CNES Multi-mission stations : Maintenance Automation

B.MAMETSA Author1*,

[a] *CNES, Toulouse, 31400, France, benjamin.mametsa@cnes.fr*

Abstract

The CNES ground stations multimission network, called the MUM network includes a set of three 11m antennas at Kourou, Hartebeesthoek and Aussaguel; 2 polar stations of similar size developed in partnership with SSC (Swedish Space Corporation) and a new set of smaller 6m antennas currently being deployed. Since the renewal of the 11m antennas completed in 2017, CNES has set up the full automation of maintenance that aims at performing:

- The automation of all the preventive maintenances which do not need a mechanical intervention
- The opportunistic scheduling of these maintenances during the station free slots
- The automatic data transfer and the recording of results on a dedicated server with specific alerts once the specify threshold are exceeded
- The reduction in the operator's working hours on the antennas

To reach this goal, all the ground station environment systems are fully integrated: the antenna equipment (mainly the basebands, tracking system, spectrum analyzer and RF signal generator), the scheduling system, the stations monitoring & control software, and the orbitography center.

Thanks to that, we are now able to optimize the allocation of the stations utilization slots, to decrease the human interventions, and to anticipate upcoming failures by checking several station parameters during a specific event as well as any parameter over a long period.

This paper deals with the way the maintenance automation is set up on CNES MUM network. Currently deployed on each CNES station, this automation aims at improving the antenna reliability to meet the evolving needs of scientific and institutional missions.

It focuses on the increase of the precision and the frequency of the preventive maintenances without overbooking the stations as they are planned during their free slots, especially outside of the working hours. Currently the automation decreases the usage time of non-mechanical maintenance by 60% with no more human intervention.

It also deals with the future challenges as the possibility to perform an automatic crosscheck between all the station maintenance results, or to perform some tests during satellites supports in order to better understand the antenna behavior and evolutions

Acronyms

ACU	Antenna Control Unit
ASX	Aussaguel S+X ground station
BER	Bit Error Rate
CADOR	Centre Automatisé Des Opérations du Réseau
CORMORAN	COnsolidation et Renouvellement des MOyens Réseau et des ANtennes (Consolidation and renewal of the network and the antennas)
DTOV	Dynamic Time Offset Value
GSN	Ground Station Network
HBX	Hartebeeshoek S+X ground station
ICARE	Infrastructure de Communication Appliqué au REseau
IDEFIX	Ingestion, Processing and Distribution of X-Band data
IVK	Inuvik S+X ground station
KRX	Kiruna S+X ground station
KUX	Kourou S+X ground station
M&C	Monitoring and Control
NOC	Network Operation Centre (CNES)
OCC	Orbit Computation Center
OCP	Outil Central de Planification (Central Scheduling System)
PASTIS	Plateforme Automatique de Sauvegarde et de Traitement des Informations Stations
PAT	Passerelle Automatique de Test (Automatic Test Gateway)
PLTM	PayLoad TeleMetry
RA	Remote Action
REGATES	REnouvellement de Gascon, Automatisation et TéléExploitation des Stations
RM	Remote Monitoring
TLM	TeLeMetry
TOV	Time Offset Value
TT&C	Telemetry Tracking & Command
WTA	Wrong Target Avoidance

1. Introduction

Designed in 2011 within the CORMORAN project, the automation of maintenance is one of the main features of the CNES ground stations. It was developed to ensure a better reliability, flexibility and availability of the ground stations in order to meet the growing needs of the future missions.

After an overview of the CNES multi-mission network, this paper focuses on automatic maintenance development and how it allows the following improvements:

- the automation of all the preventive maintenances which do not need a mechanical intervention
- the scheduling of these maintenances during the free slots of the station schedule, to avoid conflicts with operational supports
- the automatic data transfer to and the recording of results on a specific server with specific alerts once the thresholds are exceeded
- HR optimization; The decrease of operator's working hours on the antennas

The same goal is also reached on the new small ground station network where the maintenance automation was adapted to its new architecture to improve their reactivity, flexibility, agility and optimized costs

The future challenges such as the possibility to perform an automatic crosscheck between all the station maintenance results, or to perform some tests during satellites supports are treated in the end of this paper.

2. CNES Multi-Mission Stations

2.1 CNES Multi-Mission Stations Overview

The CNES Multi-Mission Network provides Tracking, Telemetry and Command (TT&C) services to all CNES satellite missions during the Launch and Early Orbit Phase (LEOP), all along the mission phase and until the End Of Life operations (EOL). It establishes platform and payload telecommunication links between a satellite and its control or mission center according to the mission needs and constraints, and it performs localization (Range, Doppler, Angles) measurements.

The CNES network is organized around central facilities located in Toulouse, France, with ground stations distributed on several continents, most on French territories and some in foreign countries, in order to provide a worldwide coverage for the satellites in polar, inclined or equatorial orbits.

- Aussaguel, near Toulouse, France
- Kourou, French Guyana
- Hartebeesthoek, South Africa
- Kiruna, Sweden
- Inuvik, North West Territories, Canada
- Patagonia, Chili
- La Reunion (2026), France, Indian Ocean
- Tahiti (2029), French Polynesia
- St Pierre et Miquelon (2030), France, Atlantic Ocean

Figure 1: CNES Stations sites

These stations are managed from Toulouse by the Network Operations Center (NOC). It is in charge of controlling the data transfers and of supervising the real time operations. It based on the following entities:

- The data transmission system composed of ICARE and some Protocol Gateways is in charge of all transfers monitoring.
- The planning tool OCP (in French "Outil Central de Planification") delivers the scheduling plan for each station taking into account the mission needs and the satellite visibilities.
- The Orbit Computation Center (OCC) is in charge of the orbit calculation and the generation of predicts (station acquisition data, pointing elements, visibilities, interferences, collision risk assessment).
- The monitoring and control system (M&C) called REGATE. After receiving the station schedules from the OCP and the satellite orbits from the OCC, it allows to configure and to manage the antennas

To meet the needs of scientific and institutional missions as well as New Space needs, two projects were developed and set up: CORMORAN and Mini-MUM.

2.2 CORMORAN Project

The CORMORAN (French acronym for "COnsolidation et Renouvellement des MOyens Réseau et des ANtennes": Consolidation and renewal of the network and the antennas) project was designed around 3 main areas [Ref.-1].

The first one concerns the NOC. It is named CADOR (French acronym for "Centre Automatisé Des Opérations du Réseau") and deals with the extension of the REGATE system to the automated management of all the communications and data distribution systems. This hosting system allows a progressive evolution of the supervision and monitoring scope using scripts to automatically operate the ICARE system and to check the right configuration between stations and control centers

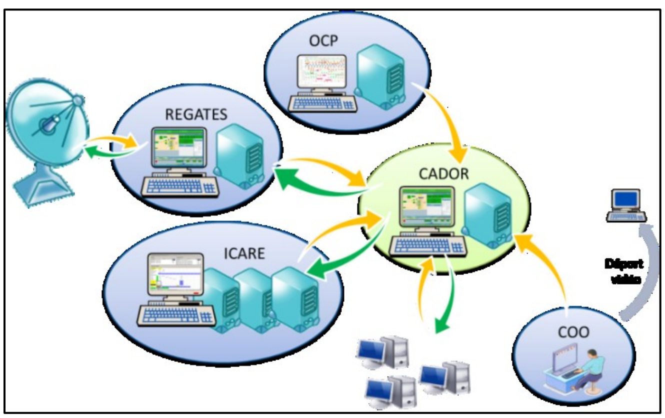

Figure 2: Automation of the Network Operations Center

The second one is a new component named IDEFIX (service for Ingestion, Processing and Distribution of X-Band data). It is based on a local subsystem set up in each station that performs the telemetry processing functions (ingestion, processing and distribution), and a central subsystem which performs the whole system synchronization functions and the management of the X band telemetry data from all the antennas (telemetry overlap, data delivery to the mission center…)

The third one covers the complete deployment of the following 11m antennas:

- Kourou in French Guyana (2015)
- Hartebeesthoek in South Africa (2016)
- Aussaguel, near Toulouse, France (2017)

Henceforth, there is the same station design deployed on these site with these following main characteristics

Table 1: Characteristics of the CORMORAN stations

Parameter	Specified Value
Antenna parameters	
Reflector size	11m
Antenna velocity (full motion)	Azimuth 15°/s | Elevation 5°/s | Tilt (3°Axis) 5°/s
Overhead passes	3rd axis (4° tilt)
Tracking type	Program & auto-track (X-Band or S-Band)
Auto-track tracking accuracy	Tracking loss < 0.5 dB on the tracked signal
Half power beamwidth	0.1°@8250 MHz ; 0.41° °@2250 MHz
X-Band characteristics	
Receive frequency range	8025-8400 MHz
Downlink G/T (@2° elevation)	>34 dB/K (guaranteed) Nominal: 36.5 dB/K
Polarization	Dual polarization RHCP and LHCP (selectable for tracking and simultaneous for telemetry)
Axial ratio when RHCP/LHCP	1 dB receive
Modulation schemes	BPSK, QPSK, OQPSK, GMSK, 8PSK, 16APSK & 16QAM
Bit rates	400 Mbps fully tunable bitrate per channel
Coding	4D-TCM (2.5/3), Viterbi, Reed Solomon (223/255) and DVB Reed Solomon (238/254)
S-Band characteristics	
Receive frequency range	2200-2290 MHz
Downlink G/T (@ 5° elevation)	>22.5 dB/K
Receive polarization	Dual polarization RHCP and LHCP (selectable for tracking and simultaneous for telemetry)
Receive modulation schemes	PM/PSK/PCM, FM/PSK/PCM, PM/PCM, FM/PCM, BPSK, QPSK, OQPSK, DQPSK
Receive Bit rates	< 2 Mbps fully tunable (modulation dependent)
Coding	Viterbi, Reed Solomon
Transmit frequency range	2025-2120 MHz
EIRP	71 dBW
Transmit polarization	Dual polarization RHCP and LHCP (tracking and telemetry)
Transmit modulation	PM, FM, BPSK, QPSK, OQPSK
Transmit Bit rates	< 1 Mbps fully tunable
Coding	Viterbi available

Beyond the dual S+X band use, the CORMORAN antennas have the following new features:

- Diversity Frequency. Usually the tracking and the telemetry reception are done for one frequency on the both left and right polarizations. Now, the antenna is also able to perform it for only one polarization but with two RF different frequencies. In both cases, the best channel is automatically selected whether for satellite missions or launchers (Ariane, Soyuz and Vega)

- Dynamic Time Offset Value (DTOV). If the satellite/launcher is in advance or late compared to its predicted orbit, a compensation is usually done by applying a fixed time offset value (TOV) to the antenna pointing elements. The Dynamic Time Offset Value is intended to compensate the effects of continuous uncontrolled or unpredictable orbit variations. This function provides the delay or advance of the satellite compared to its current ephemeris table thank to an algorithm in the Antenna Control Unit (ACU) that calculates, in real time, the optimal time correction to be applied to the antenna pointing elements.

- Wrong target avoidance (WTA function). With the increasing number of the low orbiting satellites, the risks of interferences are higher and higher, in particular for the satellites operating in X-Band and using the whole allocated bandwidth. Most of the case, this risk is materialized by an acquisition and a start of auto tracking mode of an interfering satellite before establishing the contact with the supported satellite. To avoid it, the CORMORAN stations are fitted with an ACU function that computes in real time the root-mean-square deviation between the ephemeris table and the actual antenna position. If a threshold, defined by the controller, is reached, the antenna turns on the ephemeris mode.

- The automation of maintenance that is detailed in the further chapters

2.3 MiniMum Project

The MiniMum project was initially designed to support mainly future in-flight missions resulting from the New Space [Ref.-2]. These mission profiles are largely based on nanosat-type platforms or rely on constellations of satellites of greatly reduced size. They require an increased flexibility in the ground segments, but also lower supports costs compared to large institutional or scientific missions. Even so, these complementary stations can be used more widely for all missions, as long as the required performance is sufficient. However, this type of antenna will be more efficient and more suitable for low-orbit missions.

From a financial optimization view, some technical choices have been made as the non-automatic tracking in X-band, a strong limitation of redundancy in the station, and a change of baseband equipment. These choices take into account the new concentric source that eliminates mechanical misalignment of the sources and allows a good X band telemetry reception data in S band autotrack. The chosen new baseband can simultaneity performs S and X band telemetry reception; and a complete spare batch will be available on each antenna site to limit long periods of unavailability of the stations.

To ensure a maximum flexibility for the future missions, several options have been planned as the post-installation Ka-band scalability (telemetry and tracking), variable and adaptive coding and modulation in X band, virtualization and possibility to evolve within SDR products. The maintenance automation was renewed according to the same CORMORAN station principle.

Two stations are already operational in Aussaguel (Near Toulouse, France, 2023) and Patagonia (near Punta Arenas, Chili, 2024). Three more station are to be installed in La Reunion (France, Indian Ocean, 2026), Tahiti (French Polynesia, 2029) and St Pierre et Miquelon (France, 2030)

Table 2: Characteristics of the MiniMum stations

MiniMum ANTENNA			
Diameter (m)	5,5 or 6,1		
S + X + Ka feed	Cassegrain		
Elevation range	0° +90°	**Azimuth range**	No limit
Range of 3rd axis	No limit	**3rd axis angle**	+/- 9°
Max speed (°/sec)	Azimuth : 8.5, Elevation : 6.5 3rd axis : 4.5	**Max acceleration (°/sec²)**	Azimuth : 10, Elevation : 10 3rd axis : 10

TRACKING	**S-BAND**	**X-BAND**	**Ka-BAND**
Polarization	RHCP and LHCP (combination)	N/A	RHCP or LHCP (selection)
Tracking error (deg)	< 0.05° pic (3 sigma) < 0.025° rms (1 sigma)		
Tracking loss (dB)	0,01 dB pic ~0 dB rms	0,2 dB pic 0,04 dB rms	1,85 dB pic 0,5 dB rms
Pointing accuracy (dB)	< 0.15° pic (3 sigma) < 0.1° rms (1 sigma)		
Pointing loss (dB)	0,2 dB pic 0,05 dB rms	1,5 dB pic 0,7 dB rms	Non significant
TRANSMISSION	**S-BAND**	**X-BAND**	**Ka-BAND**
Transmission Frequency Band (MHz)	2025-2120	N/A	N/A
3 dB beamwidth (deg)	1.85	N/A	N/A
Power amplifier	Solid State	N/A	N/A
Polarization	RHCP ou LHCP	N/A	N/A
EIRP (dBW)	54	N/A	N/A
Axial ratio	< 1 dB		
RECEPTION	**S-BAND**	**X-BAND**	**Ka-BAND**
Frequency Band (MHz)	2200-2300	7900-8500	25500-27000
Antenna gain (dBi)	39	50.5	58
3 dB beamwidth (deg)	1.7	0.46	0.145
G/T at 5° elevation (dB/°K)	16.0 à 5° EL, 2250 MHz	28.0 à 5° EL, 8250 MHz	32.0 à 5° EL, 26250 MHz
Axial Ratio	< 1 dB	< 1 dB	< 1 dB
Polarization	RHCP et LHCP	RHCP et LHCP	RHCP et LHCP

3. Automation of Maintenance

3.1 Objectives

For both Cormoran and MiniMum antenna, a built-in automatic testing system has been implemented. It aims at ensuring:

- The station reliability: To prevent and anticipate the station failure or a performance loss, a preventive maintenance plan is applied. The automation of each maintenance which do not need a mechanical intervention allows the right scheduling and realization of this plan.

- The station availability: each contact opportunity between the station and a satellite shall be in priority dedicated to the mission. The automatic execution allows the scheduling of the maintenance even outside the working hours.

- Flexibility: in case of an extra pass scheduling at the last minute, the COR operator can easily cancel the automatic maintenance with less priority. Moreover, this automatic maintenance can be postponed during the next free slot of the station without taking into account the working hours of the maintenance team.

- A high rate of HR time saving

This built-in automatic testing system includes several equipment described in the following paragraph.

3.2 Design

The maintenance automation was developed as a part of CORMORAN project so the following chapters deal with this kind of antenna architecture. However, the same system (equipment, monitoring, control and data collect) was adapted and implemented on antennas of MiniMum project, in a lighter version in line with the less complex architecture of these new stations.

Here is a simplified diagram of the CORMORAN antennas without the maintenance equipment.

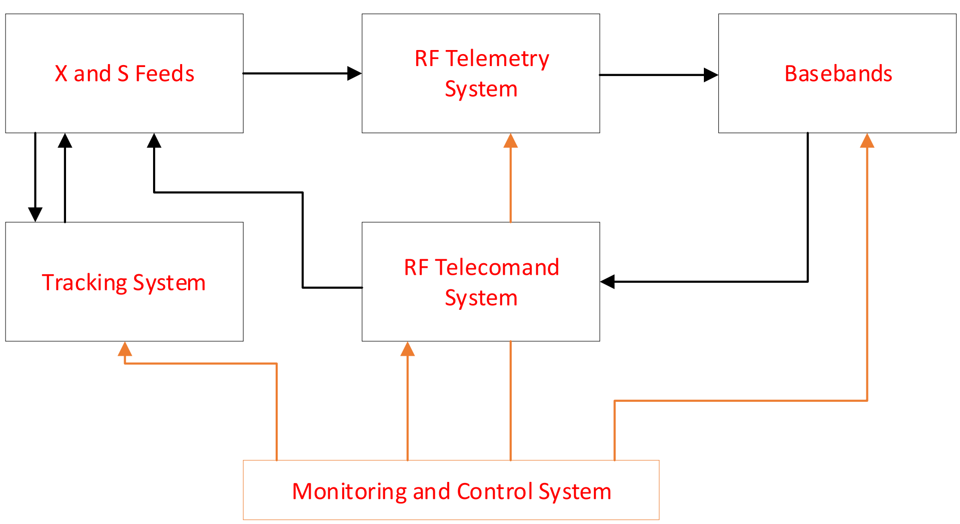

Figure 3: Antenna Basic Functionalities

In addition to these current baseband and tracking system test functionalities, a RF signal generator and a test translator equipment has been implemented. With this setup we are able to perform tests loops on both S and X channels. A spectrum analyzer was also added and is connected to 26 test points spread on the station thanks to a switch matrix (26 test inputs /1 measurement output). To ensure the connection between the M&C system and the spectrum analyzer, a piece of equipment, called PAT (for Automatic Test Platform in French), has been developed.

This built-in automatic testing system is represented on the diagram below.

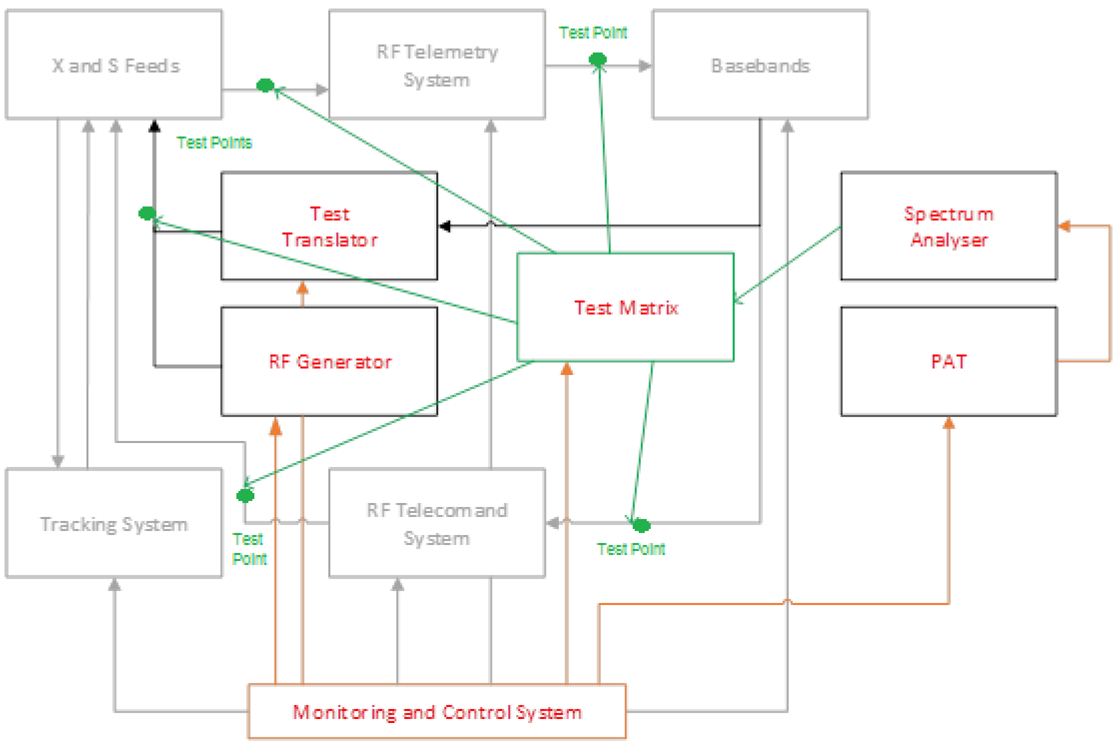

Figure 4: Built-in Automatic Testing System

The PAT system is based on a PC equipped with a piece of software and two network interface controllers, one to communicate with the spectrum analyzer and the other one to communicate with the M&C system. The functions of the PAT are to:

- Configure the spectrum analyzer parameters (frequency, span, resolution and video bandwidth, trace type, reference level, scale and the noise source) and command its basic functions: peak search, level measurement, channel power, auto-scale and print screen (png and csv files).

- Collect data from the monitoring and control system. Apart from the spectrum analyzer data, the PAT can receive and save all the other equipment data from the M&C system. It is used to complete the test results with other information (BER from the baseband, elevation and azimuth angles from the tracking system…)

- Process the test results and prepare the maintenance files with specific name and time tagging.

- Display the test results and store them into folders with a specific name for each test family. The test results are written into a file. A shared folder is set up with the spectrum analyzer and allows the PAT to collect the print screen files and to associate them to the result file.

A permanent communication link is established between the PAT and the spectrum analyzer for one hand, and the PAT and the M&C system on the other hand. Alarms are raised in case of communication failure and all the exchanges are saved into a log file. Moreover, a FTP server and the remote desktop connection are installed for the results recovery from another computer/server.

3.3 List of automatic maintenances

Thanks to this built-in automatic testing system, we are able to perform automatic maintenances as any automatic satellite support. It is the same sequence with 3 steps:

- Station configuration: the M&C system configure all the antenna equipment needed for the maintenance. If necessary, it can also get back some external pieces of information as sun ephemeris and solar flux provided by the obitography center, and activates network connections.

- Maintenance process: the M&C system performs the planned maintenance without any human intervention. One or several result files are created and saved on the PAT.

- Station standby: the antenna is configured in standby mode, ready for the next maintenance or satellite support

Progressively we upgraded the automatic maintenances to reduce time slot needed, by combining S and X band test simultaneity for example, and improve their performances. Each maintenance can be performed for a dedicated configuration (as an inflight satellite for example) or covers different ranges (frequency, modulation, etc…). Not only has the initial goal been achieved, it has also been surpassed. Here is the list of these maintenances:

- Gain over temperature G/T. This maintenance can perform a G/T measurement by using the channel power function of the spectrum analyzer to measure the sun/moon noise on the bandwidth of both tracking and telemetry channels and on both S and X band channels

- Bit error rate BER. During a file replay in loop test, the PAT gathers the station noise measured by the spectrum analyzer and the number errors given by the baseband to calculate the BER. This maintenance is also simultaneity performed on S and X band channels.

- Carrier and telemetry signal check. The carrier is up and several print screen are done by the spectrum analyzer to check the modulation, the bandwidth and the absence of spurious signal. Same sequence is performed in loop test with a simulated telemetry signal generated by the baseband to check the S and X band telemetry channels.

- Link budget. A loop test is configured to check the signal level at all test points (telemetry, tracking and commanding) and verifies there is no gain losses compared to the reference measurements.

- Gain variation on the bandwidth. The signal generator performs a loop test with a swap on the carrier. This swap covers the signal reception bandwidth and we can check the gain stability with the spectrum analyzer.

- EIRP check. This maintenance checks all the solid state amplifiers on both polarizations: output level, return losses and each module gain for different frequency.

- Doppler measurement. A loop test is configured and the frequency gap is check to be sure that the Doppler measurement performed during a satellite support is not compromised by the antenna equipment.

All these maintenance results are available on the PAT of each station but they are raw data and some external information that can be missing to totally exploit them. That is why another tool has been developed to process these results (see chapter 3.5).

3.4 Comparison between automatic and manual maintenance

The automation significantly reduces in the operator's working hours on the system. In order to maximize the ratio availability/reliability of each station, it was decided to reused a little part of this time saving to increase the maintenance frequency as mentioned on the following table.

Table3: Comparison between automatic and manual maintenance

	Maintenance duration		**Maintenance frequency**	
	Performed by operator	**Automatic**	**Before Automation**	**After Automation**
Gain over temperature	2h for S band 2h for X band	15min for both band simultaneity	1 per 3 months	1 per week
Bit error rate	1h30 for S band 1h30 for X band	40min for both band simultaneity	1 per month	
Carrier & telemetry signal	2h	15min	1 per 3 months	
Link budget	1h for S band 1h for X band	15min for both band simultaneity	1 per month	
Gain variation on the bandwidth	1h	10min	1 per 6 months	
EIRP check	1h	10min	1 per 3 months	
Doppler measurement.	2h	10min	1 per 3 months	

3.5 Maintenance scheduling

The MUM station slots are automatically planned by the planning tool OCP based on a solver that takes into account the satellite visibilities and the mission constraints. The station schedules are planned for 4 weeks and can be updated at any moment. To plan the automatics maintenances while keeping the satellite mission priority, a new software, the CMS, was developed to recover the planning edited by the OCP and identify each station free slots. On the other hand, this software lists the automatic maintenances and their constraints: duration, redundancy and some specific conditions (example, sun visibility for gain over temperature test). By this way the CMS is able to book the maintenances without impacting the missions.

The CMS does its programming each Wednesday at 05:00 am UTC and it is aiming for a booking on next Sunday night. If there are no enough free slots, the CMS looks for them during the following days. It also keeps the maintenance history. In case of overlap between a satellite mission et an automatic maintenance, due to an extra pass for example, the maintenance is automatically postponed the week after.

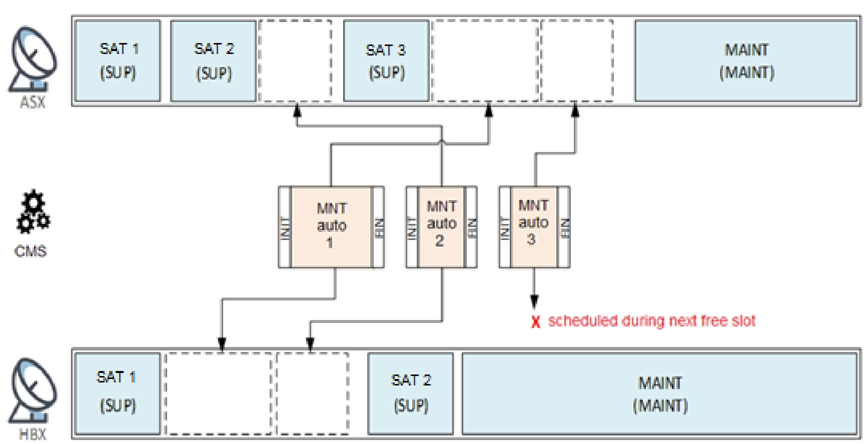

Figure 5: CMS scheduling

3.6 Maintenance Result processing

To gather all the measurements and provide a friendly user display, the maintenance results are processed by PASTIS [Ref.-3]. Initially, this software was developed to improve the access to the system equipment data generated during a satellite pass. Indeed, around 10 Mbytes of data are logged during a basic support by the different systems (tracking, baseband, M&C…) and we use them for investigations in case of anomaly. PASTIS aims at:

- Automating the retrieval and the centralization of these data on a server. Each new log is identified and downloaded maximum 15min after its creation.
- Doing a preliminary treatment on these data: conversion, formatting, new parameter computation, data extract
- Establishing a long term monitoring to check the station performance
- Providing an intuitive web interface to easily access to these data

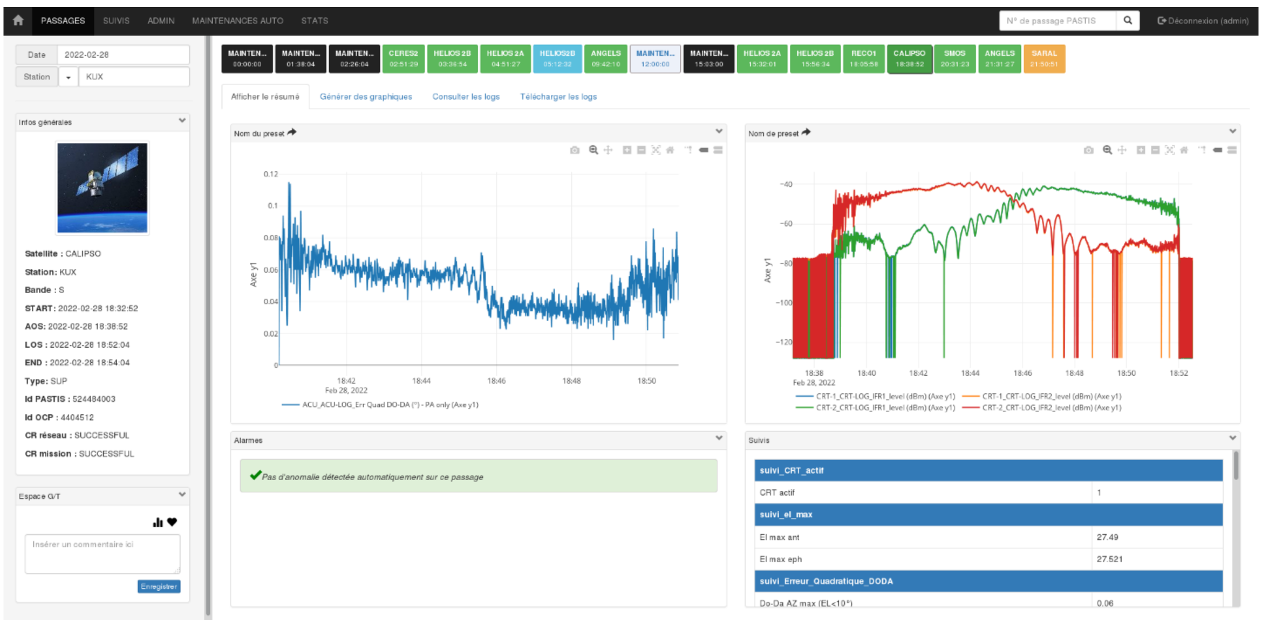

Figure 5: PASTIS web interface

With the automatic maintenance set up, it was decided to integrated the results into PASTIS. By this way, a first visualization of the test results of each station is quickly accessible and a long term monitoring is set up to detect slow degradations. The use of PASTIS also allows a crosscheck between the maintenance measurements and the equipment logs.

Here is a diagram of the interconnections between the PAT, PASTIS, the planning tool OCP and the M&C system

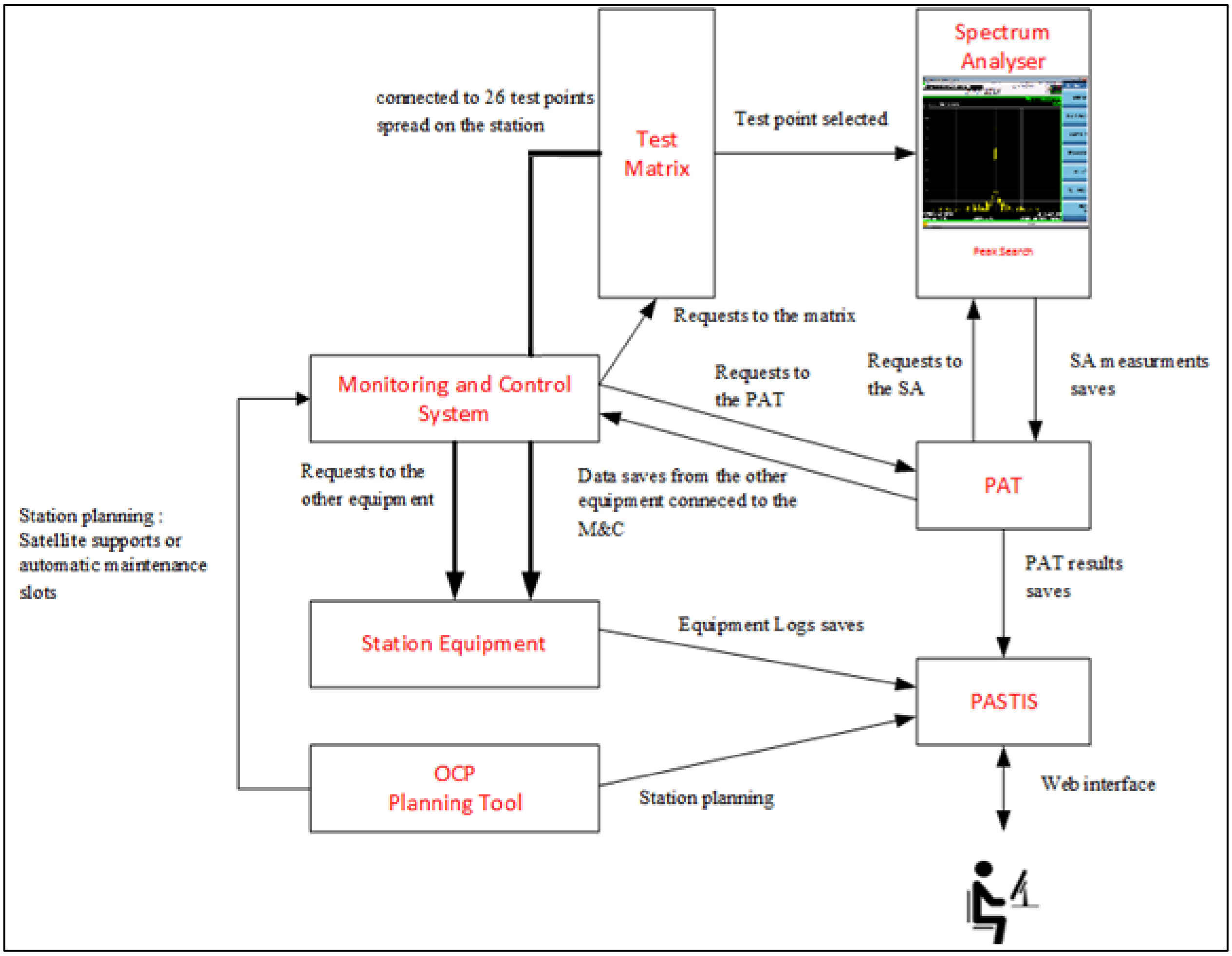

Figure 6: PASTIS and PAT interconnections diagram

Moreover, PASTIS edits a weekly report and some results are directly sent by email to the technical managers of the MUM stations.

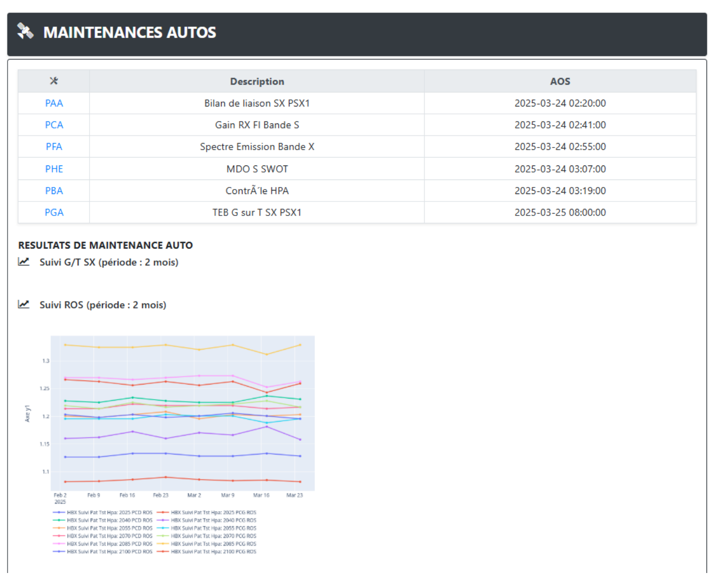

Figure 7: PASTIS weekly report

ID PASTIS : 958486057
STATION : HBX
AOS : 2024-12-31 08:00:00
COMMENT : MAINT AUTO - G sur T SX PSX1

Résultats de la maintenance :

G/T moyen par bande de fréquence :
Specs :
G/T TM S (EL=5°) >= 22.5 dB/K
G/T TM X (EL=5°) >= 34 dB/K

	GoverT (EL=5°)
Bande	
S	23.02
X	36.11

Ci-dessous, les résultats complets de la maintenance :

Freq	Point	Description	Bande	sun_noise	sun_el	sky_noise	sky_noise_el5	GoverT (sun_el)	GoverT (EL=5°)
2200.0	25	TMS_PCD	S	-26.25	60.52	-48.98	-48.37	23.65	23.04
2200.0	24	TMS_PCG	S	-26.96	60.52	-49.66	-49.16	23.62	23.12
2200.0	23	TKS_PCD	S	-42.71	60.52	-65.21	-64.77	23.42	22.98
2200.0	21	TKS_PCG	S	-42.70	60.52	-64.85	-64.73	23.06	22.94
8212.0	17	TMX_PCG	X	-49.93	60.52	-70.71	-69.70	37.41	36.40
8212.0	18	TMX_PCD	X	-52.18	60.52	-72.61	-71.38	37.06	35.83

Figure 8: Example of results email

3.7 Further Improvements

Thanks to the automation the precision and the frequency of the preventive maintenances increase without overbooking the stations. It decreases the usage time of non-mechanical maintenance by 60% and improve the antenna reliability.

However, further improvements can be made for a better monitoring of the station evolution, a better understanding of its behavior and a better anticipation of upcoming failures:

- To perform measurements during a satellite support. Loop tests performed with simulated telemetry give a good overview of the antenna performance but several external elements are not take into account as the weather and the Doppler. To measure them systematically during satellite supports would allow us to better anticipate their impact.

- To use machine learning to analyze and crosscheck all available data provided by the automatic maintenance, station equipment and satellite supports. It would enhance the station predictions.

4. Conclusions

Initiated in 2011 with the deployment of the Kourou, Hartebeesthoek and Aussaguel antennas as a part of Cormoran project, the automation of maintenance was adapted to the new small ground station and it is now fully integrated on CNES MUM network.

Thanks to it, the need to rely on human intervention is drastically reduced and, at the same time, the flexibility is such that it allows to increase the maintenance frequency to ensure higher accurate monitoring throughout the system's lifetime. By this way, the automation increases the non-mechanical maintenance precision and efficiency while reducing its usage time by 60%, and as a consequence associated HR.

The next challenges will concern the possible measurement done during satellite supports and the integration of machine learning to analyze and crosscheck all available data and enhance the anomaly predictions. The main objective is still the same: increasing infrastructure functional availability.

References

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