

EXECUTIVE SUMMARY

DISTRIBUTED INTEGRITY MONITORING

1. INTRODUCTION

1.1. BACKGROUND, PURPOSE AND SCOPE

The concept of Satellite Autonomous Integrity Monitoring (SAIM) has been proposed to overcome some of the limitations in current augmentation systems associated with remote monitoring of the navigation signals received on ground. SAIM is constrained by the fact that each satellite is able to monitor only its own navigation signals. However, autonomous monitoring on-board the satellite has the benefit of fast detection and alerting of issues. In addition, the monitored signals will not be degraded by propagation effects.

The main innovation introduced by the DIM concept is the possibility of moving or complementing some of the already-existing monitors and ground-based monitors to the satellite, in line with the SAIM approach. On-board monitors would be implemented by a *Signal Monitoring Unit* (SMU), which would include a means to retrieve the generated navigation signals, one or more GNSS receivers and a computer hosting the monitor algorithms. The introduction of some monitors on the User Segment has also been considered.

A more detailed summary of the performed work and its conclusions can be found in [RD.9].

2. REFERENCES

Reference documents, although not part of this document, amplify or clarify its contents. They are referenced by [RD.x].

Table 2-1: Applicable and Reference Documents

Ref.	Title	Code	Version	Date
[RD.1]	DIM Architecture	GMV-DIM-TN-0001	1.2	04/12/2020
[RD.2]	DIM Technologies	GMV-DIM-TN-0002	2.3	04/12/2020
[RD.3]	RTKLib Manual	-	2.4.2	29/04/2013
[RD.4]	J.W. Eaton et al., "GNU Octave Manual"	-	5	2020
[RD.5]	DIM-CD Development and Verification Plan	GMV-DIM-TN-0004	1.2	15/09/2020
[RD.6]	DIM-CD Verification Results	GMV-DIM-TN-0005	1.1	15/09/2020
[RD.7]	DIM Experimentation Plan	GMV-DIM-TN-0006	1.2	04/12/2020
[RD.8]	DIM Experimentation Report	GMV-DIM-TN-0009	1.0	04/12/2020
[RD.9]	DIM Final Report	GMV-DIM-TN-0008	1.0	04/12/2020

3. ARCHITECTURE

The first step of this study has consisted in defining a preliminary DIM architecture for a GNSS. It has included, first, the revision of the architecture of a generic GNSS satellite. Based on that and in knowledge about the environment, types of GNSS anomalies have been identified and characterised. Then, potential satellite upgrades to enable on-board integrity monitored have been explored and an architecture of monitors, distributed among the different segments, has been proposed. The most promising option for the SMU implementation is retrieving the generated signal by means of a pre-antenna signal feed and, then, processing this signal by means of a Software Defined Radio (SDR) receiver, which will generate its own internal signal replica based on an independent Oven-Controlled Crystal Oscillator (OCXO) clock. Hence, this option has been selected as the baseline for the rest of the study. Nevertheless, it has some limitations for the monitoring of events induced by the navigation transmit antenna. Actually, monitoring of antenna-induced events has been shown to be challenging.

Further details about the analyses about these aspects can be found in the *DIM Architecture* TN [RD.1].

3.1. ALLOCATION OF ANOMALIES TO SEGMENTS

Once the basic DIM architecture has been defined, the specific monitors to detect individual anomalies have been allocated to the different system segments. The main rationale to define this allocation has been, first, moving monitors for satellite-induced anomalies to the S/S, as this will enable better observability (lower C/N0 due to higher signal power, freedom of propagation effects), shorter detection times (there is no travel time) and shorter alert times (broadcast can be interrupted just after signal anomaly detection; alert flags can immediately be incorporated in the message). Anomalies induced by the GNSS mission segment will remain to be monitored on ground, whereas the user segment may protect against anomalies in the local user environment, which cannot be monitored by other means.

To enable monitoring the signals on board of the satellite, it has been proposed to include a Signal Monitoring Unit (SMU) within the GNSS satellite.

Table 3-1 provides the list of identified GNSS anomalies and their allocation to monitors and segments:

Table 3-1: Correspondence between identified anomalies and integrity monitors

GNSS Anomaly	Integrity Monitor	Location
RF Power	Satellite Power Monitor	Space Segment (*)
Signal Deformation	Signal Quality Monitor	Space Segment (*)
Inter-Frequency Bias and Code to Carrier Coherency	IFB Monitor	Space Segment (*)
	CCD Monitor	Space Segment
Phase/Frequency Jumps in Output Clock	Clock Stability Monitor (short-term stability)	Space Segment
Frequency Drift in Output Clock	Clock Stability Monitor (long-term stability)	Ground Segment
Phase Sample Noise (Clock)	Clock Stability Monitor (short-term stability)	Space Segment
	Clock Stability Monitor (long-term stability)	Ground Segment
Single Events Upsets (SEU)	N/A	N/A
Navigation Data Anomalies	Navigation Data Checks	Space Segment
Attitude Errors	Satellite Control Data Monitor	Space Segment
Unplanned Manoeuvres	Satellite Control Data Monitor	Space Segment
	Satellite Error Bound Monitor	Ground Segment
Ground Segment Induced Anomalies	Navigation Data Checks	Space Segment
	Satellite Error Bound Monitor	Ground Segment
	Global Chi-Squared Monitor	Ground Segment
Ionospheric Scintillation	FDE	User Segment
	C/N0 Monitors	User Segment
Multipath	FDE	User Segment
	C/N0 Monitors	User Segment
RF Interference	FDE	User Segment
	C/N0 Monitors	User Segment

(*) Except if caused by the navigation transmit antenna, when on-board monitoring has not been confirmed to be feasible.

4. TECHNOLOGIES

This section summarises the main monitor technologies selected as suitable for a DIM architecture, as well as the analysis methodology followed to determine a preliminary estimation of their detection performance. For a detailed description the reader is referred to the *DIM Technologies* TN [RD.2].

4.1. SATELLITE MONITORS

4.1.1.CCD MONITOR

The Code-Carrier Divergence (CCD) Monitor aims at the detection of lack of synchronization between the signal code and carrier, induced by satellite payload failures. Faults can occur on the code only, on the carrier only, or on both.

The CCD monitor proposed is a code-carrier divergence rate estimator, whose input is the difference between the pseudorange and the carrier phase measurements. The estimator differentiates the input and filters the results. When the estimation is above a certain threshold, an alarm is sent.

4.1.2.IFB STABILITY MONITOR

The Inter-Frequency Bias (IFB) is the systematic bias between two GNSS observations at different frequencies. They are caused by the hardware differential delay between the different frequencies at either the satellite, the receiver, or the combination of both.

Changes to IFB would manifest themselves as a CCD, unless the signal code and carrier phase are affected equally. The CCD monitor must detect this change, if it is large enough to create a hazard and is a ramp error. Still, a method specifically designed for detecting satellite IFB jumps, for both pseudorange and carrier phase measurements is proposed in [RD.2].

4.1.3.CLOCK STABILITY MONITOR (SHORT-TERM STABILITY)

Measuring clock stability requires a time reference whose stability is at least as good as the one of the clock that is wanted to be characterized. The method proposed in this project is to use the navigation signal captured by the SMU receiver as a means to analyse the clock stability and, as reference clock, use a highly stable Oven-Controlled Chrystal Oscillator (OCXO) clock incorporated to the SMU.

The aim of the clock stability monitor (short-term stability) is detecting the unpredicted changes of the deterministic and stochastic properties of on-board clocks. To detect these events, three different checks are introduced: The phase jump check, which is aimed at detecting non-nominal increases of the phase offset between the master clock and the reference clock; the frequency jump check, which is aimed at detecting non-nominal increases of the frequency offset between the master clock and the reference clock; and the noise jump check, which is aimed at detecting non-nominal increases of the master clock or the reference clock noise. To measure this increase, the Dynamic Allan Deviation (DADEV) is used.

4.1.4.SIGNAL QUALITY MONITOR (SQM)

The purpose of this monitor is the detection of signal deformation on-board the satellite, as part of the SMU.

The Satellite SMU receives the signal with a multi-correlator receiver in such a way that deviations are detected through the comparison of the correlator function generated from the received signal with an ideal correlation function.

The input to the SQM is the correlator outputs provided by the multi-correlator receiver of the SMU, which will filter the signal and produce the correlator outputs to be used to compare them with the corresponding threshold.

4.1.5.SATELLITE CONTROL DATA MONITOR

On-board monitoring can also have the capacity to monitor key telemetry channels for any out-of-limit values. It is common practice for satellites to have Fault Detection, Isolation and Recovery (FDIR) algorithms within the on-board computer to put the satellite into a safe state in the event of a serious fault such as a unit failure. Additional algorithms can be developed as part of a S/S integrity monitor to detect deviations in the telemetry that are significant but not large enough to trigger the FDIR.

In addition, it could be useful if GNSS satellites were equipped with accelerometers. Since the only non-conservative force that nominally impacts a GNSS satellite is the Solar Radiation Pressure, this would enable a possible detection mechanism for unplanned manoeuvres.

4.1.6.SATELLITE POWER MONITOR

A sudden change on the measured output power can decrease the signal quality at the user receiver due to a reduction of the C/N0 ratio. In addition, increments of the satellite power could lead to false locks on the user receiver.

The monitor will make use of the SMU to be placed on the satellite. At each epoch, the SMU receiver will have N samples of the output integrate-and-dump filters. With these samples, the monitor estimates a magnitude directly related to the received power. When this magnitude is greater or lower than a determined threshold, the monitor is triggered.

4.1.7.NAVIGATION DATA CHECKS

The navigation parameters disseminated by GNSS signals can be subject to anomalies. Some of these parameters can be monitored by the satellite itself with the implementation of a SMU, reducing the TTD in comparison with monitoring them from the G/S.

4.2. USER MONITORS

4.2.1.C/N0 MONITOR

In particular, due to the presence of multipath or interference, C/N0 fluctuates with time when affected by time-varying phase lag between direct and reflected signals. Since interference can be constructive or destructive, a threshold has been defined above (and below) which the C/N0 monitor will be triggered.

For an operational use of the C/N0 monitor, receiver calibration must be performed in order to characterize the C/N0 distributions in the fault-free case. This supposes a strong effort.

4.2.2.FAULT DETECTION AND EXCLUSION (FDE)

RAIM is a technique based on the consistency check of redundant measurements. RAIM monitors the navigation signals tracked by the receiver with the aim of identifying any inconsistent measurements (fault detection) and removing them from the navigation solution (fault exclusion).

In DIM, the chosen scenario is an aviation user and a classic RAIM Least Squares Residual algorithm. It would be the last barrier against the loss of integrity.

5. THE DIM CONCEPT DEMONSTRATOR

A DIM Concept Demonstrator (DIM-CD) has been developed with the goal of testing the performance of the proposed monitors and confirming (or refining) the initial conclusions of the theoretical analysis. In order to test satellite monitors, the DIM-CD simulates errors of pseudorange and carrier phase signals, and executes monitors using these signals. To test user monitors, it uses RINEX files obtained from real GNSS receivers.

The DIM-CD simulates the architecture described in [RD.1]. At high level, it can be divided into five modules, which are represented in the following figure:

Table 6-1 Summary of CCD monitor performances

Location	Conditions ¹	False alarm probability	Missed detection probability	Minimum detectable error (m/s)	Justification
Space Segment	NC / SC	10^{-4}	10^{-3}	$8.002 \cdot 10^{-5}$	Results derived from experimentation [RD.8]
		10^{-4}	10^{-4}	$8.123 \cdot 10^{-5}$	
		10^{-4}	10^{-5}	$8.213 \cdot 10^{-5}$	
Ground Segment (for comparison)	NC	10^{-4}	10^{-3}	$2.404 \cdot 10^{-2}$	Results derived from experimentation [RD.8]
	NC	10^{-4}	10^{-4}	$2.611 \cdot 10^{-2}$	
	NC	10^{-4}	10^{-5}	$2.781 \cdot 10^{-2}$	
	SC	10^{-4}	10^{-3}	$5.011 \cdot 10^{-2}$	Results derived from experimentation [RD.8]
	SC	10^{-4}	10^{-4}	$5.504 \cdot 10^{-2}$	
	SC	10^{-4}	10^{-5}	$5.939 \cdot 10^{-2}$	

Table 6-2 Summary of IFB Code monitor performances

Location	Conditions	False alarm probability	Missed detection probability	Minimum detectable error (m)	Justification
Space Segment	NC / SC	10^{-4}	10^{-3}	$4.950 \cdot 10^{-3}$	Results derived from experimentation [RD.8]
		10^{-4}	10^{-4}	$5.395 \cdot 10^{-3}$	
		10^{-4}	10^{-5}	$5.785 \cdot 10^{-3}$	
Ground Segment (for comparison)	NC	10^{-4}	10^{-3}	$1.946 \cdot 10^0$	Results derived from experimentation [RD.8]
	NC	10^{-4}	10^{-4}	$2.121 \cdot 10^0$	
	NC	10^{-4}	10^{-5}	$2.305 \cdot 10^0$	
	SC	10^{-4}	10^{-3}	$1.002 \cdot 10^{+1}$	Results derived from experimentation [RD.8]
	SC	10^{-4}	10^{-4}	$1.092 \cdot 10^{+1}$	
	SC	10^{-4}	10^{-5}	$1.183 \cdot 10^{+1}$	

Table 6-3 Summary of IFB Phase monitor performances

Location	Conditions	False alarm probability	Missed detection probability	Minimum detectable error (m)	Justification
Space Segment	NC / SC	10^{-4}	10^{-3}	$8.079 \cdot 10^{-5}$	Results derived from experimentation [RD.8]
		10^{-4}	10^{-4}	$8.205 \cdot 10^{-5}$	
		10^{-4}	10^{-5}	$8.304 \cdot 10^{-5}$	
Ground Segment (for comparison)	NC	10^{-4}	10^{-3}	$2.703 \cdot 10^{-2}$	Results derived from experimentation [RD.8]
	NC	10^{-4}	10^{-4}	$2.909 \cdot 10^{-2}$	
	NC	10^{-4}	10^{-5}	$3.061 \cdot 10^{-2}$	
	SC	10^{-4}	10^{-3}	$6.479 \cdot 10^{-2}$	Results derived from experimentation [RD.8]
	SC	10^{-4}	10^{-4}	$7.052 \cdot 10^{-2}$	
	SC	10^{-4}	10^{-5}	$7.593 \cdot 10^{-2}$	

¹ "NC" indicates "Nominal Conditions". "SC" indicates "Stressed Conditions".

Table 6-4 Summary of Clock Stability Monitor (short term stability) – Phase Jump Check performances

Location	Conditions	False alarm probability	Missed detection probability	Minimum detectable error (m)	Justification
Space Segment	NC	10^{-4}	10^{-3}	$4.211 \cdot 10^{-3}$	Results derived from experimentation [RD.8]
	NC	10^{-4}	10^{-4}	$4.599 \cdot 10^{-3}$	
	NC	10^{-4}	10^{-5}	$4.960 \cdot 10^{-3}$	
	SC	10^{-4}	10^{-3}	$1.269 \cdot 10^{-2}$	Results derived from experimentation [RD.8]
	SC	10^{-4}	10^{-4}	$1.383 \cdot 10^{-2}$	
	SC	10^{-4}	10^{-5}	$1.493 \cdot 10^{-2}$	
Ground Segment (for comparison)	NC	10^{-4}	10^{-3}	$4.181 \cdot 10^{-1}$	Results derived from experimentation [RD.8]
	NC	10^{-4}	10^{-4}	$4.546 \cdot 10^{-1}$	
	NC	10^{-4}	10^{-5}	$4.890 \cdot 10^{-1}$	
	SC	10^{-4}	10^{-3}	$5.096 \cdot 10^{-1}$	Results derived from experimentation [RD.8]
	SC	10^{-4}	10^{-4}	$5.570 \cdot 10^{-1}$	
	SC	10^{-4}	10^{-5}	$5.855 \cdot 10^{-1}$	

Table 6-5 Summary of Clock Stability Monitor (short term stability) – Frequency Jump Check performances

Location	Conditions	False alarm probability	Missed detection probability	Minimum detectable error (m/s)	Justification
Space Segment	NC	10^{-4}	10^{-3}	$4.606 \cdot 10^{-3}$	Results derived from experimentation [RD.8]
	NC	10^{-4}	10^{-4}	$5.008 \cdot 10^{-3}$	
	NC	10^{-4}	10^{-5}	$5.371 \cdot 10^{-3}$	
	SC	10^{-4}	10^{-3}	$1.579 \cdot 10^{-2}$	Results derived from experimentation [RD.8]
	SC	10^{-4}	10^{-4}	$1.729 \cdot 10^{-2}$	
	SC	10^{-4}	10^{-5}	$1.847 \cdot 10^{-2}$	
Ground Segment (for comparison)	NC	10^{-4}	10^{-3}	$5.916 \cdot 10^{-1}$	Results derived from experimentation [RD.8]
	NC	10^{-4}	10^{-4}	$6.405 \cdot 10^{-1}$	
	NC	10^{-4}	10^{-5}	$6.948 \cdot 10^{-1}$	
	SC	10^{-4}	10^{-3}	$7.176 \cdot 10^{-1}$	Results derived from experimentation [RD.8]
	SC	10^{-4}	10^{-4}	$7.791 \cdot 10^{-1}$	
	SC	10^{-4}	10^{-5}	$8.392 \cdot 10^{-1}$	

Table 6-6 Summary of Clock Stability Monitor (short term stability) – Noise Jump Check performances

Location	Conditions	False alarm probability	Missed detection probability	Minimum detectable error (σ_{ADEV})	Justification
Space Segment	NC $\tau = 1s$ $T_w = 100s$	10^{-4}	10^{-4}	$2.189 \cdot 10^{-12}$	Theoretical analysis

Location	Conditions	False alarm probability	Missed detection probability	Minimum detectable error (σ_{ADEV})	Justification
	SC $\tau = 1s$ $T_w = 100s$	10^{-4}	10^{-4}	$8.947 \cdot 10^{-12}$	([RD.2], section 6.3) ²
Ground Segment (for comparison)	NC $\tau = 1s$ $T_w = 100s$	10^{-4}	10^{-4}	$2.308 \cdot 10^{-10}$	
	SC $\tau = 1s$ $T_w = 100s$	10^{-4}	10^{-4}	$2.779 \cdot 10^{-10}$	

Table 6-7 Summary of Signal Quality Monitor performances

Location	Conditions	False alarm probability	Missed detection probability	Minimum detectable error	Justification
Space Segment	NC / SC Galileo E1	10^{-4}	$<10^{-5}$	TM A: $\Delta = 0.015$ chips	Results derived from experimentation [RD.8]
	NC / SC Galileo E1	10^{-4}	$<10^{-5}$	TM B: $\sigma = 0.8$ MNepers/s $f_d = 4$ MHz	
	NC / SC Galileo E1	10^{-4}	$<10^{-5}$	TM C: $\Delta = 0.06$ chips $\sigma = 0.8$ MNepers/s $f_d = 7.3$ MHz	
	NC / SC GPS L5	10^{-4}	$<10^{-5}$	TM A: $\Delta = 0.15$ chip	
	NC / SC GPS L5	10^{-4}	$<10^{-5}$	TM B: $\sigma = 0$ MNepers/s $f_d = 4$ MHz	
	NC / SC GPS L5	10^{-4}	$<10^{-5}$	TM C: $\Delta = 0.6$ chips $\sigma = 0.8$ MNepers/s $f_d = 4$ MHz	
Ground Segment (for comparison)	NC Galileo E1	10^{-4}	$\sim 10^{-5}$	TM A: $\Delta = 0.015$ chips	
	NC Galileo E1	10^{-4}	$<10^{-5}$	TM B: $\sigma = 0.8$ MNepers/s $f_d = 13.75$ MHz	
	NC Galileo E1	10^{-4}	$<10^{-5}$	TM C: $\Delta = 0.06$ chips $\sigma = 5.6$ MNepers/s $f_d = 10.5$ MHz	
	NC GPS L5	10^{-4}	$<10^{-5}$	TM A: $\Delta = 0.6$ chips	
	NC GPS L5	10^{-4}	$<10^{-5}$	TM B: $\sigma = 0.8$ MNepers/s $f_d = 13.75$ MHz	

² For this particular monitor, no experimental values were obtained through experimentation. However, some of the experimental tests have been used to corroborate the validity of this theoretical analysis.

Location	Conditions	False alarm probability	Missed detection probability	Minimum detectable error	Justification
	NC GPS L5	10^{-4}	$<10^{-5}$	TM C: $\Delta = 0.6$ chips $\sigma = 12$ MNepers/s $f_d = 11.5$ MHz	
	SC Galileo E1	10^{-4}	~ 1	TM A: $\Delta = 0.015$ chips	
	SC Galileo E1	10^{-4}	$\sim 10^{-2}$	TM B: $\sigma = 0.8$ MNepers/s $f_d = 13.75$ MHz	
	SC Galileo E1	10^{-4}	$\sim 4 \cdot 10^{-5}$	TM C: $\Delta = 0.06$ chips $\sigma = 5.6$ MNepers/s $f_d = 10.5$ MHz	
	SC GPS L5	10^{-4}	~ 0.9	TM A: $\Delta = 0.6$ chips	
	SC GPS L5	10^{-4}	$\sim 2 \cdot 10^{-1}$	TM B: $\sigma = 0.8$ MNepers/s $f_d = 13.75$ MHz	
	SC GPS L5	10^{-4}	~ 1	TM C: $\Delta = 0.6$ chips $\sigma = 12$ MNepers/s $f_d = 11.5$ MHz	

Table 6-8 Summary of Satellite Power Monitor performances

Location	Conditions	False alarm probability	Missed detection probability	Minimum detectable error (dB)	Justification
Space Segment	NC	10^{-4}	$\sim 1.5 \cdot 10^{-1}$	$-3.000 \cdot 10^{-4}$	Results derived from experimentation [RD.8]
	NC	10^{-4}	$\sim 3.5 \cdot 10^{-2}$	$-3.500 \cdot 10^{-4}$	
	NC	10^{-4}	$\sim 10^{-2}$	$-3.837 \cdot 10^{-4}$	
	SC	10^{-4}	$\sim 2 \cdot 10^{-1}$	$-1.611 \cdot 10^{-1}$	
	SC	10^{-4}	$\sim 5 \cdot 10^{-2}$	$-1.880 \cdot 10^{-1}$	
	SC	10^{-4}	$\sim 1.2 \cdot 10^{-2}$	$-2.061 \cdot 10^{-1}$	
Ground Segment (for comparison)	NC	10^{-4}	$\sim 3 \cdot 10^{-1}$	$-5.773 \cdot 10^{-2}$	
	NC	10^{-4}	$\sim 5 \cdot 10^{-3}$	$-8.660 \cdot 10^{-2}$	
	NC	10^{-4}	$<10^{-4}$	$-1.174 \cdot 10^{-1}$	
	SC	10^{-4}	$\sim 10^{-2}$	$-4.619 \cdot 10^{-2}$	
	SC	10^{-4}	$\sim 8 \cdot 10^{-4}$	$-5.196 \cdot 10^{-1}$	
	SC	10^{-4}	$\sim 10^{-4}$	$-5.774 \cdot 10^{-1}$	

Ground monitoring performance has been obtained for a single monitoring receiver (except for the power receiver, where it has been assumed that there are 3 receivers observing the satellite). However, the minimum detectable errors are usually several orders of magnitude lower in the space segment; hence, the disadvantage is so important that cannot be compensated by placing several monitoring receivers on ground.

In relation with the monitors proposed to be implemented in the user segment, the experimentation tests have demonstrated a little capability to detect the studied events. It has not been proven that a classical FDE implementation may play a role in a distributed integrity monitoring for the detection of local environment anomalies. Similarly, the C/N0 monitor has been shown to have a limited detection capability for ionospheric scintillation or strong multipath errors. However, its capability to detect drops in the received signal power (including those caused by scintillation or multipath) or increments of noise (e.g. due to RF interference) is believed to be still useful to protect the user from using measurements of degraded quality.

For the full details about the results of the experimentation, please refer to the *DIM Experimentation Report* [RD.8].

7. CONCLUSIONS

As summarised in the previous sections of this document, this study has enabled the definition of a Distributed Integrity Monitoring (DIM) architecture for a GNSS system, proposing an optimal allocation of integrity monitors among the different system segments and a series of technologies suitable to be implemented in these monitors.

The main innovation of the DIM architecture with regard to the current approaches for GNSS integrity monitoring is the introduction of a Satellite Monitoring Unit (SMU) to allow the detection of satellite-induced signal anomalies on board. The consortium recommendation for the SMU implementation is retrieving the generated signal by means of a pre-antenna signal feed and, then, processing this signal by means of a Software Defined Radio (SDR) receiver, which will generate its own internal signal replica based on an independent Oven-Controlled Crystal Oscillator (OCXO) clock.

The first main conclusion that has been achieved is the **clear advantage of Satellite Autonomous Integrity Monitoring (SAIM) over ground-based monitoring for all feared events originated in the satellite**, thanks to the much higher signal-to-noise ratios achieved on board, which redound to lower values of the false-alarm and missed detection probabilities, and the reduction of the Time to Detect (TTD) and Time to Alarm (TTA). These include anomalies such as code-carrier divergence, inter-frequency bias stability, short-term clock stability, signal distortions and abnormal signal power. There is also advantage for on-board monitoring of satellite control and telemetry data and some navigation data parameters, in particular, Issue of Data fields, week number and time of week.

The only exceptions are long-term clock stability and signal anomalies induced by malfunction of the navigation transmit antenna. The need of a highly stable time reference for monitoring long-term clock stability gives a clear advantage to the Ground Segment, where an ensemble of several atomic clocks can be used to define that reference. On the other hand, **on-board monitoring of the navigation transmit antenna has been proved to be very challenging**. It is not evident whether a reliable signal sample can be obtained by means of an auxiliary antenna placed in the near field of the main antenna; moreover, a monitoring approach like that may require a major redesign of the antenna itself, which is one of the most complex components of any GNSS satellite. Alternatively, monitoring of antenna may be performed on ground, using more conventional technologies, but this would prevent the simplification of ground infrastructure, which in turn should be one of the goals of implementing the DIM architecture.

On the other hand, there are still some types of anomalies that are only detectable by ground-segment monitoring, especially those caused by the GNSS Ground Segment itself. This includes errors in the navigation data (ephemerides and clocks), either affecting a single satellite or multiple of them. The Ground Segment also allows the implementation of a last-resort monitor (the Position Domain Monitor), which would compute an estimated position at the monitoring receivers by means of the same algorithms as the Safety-of-Life users would use, and then would compare this estimated position with the true one, which is known. Thus, it is confirmed that **a Ground Segment is still required as part of the DIM architecture**.

Finally, the suitability of two additional monitors implemented in the User Segment—Fault Detection and Exclusion (FDE, as implemented in classic RAIM) and a C/N0 Monitor—for the detection of anomalies originated in the local user environment—multipath, ionospheric scintillation and RF interference—has been analysed by processing real data from GNSS ground stations. Unfortunately, **the study has not been conclusive about the role of User Segment monitors in the DIM architecture**. Regarding the classic FDE, it may still be useful as a last-resort monitor, but it has not been proven to be useful for detecting these types of events originated in the local environment. On the other hand, the C/N0 Monitor has some sensitivity to ionospheric scintillation or multipath, but not enough to be considered a reliable detection method. In any case, it should not be inferred that User Segment monitors are not necessary in a DIM architecture. As a matter of fact, threatening events originated in the local user environment are only detectable at the user level, so it would be worth to continue investigating other techniques for dealing with them in the future.

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