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SAR/Galileo Return Link Service (RLS) Monitoring: An automated 24/7 global coverage system

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Abstract

Within the international Search and Rescue COSPAS-SARSAT system, the Return Link Service (RLS) is described as an operational service responsible for the dissemination of acknowledgement messages named Return Link Messages (RLM) to compatible beacons transmitting distress alerts. The end-to-end delivery of this service is based on the Return Link Service Provider (RLSP) which is an operational system interfacing on one side with the COSPAS-SARSAT network to receive the requests for acknowledgment and on the other side with the Galileo system to transmit the acknowledgments (Return Link Messages) using the Galileo satellites Signal in Space broadcasting capabilities.

The operations of the SAR/Galileo Service including the Return Link Service are entrusted by the European Union Agency for the Space Programme (EUSPA) to CNES acting as the SAR/Galileo Data Service Provider (SGDSP).

Since January 2020 when the SAR/Galileo Return Link Service was declared operational, SGDSP ensures the RLS monitoring on a 24/7 basis thanks to the MEOLUT Tracking and Coordination Facility (MTCF), a sub-system of the SAR/Galileo Ground Segment (SGS) hosted and operated by SGDSP. Among other functionalities, the MTCF allows near real-time SAR/Galileo service monitoring and control as well as performance monitoring. In particular, the MTCF computes SAR/Galileo Key Performances Indicators (KPIs) such as RLS availability or latency using the reception capabilities of a number of SAR/Galileo Reference Beacons.

The paper will provide a brief explanation of the Return Link Service provision architecture and key roles within the SAR/Galileo Ground Segment. Then, the paper will detail the different RLS performance metrics (KPIs) monitored by the MTCF as well as the main MTCF technical functions involved in the computation and visualization of such KPIs. Moreover, the paper will indicate how the KPI function has evolved and improved according to each SAR/Galileo evolution and how these improvements are key elements within the overall SAR/Galileo operational concept.

Initially, the Return Link Service (RLS) monitoring was based on SGDSP manual operational procedures run on the MTCF, shortly after, an automated 24/7 monitoring system named ALERT was setup. This ALERT tool is constantly checking key RLS parameters (performance data from MTCF and system logs from RLSP) and sends automatic notifications to the on-call SGDSP operators when certain defined thresholds are met. The paper will highlight the monitoring role of ALERT and its main benefits (robustness, redundancy, flexibility and operational process) to ensure a reliable Return Link Service provision. Real-case examples of system anomalies detected and corrected thanks to ALERT will be included in the paper.

As mentioned before, the RLS KPIs monitoring is performed using the RLM reception capability of five SAR/Galileo Reference Beacons, geographically distributed within the European coverage area. However, since the first quarter of 2022, a global coverage RLS monitoring is available. The MTCF retrieves in near-real time the Return Link Messages obtained through REGINA, a CNES-IGN worldwide network of GNSS receivers. The paper will describe the REGINA-MTCF interface and display some of the most relevant RLS performance computed globally.

The paper will illustrate each previous RLS monitoring evolution through an appropriate RLS performance metric.

To conclude, the paper will provide a roadmap for further improvements that are mainly focused on an end-to-end (beacon-to-beacon) RLS monitoring.

Keywords: SAR/Galileo, Return Link Service, monitoring.

Acronyms/Abbreviations

C/S, CS = Cospas-Sarsat	MEOLUT = MEO Local User Terminal
CNES = French National Space Agency	MEOSAR = MEO Search and Rescue
COTS = Commercial Of The Shelf	MMI = Man machine Interface
EC = European Commission	MTCF = MEOLUT Tracking Coordination Facility
ECA = European Coverage Area	PRN = Pseudo Random Noise
EU = European Union	REGINA = Réseau GNSS pour l'IGS et la Navigation
EUSPA = European Union Agency for the Space Programme	RL = Return Link
ESA = European Space Agency	RLM = Return Link Message
FLS = Forward Link Service	RLS = Return Link Service
FMCC = French Mission Control Centre	RLSP = Return Link Service Provider
GMS = Ground Mission Segment	SAR = Search and Rescue
GNSS = Global Navigation Satellite System	SGS = SAR/Galileo ground Segment
ID = Identifier	SGSC = SAR/Galileo Service Centre
IOCA = Indian Ocean Coverage Area	SGDSP = SAR/Galileo Data Service Provider
KCP = KPI Collection Platform	SiS = Signal in Space
KPI = Key Performance Indicator	UTC = Coordinated Universal Time
MEO = Medium-altitude Earth orbit	VoIP = Voice over Internet Protocol

1. Introduction

The SAR/Galileo service contributes to Cospas-Sarsat Forward Link Service since December 2016 providing an operational SAR/Galileo Ground Segment and SAR payloads on-board of the Galileo satellites. In January 2020, the SAR/Galileo Enhanced Service was declared operational with the introduction of the Return Link functionality [1]. This service enables to disseminate acknowledgment messages named Return Link Messages (RLM) to distress beacons transmitting distress alert in RLS protocol.
It is important to note that Galileo is the only GNSS constellation allowing the provision of the worldwide Return Link Service which is a great improvement from the existing Cospas-Sarsat.

The European Union Agency for the Space Programme (EUSPA) entrusts to CNES the operations of SAR/Galileo Service and in particular, the operations of the Return Link Service. CNES is the SAR/Galileo Service Center (SGSC) meaning the hosting site and operating centre for the SAR/Galileo Service provision. As SAR/Galileo Data Service Provider (SGDSP), CNES ensures the SAR/Galileo Ground Segment (SGS) operations management and SAR/Galileo Service performances monitoring.

2. Return Link Service

The delivery of the Return Link Service is based on the Return Link Service Provider (RLSP) which is an operational system interfacing on one side with the Cospas-Sarsat network to receive the requests for acknowledgment and on the other side with the Galileo system to transmit the acknowledgment messages (Return Link Messages) using the Galileo satellites Signal in Space (SiS) broadcasting capabilities.

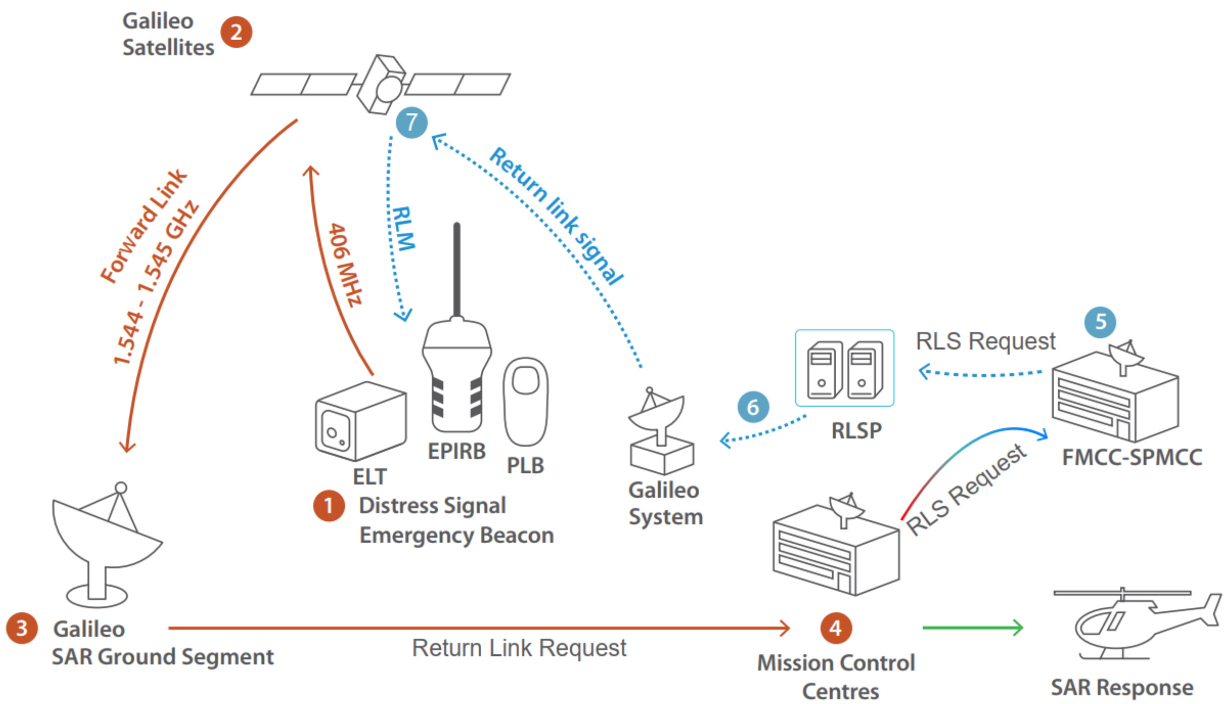

Fig. 1. SAR/Galileo Forward Link (red) and Return Link (blue) Services

Galileo supports the SAR service by equipping its satellites with a SAR payload that relays beacon distress signals towards Cospas-Sarsat. Signals are received by one or several Medium altitude Earth Orbit Local User Terminals (MEOLUTs) in charge of determining the location of the beacon. The MEOLUT sends the estimated beacon position and other relevant data to a Mission Control Centre (MCC) which alerts the rescue services. In case of RLS-capable beacon which transmits the distress alert in RLS protocol, the MCC communicates also with the Return Link Service Provider (RLSP) through the French MCC (FMCC), both located in CNES Toulouse. The RLSP sends the Return Link Message to the Galileo Ground Mission Segment (GMS) that inserts the RLM data in the C band mission uplink and finally, the Return Link Message is downlinked to the beacon in the navigation signal. There are two types of RLM: short RLMs composed of 80 bits and long RLMs with 160 bits.

3. Return Link Service monitoring

3.1 KPI Collection Platform (KCP)

As SAR/Galileo Data Service Provider (SGDSP), CNES monitors the SAR/Galileo Service performances meaning both the Forward Link Service and the Return Link Service performances through Key Performance Indicators (KPIs). Two main elements of the SAR/Galileo Ground Segment (SGS) are used for monitoring purposes:

- The MTCF (MEOLUT Tracking Coordination facility) located in the SGSC in Toulouse (France) and more particularly, its component called KPI Collection Platform (KCP),
- A network of five SAR/Galileo Reference Beacons (REFBEs) located in Maspalomas (Spain), Spitsbergen (Norway), Larnaca (Cyprus), Toulouse (France) and Santa Maria (Portugal). These beacons are geographically distributed within the European Coverage Area (ECA) and suited for service monitoring meaning that their emissions follow a specific periodic transmission plan. The operational acceptance of additional REFBEs to cover the Indian Ocean Coverage Area (IOCA) is on-going (see section 6.1).

Fig. 2. SAR/Galileo Reference Beacons (REFBE) distribution over the European Coverage Area (ECA)

The MTCF main functionalities are:

- The tracking schedule management: the MTCF is in charge of receiving and processing MEOSAR satellite orbital data and generates an optimised coordinated SGS tracking plan that is disseminated to the European MEOLUTs, taking advantage of the network configuration for optimal service performance and coverage.
- The SGS data provision and archiving: the MTCF provides a redundant link for files exchange with the European MEOLUTs and is the SGS long term data archive facility.

In addition, the MTCF hosts the KCP that ensures the overall SGS infrastructure, SAR/Galileo FL and RL services monitoring. The KCP continuously and automatically generates and displays performance statistics based on the SAR/Galileo Reference Beacons (REFBEs) transmissions.

The MTCF is composed of five nominal servers and five spare servers ensuring the redundancy and robustness of MTCF architecture.

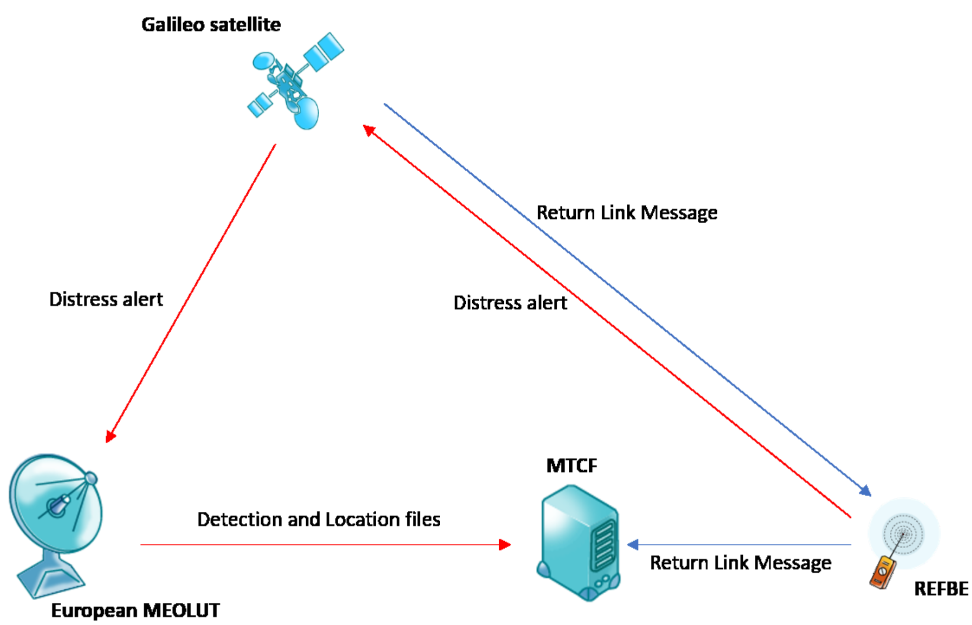

Fig. 3. Data retrieval by MTCF for FL (red) and RL (blue) KPIs computation

The bursts emitted by the SAR/Galileo REFBEs are collected by the European MEOLUTs which transfer periodically detection and location files to the MTCF. Thanks to MTCF data access, the KCP generates near-real time SAR/Galileo FL service KPIs. The FL KCP MMI displays mainly detection and location statistics and SGS elements availability.

Regarding SAR/Galileo RL service KPIs, all RLM test messages received by the SAR/Galileo REFBEs are retrieved and stored at MTCF level allowing the KCP to generate near-real time RLS KPIs. A dedicated KCP RL MMI displays RLS statistics as detailed in the following sub-section.

For RLS KPIs, the KCP needs to retrieve from SAR/Galileo REFBEs the next information:

- SAR/Galileo REFBE beacon ID,
- RLM test data meaning short RLM test (80 bits) represented in hexadecimal string of 20 characters [2]:
  - Beacon ID (60 bits)
  - Protocol flag (1 bit)
  - Country code (10 bits)
  - Protocol code (4 bits)
  - Identification data (24 bits)
  - Arbitrary (24 bits)
  - Message code (4 bits) set to 1111 for RLM test format
  - Parameters (16 bits)
- RLM reception time at SAR/Galileo REFBE level,
- Satellites through which the RLM is relayed.

3.2 *RLS Key Performance Indicators (KPIs)*

The RLS monitoring is based on the computation of four KPIs described hereafter [1].

Table 1. Return Link Service monitored KPIs

KPI	Description	Target
RLM Delivery Latency	The End-to-End RLM Delivery Latency for the RLM after activation of the beacon shall be under 30 minutes to ensure the RLM is broadcast while the beacon is active. The End-to-End RLM Delivery Latency includes two contributions: 1. The Forward Link path latency: the time taken by the RLM request to reach the RLSP (in red on figure 3), 2. The Return Link path latency: the time required for the RLM request to be processed by the RLSP, transmitted within the Galileo SIS and received by the beacon. This latency is called the Galileo RLM Delivery Latency (in blue on figure 3).	Galileo RLM Delivery Latency within 15 min shall meet 99%. End-to-End RLM Delivery Latency within 30 min shall meet 95%.
Probability of RLM Delivery	The probability of RLM delivery to a RLS-capable beacon.	RLM Reception Probability shall meet a monthly target of 99%.
RLSP Availability	The time the RLSP is operational.	The RLSP Availability shall meet a monthly target of 99%.
RLS Availability	The time the RLS is operational and providing the service to the end-users.	The RLS Availability shall meet a monthly target of 99%.

1- <u>RLM delivery latency</u>

The end-to-end RLM delivery latency is the time from the beacon first burst emission with RLS protocol to the RLM reception at the beacon, in other words, the beacon-to-beacon latency (red and blue signals illustrated in figure below).

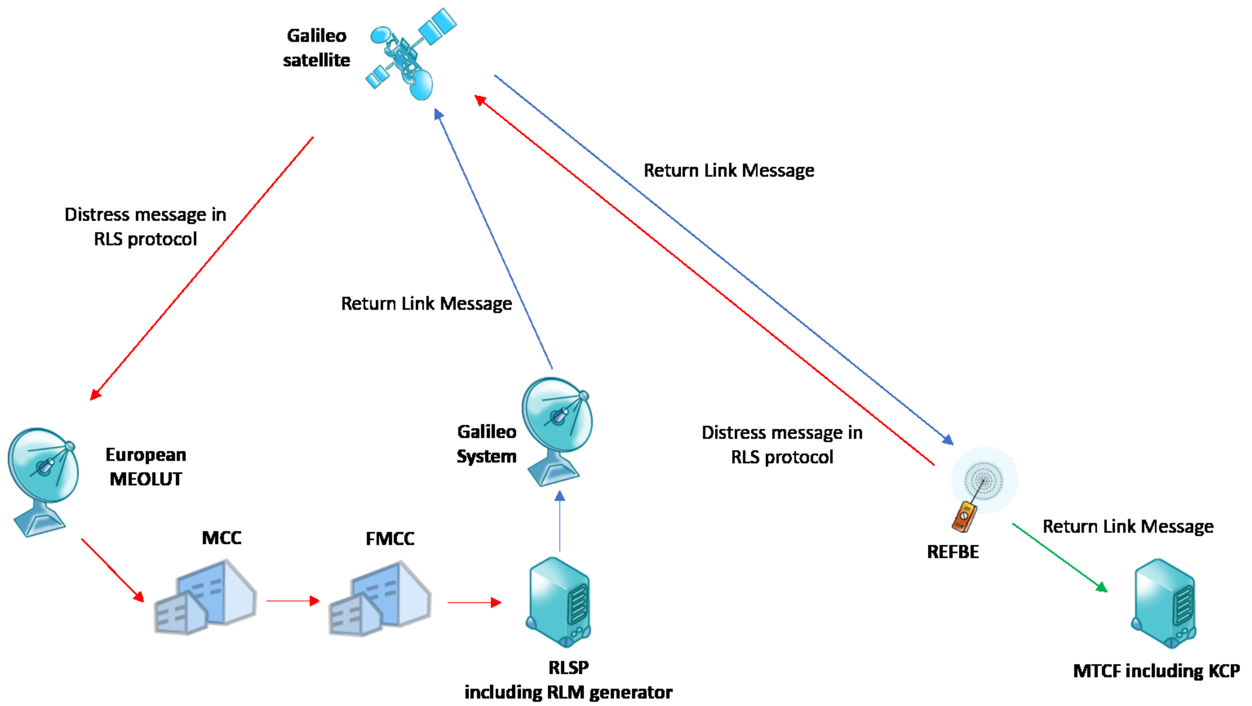

Fig. 4. End-to-end RLS monitoring: forward link path (red) and return link path (blue)

For the time being, the end-to-end RLM delivery latency is not computed but only the Galileo RLM delivery latency is monitored meaning that the forward link path latency is not taken into account in RLS monitoring. Indeed, currently, SAR/Galileo REFBEs are not RLS-capable meaning the emitted bursts are not in RLS protocol but they are able to receive RLMs. That's why, for RLS monitoring purposes, artificial short 'RLM test' messages are generated from the RLSP by a dedicated component called RLM generator, then the RLM is sent as an operational RLM to the SAR/Galileo REFBEs and retrieved by the MTCF for RLM delivery latency computation. The RLM generator sends periodically RLM tests to each SAR/Galileo REFBE according to a transmission plan defined by SGDSP and registered at KCP level.

The KCP computes the Galileo RLM delivery latency thanks to short RLM test content and more particularly, to the parameters fields that are specifically filled by the RLM generator for RLS monitoring goal:

- The first 8 bits correspond to the RLM sequence number meaning the hour of the week,
- The 7 following bits are a counter indicating the number of elapsed hours since the previous emission of a RLM by the RLM generator to the same SAR/Galileo REFBE,
- The last bit is a parity bit.

Thus, the Galileo RLM delivery latency is computed by the KCP knowing:

- The RLM sequence number which provides the time of RLM emission by the RLM generator,
- The time of RLM reception at SAR/Galileo REFBE level.

2- Probability of RLM delivery

The KCP knows the RLM transmission plan for each SAR/Galileo REFBE that refers to the creation time of RLM tests by the RLM generator. So, the KCP computes the probability of RLM delivery by comparing the number of RLM tests received by a SAR/Galileo REFBE with the expected number of RLM tests.

3- RLSP availability

This KPI is based on the counter setup by the RLM generator in the RLM parameters fields. Indeed, if the RLSP is not operational, it will not send the RLM tests created by the RLM generator and the counter will increase and indicate the number of hours from the last RLM test emission. Thus, if this counter is higher than 1 when the KCP decodes the RLM test content, it means there was a RLSP unavailability and the duration of the unavailability is deduced from the value of the counter.

4- <u>RLS availability</u>
The KCP computes the RLS availability by checking that among all SAR/Galileo REFBEs, at least, one REFBE has received one RLM during a configurable period which is currently set to 10 minutes.

In this paper, most of provided examples will be based on 'RLS availability' KPI.

3.3 Operational process and KCP improvements

For operational needs, four MTCF workstations display both KCP FL and RL MMIs. The KCP performs automatic computations on 3-hours slots. Then, results can be visualized on different periods (last 3 hours, last 24 hours, last 30 days, last year or current month) thanks to tables, plots graphs and GANTT graphs.

The figure below is an actual example of KCP RL MMI view that displays the RLSP and RLS availabilities on a GANTT view: in green, the available periods and in red, the unavailable ones.

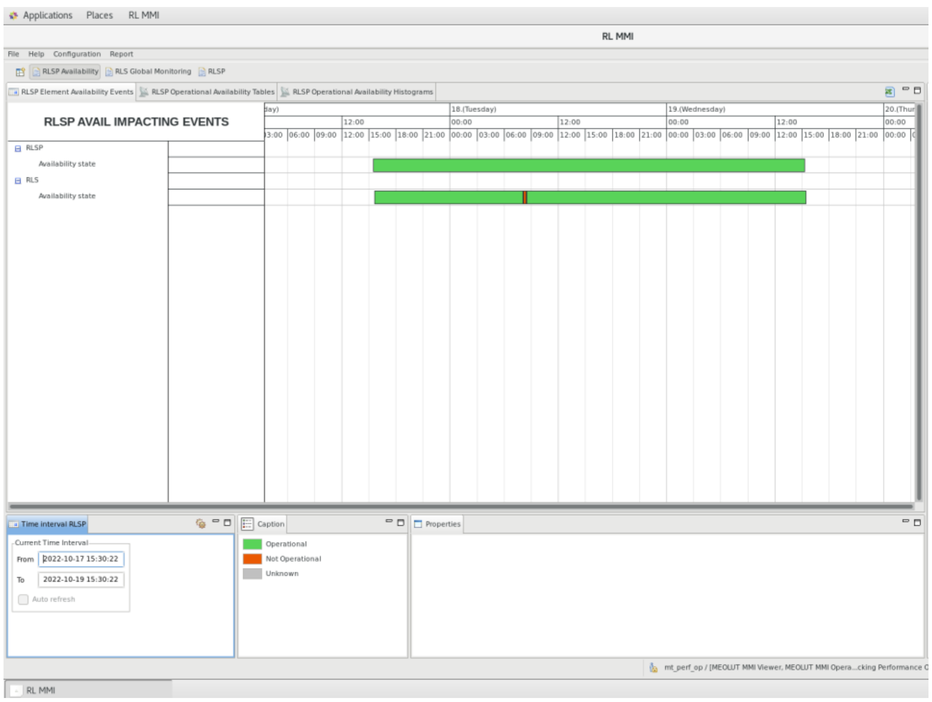

Fig. 5. KCP MMI view of RLSP and RLS availabilities with in red, a RLS unavailability slot

The KCP also generates automatic performance reports and allows SGDSP operators to manually launch KPIs' recomputations in case of input data issue.

SGDSP operators perform a daily checklist on KCP in order to monitor the RLS KPIs and then, deliver the status of the SAR/Galileo Return Link Service on a monthly report. The SAR/Galileo performance reports are publicly available every quarter [3].

To improve the monitoring of RLS, KCP enhancements are yearly performed according to SGDSP operators' feedbacks and needs. In case of major blocking anomalies, some lessons learnt are established and can lead to MTCF or KCP improvements in terms of statistics display, logs provision…

Regarding the high expectation of RLS performances, it is required to monitor the RLS provision on a 24/7 basis.

4. RLS automated 24/7 monitoring

4.1 ALERT for RLS monitoring

Initially, the Return Link Service monitoring was based on SGDSP manual operational procedures run on the MTCF and, shortly after, an automated 24/7 monitoring system named ALERT was setup. The ALERT tool is a Micromedia International COTS [4] that allows to raise alarms on RLS status via phone calls, SMS and mails to on-call SGDSP operators.

The figure hereafter describes the functional architecture of ALERT.

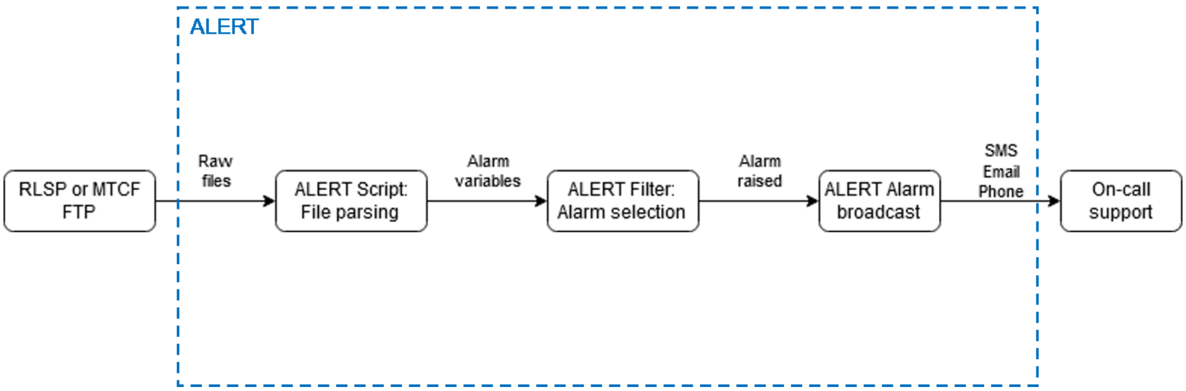

Fig. 6. ALERT functional diagram

ALERT retrieves key RLS parameters from both SGS elements:

- The MTCF provides text files containing the RL KPIs status (nominal, warning, critical) computed by the KCP. All the following parameters are configurable on MTCF side:
    - o The status thresholds,
    - o The computations' timespans,
    - o The frequency of files generation.

  Figures 7 and 8 are examples of files provided by the MTCF on the RLS availability.
- The RLSP delivers system log files containing status of its components. Figure 9 illustrates this type of RLSP file delivered to ALERT.

```
RLS Availability hourly = OK; Comment = 100.0%;
RLS Availability daily = OK; Comment = 100.0%;
```

Fig. 7. RLS Availability (OK status) provided by MTCF to ALERT

```
RLS Availability hourly = CRITICAL; Comment = 0.0%;
RLS Availability daily = WARNING; Comment = 90.0%;
```

Fig. 8. RLS Unavailability (CRITICAL status) provided by MTCF to ALERT

```
Service: ha2
Host: [redacted]
Type: HARD
State: OK
Last check: 22/12/2022 09:07:16
Last OK: 22/12/2022 09:02:54
Output: OK:  up(1)
```

Fig. 9. Log of RLSP firewall status provided to ALERT

ALERT notifies the on-call SGDSP operator in case of warning or critical status meaning that the RLS is degraded or not operational. There are three broadcasting media that have been configured according to the alarm criticality: phone calls, SMS and mails. In case of phone call, the on-call SGDSP operator shall acknowledge the alarm thanks to a 3-digits code.

4.2 Operational benefits

Regarding the operational point of view, ALERT is very useful allowing to monitor the RLS without planning intervention of SGDSP operators on CNES site out of business hours and ensuring an automatic 24/7 monitoring avoiding human mistakes. This tool presents three main operational benefits:

1- <u>A robust and redundant architecture</u>

ALERT is composed of two servers in hot redundancy meaning both stations are running permanently in parallel and both are connected to RLSP and MTCF. The spare server retrieves and processes RLSP and MTCF files only in case of detected issue with the prime server.

In addition, both servers are connected to independent broadcasting media: each ALERT server has its own analogic modem for phone call and dedicated network connections for SMS and mail.

Both ALERT servers are connected between them and share dynamic parameters like alarms, acknowledgments, calls, programmed calls.

The overall network architecture complies with redundancy requirements.

Since October 2022, to improve robustness, Voice over IP (VoIP) is operational and used as backup of analogic modem for phone calls.

2- <u>A configurable and scalable tool</u>

ALERT is fully configurable that means script, filter and alarm blocks of figure 6 have been configured by SGDSP according to RLS monitoring needs and can be easily changed if required with respects to RLS evolutions. For example, the broadcasting media can be configured according to the criticality of the alarm, different media can be selected for a same alarm and the frequency of alarms' repetitions can be tuned. SGDSP has been trained to be independent on script developments and configuration changes. Thanks to this flexibility, ALERT can be adapted according to specific operational periods as no alarm sending in case of RLSP planned maintenance.

ALERT MMI displays the status get from MTCF (figure 10) and RLSP (figure 11) inputs and all logs related to ALERT actions.

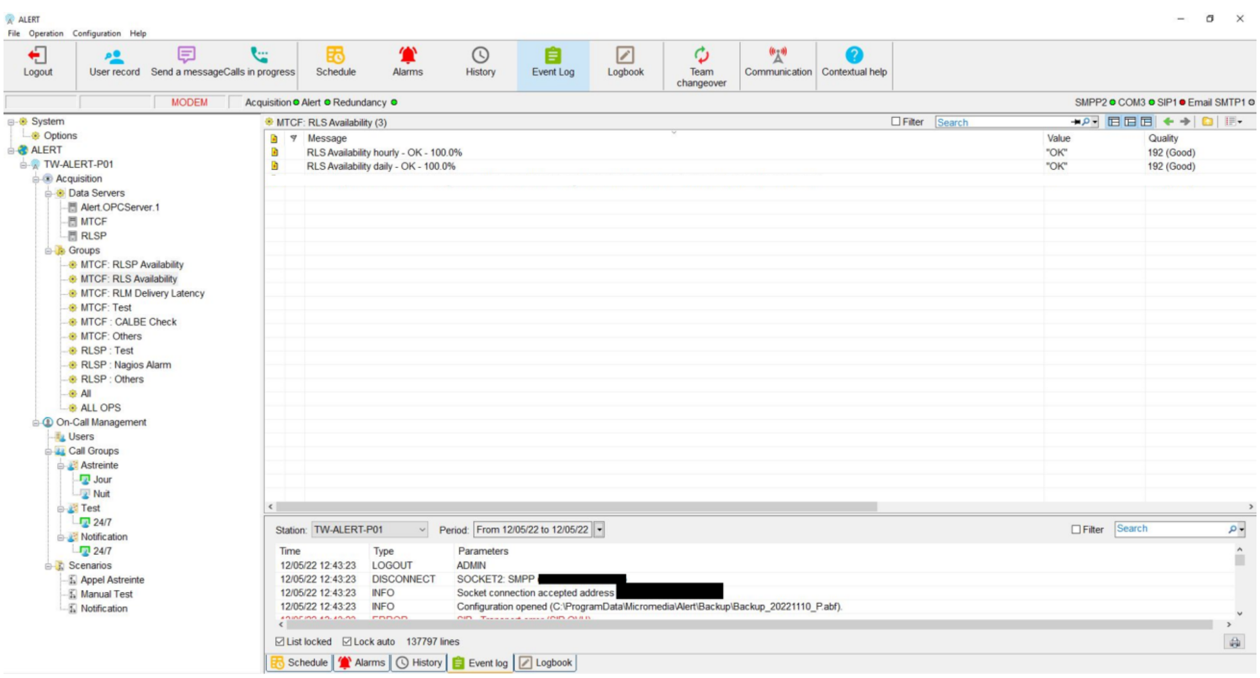

Fig. 10. RLS Availability view on ALERT MMI

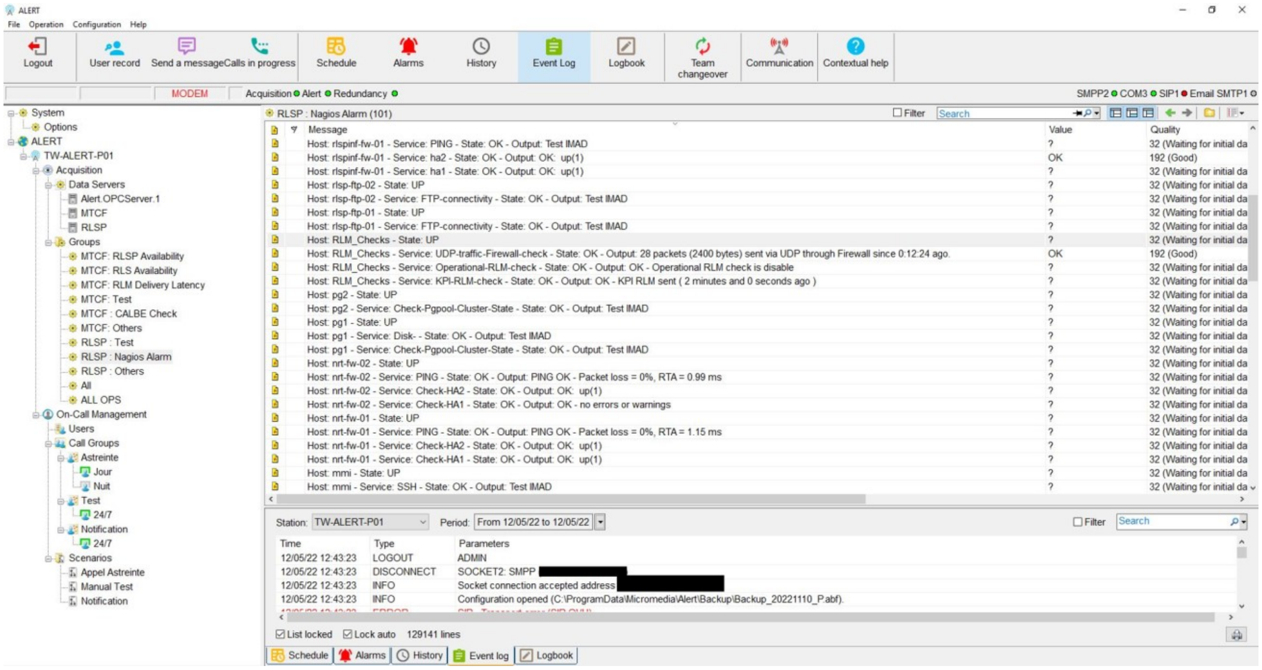

Fig. 11. RLSP alarms view on ALERT MMI

3- <u>A reliable tool</u>

ALERT monitors itself by checking in real time that some functions are up and running. The following functions are configured to be monitored:

- Communication between ALERT and analogic modem,
- Redundancy link between ALERT servers,
- Running of MTCF and RLSP scripts.

In case of issue on one of these functions, an alarm is raised to SGDSP operators.
Moreover, tests functionalities can be configured and are used by on-call SGDSP operator before weekends. It aims at ensuring the end-to-end alarming system is running well. This test deals with sending a test file from MTCF to ALERT and receiving a phone call from ALERT.
Concerning maintenance, a support is provided by Micromedia in case of incident on ALERT or expertise need for script development and configuration.

4.3 Actual operational proof of ALERT efficiency

ALERT allows to ensure a reliable RLS provision. This can be proved by an event that occurred on February 12th 2021: a RLS unavailability quickly detected by ALERT. In this case, the KCP computed a RLS unavailability from 19:20 UTC to 20:40 UTC, then the MTCF sent a file with critical status to ALERT at 20:40 UTC and so, ALERT called immediately the on-call SGDSP operator. Without ALERT, this RLS unavailability would have been detected during the operational daily checklist meaning on February 13th 2021 and so, too late regarding the RLS availability KPI target.

The RLS is monitored on a 24/7 basis by SGDSP over the European Coverage Area (ECA), but the RLS is a worldwide service. That's why it is also useful to monitor the RLS provision on a global coverage.

5. RLS worldwide monitoring

5.1 REGINA for RLS monitoring

As detailed in this paper, the RLS monitoring is performed using the RLM reception capability of five SAR/Galileo Reference Beacons that are geographically distributed within the European Coverage Area (ECA). Since the first quarter of 2022, a global coverage RLS monitoring is available thanks to REGINA, a CNES-IGN worldwide network of GNSS receivers [5] [6]. The RLM generator creates RLM tests that are sent to REGINA receivers and then, the MTCF retrieves in near-real time these RLMs received by REGINA receivers in addition to those received by the five SAR/Galileo REFBEs to compute RLS KPIs.

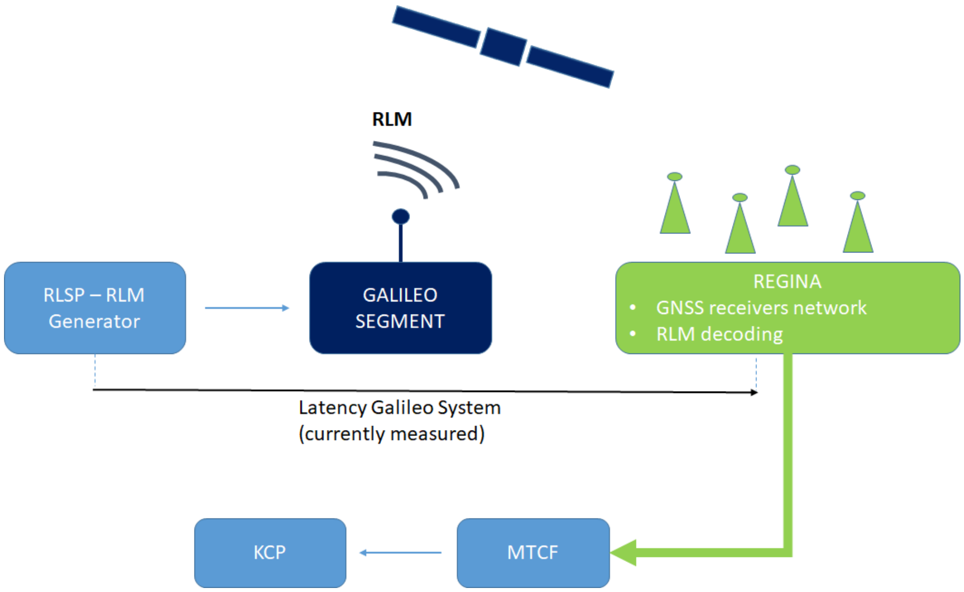

Fig. 12. REGINA data retrieval for global coverage RLS monitoring

For the time being, 17 of REGINA stations are currently operational and capable to extract the RLMs from Galileo SiS. Only 16 of them are used for RLS monitoring as it is sufficient and it avoids the RLS bandwidth saturation. These stations are distributed all over the world allowing to monitor the RLS provision on global coverage.

Fig. 13. REGINA receivers worldwide distribution (in red, receivers capable to extract the RLM from Galileo SiS)

To ensure the RLS provision monitoring even if a station is out of service, two backup stations are associated to each nominal station in the KCP configuration in order to use RLMs received on backup stations in case of no reception at the nominal one. Only one RLM test will be sent by the RLM generator to each REGINA station on a

24-hours period. The current RLM test transmission plan and nominal/backup stations configuration that have been defined by SGDSP are detailed in the table below.

Table 2. RLM test transmission plan and KCP configuration of REGINA GNSS receivers

Station	Lat (°)	Long (°)	Alt (m)	Beacon ID	Transm. time (UTC)	Back-up station1	Back-up station2
THTG	-17.577	-149.61	97.99	9C62FFFFFFFFF00	01:01:00	KIRG	NRMG
HARB	-25.887	27.7072	1558.08	9C62FFFFFFFFF01	02:01:00	SEYG	NKLG
YEL2	62.4813	-114.48	181.01	9C62FFFFFFFFF02	04:01:00	STJ3	TLSG
DYNG	38.07855	23.93243	510.60	9C62FFFFFFFFF03	05:01:00	TLSG	METG
AREG	-16.465	-71.493	2489.34	9C62FFFFFFFFF04	07:01:00	KOUG	STJ3
KITG	39.1334	66.8867	620.63	9C62FFFFFFFFF05	08 :01:00	METG	DYNG
METG	60.2419	24.3842	59.70	9C62FFFFFFFFF0E	10:01:00	TLSG	YEL2
PTGG	14.5354	121.041	86.94	9C62FFFFFFFFF07	11:01:00	GAMG	KITG
KOUG	5.09847	-52.64	107.25	9C62FFFFFFFFF08	13:01:00	AREG	STJ3
SEYG	-4.6787	55.5306	-37.09	9C62FFFFFFFFF0F	14:01:00	HARB	NKLG
TLSG	43.5497	1.48504	208.75	9C62FFFFFFFFF0A	16:01:00	METG	DYNG
GAMG	35.5901	127.92	927.97	9C62FFFFFFFFF09	17:01:00	PTGG	KITG
NKLG	0.35391	9.67213	31.5	9C62FFFFFFFFF0C	19:01:00	HARB	SEYG
NRMG	-22.228	166.485	160.36	9C62FFFFFFFFF0B	20:01:00	KIRG	THTG
STJ3	47.5954	-52.678	154.52	9C62FFFFFFFFF06	22:01:00	YEL2	KOUG
KIRG	1.35458	172.923	36.2	9C62FFFFFFFFF0D	23:01:00	THTG	NRMG

In order to take into account REGINA receivers' data for RLS monitoring, RLMs received by each REGINA station are decoded and formatted at REGINA mission center to comply with format of SAR/Galileo REFBEs' RLM data (detailed in section 3.1). Then, REGINA mission center sends them every 15 minutes to the MTCF. One file per REGINA station is transmitted to the MTCF containing all RLMs received by the REGINA station during the 15-minutes slot.

Over the four RLS KPIs, only two are computed and displayed with REGINA's data:

- The RLM delivery latency,
- The probability of RLM delivery.

These RLS KPIs are computed and displayed by the KCP separately from RLS KPIs based on SAR/Galileo REFBEs. The KCP computes RLS KPIs on a 3-hours period as for SAR/Galileo REFBEs.

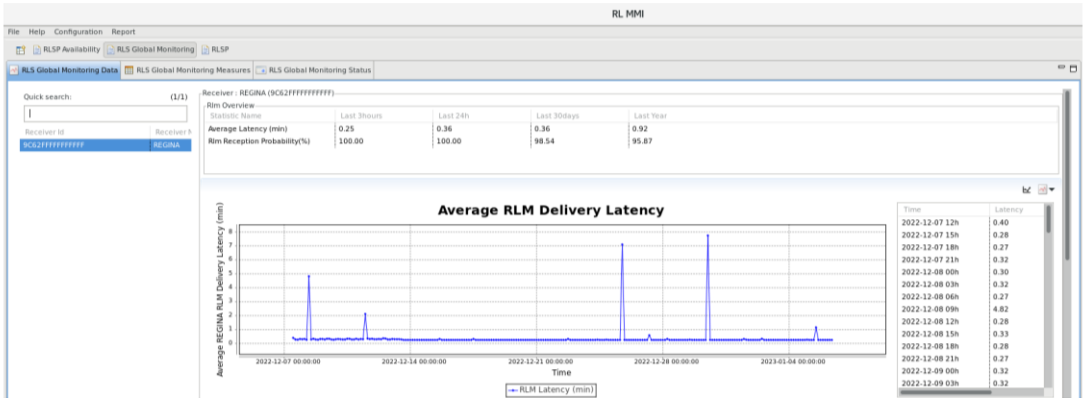

Fig. 14. Display of ‘RLM delivery latency’ KPI for REGINA at KCP level

REGINA mission centre sends also receiver status files to the MTCF containing the status of REGINA receivers which can be “OFF” or “ON” according to receiver or network outage. Each time the status of a REGINA station changes such a file is transmitted to the MTCF with a delay of around 20 minutes between the outage and the status file generation by REGINA mission center. The status of each REGINA station is displayed on a KCP view: “ON” status in green and “OFF” status in red.

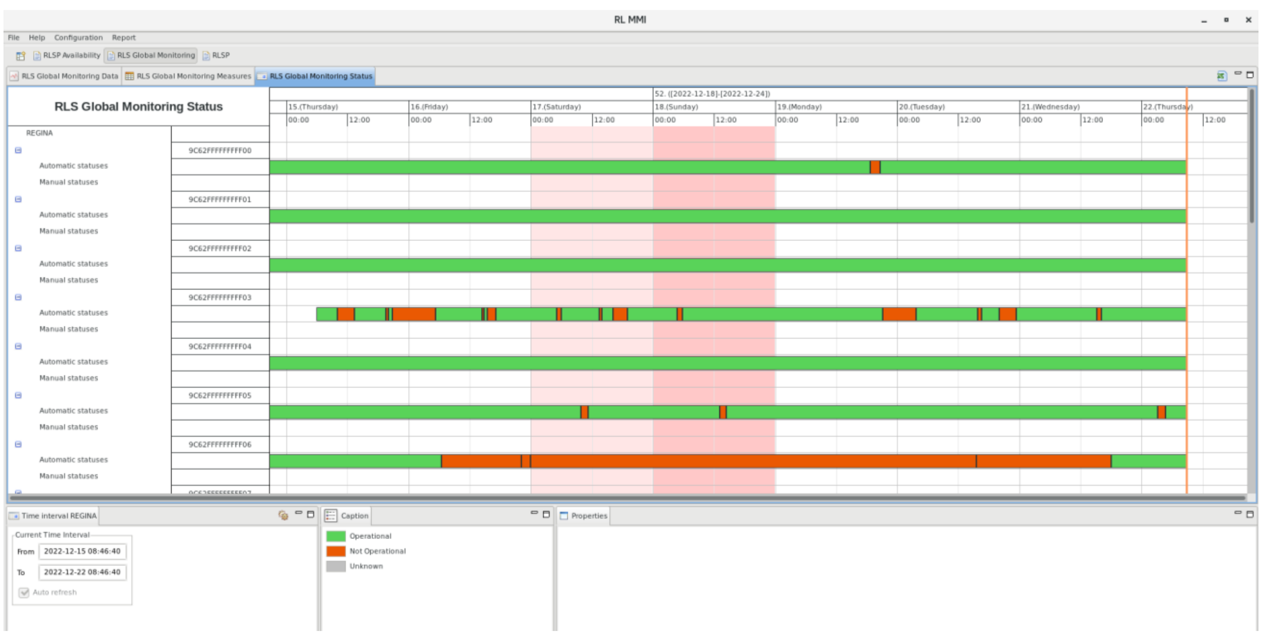

Fig. 15. Display of REGINA receivers’ status at KCP level

Initially, REGINA receivers’ status were used by the KCP to consider or not the REGINA station into RLS KPIs computation. When a REGINA receiver was “OFF”, the KCP took into account the RLMs received by the REGINA station configured as its backup station. But, due to the non-real time delivery of receiver status files, incoherent results in RLS KPIs were raised and the computation process was considered as not representative enough. As a consequence, REGINA receivers’ status were rapidly used for troubleshooting purpose only and no more for RLS KPIs statistics.

5.2 Operational concept and benefits

Regarding the operational concept, some operational processes have been setup between SGDSP and REGINA mission centre operators. In case of planned maintenance on REGINA stations, SGDSP operators are informed by mail. On the contrary, if a SAR/Galileo Ground Segment planned maintenance impacts the interface MTCF-REGINA, SGDSP operators notice REGINA mission centre by mail. Moreover, REGINA mission centre operators provide REGINA stations status to SGDSP in case of long duration outages. SGDSP operators can add manually a REGINA station unavailability on the KCP to display it on the REGINA receivers status view.

SGDSP performs operational daily checklists and monthly performance reports on RLS KPIs from REGINA as done on SAR/Galileo REFBEs. Additionally to RLS KPIs targets achievement, SGDSP performs statistics on REGINA data to highlight the worldwide efficiency of RLS provision. SGDSP compares the performances of the RLM delivery latency proportions (the proportion of RLM received under 5 minutes, between 5 and 15 minutes and upper 15 minutes) between the reported month and the mean of the last 12 months. The figure below, reporting statistics on November 2022, proves that the target of 99% for RLM delivery within 15 minutes (table 1) is highly achieved on a global coverage and that most of RLMs are delivered within 5 minutes.

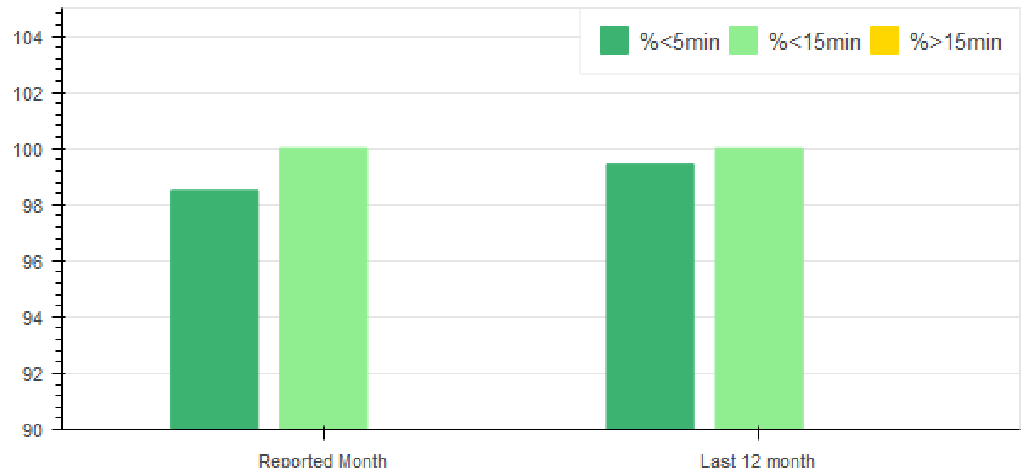

Fig. 16. RLM delivery latency proportions reported on November 2022

5.3 RLS worldwide monitoring improvements

According to operational feedbacks, RLS global coverage monitoring enhancements are on-going in order to improve troubleshooting. The following two perspectives will be setup at KCP level for RLS KPIs computation and display:

1- <u>Focused on RLM</u>
The KCP will compute the RLM delivery probability and latency with the first RLM received by any REGINA station without taking into account the reception by the expected nominal or backup stations. Two examples illustrate this RLS KPIs computation process:
   - Example 1: if at least one RLM is received by one REGINA receiver while not received by the nominal and backup stations, then the probability of RLM delivered is 100%.
   - Example 2: if the RLM is received within 1 minute by one REGINA receiver and within 15 minutes by the nominal station and 6 minutes by the backup station, then the RLM delivery latency is 1 minute.

2- <u>Focused on REGINA receiver</u>
The KCP will compute the RLM delivery probability and latency with the first RLM received by either the targeted nominal or backup REGINA receiver. In this case, the first RLM received is considered whatever it is received first by the nominal or the backup station. Two examples illustrate this RLS KPIs computation process:
   - Example 1: if at least one RLM is received by one REGINA receiver while not received by the nominal station nor the backup one, then the probability of RLM delivered is 0%.
   - Example 2: if the RLM is received within 1 minute by one REGINA receiver and within 15 minutes by the nominal station and 6 minutes by the backup station, then the RLM delivery latency is 6 minutes.

While regular improvements are performed on KCP, ALERT, REGINA and RLS KPIs computation, there are on-going major enhancements to strengthen the RLS monitoring.

6. RLS monitoring improvements

6.1 RLS monitoring on Indian ocean Coverage Area (IOCA)

As described in this paper, the RLS monitoring is based on five SAR/Galileo Reference Beacons distributed over the European Coverage Area (ECA) and worldwide REGINA receivers. Operational acceptance of two additional SAR/Galileo Reference Beacons is on-going to extend the RLS monitoring coverage. Indeed, these REFBEs are located in La Réunion and Kerguelen islands allowing to focus on the RLS provision over the Indian Ocean Coverage Area (IOCA).

A 8th SAR/Galileo REFBE is also planned to be deployed in the ECA area and more particularly, in Greenland to monitor the RLS provision on ECA limits.

6.2 End-to-end RLS monitoring

The main foreseen RLS monitoring enhancement deals with the end-to-end RLS monitoring. This evolution will improve the computation of the KPI 'RLM Delivery Latency' because for now, only the Galileo RLM delivery latency is provided. In order to setup this beacon-to-beacon RLS monitoring, the five SAR/Galileo REFBEs are progressively replaced by RLS-capable beacons. These new SAR/Galileo REFBEs will be able to:

- Emit distress alert in RLS protocol via the Cospas-Sarsat Forward Link path,
- Process received RLM (acknowledgment) and not only transfer it to the MTCF as done by the current SAR/Galileo REFBEs,
- Send back the RLM request cancellation to the RLSP allowing to stop the emission of RLMs by the RLSP.

A configurable transmission plan will allow these SAR/Galileo REFBEs to periodically send again distress alert in RLS protocol after previous acknowledgement reception.

On the other hand, a SGDSP study is on-going to face the following remaining points to compute end-to-end RLS KPIs:

- Impacts on Cospas-Sarsat FL bandwidth and MCCs: SAR/Galileo REFBEs will use RLS location test protocol which is not transparent but automatically processed by MCCs reducing operational impacts. The data flow for RLS monitoring could impact MCCs and the Cospas-Sarsat FL bandwidth. The SAR/Galileo REFBEs transmission plan shall be optimised to not disturb operational FL message processing.
- Impacts on FMCC and RLSP: after sending a RLM request cancellation, a SAR/Galileo REFBE shall be considered as a new REFBE with a new RLM request according to its transmission plan and not rejected.
- Impacts on KCP: currently, 'RLM delivery latency' and 'RLSP availability' KPIs computations are based on parameters included by the RLM generator in the RLM. The way to compute these KPIs by the KCP without these parameters or the possibility to keep using the RLM generator (with potential evolution at RLSP level) are under discussion.

7. Conclusion

The Return Link Service provision is monitored by SGDSP thanks to the KCP located in CNES Toulouse. Trustworthy and automatic 24/7 monitoring tool (ALERT) is fundamental to support the SAR/Galileo concept of operations and with the committed performance of high-available complex systems like the SAR/Galileo RLS. Since 2022, the use of REGINA receivers' data enlarged the RLS performance monitoring to a global scale. Continuous monitoring improvements are also fundamental to maintain a world-class SAR/Galileo Return Link Service delivery to the end users.

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References

[1] SAR/Galileo Service Definition Document, issue 2.0, January 2020, Galileo SAR Service Definition Document (gsc-europa.eu).

[2] Signal-in-Space Interface Control Document, issue 2.0, January 2021, Galileo_OS_SIS_ICD_v2.0.pdf (gsc-europa.eu).
[3] Performance Reports, Performance Reports | European GNSS Service Centre (gsc-europa.eu).
[4] Micromedia International, https://www.micromedia-int.com/.
[5] REGINA, https://regina.cnes.fr/.
[6] C. Velut, L. Jolivet, B. Garayt, T. Donal, J. P. Cardaliaguet, A CNES/IGN worldwide GNSS receivers network for IGS and navigation: overview and perspectives, 6th International Colloquium – scientific and fundamental aspects of the Galileo programme, Valencia, Spain, 2017, 25 – 27 October.