Advanced RAIM System Architecture with a Long Latency Integrity Support Message

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ABSTRACT

Advanced Receiver Autonomous Integrity Monitoring (ARAIM) is a promising concept enabling aviation safety of life operations, in particular approaches with vertical guidance [1]. The benefits of ARAIM would include a reduced ground infrastructure, a reduced dependency on any one GNSS core constellation, and, in general, a lesser exposure to single points of failure. In ARAIM, as in RAIM, the aircraft compares the various ranging measurements that it makes to different satellites to ensure that they are consistent with each other. However, for the aircraft to meet its integrity requirement, the satellites must perform within a certain set of expectations. Current GNSS ground segments deployed or under deployment may not offer sufficient guarantees that these expectations will always be met. For this reason, ARAIM will require an independent ground monitor that would provide an Integrity Support Message to the users. Each threat would need to be mitigated by a combination of three elements: the ground segments of the constellations, an independent ground monitoring network, and the user receiver.

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 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 identified key issues affecting the potential use of ARAIM [1]. Among these key issues are the reliance on the core constellations' providers for the characterization of the nominal and faulted behavior, the possible persistence of faults, the possibility of faults affecting all constellations simultaneously (due to erroneous Earth Orientation Parameters), as well as sovereignty and liability issues.

In order to advance in the design of ARAIM, a set of representative ARAIM system architectures was introduced in [3]. In this paper, we describe an architecture that minimizes the ground requirements and is close to today's Receiver Autonomous Integrity Monitoring (RAIM). We will specify, among other elements, the reference network, the role of offline monitoring, the level of trust given to core constellation providers, and the ISM delivery method. Then, we will outline a possible path to transition from current horizontal RAIM to ARAIM both for the receiver and the Air Navigation Service Provider.

INTRODUCTION

New constellations, new signals, lower clock and ephemeris errors, increased inherent integrity

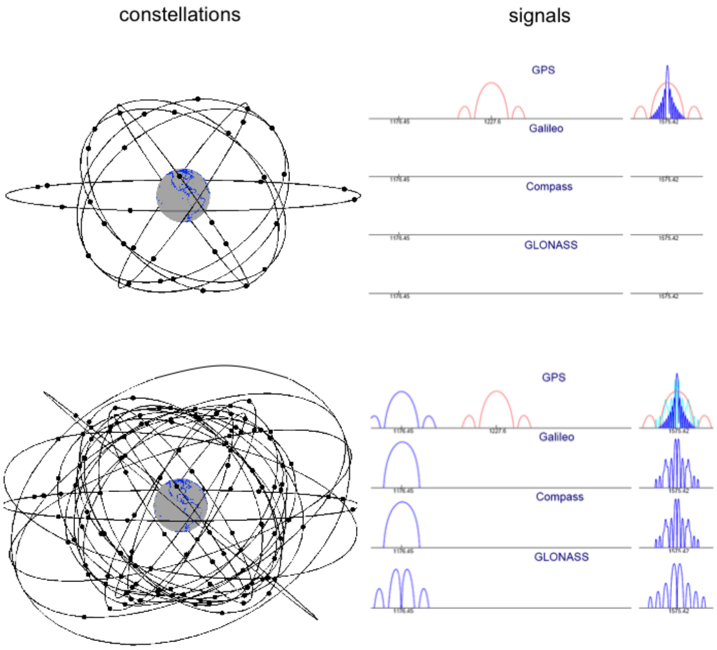


Figure 1. *Constellations and signals used for civil aviation now (top row) and in the next twenty years (bottom row)*

GNSS is currently undergoing major upgrades: new constellations are being launched (Galileo and Beidou) and expected to be fully operational by the end of the decade. GPS and the new constellations will have signals in both L1 and L5, allowing users to remove the ionospheric delay affecting the pseudorange errors (Figure 1). Finally, improvements in both the on-board clocks and the ground segments are reducing the errors due to clock and ephemeris to standard deviations below a meter (for GPS). As a consequence of all this, users will have more accurate pseudoranges, stronger geometries, and much more redundancy. This has naturally led to consider extending RAIM (which is used for horizontal navigation) to vertical guidance [8]. Today, vertical guidance with GNSS is provided by Satellite-based Augmentation Systems (SBAS), which requires both a real time ground monitoring system and a geostationary satellite to send the corrections and error bounds, and does not provide global coverage (although there is now coverage in both North America, Europe and Japan; and SBASs are being developed in Russia, India, and Korea).

ADVANCED ARAIM CONCEPT

The Advanced RAIM concept is an extension of RAIM to multi-constellation and dual frequency that would provide vertical guidance. Because of the higher level of integrity required for vertical guidance, the increased number of satellites, and the tighter required error bounds, it is not possible to simply use the current RAIM algorithms for vertical guidance. On the receiver side, multiple faults may have to be included in the threat space, as well as nominal biases. However, the biggest change is in the source of the assumptions used by the receiver [1]. Instead of relying on the characterization included in the navigation data and fixed probabilities of fault, the user receiver would use an error characterization generated by the Air Navigation Service Provider (ANSP), the Integrity Support Message (ISM), as illustrated in Figure 2.

The ISM would characterize each satellite with a set of parameters allowing to compute the nominal behavior of the pseudorange error ($\sigma_{URA,ISM}$, $\sigma_{URE,ISM}$, b_{nom}), the probability of fault in one satellite (P_{sat}), and the probability of fault in up to all satellites within one constellation (P_{const}) [1],[2],[8].

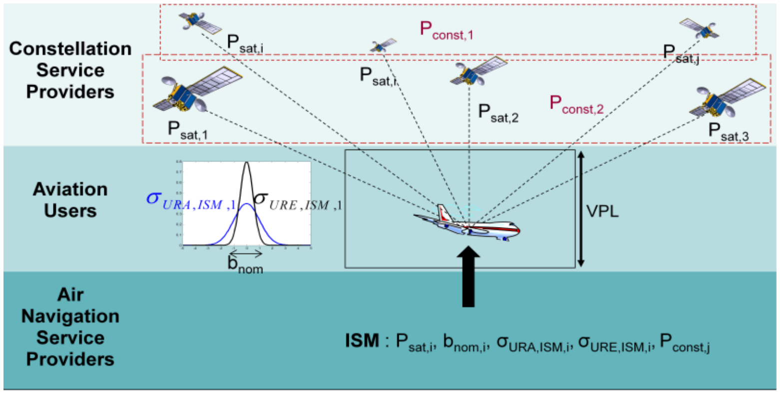
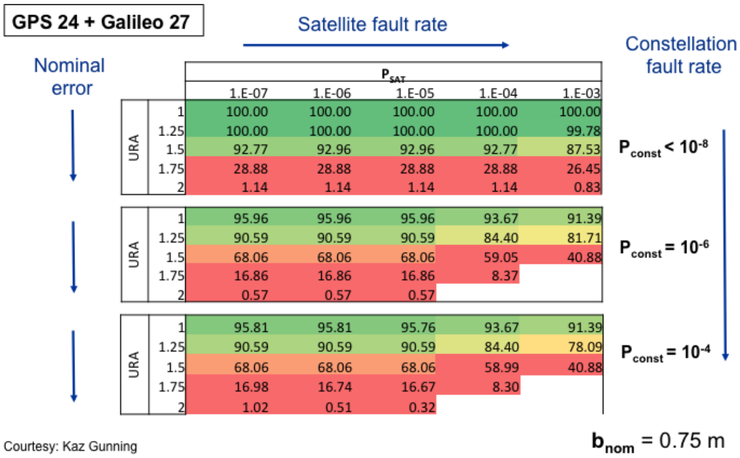


Figure 2. *Advanced RAIM concept with the three key parties: Constellation Service Providers (CSPs), Air Navigation Service Providers (ANSPs), and Aviation Users*

ARAIM Availability as a function of ISM contents

The ARAIM concept is appealing because with the expected pseudorange accuracy of the modernized constellations and somewhat conservative assumptions on the probabilities of fault (at least compared to RAIM), simulations show that it might be possible to obtain worldwide coverage of vertical guidance with high availability [8]. Table 1 shows a set of coverage results for a constellation of 24 GPS satellites and 27 Galileo satellites. The settings for the simulation are the same as the ones in [8], except for the parameters specifically listed in the table. Each figure shows the fraction of the globe that has 99.5% availability of LPV-200. As can be appreciated, performance is very sensitive to the parameter P_{const}.


GPS 24 + Galileo 27

Satellite fault rate

Nominal error

Constellation fault rate

	URA	P_{SAT} 1.E-07	1.E-06	1.E-05	1.E-04	1.E-03
$P_{const} < 10^{-8}$	1	100.00	100.00	100.00	100.00	100.00
	1.25	100.00	100.00	100.00	100.00	99.78
	1.5	92.77	92.96	92.96	92.77	87.53
	1.75	28.88	28.88	28.88	28.88	26.45
	2	1.14	1.14	1.14	1.14	0.83
$P_{const} = 10^{-6}$	1	95.96	95.96	95.96	93.67	91.39
	1.25	90.59	90.59	90.59	84.40	81.71
	1.5	68.06	68.06	68.06	59.05	40.88
	1.75	16.86	16.86	16.86	8.37	
	2	0.57	0.57	0.57		
$P_{const} = 10^{-4}$	1	95.81	95.81	95.76	93.67	91.39
	1.25	90.59	90.59	90.59	84.40	78.09
	1.5	68.06	68.06	68.06	58.99	40.88
	1.75	16.98	16.74	16.67	8.30	
	2	1.02	0.51	0.32		

Courtesy: Kaz Gunning

b_{nom} = 0.75 m

Table 1. *99.5% availability coverage results as a function of URA, P_{sat}, and P_{const}.*

THREAT SPACE

	Nominal	Narrow fault	Wide fault
1-Clock and Ephemeris	Orbit/clock estimation and prediction and broadcast limits	Includes clock runoffs, bad ephemeris, unflagged manoeuvres	Erroneous EOPP, inadequate manned ops, ground-inherent failures
2-Signal Deformation	Nominal differences in signals due to RF components, filters, and antennas waveform distortion	Failures in satellite payload signal generation components. Faulted signal model as described in ICAO	N/A
3-Code-Carrier Incoherence	e.g. incoherence observed in IIF L5 signal or GEO L1 signals	e.g. incoherence observed in IIF L5 signal or GEO L1 signals	N/A
4-IFB	Delay differences in satellite payload signal paths	Delay differences in satellite payload signal paths TBC	N/A
5-Satellite Antenna Bias	Look-angle dependent biases caused at satellite antennas	Look-angle dependent biases caused at satellite antennas	N/A
6-Ionosphere	N/A	Scintillation	Multiple scintillations at solar storms
7-Troposphere	Nominal troposphere error (after applying SBAS MOPS model for tropo correction)	N/A	N/A
8-Receiver Noise and Multipath	Nominal noise and multipath terms in airborne model (TBC Gailleo BOC(1,1) and L5/E5a))	e.g.: receiver tracking failure or multipath from onboard reflector. TBC	e.g.: receiver tracking multiple failure or multipath from onboard reflector. TBC

Table 1. *Summary of the threat space (from [8])*

Table 1 shows a summary of the threats that need to be taken into account when computing a position error bound of an aviation receiver. The first column (Nominal) includes all the errors that are always present, and whose magnitude is not expected to change, or only slowly. The second column (Narrow faults) shows the faults that can affect each satellite independently and cause the pseudorange error to grow well beyond its nominal behavior. The third column lists the faults that could cause a whole constellation to be faulted. In Advanced RAIM, the first column is bounded by $\sigma_{URA,ISM}$ and b_{nom} (for the five first rows, as the other ones are covered by models that are hardcoded in the receiver), the second one is described by P_{sat}, and the last one by P_{const}. The challenge of an ARAIM architecture is to make sure that the parameters used by the user receiver correctly account for this threat space.

LONG LATENCY ARAIM ARCHITECTURE OVERVIEW

One of the main advantages of ARAIM is the reduced complexity and cost of the ground monitoring performed by the ANSP compared to SBAS. The ARAIM architecture presented here aims at reducing as much as possible the ANSP ground monitoring, while retaining control over the characterization of the space segment through a quasi-static ISM. This may be achieved by eliminating any real-time or near real-time process by the ANSP, and by reusing existing reference receiver networks. This necessarily implies a long latency ISM. As with RAIM, there is no monitor alerting the user of satellite faults within minutes or even hours. Instead it is assumed that the Constellation Service Providers (CSPs) will ensure that the prior probabilities specified in the ISM are not exceeded. In other words, the ANSPs trust that the CSPs will make sure that fault rates are bounded, and that faults are resolved within a finite time, should one occur. However, unlike RAIM, the ANSP will have a way of adjusting and correcting the assumptions that are made by the user receivers, either to improve availability and performance, or to prevent integrity failures.

This architecture would be based on a global sparse network for offline monitoring. This network need not be dedicated and could reuse existing networks (like SBAS, CORS, or IGS). Its size would need to be sufficient to calculate precise orbits. The ISM would be updated monthly and could be broadcast through a wide range of channels: globally (using spare bits in GPS or Galileo etc), published in the approach plate (and loaded in the flight data base), locally (through a VHF Data Broadcast), or even at the regional level (through a geostationary satellite).

The defining characteristic of this architecture is that the ISM would be generated offline, using automated tools but with the possibility of human intervention. In the case of an unexpected gross violation of the assumptions, Air Traffic Control could deny ARAIM use (just like it would deny RAIM use).

The ISM would be generated as a function of:

- service history,
- core constellation performance commitments,
- known design elements – communication with core constellation providers, and
- offline monitoring.

There would not be a real time or near real time warning from the ground were a fault to occur. Instead, it is assumed that the constellation ranging performance would be within the bounds defined by the Integrity Support Message. Since the contents of the ISM are determined based on past performance (be it service history or recent history), there is necessarily an assumption of stability, although not of stationarity. It would be assumed that the constellation performances would not degrade significantly over an update period of the ISM.

In the next three sections, we describe the role and the conditions that must be fulfilled by each of the three parties: the CSPs, the ANSPs, and the user receiver. Table 2 summarizes the choices made in this architecture.

CONSTELLATION SERVICE PROVIDER ROLE

Service history

For a core constellation to be included in the ARAIM position solution, it would be essential that a good service history has been demonstrated. Any event that could have caused serious integrity risk in an ARAIM user would cause a constellation not to be deemed suitable for ARAIM, and therefore not included in the ISM. Trust in the constellations included in ARAIM would be partly acquired through the analysis of service history. For this reason, service history should be documented to a much more precise and unambiguous extent than today. For example, there are still faults that are not verified, there are gaps in the pseudorange measurements, and signal deformation effects should be quantified further in the standalone case (and for dual frequency users). It is worthwhile mentioning here that one of the most important pieces in the approval of WAAS LPV-200 operations was the analysis of service history over three years.

Service performance requirements

Performance commitments are essential in this architecture because even if stationarity were assumed in the fault statistics, the service history would not be sufficient to guarantee low bounds on the prior probabilities. A constellation could only be included in the ARAIM solution if performance commitments are published, sufficient, and met. In particular:

- onset probabilities of fault must be bounded,
- under nominal conditions position errors must be bounded by the error bound deriving from the broadcast SISA/URA,
- faults must be removed within a specified time, and
- signal deformation and code carrier coherence bounds should be included.

It is unlikely that a CSP would accept liability if the performance commitments were not met. The ANSP generating the ISM would have to decide whether the performance commitments of a given CSP are trustworthy.

Known Design Elements and Communication between CSPs and ANSPs

In this architecture, it would be expected that core constellation providers understand the threats that can affect aviation users. In turn, ANSPs would need a good understanding of some of the processes that are critical to the assumptions necessary for ARAIM. An important example is the processing of Earth Orientation Parameter Prediction (EOPPs): CSPs need to ensure that the probability of a common EOPP fault across constellations can be considered negligible by the airborne monitor. Because changes in the CSP processes and operations (at both ground and satellite level) could lead to new fault modes, it would be desirable for such changes in operations to be communicated in advance to ANSPs. To a certain extent, this is already happening between GPS and WAAS.

ISM Latency	**Broadcast channel**	**Reference network**	**Bounding methodology**	**Wide faults treatment**	**ISM contents**
30 days not automatic	CSP spare bits VDB approach plate	global but not dedicated subset dedicated to SDM	offline: service history offline monitoring service performance commitments	can affect each constellation independently cross constellation check space ephemeris updates	$P_{sat,i}$ $b_{nom,i}$ $\alpha_{URA,i}$ $\alpha_{URE,i}$ $P_{const,j}$

Table 2. *Architecture summary*

AIR NAVIGATION SERVICE PROVIDER

The role of the Air Navigation Service Provider in this architecture is to make sure that the characterization of the pseudoranges used by the user receiver leads to a safe error bound on the position. The role would not be, as in the case of augmentation systems as SBAS or GBAS, to alert users that a certain set of satellites is faulted. Instead, the Integrity Support Message would characterize the long term behavior of each satellite and each constellation, and act as a layer between the Constellation Service Provider and the user receiver.

Reference Network

The reference network used to generate the ISM would need to be global, as the ISM is meant to be valid anywhere on the globe. Because of the long latency nature of the ISM, there are no stringent requirements on the latency of the measurements, as there are with SBAS. For this reason, a global network based on already existing networks as IGS, NGA or CORS could be appropriate. The data would have to be of good quality – and the stations chosen carefully-, but it would not need to be at the level of the SBAS reference receivers in terms of reliability. Instead, the reliability of the overall set of measurements would be obtained through redundancy, as the cost of additional receivers would low (mostly the cost of downloading the data). Because the measurements might not be under the control of the ANSP, it would be essential to make sure that they come from a variety of independent and trustworthy sources.

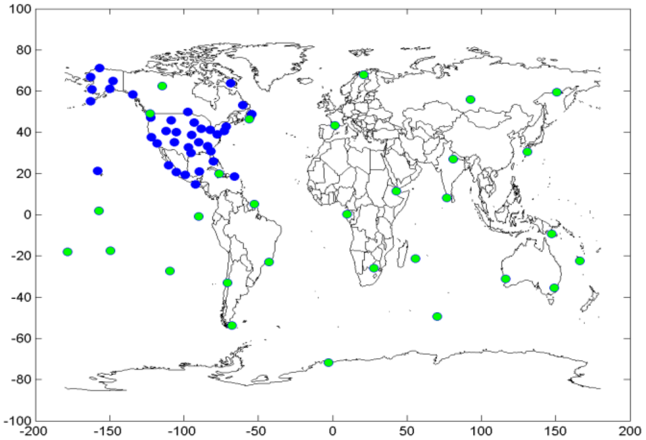


Figure 3. Notional reference network for ARAIM offline monitoring

The size of the network would have to be sufficient to compute precise ephemeris, and with sufficient redundancy that faults in a large number of receivers would be detected. In addition to this global ad-hoc network, it would be necessary to add a reduced set of receivers capable of assessing the effect of signal deformation. This set of receivers would not need to be distributed across the globe. Its only requirement would be that it can see each satellite at some point and during a sufficient time span. Because it is unlikely that the statistics necessary to assess signal deformation are available in the ad-hoc network, this network might have to be fielded by the ANSP, or exploit resources that are already available, like an SBAS network. Figure 3 shows a notional network comprised of a global ad-hoc network and a sub-network of dedicated receivers for signal deformation monitoring (in this case the 38 stations of the Wide Area Augmentation System).

Offline Monitoring and ISM generation process

The offline monitoring would follow a process similar to the offline monitoring done in WAAS [4], which is reported quarterly and can lead to modifications in the constants assumed by the WAAS safety algorithms (these include bounds on the nominal ephemeris error and the probability of satellite fault). The type of analysis that would be necessary would be very similar to the ones performed by the FAA TEC center and reported in the Performance Analysis Reports for both GPS and WAAS [5].

While most of the analysis would rely on automatic tools (just like they rely on automatic tools for the safety analysis of WAAS [6]), there would be room for human intervention to handle exceptions. For example, if a receiver used in the generation of precise ephemeris appeared to be faulty, the list of receivers would be updated to exclude it or replace it. Also, in the case a fault had different effects depending on the type of receiver, it might be necessary to initiate an investigation. As a general rule, human intervention would only be necessary in ambiguous cases.

Offline monitoring algorithms

The ISM would consist of P_{const} for each constellation, P_{sat}, b_{nom}, α_{URA}, and α_{URE} for each satellite. The parameters α_{URA} and α_{URE} would multiply the URA provided by the CSPs to form $\sigma_{URA,ISM}$ and $\sigma_{URE,ISM}$, that is:

$$\sigma_{URA,ISM} = \alpha_{URA}\sigma_{URA,CSP}$$

There would be at least two types of range error analysis. The first one would be an analysis of the difference between precise ephemeris and the broadcast ephemeris. After computing the precise ephemeris for each satellite over a certain period (for example 30 days), the pseudorange error resulting from the errors in the broadcast ephemeris could be computed (either over a grid of users or the worst case projection). The resulting residuals would then be normalized by the applicable URA (the one broadcast in the navigation message). The resulting empirical distribution would then be assessed as described in [7], for example.

The second type of analysis would assess how the errors combine to form the position error. This could be done both by analyzing the effect of the clock and ephemeris alone by using the residuals from the previous analysis, or by including the additional sources of error on the reference receivers (in which case we do not need the precise ephemeris, as we have the exact location of the reference receivers). The correlation between the range errors could be evaluated by using the chi-square statistic, as explained in [7].

The parameter b_{nom} would be determined by the analysis of the effect of nominal signal deformation on the pseudorange error.

The probability P_{sat} describes the state probability of a satellite to be faulted. The adequacy of these this parameter could be evaluated by examining the service performance commitments, the previous fault rates, and the empirical distribution of pseudorange errors (of a period of a year, for example). This could be done by making sure that for at least a fraction $1\text{-}P_{sat}$, the Gaussian distribution with standard deviation $\sigma_{URA,ISM}$ would be an adequate overbound of the empirical distribution (a fraction of the nominal bias could also be used for this overbound, but not all as it is meant to account for antenna biases and signal deformation). The value for P_{const} would be mostly determined by service history (no constellation fault should have been observed) and the service performance commitments, meaning that the offline monitoring would only ensure that no constellation wide fault has occurred in the last time period.

Finally, an end around integrity check should be applied to all the receivers in the reference network by applying the ARAIM airborne algorithm to each one of them.

ISM generation

The ISM would not be expected to change often. It would be expected to change, among other reasons, when:

- new satellites enter in service and have sufficient service history to be included in the ARAIM solution,
- $\sigma_{URA,ISM}$ or P_{sat} are too small for a given satellite
- $\sigma_{URA,ISM}$ or P_{sat} have margin and lowering them could bring availability benefits

Any change in the ISM would probably require human intervention.

Latency

The latency of the ISM should be long enough to allow the time to perform the different analysis outlined above, which might require human intervention. A latency of 30 days seems appropriate in this respect, and it is also in line with some of the broadcast methods outlined in the following paragraph.

Broadcast Channel – ISM distribution

Because of the long latency of the ISM, there would be many options to transmit the ISM to the user receiver. We discuss three of them here. One option, perhaps the most appealing, would consist in broadcasting the ISM through spare bits in the navigation message of one of the constellations. Concretely, after generation by the ANSP, the ISM parameters (or complete message) would be transmitted to the ground segment of one of the constellations. The ground segment would only act as a pipeline.

Another option would consist on including the ISM parameters to the electronic approach plate of each approach approved for ARAIM. This option is especially attractive because the approach plate already contains data that is safety critical. Also, the latency of 30 days would be compatible with the update rate of the approach plate. Similarly, the ISM could also be delivered via a VHF Data Broadcast at the airport.

USER RECEIVER

The user receiver would implement a residual check and compute the Vertical Protection Level (VPL) (and other figures of merit) assuming that the ISM contents are a conservative representation of the GNSS core constellations. A baseline algorithm is specified in [2]. It would also have additional safeguards, including step detectors and the staggering of ephemeris updates. This last barrier would place limits on the occurrence of constellation wide faults (both within one constellation and across constellations), by making sure that only one satellite ephemeris gets updated at a time. This would reduce the possibility of including a fault that affects all satellites simultaneously.

The error models used to cover the residual tropospheric delay, the multipath, and the receiver noise would need to have built-in margin. This is especially true of the multipath and receiver noise, because its relative contribution to the nominal error bound is larger in the dual frequency case than in the single frequency case (not only it gets multiplied in the dual frequency combination [9], but the overall error bound is smaller than in current SBAS).

INTEGRITY APPROACH

As mentioned above, the long latency architecture presented here requires a certain level of stability in the constellation performance. Constellations could degrade overtime, but they should not do it catastrophically. The role of the ANSP is to make sure that performance is well represented by the ISM up to the point that the ISM is distributed. The role of the CSP is to make sure that this performance stays the same in the future, or does not degrade above the margins built in the ISM (from the point of view of the ANSP, this is guaranteed by the publication of service performance commitments). The role of the user receiver is to make sure that the position error bounds and other figures of merit (VPL, HPL, EMT, and accuracy) computed assuming the performance specified in the ISM is safe.

Wide faults

Wide faults are characterized by $P_{const,j}$. This means that the probability of up to all satellites being faulted in one constellation j is bounded by $P_{const,j}$. For the receiver, it means that this fault must be monitored [2] as soon as this value exceeds the available integrity budget.

This architecture assumes that the likelihood of a fault affecting a substantial number of satellites in all constellations is negligible by the time they reach the residual check. This assumption cannot be avoided in a long latency ARAIM architecture because the receiver can be blind to such faults, that is, they can grow unlimited without appearing in the residuals.

This assumption is reasonable for because constellation faults in GPS have not been reported since IOC. In addition, the only known mechanism for the occurrence of a cross constellation fault is the use of erroneous Earth Orientation Parameter Predictions. These parameters are updated at a very low rate (days) by the ground segment of the core constellation. It is unlikely that they would be updated simultaneously (and pass the safety checks) in all constellations. It could also be possible to coordinate these updates across CSPs (although it might be more problematic to require CSPs to coordinate them). Finally, as discussed above, the receiver itself can further reduce the possibility of a cross constellation wide fault by staggering the ephemeris updates.

Sensitivity to ISM parameters

As part of the safety case, it will be necessary to study the sensitivity of the formal integrity risk to changes in the constellation performance that are not covered by the ISM parameters. Among other analyses, the following should be performed: the effect of a larger P_{sat} or P_{const}, the effect of larger URAs, and the effect of a constant bias on a given satellite for more than 30 days (the latency of the ISM). By the definition of the VPL, the integrity risk will be larger than the total allowed budget. The object of this study should be by how much, and how it would affect users (for how long and where).

PROPOSED PATH TO ARAIM WITH VERTICAL GUIDANCE

In this section we describe a path to transition from the current situation to ARAIM with vertical guidance. The approach would consist on initially developing multi-constellation ARAIM for horizontal navigation. As shown in [9], this first phase would lead to horizontal navigation with very high availability and higher levels of service (for example RNP.1). The final objective would still be the worldwide coverage of vertical guidance (LPV-200), achieved by gaining confidence in the system during the first phase.

Default ISM and receiver standards

The receiver developed for the first phase would be the same as the receiver for the second phase, that is, there would not be a receiver update or standards update between the two phases. In the first phase, the ARAIM receiver would use a default ISM for horizontal operations including Non-Precision Approach (NPA). The parameters in the default ISM may differ from later versions which would support vertical operations, but it would be in the same format.

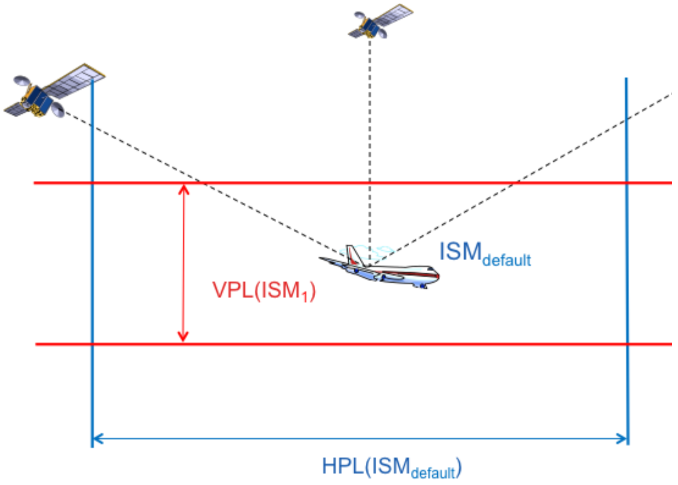


Figure 4. *Possible approach to transition from horizontal guidance to vertical guidance.* $ISM_{default}$ *would be hardcoded in the receiver and used for horizontal operations including NPA.*

Transition for the ANSP

This strategy would also allow ANSPs to evaluate multi-constellation ARAIM for vertical during the first phase (Figure 5) while providing immediate benefits to aviation users. The first phase could start as soon as the new constellations provide availability benefits and can be trusted by the ANSPs for horizontal navigation, which means that they do not need to be fully deployed.

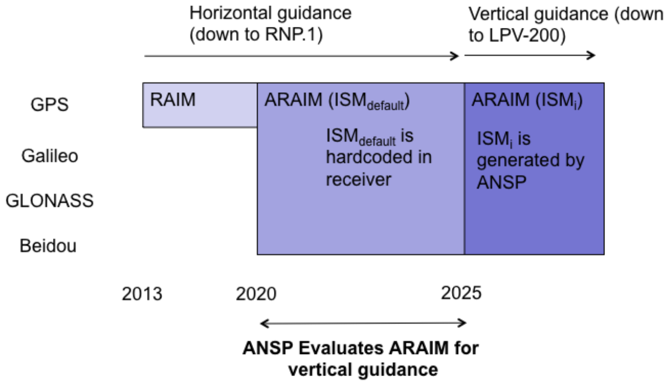


Figure 5. *Notional timeline of a transition to ARAIM with vertical guidance*

Constellation Service Provider	Good service history with PR accuracy <1 m Publication of service performance commitments Communication with ANSP if changes in operation
Airborne receiver	Multiple faults Nominal biases Multiple constellation Dual frequency L1 L5, ISM
Air Navigation Service Provider	Monitor nominal behavior of constellation and fault rates Generate ISM and disseminate (every 30 days)

Table 3. *Conditions to be fulfilled by the three parties to enable a long latency ARAIM architecture*

SUMMARY

Advanced RAIM has the potential of providing worldwide vertical guidance with a ground system less expensive and complex than SBAS. In this paper, we have presented the outline of an ARAIM architecture with a long latency Integrity Support Message. Table 3 summarizes the main characteristics of this architecture and what would be necessary to realize it. The ISM would be generated offline based on good service history, service performance commitments, and offline monitoring by the ANSP. The reference receiver network would be global, not necessarily dedicated, and would have very low requirements on latency. The ISM would be distributed either through spare bits in one or several core constellations, would be part of the electronic approach plates, or would be broadcast locally through a VDB.

The development of ARAIM could be divided in two phases. In the first phase, multi-constellation ARAIM would provide horizontal navigation with very high availability using a hardcoded default ISM. In the second phase, after evaluation by the ANSPs and the generation of an appropriate ISM, ARAIM would be used for vertical guidance. The second phase would not require a new set of avionics, as the receiver standards would be set in the first phase.

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