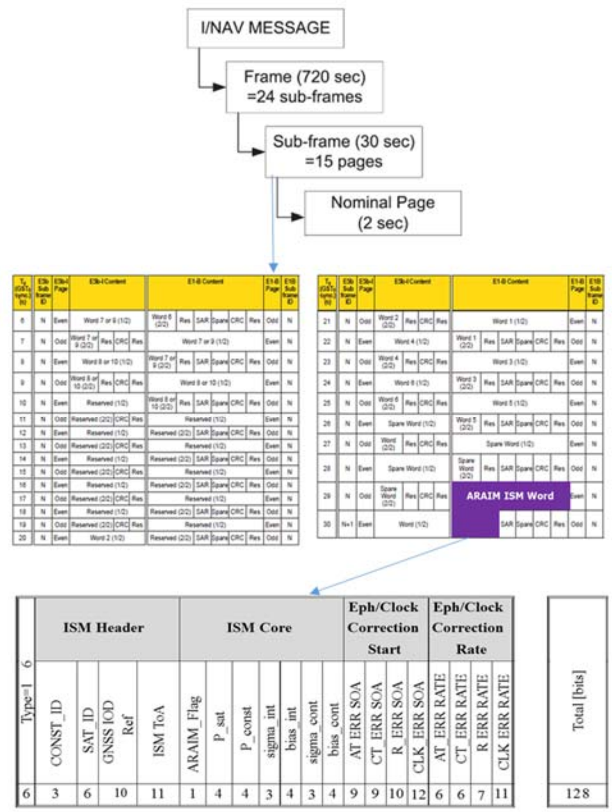

Figure 3. Potential I/NAV layout with ARAIM ISM word (Courtesy ESA).

A similar scheme has been developed for GPS C/NAV which results in an effective bit rate of 3 bps for ARAIM. It will be described in the next ARAIM TSG report.

NOTIONAL ARAIM ROADMAP

The ARAIM TSG has concluded that ARAIM services should be implemented incrementally, beginning with an offline horizontal only service, H-ARAIM, to support near-term, proposed multi-constellation (MC) applications. A global vertical service, V-ARAIM, can be implemented once sufficient data is collected and experience gained to demonstrate safe operations. Analysis and experience with observed data will determine whether additional monitoring capabilities may need to be implemented.

Horizontal ARAIM Introduction

A number of users have identified the need for near-term RAIM services which can safely handle MC signals. While standard RAIM algorithms could be adapted to support MC, ARAIM provides a more effective and safe approach for MC implementation enabling the use of less conservative constellation performance assumptions. The ISM provides a means to adjust constellation assumptions in a safe manner without affecting the aircraft certification and while avoiding overly conservative assumptions during initial fielding when data from new constellations maybe limited. Additionally, it allows for these assumptions to be adjusted if a constellation's performance changes over time as the constellations evolve. This will lead to higher availability, reliability and user confidence in un-augmented GNSS services.

EUROCAE currently has plans to publish MOPS for GPS/Galileo in conjunction with the DFMC SBAS services. This will likely require a RAIM service in support of horizontal navigation and surveillance requirements. Similarly, RTCA has been asked to develop a GPS/CLONASS MOPS. H-ARAIM could provide a safe and effective means for using GPS, Galileo, and GLONASS in conjunction with each other.

In addition, H-ARAIM could provide services prior to 2025 in areas other than aviation:

- The Arctic Ocean requires navigation with integrity for energy exploration, eco-tourism and shipping.
- Maritime and Rail have an increasing need for robust, accurate GNSS horizontal guidance. H-ARAIM will provide additional means for increased safety in utilising MC signals for horizontal guidance for user communities beyond civil aviation.

These above-listed applications are expected to be the first opportunities for H-ARAIM implementation.

H-ARAIM implementation will require ANSPs and CSPs to reach agreement on new performance commitments and offline monitoring processes. It is expected these can be implemented by the respective parties at low cost and low risk. Similar challenges exist in terms of liability and sovereignty as for current classical RAIM and these need to be resolved.

The standards for H-ARAIM would be written to be as compatible as possible with V-ARAIM. This will be helped by the fact that the reference user algorithm [2,3] is the same in both cases. Similarly, the ISM interfaces for H-ARAIM will be designed to be forward compatible with the ISM interfaces needed to support V-ARAIM (e.g. reserve sufficient communication link data bandwidth to support potential, future features for V-ARAIM). However, the main objective would be to gain immediate benefits of H-ARAIM to support MC signals while gaining data and experience which could be used in future evaluation of ARAIM for V-ARAIM. It is believed H-ARAIM can be implemented with offline monitoring at low risk, so initial efforts will focus on requirements development and validation for offline ARAIM.

Vertical ARAIM services

Once H-ARAIM services have been implemented and GPS/Galileo achieves FOC, each with 24 operational satellites with dual frequency capabilities (circa 2024) and Performance Commitments from the core constellations for dual frequency services are published, it will be possible to assess ARAIM with offline monitoring and its ability to support V-ARAIM services.

The ARAIM TSG has assessed the level of performance for precision approach down to 200 ft decision height (LPV-200) and used performance requirements established under the WAAS LPV-200 program [3]. This criterion has been used to demonstrate one acceptable means for achieving such operations with WAAS; however, this criterion will need to be reviewed in the context of the ARAIM concept and the specific safety hazard applicable to the target operations (e.g. ARAIM specific safety case for LPV 200 or for CAT I approach operations). Additionally, the ARAIM TSG and stakeholders may examine additional criteria and safety cases to extend vertical services to cover other, more stringent operations (e.g. Special Authorization CAT II, autoland).

We expect SBAS to dominate vertical guidance for an extended period of time (e.g. 15 years). Testing and evaluation of V-ARAIM services will proceed in the meantime and could be implemented based on user needs and the presence of sufficient evidence supporting its safety case.

After an evaluation period, interested ANSPs and users may seek operational approval for vertical guidance based on the performance targets set by a dedicated safety case. ANSPs and regulators will need to verify offline monitoring and CSP performance against these safety targets and the commitments documented in the standards.

This may be possible without any modification to the H-ARAIM software or interfaces. However, additional offline or online monitoring fidelity may be required to achieve more demanding vertical guidance operations, and H-ARAIM standards will likely need to be updated to enable V-ARAIM services.

SUMMARY

At this point, ARAIM is in the R&D stage. In particular, we expect SBAS to dominate vertical guidance in the next years. Still, ARAIM does offer important capabilities that complement SBAS, and could at some point provide global vertical guidance without GEOs.

The ARAIM TSG has defined ISM message structures to show that, for both the offline and the online architecture, the ISM content could be broadcast through GNSS (which appears to be the preferred channel if the integrity support information needs to be updated).

For the eventual deployment of services, the ARAIM TSG recommends to start with Horizontal ARAIM in an offline architecture (with very long latency). The standards for H-ARAIM will be developed to be as forward compatible as possible with Vertical ARAIM. Then, the experience with H-ARAIM will shape the final Vertical ARAIM architecture.

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