CNES Ground Network renewal:
Challenges to increase capacity and to reduce costs

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The 26 years old TT&C Ground Network of CNES needs some refurbishments and extensions. A project called « Cormoran » was recently decided to replace the eldest TT&C stations, to expand services to data reception (in X-band) and to increase interoperability and automation.
Beyond the usual technical and performance challenges which are derived from the satellite mission requirements, high level objectives of enhanced capacity and reduced costs were assigned to this project by the CNES Management.
In fact, the workload of the GN is expected to be multiplied by 3 to 4, in the next 5 years. This increase is considered beyond what can be covered at a reasonable cost with the support of an external GN (e.g.: commercial GN). Therefore, it is a real challenge for the project to propose innovative and efficient solutions to cope with the extra load and to maintain the running costs under their current level.
This paper will first introduce the context of the CNES GN and the rationale for its evolutions. It will then describe the components of the "CORMORAN" project and will detail how each of them will contribute to the high level objectives: the features of the new systems will be presented, among which the automation of the network operations center, the modernized stations and their automated maintenance and the original data distribution system intended to reduce the bandwidth requirements on communication lines. Finally, the paper will conclude with a summary of the awaited outcomes of the ongoing developments, in quantified terms of increased GN capacity and stable running costs.

1 – Introduction

The French Space Agency, CNES, has been operating an S-band Ground Stations Network (GSN) for more than 26 years. This is a multi-mission asset that provides Tracking, Telemetry and Command (TT&C) services to all CNES satellite missions (currently 17 in flight satellites) in Launch and Early Orbit Phase (LEOP), in mission phase and in the End Of Life operations (EOL).
On occasions, the spare capacity of the network may be used to provide same services to satellites of other space agencies in the frame of cross supports or to launchers, on a non interference basis. Also, supports to satellite of other organizations are possible, always for short duration operations and under special conditions: the main rule here is that CNES will not compete with commercial providers of same services in open calls for tender; the exceptions to the rules are when the risks for a first mission must preferably be assumed by an Agency, when the support is requested to CNES under an inter-government umbrella or when the CNES assets are the only ones capable of providing the required services (e.g.: technical features or geographical location of the antennas).

In this context, the main challenges for CNES are to guarantee the availability of the required services to all users and to provide high quality services at a reasonable cost. This must be true whether the users are CNES missions or external missions. It must also remain true along the evolutions of the facilities, both in the case of their refurbishment to fix obsolescence issues and in the case when upgrades are required to establish compatibility with new satellite missions that rely on new standards or need enhanced performances.

This paper will explain how CNES has addressed these challenges in the frame of the CORMORAN project and what the expectations out of the associated developments are.
A quick overview of the CNES multi-mission GSN architecture and components will first be provided. Then the evolution cycle of the GSN will be described with a definition of the criteria used by CNES to select between refurbishment, replacement or termination of the assets, balancing each decision with the possibility to purchase services from commercial providers of station services. Then the application to the case of the present situation and the on-going developments will be described and commented.

2 – The CNES Ground Station Network

The facts that a significant share of the station sites is on French soil and that the network is operated under the sole responsibility and control of CNES is one main strategic requirements in the definition of the GSN, in order to guarantee the access to the national satellites in any circumstances. Therefore, the CNES Network is organized around central facilities located in Toulouse, France, with ground stations distributed around the world, most on French territories and some in foreign countries.

The Network central facilities assume both the role of communication node, providing point of access to users or to external providers, and the role of Network Management Center. They are composed of:
- the Central Scheduling Office ("Bureau Central de Planification", BCP) in charge of the establishment of the station utilization plan and of the conflict resolution;
- the Network Operations Center (NOC) in charge of controlling the data transfers (telemetry, command, tracking, orbit, various files) and of supervising the real time operations (activation of configuration instances, execution of recovery procedures, activation of on call maintenance services);
- the Orbit Computation Center (OCC) in charge of the orbit calculation and of the generation of predicts (station acquisition data, pointing elements, visibilities, interferences, collision risk assessment).

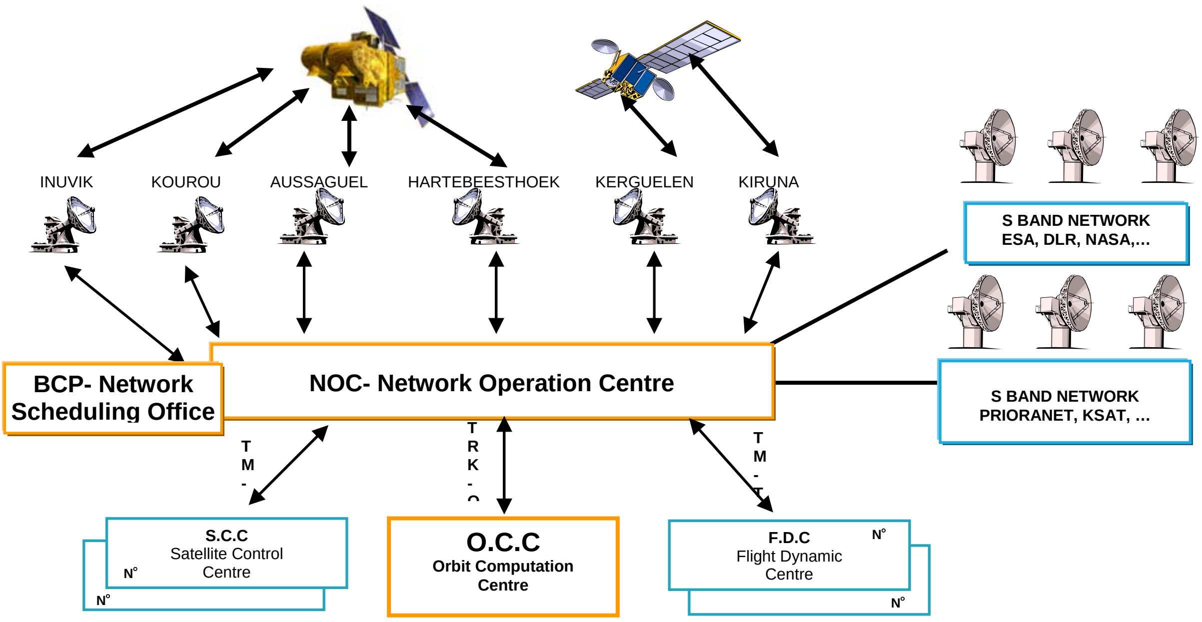

Figure 1: CNES Ground Station Network architecture.

The BCP is manned only in normal working hours as the scheduling activities are executed off line and the Network Controllers in the NOC have the possibility to modify the station utilization plan for short notice modifications. The establishment of the station utilization plan is made four weeks in advance by means of the OCP ("Outil Central de Planification") which is based on a constraint solver software [Ref. 1]: requirements from the projects in terms of contact duration and distribution are combined with station constraints (masks, maintenance timeframes, etc…) to establish the plan that satisfies all users. In the last two weeks preceding the support, only manual modifications of the program can be made to cope with late support requests or station unavailability.

The NOC is manned, 24/24 7/7, as the supervision and control of the operations require the presence of a Network Controller. The operations on the data transmission systems, ICARE and some Protocol Gateways [Ref. 2], are still manual, while under nominal conditions, they mainly consist in the management of the support instances and in the activation of the corresponding support configurations. Only the monitoring and control (M&C) of the ground stations is driven by an automated process based on the REGATES system, by which the station activities are executed in a timely manner, according to the station scheduling and the pass plans (Sequence of Events) provided by the users.

The OCC is manned only in normal working hours while all calculations and generation of predicts are made by the flight dynamics automated software. The presence of the OCC engineers is mainly to expertise the execution of the operations and to conduct non routine analysis or activities. For what regards the station operations, the visibility predicts are sent to the OCP and the station acquisition data to the station antenna control units, on a daily basis.

The CNES GSN provides a worldwide coverage for the satellites in polar, inclined or equatorial orbits. The ground station sites are located in:

- Aussaguel, near Toulouse, France: four S-band TT&C and two X-band receive antennas;
- Kourou, French Guyana, South America: one S-band TT&C antenna;
- Kerguelen, French Overseas Territory, South of the Indian Ocean: one S-band TT&C antenna;
- Hartebeeshoek, South Africa: two S-band TT&C antennas thru agreements with the site owner, SANSA (South African Space Agency);
- Kiruna, Sweden: one S-band TT&C and X-band receive antenna and several other ones thru agreements with the site owner, SSC (Swedish Space Corporation);
- Inuvik, North West Territories, Canada: one S-band TT&C and X-band receive antenna and another one as back up, thru agreement with the site co-owner, SSC.
- Station Simulator in the CNES Toulouse Space Center: facility with same equipment as in the stations, except the antennas, to perform RF compatibility tests and other maintenance, training and test activities.

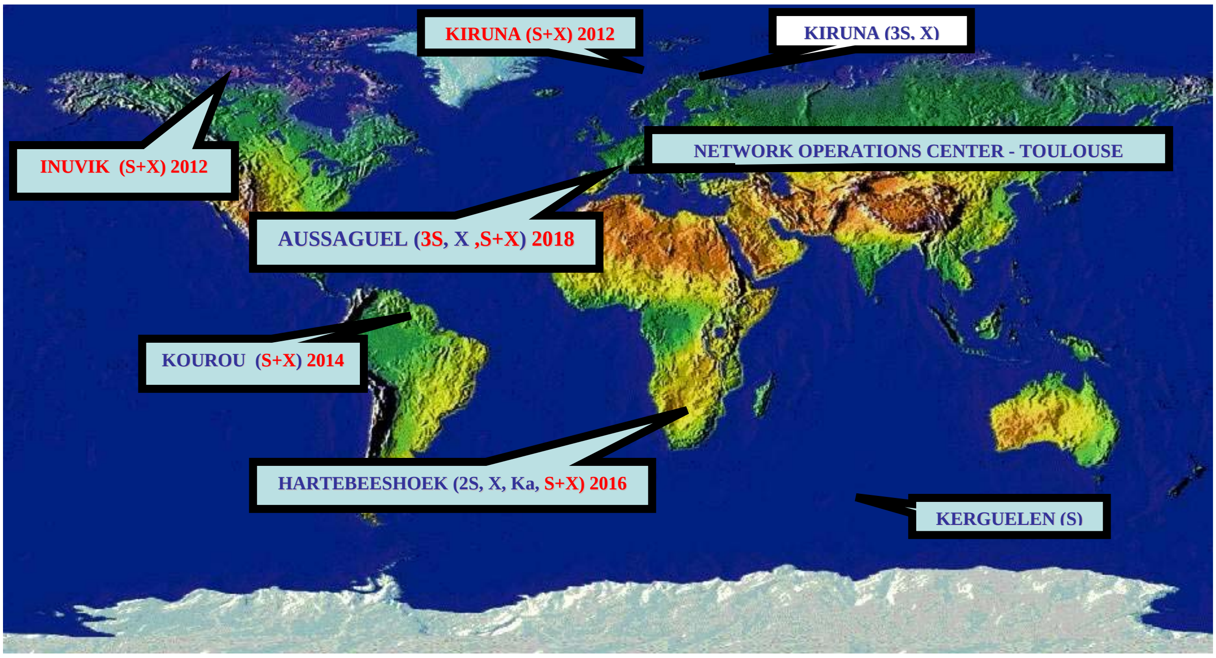

Figure 2: CNES station sites.

While the last two stations are very new and will start operations in 2012, the TT&C antennas in Aussaguel, Kourou and above all Hartebeeshoek are getting old and maintenance and procurement of spare parts become more and more difficult.

To facilitate the operations and the maintenance of the Ground Stations, it is the CNES policy to have the same equipment deployed in all stations. This is applied and effective in all stations for what concerns the processing and communication, or other back end equipment. However not all antennas are identical.

The routine operations are automated and driven by the REGATES M&C system [Ref. 3]. This system also authorizes remote control of the station operations from the NOC or locally from the station. These alternate modes on one station may be simultaneous of the automated mode on the rest of the network; they are mainly used for maintenance, tests or special operations phases for which the support instances cannot be automated and the coordination is still via voice. When conducted from the station, the operations are made by the station technicians as no station controller team was maintained on site after the automation of the station operations in 2005.
Up to now, the loading of the Network with routine operations was in the order of 80 to 85% of its capacity (average over years). The remaining capacity is to provide security to the satellites in case of emergency and

may remain unused some years; Also, it is used to perform LEOPs, EOLs or other types of exceptional operations, both for CNES satellites or for cross supports to partners.

A maintenance plan is executed in the stations to guarantee the availability of the ground stations. This involves preventive, corrective and evolution maintenance which in average represent between two and three hours of station unavailability per day. Taking into account the presence on site of the station technicians, the maintenance activity is performed during working days and normal working hours, which in some cases means a station unavailability for maintenance that conflicts with the satellite visibilities.

To cope with the risk of unavailability of the ground stations or to augment the Network capacity in case of peaks of activities, agreements are in place with other space Agencies and with commercial providers of station services to obtain external station supports, usually for some short duration phases: LEOPs, Emergency, antenna back up, EOL operations.

3 – The evolution cycle of the CNES GSN

The guidelines for the evolutions of the ground stations are provided by an Infrastructure Roadmap in the CNES system for preparation of the future. This level of roadmap gets mission profiles and high level requirements from the Thematic Roadmaps (Science, Earth Observation, Defense, etc…) and provides inputs to the Technical Roadmaps which will elaborate more detailed plans, in particular in the domains of the R&T and the standardization to be conducted. The current version of the Stations Roadmap is four years old and will be revisited in 2012 for updates and complements. It was established concurrently and consistently with other infrastructure roadmaps such as those for:

- The command and control ground segments
- The mission ground segments
- The TT&C ground to satellite interfaces
- The Payload data satellite to ground interface

This set of roadmaps is the basis for the definition of the components of the future Space Segments of CNES, concretized in the Myriade Evolution (micro-satellites up to 400 Kg) and ISIS (modular platforms above 400 kg) projects: it is expected that a majority of the CNES future missions will be based on either one of these Space System concepts and that they may share components, in particular for ground architectures and ground stations.
Examples of guidelines of interest for this paper are the utilization of the CCSDS standards and the SLE for the ground to ground exchanges, or the utilization of multiple channels in X-band associated with Bandwidth Efficient Modulations for the payload data dumps.

Independent of the roadmaps, the actual evolutions of the CNES GSN are triggered by either the obsolescence of some major components of the system or the need to upgrade the systems to answer requirements from decided satellite projects that cannot be covered with the existing features of the GSN assets.

On these aspects and in average every two to four years, a complete overview of the situation is made by the management of the ground network, to decide the framework and the objectives of the next evolutions, and to establish the programmatic conditions for such developments. The following criteria are addressed:

- Application of the guidelines from the Stations Roadmap ;
- Technical requirements from the future projects that cannot be satisfied with the existing assets ;
- Status of obsolescence of the systems in the network ;
- Status of the network capacity with respect to the evolution of the workload, in total throughout the network but also for each of the sites ;
- Potential options to reduce the running costs of the network and to provide services to the users at a “competitive” cost.

In each development, lessons learned from previous implementations and the subsequent operations are also taken into account. This aspect will not be developed here as was presented in a previous SpaceOps conference [Ref. 4].

Application of the roadmap:
In this context, the station roadmap promotes the current multi-mission architecture, the deployment of S+X band antennas and the utilization of COTS and standards that are compatible with the future CNES systems. Thru the utilization of standards, compatibility with other space Agencies is also targeted.
The last project carrying evolutions of the GSN, HOMERE, conducted in 2007 – 2010, was driven by the Stations Roadmap and federated several ground stations into the multi-mission network, also centralizing their

scheduling (the OCP system) and their communications management. This project was also the occasion of the initial deployment of the SLE in the CNES Network.

Technical requirements:
As part of the new features required by the projects, the following cases may justify a major evolution:
- need for an extended geographical coverage;
- need for different frequency bands;
- need for new services or technical features.

These were the main technical drivers for the recent deployment of the two new antennas in Kiruna and Inuvik where extended coverage of polar regions was required and an X-band telemetry reception service was needed. The polar station project was conducted with the SSC, in a partnership covering both the development and the utilization phases of the stations and by which costs and capacity are shared in a coordinated way [Ref. 5].

Obsolescence of the systems:
Today, considering that the CNES network is about 26 years old, it is obvious that most of the original systems were already replaced once or twice, and are still relatively recent. Based on experience, it is considered that the lifetime of the electronic and software components will not exceed eight to twelve years, after what, modifications and evolutions become difficult, due to obsolete technologies.
The main question mark remains with the antennas which, according to studies on their ageing and considering the trend of their daily duty cycle (20 to 35 supports per day, depending the antenna), are not expected to exceed 30 to 35 years lifetime, assuming the execution of a strict sustaining maintenance plan.

Evolution of the Network Capacity:
Ideally, the Network Capacity should remain as close as possible to the cumulated total requirements of the supported missions. This being said, it is obvious that some margins must exist so that special operations, quick reconfigurations or emergency situations may be efficiently addressed. For instance, in the Network availability scheme, it is said that in case of failure of a station to support one pass, the same or another station will be made available to provide a replacement pass, within the next revolution for a LEO satellite. To satisfy this type of requirement, the CNES Network relies on its own internal margins and on the spare capacity of the external networks in support.

Along the years, it has become clear that a spare capacity is desirable in each site but most of the time it is not homogeneously distributed throughout the Network. To make sure of the situation in the future, simulations are required to evaluate the global margins and the margins per station, accordingly with the evolution of the Network mission model and the distribution of the workload. CNES makes use of the same scheduling software as the one based on the OCP to evaluate the loading feasibility and distribution.
For CNES, such simulations are conducted as often as necessary to analyze the changes in the mission models. Such changes may relate to schedule changes of new missions, to changing requirements or to some events with the in-flight satellites (lifetime extension, failure, planned end of life, etc…). The conclusions of these loading simulations may be quite different depending the analyzed periods; for instance the following findings may occur:

- the capacity of the stations and of the network is sufficient with reasonable margins ;
- capacity is missing in the network, on a short or long term basis, globally or on a site ;
- capacity is in excess in the network, on a short or long term basis, globally or on a site.

Of course, the potential consequences and decisions may be very different, according to the case.

Before any significant investment is made on the Network, it is the rule in CNES to analyze the fluctuations of the workload will not justify opposite decisions for the very assets on which investments are to be made. In such case, the loading for the global Network and for each station is the criteria, as it will justify the sustainability of the asset. This analysis also allows making sure that the Return on Investment will be satisfied long in advance to any period of uncertainties.

Running costs and service usage costs:
The running cost of a GSN may be assimilated to a flat rate whatever the actual loading of the stations is, as long as the architecture is stable and the operating modes remain unchanged.
When purchasing station services, the price for such services is proportional to the quantities. The drawback is that the cost of the station services just increases if your satellite missions require more passes. The advantage is that if your requirements diminish, the costs will decrease and remain adapted to your needs.

In this context, the comparison between the two options, to own its own asset or to purchase services, if made at the level of a single project, generally concludes on the interest of the purchase of services as the procurement of totally new assets is too expensive.
Same comparison may reach the opposite conclusion if your situation is of an existing Network and very high workload. This is the case of the CNES Network, in spite of the number of ground stations, as the current workload with seventeen satellites and some more to come justifies the choice of a CNES owned network.

Nevertheless, the situation may change with time and events and, of course, it must be analyzed with each new project, with respect to the available capacity of the Network:

- a new satellite mission whose requirements may be accommodated within the available capacity of the Network may very well be at no extra cost for CNES; this has been the situation in the last ten years, the new satellites replacing in an almost consistent schedule those which were de-orbited ;
- to the contrary, an increase of the mission requirements beyond the existing capacity may result in the need for additional stations, either to be procured if the total requirements are stable in the long term, or in the need to purchase external services, if the need is temporary only; in either case, the running cost of the Network increases accordingly to its capacity. This is the case CNES has anticipated when making the decision of the new polar stations in 2008;
- finally, a drop in the requirements from the projects may lead to a situation where the capacity is unused and the running costs are no longer justified; in this case, the capacity must be reduced and some stations be placed in dormant mode (survival maintenance only and reduced or no operations) or finally be phased out. This is the situation CNES has faced with its Ku-band stations, in Aussaguel and Kourou, which have been phased out recently, after several years with minimal maintenance.

The close relationship between the network capacity and the cost for the rendered services was translated into the definition of the “Network hourly rate” by which the CNES projects are charged for their share of the utilization of the multi mission Network. This hourly rate is computed every year as follows:

$$HR = E / C$$

Where “E” represents all expenses made to run the Network: external costs for maintenance and operations, manpower and share of the technical means used for the network activities (computers and networks, communication lines, quality supports, etc…). It must be pointed out here that the cost of all communication lines between the NOC and the stations is accounted in the calculation of “E”.

and

“C” represents the Network Capacity.

The Network capacity that may actually be used by the satellite missions: it takes into account structural unavailability and limitations. It results from the addition of the individual multi mission station capacities pondered with a Network limitation factor, as follows:

$$C = (C1 + C2 + \ldots +C6) * t$$

Where “t” is the limitation factor of the NOC which can only support four simultaneous passes with one Network Controller shift (as is the case today), whereas the multi mission Network is fitted with six main antennas,

and

Each station has an average daily capacity of:

$$Ci = \mu * p * 24 \text{ hours}$$

With “µ” = remaining availability of the stations out of tests and maintenance activities (currently 90 %)
and “p” = remaining availability of the stations considering the lost time in between passes that cannot be used due to too short duration or to low probability of a satellite pass at that time (currently 80 %).

This calculation is typical of the CNES mission profile with mainly LEO satellites. However, for the sake of simplicity, the same rate is used when, on occasions, the Network is used for MEO or GEO satellites.

The predicted Network hourly rate is a perfect indicator that can be used to measure the efficiency of the investments made by CNES with its GSN evolutions and to anticipate the effect of such evolutions on the total costs of the CNES projects.

4 – Rationale for the CORMORAN project and assigned objectives

CORMORAN is a French acronym that stands for "COnsolidation et Renouvellement des MOyens Réseau et des ANtennes": Consolidation and renewal of the network and the antennas. This project was the result of a new iteration on the evolution cycle of the Network conducted in 2009 - 2010; the rationale for the evolutions was this time a combination of several factors as follows:

a) Satellite projects technical requirements:

Considering the projects in the CNES mission model for the upcoming 10 – 15 years and also the trends coming out of the CNES roadmaps and the phase 0 studies, it was confirmed that the major evolution required for the CNES GSN is the availability of X-band data reception in low or mid latitude sites. As the recommendations of the CNES Stations Roadmap in this domain had been recently applied in the specifications of the polar stations, the CORMORAN project was tasked to align to these recommendations and specifications; this includes among other characteristics:

- Large dishes enabling for very high data rates ;
- Possibility for overhead passes with minimum altitude of satellites around 400 km ;
- Enhanced phase noise features to enable for the use of present and future bandwidth efficient modulations;
- Polarization diversity in tracking and telemetry ;
- Homogenous architecture and same choice of processing equipment for the receive chain in all stations.

On the TT&C side, no major change in the requirements from the projects was detected.

Two studies were conducted to consolidate the overview of the users' requirements and assess the need to:

- Maintain the capability to provide S-band TT&C supports to Geostationary satellites ;
- Track and receive S-band telemetry from the European Launchers (Ariane, Soyouz and Vega).

Both studies had a positive conclusion:

- there is an obligation to continue the back up services to existing satellites but also, the geostationary orbit is still part of the options studied in CNES phase 0 projects; moreover, the link budgets are similar to those required to support MEO satellites (currently Galileo LEOPs) or under conditions HEO satellites.
- the multi mission antenna in Kourou will be used to support all launches from French Guyana and the one in Aussaguel should continue to support the Soyouz launches for the Galileo series; however, due to the many different standards used by the launchers, it was decided to limit the specifications to the minimum set of features to support such missions (2 Ghz couplers to connect a hosted telemetry processing unit, tracking in frequency diversity, real time pointing of the antenna).

b) Evolution of the workload:

It was identified that the project requirements would progressively and in less than seven years bring the loading of the Network to a level, three to four times higher than the level of 2009.

An extension of the Network capacity had to be considered. However, it was not clear initially if some stations would be impacted more than others; therefore loading simulations were conducted and concluded that not only polar sites were concerned but also equatorial and mid latitude stations. Nevertheless, no need for additional sites was demonstrated, just the need for additional X-band assets on the existing sites was established.

As the impact was global over the existing Network and it is not reasonable to imagine a solution with multiple CNES antennas on each site, it became clear that, at least in some periods, the utilization of back up antennas on the same sites or the purchase of external supports could be required, more than today, to find viable solutions. It was verified that the existing agreements for procurement of such services could cover the needs but it was decided that alternate offers should be evaluated, with the objective of a wider range of solutions and prices.

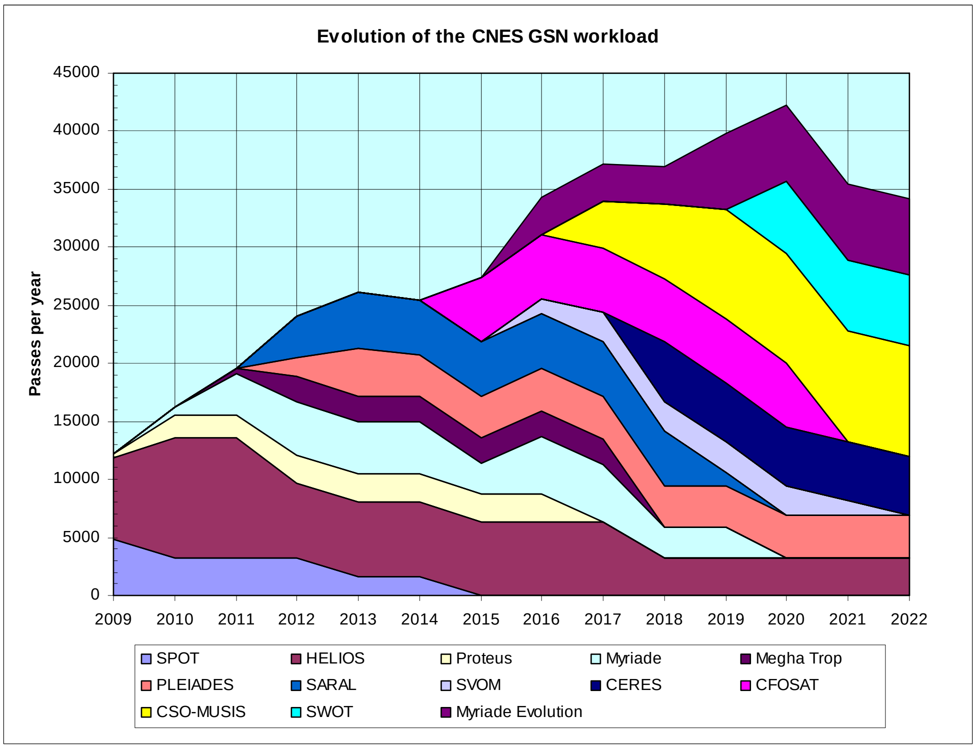

Figure 3: Evolution of the CNES Ground Station Network workload.

In order to minimize the utilization of such solutions, as their cost may be significant, the need to augment the intrinsic capacity of the assets was recognized and was given as a special objective to the CORMORAN project.

c) Major obsolescence issues:

As the requirements from the projects clearly extend the need for the S-band ground stations beyond 2020 and the existing stations will be more than 35 years old at that time, it became clear that with the new satellite project requirements there was an opportunity to decide of the replacement of the old antennas for which obsolescence issues had been identified. This concerns the multi mission antennas in Aussaguel, Kourou and Hartebeeshoek, as previously indicated, but also one of the two existing X-band stations, the one in Toulouse used for Parasol satellite which doesn't meet the requirements for future projects (small dish) and in addition would need significant investments to guarantee its sustainability. The objective of replacement of these old antennas was assigned to the Cormoran project, including the constraint of continuity of service to the in-flight satellites.
Being less than 20 years old, Kerguelen antenna and other back up antennas on various sites are out of the scope of the Cormoran project and will be considered in future iteration of the evolution cycle, as it was already identified that the project requirements on those antennas also extend beyond 2020.

At the same time, the provider company of the telemetry command and ranging (TCR) processors in the CNES multi mission stations, Zodiac Data System, had made announcement of the termination of the manufacturing of their product line, based on the Enertec 3801, and of the information that software evolutions and maintenance would also be terminated, respectively in 2012 and after 2013 (depending the evolution of their stock of spare parts). This was more recently confirmed. While the equipment in place covers most of the requirements for present and future satellites, enhanced specifications were engaged in the frame of the replacement of these units in the CNES stations by the Cormoran project (e.g.: GMSK for downlink telemetry; QPSK uplink with Doppler compensation; Code Ranging as per ECSS E50-02).

d) Cost reductions:

After the integration of the new polar stations in the Network, a significant increase of the running costs was expected, mainly related to expenditures to operate the new stations rather than related to the CNES manpower to drive the operations and maintenance.

In the case of the Cormoran project, the objective assigned to the team was clearly to maintain the global running cost at a close level to the one resulting from the previous evolutions. A limited increase was expected as a result of the combined effects of:

- on the increase side, the augmented bandwidth on communication lines and the deployment of additional systems in the Network, in particular for the multi mission X-band services;
- on the decrease side, the modernization and the automation of the assets and their operations.

As a combination of the increases in its capacity and its running costs, it was expected that the "Network hourly rate" would remain stable.

5 – The components of the CORMORAN project

Based on the required evolutions of the Network and on the objectives assigned to the project, the following components were identified for CORMORAN, to be developed in a loosely dependent schedule.

1. Replacement of the multi mission TT&C antennas in Kourou, Hartebeeshoek and Aussaguel, in this order, with new TT&C and data reception antennas on the same sites. The satellite project requirements imply the availability of a mid latitude capacity for data reception from 2014, and the availability of a complete upgraded set of stations in 2017. The order of development of the new antennas was chosen to also take into account the obsolescence issues and the availability of back-up antennas in Hartebeeshoek and Aussaguel.

2. Replacement of the telemetry command and ranging (TCR) processors in all of the CNES multi mission stations. The main driver being the obsolescence of the equipment, the detailed schedule of such replacement is not strictly related to project needs. It was chosen to start the deployment with the polar stations and to then align to the deployment of the new antennas. Some flexibility was left in the deployment schedule for Kerguelen, the back up antennas on various sites and the test facilities: the project is free to adapt this schedule according to its own needs, for instance to validate the new system in the station simulator facility, or to take any opportunity for deployment, according to the schedule changes with other components of the project and the manpower resources then becoming available.

3. Development of a multi mission ingestion and file distribution system, "Idefix", devoted to the X-band data, to be deployed in the stations and in the NOC.

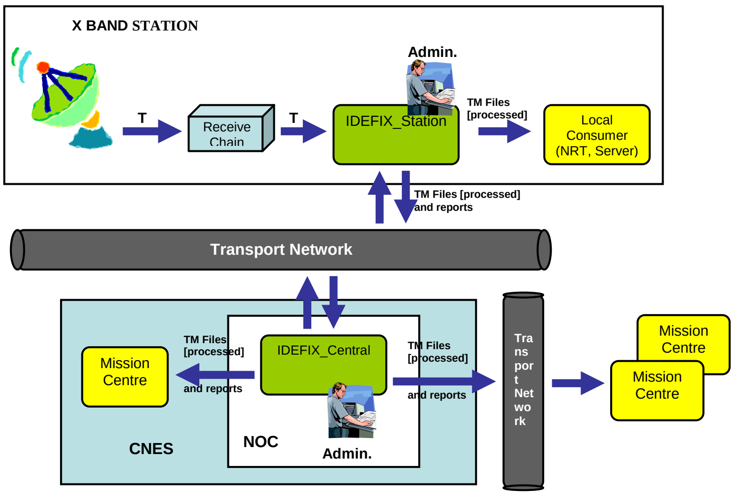

Figure 4: Architecture of the Idefix system.

This new system should first be installed in the polar stations, to replace the current mono-mission solution, and then in the new antennas in a consistent deployment schedule. Among the features of interest of the Idefix system are:

a. Processing of single or multiple channels from the satellite to ground interface, and parallel processing as required ;
b. Processing of frames or packets and the creation of files with data sorted per VC or APID ;
c. Local optimization and elimination, before transmission from the station to the users, of the useless data: trash, filler data, duplicated segments, not supported channels, etc… (per configuration options) ;

d. Global optimization and elimination, before transmission from the station to the users, of the data already received by other stations (per configuration options) ;
e. Reporting and statistics to the users ;
f. Temporary storage in the station or in the NOC ;
g. File transfer to a server that may be located in the station (e.g.: for Near Real Time Application), in the NOC or at the User premises ;
h. Management of security and of priorities in data transfers.

4. Extension of the current automation in the NOC to the management of all the communications and data distribution systems. This development is based on the Regates M&C system that already drives the automated operations of the multi mission stations. All instances of the Network services may be executed in parallel under the single control of the Network Operations Automated Control System, "CADOR". The system will control all systems and activities in the stations and the NOC.

5. Full deployment of the SLE over the Network and of the CCSDS interfaces for exchanges of orbit, pointing and tracking data between the OCC and the users of the Network. This evolution had been initiated with the implementation of the CCSDS provider capacity in the frame of the Homere project and will continue under the Cormoran project with the retrofit of the eldest CNES control centers. Depending the expected lifetime of the supported missions, the solutions in this domain range from refurbishment of the data acquisition software in the control centers to implementation of protocol gateways in between the control centers and the network facilities (NOC or OCC).

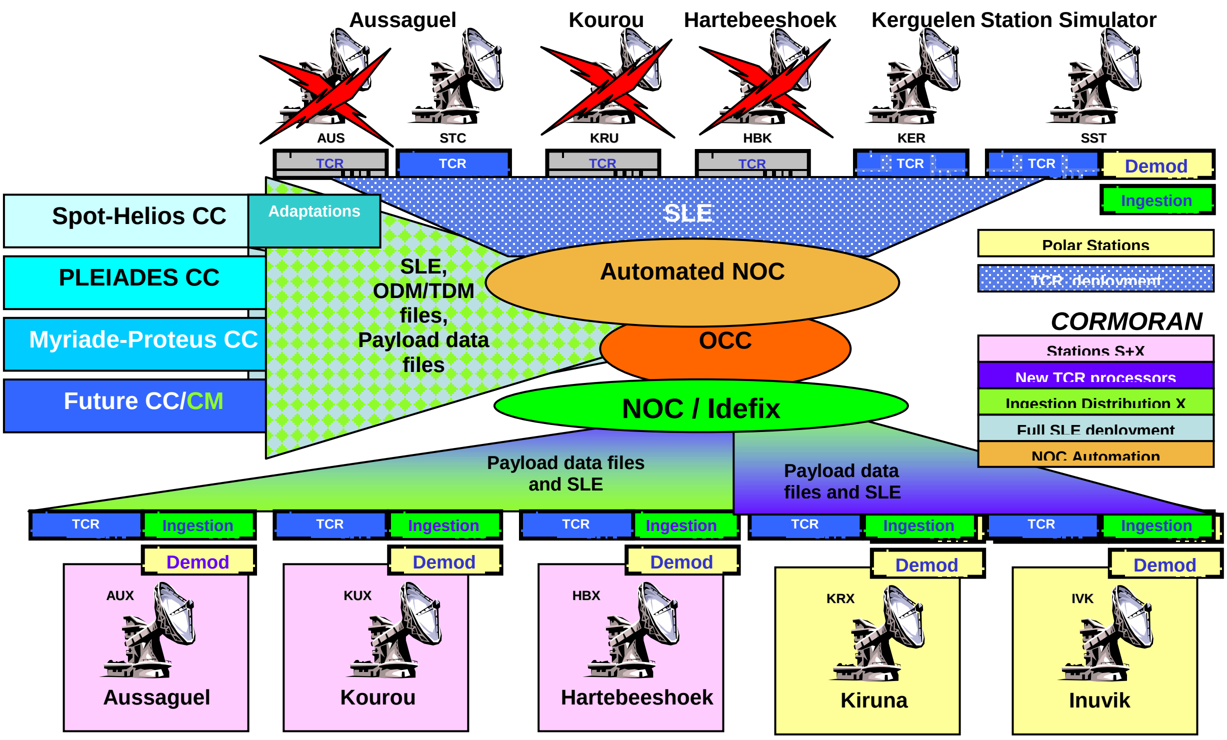

Figure 5: Components of the Cormoran project.

6 – Contribution of each component to the objectives

This section provides an overview, for each of its components, on the choices and evaluations made by the Cormoran project to comply with both objectives to master the running costs and to increase the intrinsic capacity of the Network. Only those choices having a significant impact are mentioned here, while, going down into details, many more could have been mentioned.

New antennas:
<u>Cost reductions:</u>
The main axes for cost reduction in the development of the antennas are:

- The re-use of existing sites: infrastructure and site services already in place;

- The planning for development of the three antennas, spread over six years: no peak requirement on project team manpower,
- The decision to have fully identical antennas on the three sites: recurring costs for the second and third antennas; simple duplication of M&C software from site to site ;
- The integration of the antenna in the existing Network architecture, implying the re-use of the existing interfaces for the communications and M&C interfaces: no development; system security already covered; reduced validation; reduced operator training; etc…
- The utilization of COTS for the majority of the sub-systems: recurring costs already with initial developments.

Also, some of the above choices are expected to have positive effects with the running costs of the stations:

- Identical antennas and systems will reduce the maintenance and operation costs ;
- The utilization of COTS will also reduce the maintenance costs, among other typical advantages expected from the utilization of COTS.

Finally, some proposals made and features specified by the Cormoran project should have additional effect on the running costs:

- The replacement of both one antenna in Aussaguel and one antenna in Toulouse with only one new antenna in Aussaguel: reduced maintenance costs ;
- The proposal to phase out the old antenna on each site very soon after the qualification of the new antenna (about six month overlap for first site, less for the next ones): no duplication of maintenance over a long period.

<u>Capacity increase:</u>
Some specifications by the Cormoran project should have a positive effect on the capacity of the new antennas:

- As the stations are designed to support simultaneously S-band TT&C and X-band data reception operations, this feature will allow to address in one pass requirements that were previously supported in distinct passes with different antenna assets. This provides an increase of capacity, as it allows to address two requirements in the same instance of station service, which in the case of CNES is a real advantage, most of the satellites to be supported requiring both services from the Network.
- The two points hereafter are expected to increase the station availability out of maintenance activities (“µ” in the calculation of capacity, as per above section 3) and the station intrinsic capacity.
    - The selection of modern antennas: obviously, those will require less time for normal maintenance and shorter downtimes for repair, including in case of mechanical parts failures, compared to the existing antennas for which those aspects were not optimized ;
    - The specification of many measurement points in the station architecture, in order to connect test and measures equipment and to enable automated maintenance activities: automation of the maintenance is critical with respect to the definition of the station capacity as it enables the performance of the preventive maintenance out of normal working hours and provides enough flexibility to avoid conflicts with operational supports to satellites.
- The time to change configurations and to prepare for the next support is critical in a multi mission ground station; the following aspects will improve the Network performance in this respect and should increase the station availability in between passes (“p” in the calculation of capacity, as per above section 3) and the station intrinsic capacity.
    - Fast M&C interfaces of the new equipment: those are expected to provide faster response times due to the technologies used to support them (e.g.: Ethernet versus IEEE).
    - The equipment is supposed to have more efficient interface in terms of integration and relevance of the information in the M&C parameters: this should improve response times and security of the operations; one special feature is the capacity of the equipment to memorize a complete support configuration that may be called back for each satellite with one command, instead of setting up individually hundreds of parameters to establish the next support configuration.

TCR processors:
Being station equipment, the TCR processors will bring the same advantages as the other ones mentioned here above, in particular for what concerns:

- <u>Costs</u>: benefits of the implementation of COTS ;
- <u>Capacity</u>: increase of station availability in between passes (see also comments on the deployment of SLE hereafter).

Idefix:

Cost reductions:

As the X-band data reception and distribution is a new service added to the legacy TT&C services of the Network, the implementation of an additional system means some costs that were not supported in the previous definition of the CNES GSN.

However, two characteristics must be mentioned that clearly aim at reducing cost for this new service:

- Idefix was designed as a multi mission system: the objective was to offer a service that may provide support to all satellites without multiplicity of hardware in the station; In many cases, the ingestion and storage equipment in the station was designed as a mono mission equipment, resulting in many racks of equipment and their associated maintenance costs or ad-hoc operations requirements ;
- Other features of Idefix that are expected to reduce the Network running costs are the local and global optimization software that will eliminate any data that doesn't need to be transferred. This is intended to reduce the requirements on communication lines bandwidth, on individual mission passes or cumulated over parallel / consecutive mission passes and data transfers, and therefore the associated line costs. Along with the start of operations on new satellites, CNES has a plan to progressively increase the bandwidth from the current 1 to 2 Mbps, to some 30 to 45 Mbps (polar stations) in the next 5 years; the rate of this increase will be reduced and mastered using the optimization features of Idefix.

It is difficult to quantify the savings on the communication lines as this will depend on the final strategy and schedule for upgrades of the line bandwidths, but it is estimated that it is worth the investment, in the order of 1 M€ for Idefix, according to the high cost and the number of communication lines in the Network.

Capacity increase:

More than the objective of the increase of capacity, the concern of the Cormoran project with the Idefix component was not to reduce the capacity by combining the constraints of the real time passes and of the data transfers after the passes. The requirements on processing times are very high on the system as satellite passes may be separated by as low as 5 minutes. Therefore in addition, the Idefix system has been conceived in a multi mission approach and with a capacity for parallel processes of real time acquisition, near real time ingestion and post pass data transfer. That way, each satellite pass will be supported independent of the previous and next ones. Of course, the communication line capacity has to provide a sufficient bandwidth to deliver the data with the latency required by the projects.

Based on these specifications of the Idefix system, it is anticipated that the scheduling of the data reception passes will just consider limited pre pass activities (e.g.: antenna pointing elements loading, equipment configuration set up, antenna pointing), pass time frame from acquisition to loss of signal, and very short post pass activities (e.g.: antenna into standby safe position). No extra time will be added for post pass data transfers.

NOC automation:

Cost reductions:

Speaking the automation of the NOC systems, one has to remember that today, the Network operations are conducted by the NOC controllers in a shift of 24/24 and 7/7. The controller on shift is required to support up to four station passes in parallel, controlling the systems in the NOC, monitoring the station automated operations and fixing any problem. The team is composed of eight (8) controllers, in compliance with the French laws for workers on shift positions. The increase of the Network loading would justify to have a second controller on shift as from 2014 as the number of simultaneous passes will very often reach five or six. Therefore, the automation of the NOC, as it permits to continue the Network operations with one shift, might correspond to savings in the order of 500 to 600 k€ per year. The expense of about 1 M€ on CADOR is justified as the return on investment may be very short.

Of course, automation is expected to also bring reliability and security with the operations. This is the case with CADOR as the M&C software will address and fix a number of degraded or failure cases (switchover to back up equipment, configuration changes, reaction on events, etc…). At this stage, it is not planned to rely on the system only. Decision was to just convert the positions of controllers into positions of supervisors of operations in charge of managing major failures or short notice requirements. At a later stage, unmanned operations could be considered but this will certainly have prerequisites such as the validation of a CADOR application software fully robust to failures and the improvement of service management interfaces with the users, in particular in the domain of short notice operations. Additional cost reductions could then be considered.

Capacity increase:
At the same time, this automation will cancel the Network limitation factor ("t" in the calculation of capacity, as per above section 3) as this limitation is effective today in the station scheduling procedures: only four passes are accepted in parallel, while the number of stations is higher (six antennas, not counting the back up antennas). This will induce a major gain in the overall Network capacity when this limitation is removed

SLE full deployment:
Cost reductions:
The previous evolution project conducted with the Network, Homere, had set the grounds for the implementation of the new CCSDS standards for ground to ground data exchanges. The objective of Homere was to prepare for the future as it had then been decided that such standards would be compulsory for all new projects requiring services from the Network, the first one been Pleiades. However, the retrofits to SLE of the interfaces with the Proteus and Myriade satellite series had been achieved. The objectives were cost reduction in the long term, but also reactivity and efficiency in the implementation of cross supports with partners.

The Cormoran project will now take into account the retrofit of all remaining control centers.
The various solutions that will be implemented may certainly increase the running costs of the control centers wherever new components are to be added (e.g.: protocol adaptations or gateways). However, to minimize the possession and running cost of the additional systems, these developments will be based on existing gateways that will be adapted for the purpose. Anyway, those cases are limited in number and in duration, as per the remaining lifetime of the missions (SPOT and HELIOS control centers).
For other control centers and flight dynamics facilities, the retrofits consisted in the implementation of software already used and qualified with other projects. The risks and costs are then minimized. This applies mainly to the orbit and tracking data interfaces to the satellites in the current Proteus and Myriade families.

Capacity increase:

- The deployment of the SLE throughout the Network should be as efficient on the increase of capacity as on the cost reduction: today, the TCR processors in the stations still have a dual boot in order to select between the legacy protocol or the SLE protocol; as a consequence, the station set up between passes takes 2 to 3 minutes more than it should be, when consecutive satellite supports do not use the same ground to ground protocol. The decision to only operate SLE over the Network on the provider side will be beneficial both in the frame of the replacement of the TCR equipment as only one interface is specified and on the set up time of the stations. This aspect will increase the station availability in between passes ("p" in the calculation of capacity, as per above section 3) and the station intrinsic capacity.

7 – Expectations from the ongoing developments

As previously introduced in the present paper, among the objectives assigned to the Cormoran project are the increase of capacity for the Network and the limitation of the increase on the running costs of the Network. The indicator to evaluate the success of the project in fulfilling these objectives will be the "Network hourly rate".

As the project was actually initiated in 2010-2011, only predictions are available at this stage. Such predictions are based on the following main assumptions on the planning:

- Full SLE deployment in the 1st quarter of 2013;
- Delivery of Idefix and implementation in the polar stations in the 2nd half of 2013; Subsequently, Idefix will be implemented in the new S+X band antennas along with their own development schedule ;
- Delivery of the new TCR equipment in the 1st quarter of 2013 and progressive implementation in all sites, as per their own schedule for the new S+X antennas and according to needs or resource availability for the other stations. The global targeted deadline for complete implementation is end of 2015, excepted to occur with the last Cormoran antenna.
- Delivery of CADOR and start of fully automated operations in the NOC, as from the 1st quarter of 2014.
- Delivery of the new S+X band antenna in Kourou in the last quarter of 2013 and start of operations six months later.
- Delivery of the new S+X band antenna in Hartebeeshoek in the 3rd quarter of 2015 and start of operations six months later.
- Delivery of the new S+X band antenna in Aussaguel in the 3rd quarter of 2017 and start of operations six months later.

Considering this planning and the plans elaborated by the Cormoran project, relative to the capacity of the GSN, a prediction of the evolution of the capacity has been established as shown in the figure below.

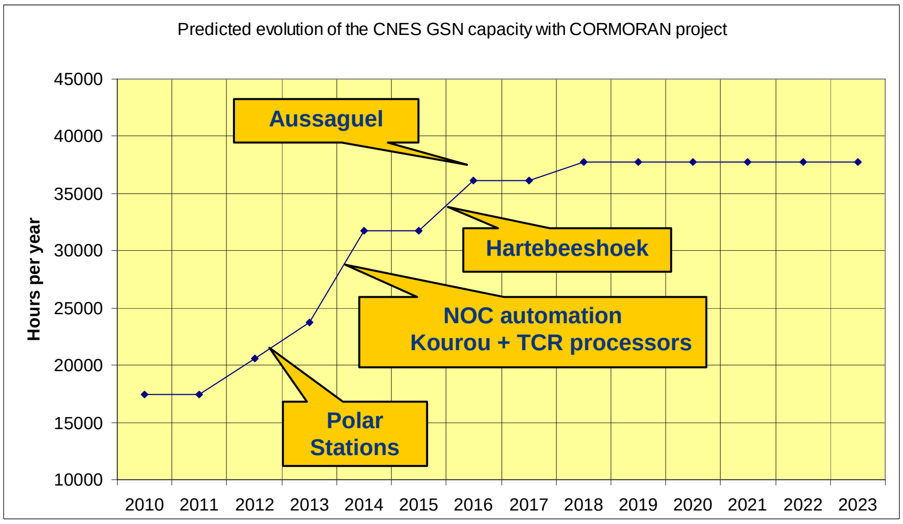

Figure 6: Predicted evolution of the CNES Network capacity.

This demonstrates the anticipated efficiency of the measures proposed by the project. However, it must be understood that the actual capacity will need to be measured throughout the development of the Cormoran components, to verify the predictions and initiate any corrective actions as may be required.

Moreover, as the prediction gets close to the mission model in section 4 above but doesn't exceed the figures by a large, this already leads the CNES Network team to consolidate the following actions:

- perform network loading simulations, as required with the project schedule changes (launch postponements, lifetime extensions, failures) to evaluate the resulting model and identify peaks or drops of activities ;
- extend existing agreements for support from external stations, either as back up on the same site or as complements from other sites ;
- establish new agreements with other providers of network services to diversify the options and increase the chances to find solutions on short notice ;
- consider new iterations and studies on the subsequent evolution of the CNES Network to identify the course of appropriate actions to be taken (this very likely not before 2014).

Also a model has been established on the evolution of the running costs of the Network. As a conservative and pessimistic assumption, it was modeled that, after the increase relative to the polar stations, the running costs of the Network would remain stable or within + / - 10 % of that level. It is expected that the expenses of the Network would remain stable and the manpower to operate the systems would slightly increase in the initial periods of operations of the new systems, in particular for those being operated for a time in parallel with the system they are to replace. As a result of this model, the predicted evolution of the Network hourly rate is foreseen to follow an evolution as shown in the figure below.

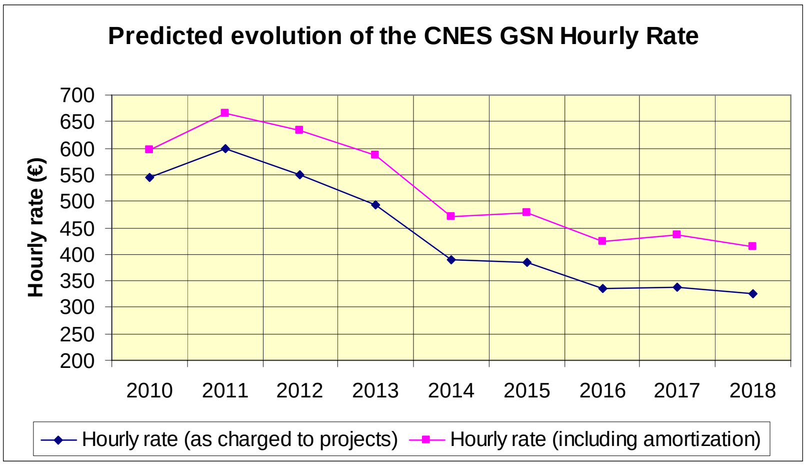

Figure 7: Predicted evolution of the CNES Network hourly rate.

8 – Conclusion

The analysis conducted in the frame of the Cormoran project, has the interest to go beyond the usual criteria of the management of a development project, usually based on the performance – schedule – cost triplet, and to take into account, in the project objectives, parameters that belong to the objectives of the operators of the ground assets: in this case, the capacity and the running costs of the stations.

One advantage of the approach for this project is that these objectives are shared between the engineering team developing the systems and the operations team who will provide services with them. The effects of any choice in the design or the features of the new system may be evaluated with comparison to the replaced systems or the previous operational concepts

The indicator that was selected, the Network hourly rate, is calculated every year based on the results of the previous year; therefore it will be easy to measure the actual performance of the Cormoran project.

References

[Ref.-1] Damien Servant, Isabelle Hernandez-Marcellin, Patrick Charlot (CNES) "The new CNES station scheduling system": both an operational and simulation tool" Space Ops 2012 in Stockholm.

[Ref.-2] Jean-Claude Rubio and Jean-Michel Roquebert (CNES) "Icare – Migration of CNES Ground Station Communications to Internet Protocol" Space Ops 2004 in Montreal.

[Ref.-3] Patrick Landrodie and Laurence Houpert (CNES), Josian Anesi, Benoit Goudy, Guilhem Suarez, Thierry Racaud (Cap Gemini) "Regates – A new generation of automated M&C system" Space Ops 2006 in Rome.

[Ref.-4] Jean-Marc Soula, Olivier de Beaumont, Marc Palin (CNES) "The CNES ground networks: lessons learned and future plans" Space Ops 2008 in Heidelberg.

[Ref.-5] Mikael Stern (Swedish Space Corporation), Erhard Diedrich (DLR), Jean-Marc Soula (CNES) Space Ops 2010 in Huntsville.