CNES Ground Stations Multi-Mission Network : The Art of Scheduling

Christophe Lamant[a]

[a] *OCP Technical Manager, CNES DTN/TSA/LMC, France,* Christophe.Lamant@cnes.fr

Abstract

The French Space Agency, CNES, operates a Ground Stations Network composed of more than ten antennas allocated all around the world to provide Tracking, Telemetry Command (TT&C) support and to deliver mission data (X-band services) to several space missions (currently about twelve in flight).

One of the major challenges is to automatically establish a planning, scheduling the daily ground stations passes in accordance with mission constraints. The system in charge of this process is named OCP (for Outil Central de Planification in French) and is also used to perform simulations upon longer periods basis (about one year to evaluate the Network capability to cope with a new mission needs, for instance).
The computation is performed by an inner OCP component, named solver, based on constraints programming algorithm.

A previous paper, written for SpaceOps 2021 and titled CNES Ground Stations Network Scheduling:
Prototypes to select the best solver, presented the approach implemented to evolve the OCP solver.
We had organized a complete call for tender in order to contract:

- the procurement of three different prototypes delivered by three different companies referenced in planification methods,
- the support for running the comparison tests,
- and then the development and maintenance of the solver from the best prototype.

At that time, the Local Solver company had just been selected to develop the complete solver.
Since, the new solver has been developed in accordance with the specifications established in the call for tenders including:

- compatibility with the OCP global system,
- new thematic developments, changes in constraints,
- improvements in terms of use

Furthermore, the new solver results have been cross-validated with the old solver before going into production. In the meantime, this process gave the opportunity to refine the solver optimization algorithms.

First of all, this paper will present the dedicated tests, difficulties observed during cross validation and the followed process to switch this new solver operational

Then, an overall presentation of the OCP system will be performed:

- the main functionalities and the architecture
- the current planification process and the different types of constraints to be fulfilled by the solver (according to operational missions and maintenance team needs)
- the significant improvements brought by the new solver will be emphasized

Finally, the paper will conclude with an overview of possibly future improvements of OCP System dedicated to incoming missions and opportunities given by new technologies (such as virtualization, web design, …).

Acronyms/Abbreviations

CNES	=	French National Space Agency	GEO	=	GEostationary Orbit
KPI	=	Key Performance Indicator	LEO	=	Low Earth Orbit
BCP	=	Bureau Central de Coordination (Scheduling Center)	GTO	=	Geostationary Transfert Orbit
NOC	=	Network Operation Center (COR)	HMI	=	Human Machine Interface
OCC	=	Orbit Computation Center (COO)	OS	=	Operating System
CPU	=	Central Processing Unit	VM	=	Virtual Machine

1. Introduction

The OCP Scheduling system is a client-server system composed of an application server based on a tomcat server.

The dedicated OCP application is coded in JAVA and was interfaced using a system of listener to communicate with a dedicated solver based upon Ilog system.

The client is a rich JAVA client directly downloadable from the server with a web browser using Java Web start application-deployment technology to install on the client computer.
The solver upgrade led to change the communication between the tomcat and the solver to integrate it as a Web Service using a REST API.

The planning is supposed to be computed weekly for one week using specific constraints by the "solver". The HMI enable the scheduling officer to edit the planning directly. The Satellite control centers(CCC) are also able to send change requests to get extra passes or to adjust their planning for specific needs. These modifications are validated by the scheduling officer. He will also check that the specific constraints are still respected with the "verification tool".

The table below sets out the main generic constraints available for planning computation.

Set of constraints	Name of constraint	Description of need	Example
Satellite	TYPE 1	The number of slots with a duration greater than a threshold for a given time range.	Three slots of more than 10 minutes between 06:00 and 14:30.
	TYPE 2	Minimum or maximum deviation between two consecutive reserved slots	At least 60 minutes between two slots
	TYPE 3	Cumulative duration (minimum or maximum) of slots over a given time period	Minimum of 30 minutes cumulated between 06:00 and 12:00.
	TYPE 4	Station selection priority	Priority 1 for ASX and HBX stations; Priority 2 for the KUX Station.
	TYPE 5	Number of simultaneous slots for a set of satellites	One single simultaneous satellite pass between Sat2, Sat4 and Sat5 between 14:30 and 24:00, regardless of the station.
Station	TYPE 2	Minimum maintenance duration over a given period	Two hours of maintenance between 09:00 and 12:00.
	TYPE 4	Minimum/maximum number of slots per period in days, week or month	Maximum of 70 weekly passes for the STC station.
	TYPE 5	Cumulative Minimum/maximum duration of slots per period in days, week or month.	Maximum 600 min. of daily cumulative slots over STC.
	TYPE 6	Order of priority for satellites using each station	For the ASX station, SPOT2 and SPOT4 satellites are priority 1 and SPOT5 satellites are priority 2.

The server and the solver are 2 different software developed by CAPGemini for the framework and LocalSolver for the new solver.

2. Development of the new solver

The development of the solver was carried out using an Agile method with 6 sprints planned every 3 weeks to gradually integrate the existing constraints into the old solver.
The first step was to integrate the new solver into the OCP framework. But to ensure binary compatibility with LocalSolver solver technology, OCP framework had to be upgraded from linux CentOS 6 to CentOS 7.

Then with the COVID-19 epidemic, we had to find new way to adapt the development and integration of the OCP solver.

Exchanges between the two development teams where facilitated by giving remote access to pre-prod solver accessible by internet and periodic coordination meetings.

3. Unit tests

Each constraint was validated with unitary tests over short and long periods of scheduling.
Typically for constraint Satellite type 1, around 20 calculation scenarios were built on the OCP server :

1 CSAT-1 with 3 slots in 1 time slot
1 CSAT-1 with 1 to 3 slots in 1 time slot
3 CSAT-1 with 1 slot in 3 separate time slots.
3 CSAT-1 with 1 slot in 3 non-disjoint time slots
3 CSAT-1 with slots in different frequency bands S and X
1 CSAT-1 with the longest slot in 1 time slot
1 CSAT-1 with the first slot in 1 time slot
1 CSAT-1 durée minimum
1 CSAT-1 with the maximum number of slots in 1 time slot
1 CSAT-1 with one or more days of the week in 1 time slot
26 CSAT-1 cyclical constraints

Some "impossible tests" where also planned to evaluate the ability of the solver to act against situations without complete solutions, either:

- Prevent before computing
- Propose the best solution with a critical analysis
- Abort computation with an understandable message

4. Combined tests

Then when all these tests have been completed, the different constraints where tested combined as they are actually on specific satellites scheduling.

For instance, CFOSAT or SARAL: CSAT-1 + CSAT-2 + CSAT-4 + CSTA-6.

These tests were run for each specific satellite scheduling already configured in old OCP in order to validate solver's ability to find correct solutions.
The results were quickly evaluated considering specific KPI (total number of slots, gap between to slots, …) booked by day.

Then some complex tests where led to ensure correct priorities where given to find solutions when different satellites scheduling where combined for computation over a week or a month.

On these computations; quick tests were not sufficient, it was too long to verify using the Excel planning produced by the specific tool.

5. Cross validation for the old constraints with the old OCP

The next step was to operate on a dedicated modified OCP able to ingest the output file produced by the solver and to run the OCP verification tool.

As the two systems were on different networks, the cross validation was a very complicated process to conduct, specifically with non-regression tests.

Furthermore, as some constraints had evolved (Satellite type 3), the cross validation was limited to the solver versions before integration of the modified constraints.

6. Cross validation for the modified constraints with the new OCP

Finally, after a while, the new OCP tool was delivered and the integration of the solver as a Web Service was tested and debugged.

Additional cross-validations were performed using the new system to validate that the modified constraints worked correctly in the solver and in the OCP verification tool.

Long term simulations were also run to verify the scalability of the solver, but the 2016's computer was too short in RAM (16 GB) and we could not conduct a simulation for more than 2 months at a time. So 6 months can currently be run in 3 times.

Current performance is pretty good, less than a minute for 1 week of computing. The computation times depends on the difficulty of finding a complete solution. for instance, if many slots have already been booked, a partial solution will take longer to calculate than a complete solution.

7. Cross validation between the old and the new OCP

This period of time was dedicated to ensure the correction of bugs introduced by different functional modification and by the OS upgrade.

During 2 months, the computation of the week was conducted on the 2 OCP systems to verify the correctness of the new solver.

The result of each computation for one week was evaluated by comparison between the 2 plannings, and dedicated KPI:

- number of satellite slots per satellite mission
- number of satellite slots per station per satellite mission
- gap between slots at the week change date

The old solver was often unable to find a solution for 2 or 3 days per week, unlike the new one, which found a complete or partial solution for each day. For days without a complete solution, it provides details of the constraints that were partially met.

The final version of the solver was achieved after 43 versions due to the gradual integration of features.
Since users' needs permanently evolve and missions are still more complex, we sometimes find some anomalies on constraints barely used. We currently have reached the version 50

8. Présentation of the OCP booking system task

Support booking services enable the planning of resource usage and the provision of station network services. The interfaces and booking activities differ according to the phase and type of support. The role of the OCP is to manage a set of heterogeneous missions and stations to build an optimized planning that will be ingested by the different network systems in order to let users operate their satellites.

8.1. Routine phase

8.1.1. Initial booking

The support services are booked automatically by the Central Planning Tool on the basis of:

- A list of the **visibilities** of all the satellites supported by all the stations in the network. These lists are provided daily by the OCC (COO) on the basis of the determined orbit parameters.
- The **constraints** (needs) expressed by each **mission** team. These constraints are defined jointly by the user and the network teams and are managed by the OCP operations manager.
- **Station constraints** (needs) such as downtime slots for maintenance or due to serious breakdowns.
- **Slots** that may have **already been planned** or **prohibited** by the CCC via the PASS-REQ interface.

The OCP constraint types allow the S-band and/or X-band support service requirements to be expressed as:

- a number of visibilities lasting longer than a threshold value over a given time period and for a given list of stations
- Min/max time delay between two consecutive visibilities
- The cumulative visibility time over a given site over a given time period and a given list of stations:
    - The list and order of priority of usable stations
    - The duration of overlap between two stations
    - Simultaneous support of several stations for a given time period
    - The need for continuous visibility over a given time period

The S-band and X-band constraint sets are expressed separately. If both S-band and X-band requirements are expressed for the same mission, when calculating the planning the OCP tries to book visibilities on dual-band stations as a priority in order to optimize station use.

8.1.2. Changes to bookings

Users can modify the initial programming by making adjustments (cancellation, addition of a slot, replacement of a slot by another) via the remote OCP HMI, the PASS-REQ interface or by calling the BCP (during working hours) or the COR (outside working hours). Possible conflicts between a particular request and slots that have already been booked for another mission are managed by the BCP or the COR operator who will rely on the on-call network engineer if necessary.

Any change in planning will result in a new release of OCP outputs (different types of files POG, STA-PLAN, etc.). Updated plannings are provided to each mission as a file in the mission dedicated format. Updated plannings are also provided to network operators when the station is used as a partnership or as an external service. Updated plannings or availability plannings are also provided by station network operators to be ingested by the OCP

8.2. Specific phases of orbit acquisition, drifting and withdrawal from service

In these phases, which usually last a short time, operations are sometimes planned in real time or at very short notice, which is incompatible with planning four weeks ahead. Furthermore, the support slot requirements are not easily translated into constraints that can be used by the OCP software.

The support services are therefore booked manually on the basis of the schedule calculated for routine operations either by the user via the remote OCP HMI or the PASS-REQ interface, or by the BCP on the basis of the needs expressed directly by the user or via the network engineer.

However, for the deployment of electrically powered GEO satellites, the positioning phase lasts several months.
So, an automated process has been implemented using specific OCP constraints dedicated to this type of activity.

9. OCP Capabilities

The System is able to **ingest** different type of files:

- Satellite **visibilities** produced by OCC
- **Plannings** from network operators
- Requests from CCC for booking or prohibit slots
- Answer to external station booking request

Also the system **produces**:

- Planning in many different formats to different CCCs
- Booking request to network operators
- Booking answer to network operator

Files are either collected from the NOC exchange server or from remote servers using standard protocols (ftp or sftp).
They are also either provided to the NOC exchange server or to remote servers in the same way or sent by e-mail.

The OCP allows you to launch a planning **calculation** over a given horizon. It also allows you to **verify** compliance with constraints by identifying unmet constraints and unexpected reservations.

All these actions are controlled using the HMI

All ingestions and productions can either be operated **manually** through the HMI or running **automated** tasks.
However, if a conflict occurs, like 2 satellites overlapping on a station, the resolution may be left to human being.

The system integrates also a reporting tool to characterize the success of the passes included in the schedule. The reporting data allows the calculation of MUM network statistics in terms of success, anomaly, quantity sorted by satellite or station.

These calculations are carried out by an external tool called OCBS which allows the production of standardized monthly reports including detailed tables of figures and explanatory diagrams.

The OCP HMI has a schedule viewing tool in the form of a Gantt chart, adapted to suit CNES needs:

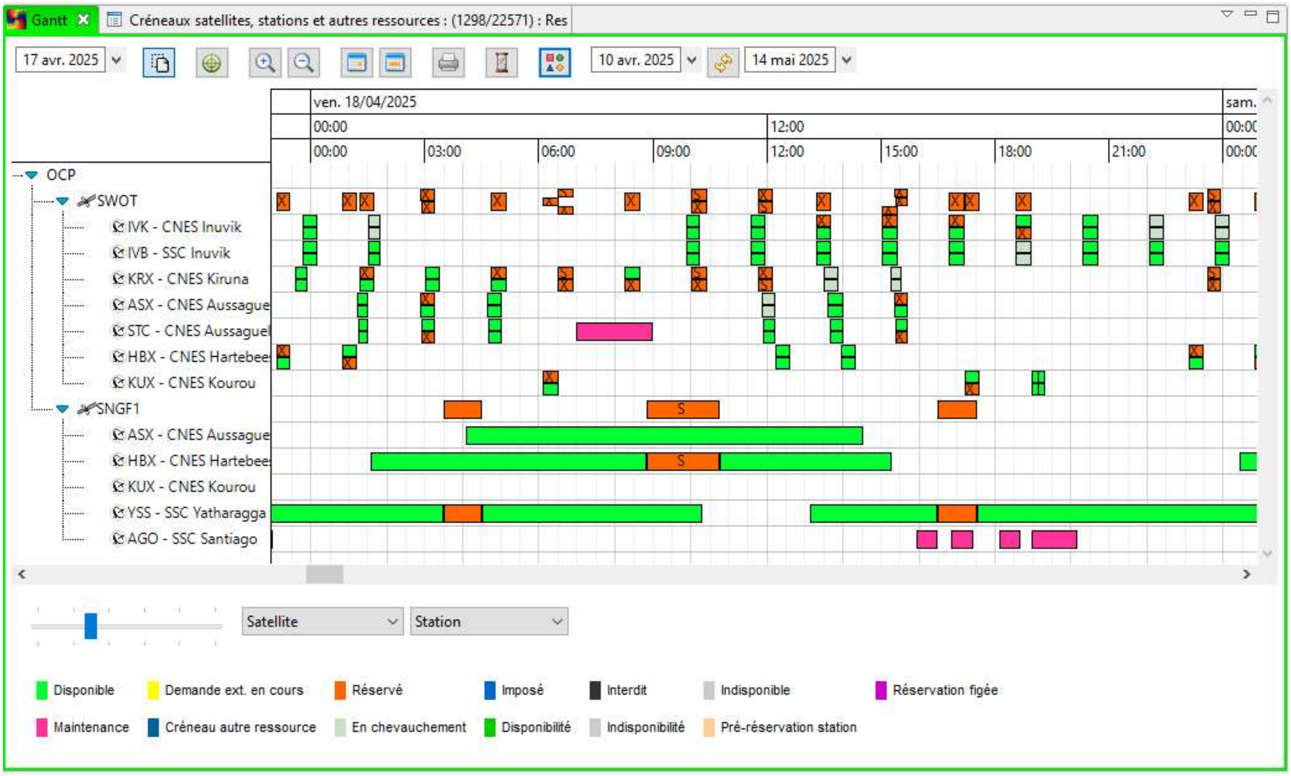

Figure 1. OCP Timeline sorted by satellite

- **Orange** color is for *booked* satellite slots, **green** is for satellite passes *available* for booking, **grey** is for *unavailable* passes and **pink** slots are station *maintenance* slots.
- **SWOT** is a LEO scientific mission satellite operating in S and X bands.
- **SNGF1** is a GEO GOVSATCOM satellite with electrical propulsion currently on a GTO orbit with 3 slots for Tracking, Telemetry and Command (TT&C) support and in S-band.

In summary, the OCP planning system allows you to achieve these three main tasks

1. Weekly computation of the fourth week's schedule.
2. Permanent management of the schedule for the MUM network and CNES partner stations.
3. Review of supports provided.

In terms of schedule computation, there are three use cases:

1. Computing the "real-life" schedule of week W+3 (Monday at 00:00 to following Monday at 00:00) either automatically (planned task) or manually (via the OCP HMI).
2. Computing a "partial" schedule in manual mode if the automatic mode fails.
3. Allowing the following simulations over a maximum of six months:
    - Computation of the schedule to define the mission constraints
    - Computation of the schedule to verify the sizing of the MUM network, as regards future missions

10.Future of the OCP

The current system was designed to be operated manually. The operational quality provided by the new solver have drastically reduced operator work. The version in production for a year is capable of automatically validating change requests while synchronizing with our station network operators. However, this does not meet all needs, especially when a change must be completed within few hours.

The current system needs to evolve. The need for secure remote access requires a complete overhaul of the system and a move to a 100% web-based interface, abandoning the Java rich client platform. Furthermore, the increased load of supports operated by NOC (+300%) requires a review of the ingestion and distribution processes, which are currently far too slow.

Finally, the new missions currently being prepared require a rethink of the current system, for instance:

- In particular, by proposing less rigid constraints, modifiable weekly.
- Offering time slots for a cluster of satellites, leaving the CCC the ability to directly operate the satellite(s) of their choice in the time slot made available.

Acknowledgements

The author thanks members of NOC team for providing relevant information that could be integrated in this paper.