NOSYCA: A NEW SYSTEM FOR BALLOON OPERATIONS

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ABSTRACT

This document presents the New Operational SYstem for the Control of Aerostats (NOSYCA). This new system uses IP for the board to ground interface allowing implementation of new payload operations concepts.

CNES has been launching for a long time different types of stratospheric balloons in order to allow the scientific community to study the atmosphere or to realize astronomical observations. This kind of vehicle is particularly adapted for the measurements, the characterizations, and the modeling that the scientists have to realize in the present period of global warming.

Of course, the operators of balloons have to protect the over flown populations.

In this context it is necessary to have an at once very versatile payload TT&C architecture, and a reliable and safe command / control system.

Mindful of the need to protect of goods, persons and environment the CNES decided, in 2007, to carry out the development of a New Operational System for the Control of Aerostats named NOSYCA.

This new system takes into account:

- More than 40 years experience of stratospheric balloon operations at different latitudes (Polar, Mediterranean and Equatorial flights).
- The heritage of last flights where CNES's developments were tested : low consumption transceivers, Programmable Logic Controllers for Iridium and Inmarsat communication management, TCP/IP routers, renewable energy systems, payload scientist on-board interface,…

This ambitious development demonstrates the willingness of CNES to provide the scientific community with a very reliable and high-performance system.

GENERAL DESCRIPTION

NOSYCA will be a new command-control system designed for the stratospheric balloons of the CNES. This system has to be fail safe regarding the protection of the over flown populations. This new system includes three board to ground interfaces, one based on internet protocol, and two using satellite data transmission services. These interfaces provide data link services for command-control and the payloads. NOSYCA is a no single point failure system operated through 3 different communication links: S-Band radiofrequency, Iridium and Inmarsat. The complete system can be represented as shown in figure 1.

The IP board to ground interface has a high bit rate of 1.75 Mb/s. The use of TCP/IP enables the scientists to access in real time their data through a standard internet link.

The on board architecture is divided into three separate OBCs. Each of them consists of modules used to interface the OBC with external devices like GPS receiver, RADAR transponder, or balloon actuators (gate of unballasting, valves …).

This technological choice contributes to reduce on site preparation time, and to offer the operators a flexible architecture.

The ground segment includes S Band stations supporting the board to ground IP interface, a balloon control centre, an emergency control centre and four payload control centres. The balloon control Centre is used in nominal mode including the activation of the on-board redundancies, and the emergency control centre is used only in case of a general failure of the balloon control centre. As shown below (see figure 1) every control centre is connected with Iridium and Inmarsat data transmission services. Depending on the scientific mission altitude profile and the flight duration the ground segment could include several stations remote controlled by the control centre.

The ground network architecture allows operational team to control one or two flights at the same time, and to prepare and verify payloads on ground during flights.

Furthermore the ground stations and the control centres are installed in shipping container in order to allow easily stratospheric balloons launch campaign anywhere in the world.

This system is an important investment which

Proc. '20th ESA Symposium on European Rocket and Balloon Programmes and Related Research'
Hyère, France, 22–26 May 2011 (ESA SP-700, October 2011)

demonstrates the will of the CNES to give to the scientific community a high-performance and modernized tool.

The development of the complete system has been possible thanks to the industrial partners of the CNES:

- ELTA for the board segment and the ground station ;
- CAP Gemini France for the ground segment applications ;
- BT Services France for the ground network architecture ;
- NAUROY Frères for the mobile infrastructures.

ON BOARD ARCHITECTURE

The "on board" architecture includes three computers installed in two different gondolas. This distribution is due to the fact that a stratospheric balloon contains two parts which fly together then land separately : the envelope of the balloon and the flight train. A gondola including an electronic set is tied to the envelope of the balloon and an other one including two computers and the payload board to ground interface is incorporated in the flight train. This Gondola is named "Operational Gondola" (see figure 1). Classically the payload is installed at the bottom of the flight train. The link between the payload and the OG is based on "Wireless" technology.

The system allows to build different flight configurations. The CNES balloon team will be able to operate two different on board architectures. Below we are going to present both of them. The first one will be qualified, and available in 2013.

Most important characteristics

<u>"Fail-safe" architecture</u>

The CNES safeguard rules impose strict safety considerations and require proofing against a single point failure or against failure propagation on all critical functions.

Availability rate of the equipment is also imposed. This redundancy requires a separation of the controlling systems all the way from the Control Centre to the commanded organs located on the balloon and on the flight train.

These requirements are respected in the NOSYCA architecture defined by the CNES.

For each set of electronics the fail-safe design philosophy is:

- Avoid at all costs any unwanted commands (for example, unwanted separation, unwanted gas valve opening).
- Avoid at all costs failure propagation.

The CNES system philosophy is that the Control Centre:

- Detects any possible failure.
- Switches to the isolated redundant system in case of failure.

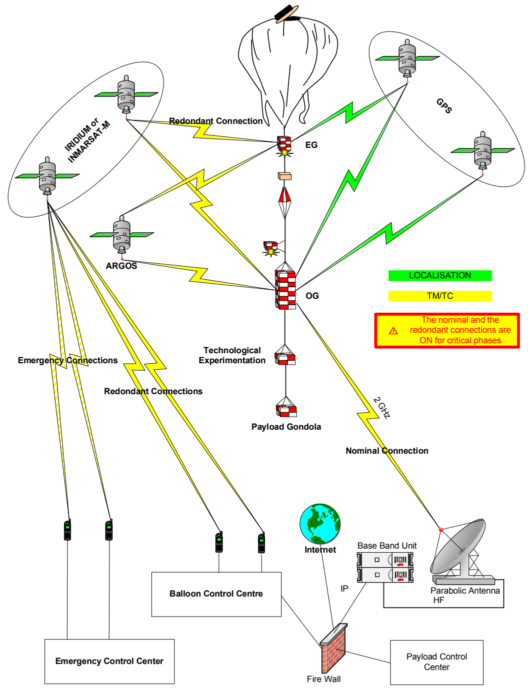

Figure 1. On board global architecture with intermittent HBR connection

Supported "critical" functions

The operational electronics commands and monitors the following critical functions:

- Balloon Piloting (gas jettison and ballast jettison).
- Separation (pyrotechnical bolt cutter).
- Aeronautical navigation safety (Radar transponder and strobe light for navigation in air corridors).
- Localization (LLA : Longitude, Latitude, Altitude and speed vector of balloon).

A. Architecture with permanent high bit rate connection

This configuration includes only two connections : S-Band radiofrequency and Iridium. The control of the aerostat is performed through the high bit rate, S band connection in nominal mode, and through a satellite link as redundancy.

For this architecture, the OG contains two sets of isolated electronics used for command and control of the balloon, each with its own means of communications with the ground segment :

- ITAC (Interface de Télé Acquisition et de Commande) including the S Band modem for the nominal board to ground link;
- ULIS (Unité Légère d'Interface Satellitaire)

including an Iridium modem for the redundant board to ground link.

The OG redundant connection is able to locate the flight train after it falls below the radio electric horizon of the ground station at the end of the flight. The envelope gondola (EG) contains a single set of electronics (SIRSE : Système Iridium de Suivi d'Enveloppe) for further redundancy of localisation and aeronautical navigation safety (see figure 3). This set uses a SDB (Short Burst Data) Iridium modem to perform the board to ground interface. ITAC and ULIS are based on a common architecture : the NOSYCA OBC (On Board Computer).

A short duration flight will typically consist of a SIRSE module for the envelope gondola, an ULIS OBC, an ITAC OBC for OG (see figure 2), and a SIREN electronic set in the pay load gondola. Each of them is supplied by a dedicated battery designed for the flight duration.

The main characteristics of the dedicated board to ground high bit rate interface are as follows:

- TM & TC Frequencies : S band ;
- TM Modulation & channel coding : QPSK Viterbi & Reed-Solomon ;
- TC Modulations & channel coding : QPSK Viterbi & Reed-Solomon ;
- TM bit rate : 1,75 Mb/s useful (without error correcting code) ;
- TC bit rate : 95 kb/s useful (without error correcting code).

A software managing the QoS (Quality of Signal) of IP is implemented in the ground and in the on board IP routers in order to define and apply priority rules concerning the different data flow types. A specific QoS class is allocated to each type of data flow. So with the management of these QoS classes it becomes possible to guarantee a minimum bandwidth for each flow and to prioritize the critical data in regard of non critical data. For example the first quality level is allocated to Command-Control TC, the second one to Command-Control TM, the third one to the pay-load TC and the last one to the pay-load TM. These IP board to ground network principles were defined and validated within the framework of an R&D performed by CNES in 2000.

In addition to essential operational flight functions, NOSYCA offers a real time data link to the scientist payload gondola which houses an interface adaptor (SIREN) connecting the experimentations to the board to ground high bit rate interface.

The SIREN includes an IP router, and implements serial link configurable interfaces.

The Scientist mission control centre contains an analogous SIREN unit. This SIREN ground and board pair provides the following types of communications interfaces or services to the scientist :

- Ethernet / IP.
- NTP (provided by a NTP server).
- 1PPS output.
- Up to 8 RS232 asynchronous full duplex channels.
- One RS422 synchronous TM data link for high speed science data.
- On-board open drain outputs available for on/off type commands.

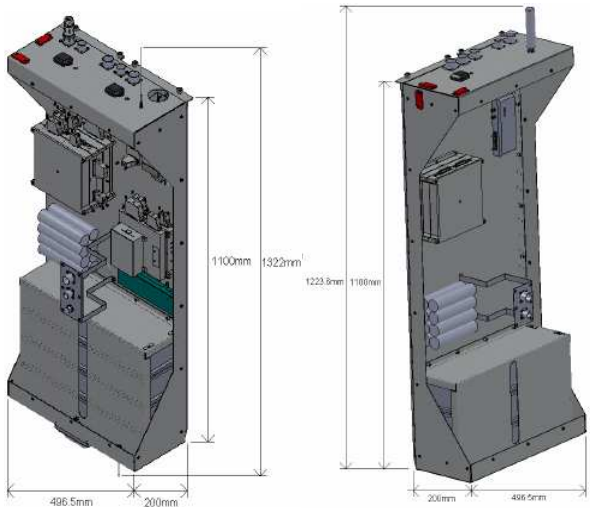

Figure 2. ITAC & ULIS modules for a 72 h flight

Of course, the classical synchronous and RS232 scientist connections are simultaneously available with the IP scientist team link. With this payload data link architecture it is possible to configure the onboard SIREN (change the bit rate, change the type and the bit rate of the serial link) by a remote control software implemented in the SIREN electronic set on ground.

In addition, and according to the exact flight configuration, each OBC provides the following flight functions :

Communications with the Control Centre via an authenticated protocol based on CCSDS rules.

- Storage of all TM, TC and on-board events.
- Physical measurements (air temperature, air pressure, gaz temperature, gaz pressure). OBC measurements (voltage, current, temperature of all major circuits) accelerometers for shock detection at landing.
- Imaging of the flight chain via an in-built camera in the ITAC S Band electronics (optional).

In order to reduce the global weight and to ease the payload on ground tests, the on board SIREN electronic set is linked to the OG by Wi-Fi connection. This connection is designed with consumer products adapted to the balloon environment (low pressure, and low temperature).

Of course, because of the use of a ground station network this configuration is useful for short term flight only (about one to three days)

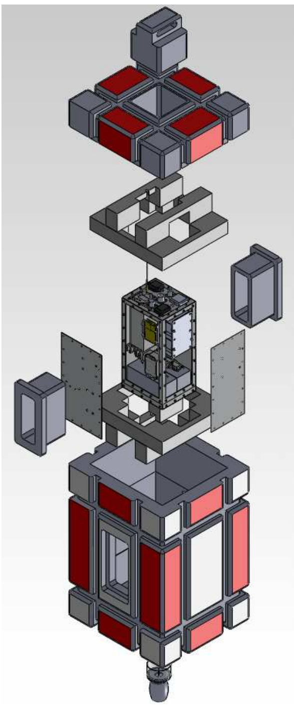

Figure 3. SIRSE module including a RADAR transponder, and a strobe light in the Envelope Gondola

B. Architecture with intermittent high bit rate connection (see figure 1)

This configuration allows performing flights without any constraint regarding the ground station network coverage. Because in this case the system is able to uses only satellite connections to perform the control of the aerostat. The high bit rate connection is available only when the balloon is in a station coverage area.

This configuration will typically consist of a SIRSE electronic set in the envelope gondola, an ULIS module and an ITAC module with two board to ground interfaces (S-Band and Inmarsat) in the Operational Gondola.

In this configuration it is possible to install a serial link (RS 485) between the ULIS module and the payload.

This interface is directly connected to the payload control centre through the satellite data link..

The choice of Iridium and/or Inmarsat (included in ITAC) depends upon mission requirements, in particular whether the Inmarsat constellation will be visible from the balloon for the duration of the flight. Because of the limitation of Inmarsat and Iridium communications channels (currently limited to 2.4 Kbps full duplex) the system has to manage the on board memory where all the TM is recorded. For this function the CCSDS format of TM frame is very useful.

C. Generic OBC Architecture

The OBC uses a distributed architecture in order to avoid failure propagation. This architecture also gives the NOSYCA on-board system a flexibility in its configuration and will allow for easier evolutions as technology progresses in the future. The distributed architecture consists of micro-controllers implanted on stacked pluggable boards. The allocation of the micro-controller functions was decided during fail safe analysis at the architectural design phase. Micro-controllers serving critical functions also have critically tested firmware. A management micro-controller is used for validating and authenticating telecommands from the Control Centre and for preparing telemetry packets for transmission to the Control Centre.

The various micro-controllers communicate with the management micro-controller over on PCI bus, which has electrical fault protection barriers to avoid a faulty micro-controller inhibiting the whole bus.

D. Other architectures

Because of the versatility of the system it is possible to imagine other on board configurations. For example, the CNES plans to design an architecture based on "intermittent high bit rate connection" architecture including solar generator in order to allow long duration missions (up to ten days).

GROUND SEGMENT

A. Ground segment global architecture and main characteristics

The NOSYCA Ground Segment is the new management and control system of the CNES balloons. It has been designed with the primary objective to meet safety requirements. It is designed around a secure IP network and adapts to all configurations of the board. It also incorporates a host platform providing data transport for data of the payload (see figure 4).

Ground Segment includes:

- A ground network for data transmission providing transport to science and control command flows, providing also a link to the S-band stations supporting the board to ground IP interface.
- The scientist host interfaces (called SIREN). The ground network architecture can accommodate up to four scientific missions at the same time.
- The host interfaces with the test facilities for the scientific payload and board OBC. These tools can be used during the flights operations.

- A balloon control centre and an emergency control centre that provide the necessary functions for management and control of balloons. The balloon control centre is connected to the S-band . stations. Each control centre is connected with an Iridium and an Inmarsat modem for data transmissions Management and supervision of the ground segment facilities (weather and trajectory analysis tools, ground segment supervision means, data management tools , …).

The balloon control centre has two distinct ways to communicate from ground to board: via the IP protocol through a network of S-band stations, and via the RS232 asynchronous protocol using Inmarsat and Iridium data transmission modems. This control centre may control up to five S-band stations and six low bit rate modems : one local S-Band station and 4 remote stations. Science data and control command data are sent to the remote stations through the web.

The emergency control centre communicates with the on board systems through one Iridium modem and one low bit rate Inmarsat modem.

The ground segment architecture can adapt to various mission configurations from a configuration using only the single high bit rate link (payload requiring a S-band station) to configuration using only the low-speed data transmission or a mixed configuration.

A single ground segment is able to drive two flights simultaneously (it means without losing the ground to board connection). Alternately, it may also follow an up to 20 balloon flights.

The ground segment architecture organized around these two control centres has been designed to be fail safe regarding the protection of the over flown population.

The ground segment architecture satisfies the CNES safety regulations criterion.

In a continuing effort to always ensure the control of the balloon and to ensure the protection of the over flown population, the control command flow is the most critical. It is always available with a higher priority to any other flow.

B. Ground IP data transmission network

The ground IP network supports the IP control command and science data flows. It offers a bit rate of 1.7 Mbps for science data and 2.4 Kbps for the command-control data.

The science and the control-command data flows are independent : there is no interaction between them. Some bandwidth is reserved to ensure the balloon command-control in safe conditions, while the remaining bandwidth is made available to the scientist teams.

The ground network can address one local S-band station, and four remote S-band stations.

Four scientist teams and their payload can be connected simultaneously.

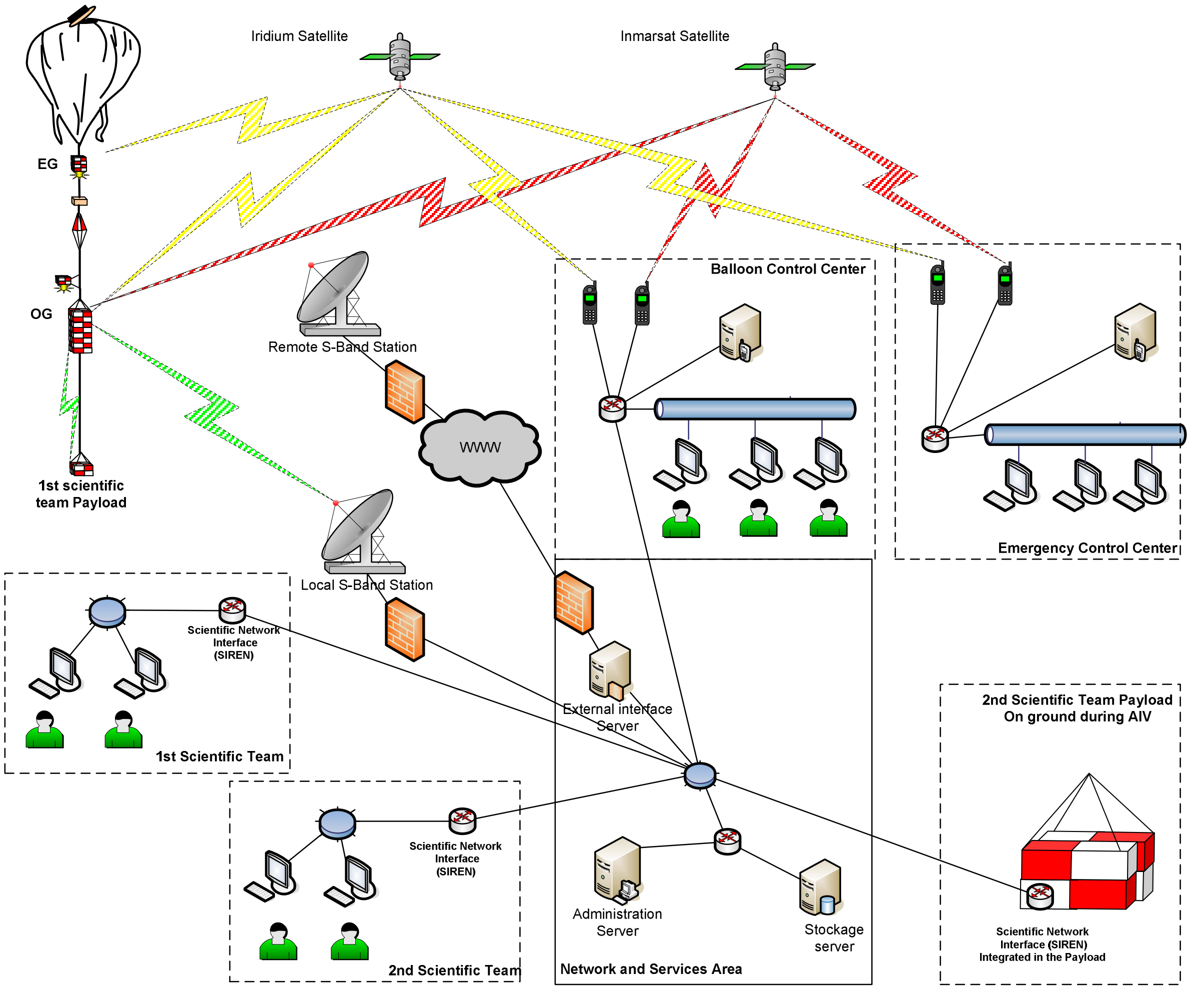

Figure 4. The NOSYCA ground segment

C. Safety of the data transmissions

The ground segment can host up to four scientific missions at the same time. Each mission is independent of the others. The ground segment provides the partitioning of transmission and communications between the scientific laboratories and their payloads : each mission is isolated from the others.

The system partitioning ensures also that an infection of a computer with a virus can not spread to the rest of the ground segment or scientific payload.

The ground segment offers to the scientists the opportunity to access the Internet, safely for the rest of the ground segment.

D. SIREN a new concept to manage the payload interfaces

The SIREN equipment is an interface between the scientist teams and their payloads.

There is a ground SIREN that interfaces with the payload control centre and an on board SIREN that interfaces with the payload.

The SIREN operates in pairs : a ground SIREN is associated with an on board SIREN.

The correspondence between SIREN must be unambiguous as they are the two ends of a single IP tunnel : for a given payload we will use a given couple. This IP tunnel will be the transmission link during all the different phases (payload preparation in lab, payload tests on campaign site and of course the flight).

This unique tunnel is routed on campaign site by the NOSYCA ground segment depending of the phase. The ground segment manages NAT (Network Address Translation) tables and translates the tunnel addresses in order to route them through the IP NOSYCA network.

<u>First phase :</u> Payload preparation in lab

Before integrating a new payload, the CNES will provide to the mission Principal Investigator (PI) a couple of configured SIREN.

In the lab it is then possible to simulate all the constraints of the connectivity between the mission centre and the payload (see figure 5). This link is representative of the ground to board link even without being connected to the ground segment (data rate limitation for example).

<u>Second Phase :</u> Payload Intégration and Tests on campaing site.

The couple of SIREN is left available to the PI until the beginning of the balloon campaign. Upon arrival on the campaign site the couple of SIREN is connected to the NOSYCA network (see figure 6) and the scientists can perform their payload integration tests.

During the ground global tests before the installation of the payload in the flight train, the scientists can control their gondola either directly or through CNES gondola bench (see figures 6 and 7). The tests can thus be made in conditions close to of flight.

<u>Third phase :</u> The launch and the flight

The SIREN is also used in operations. Of course, the SIREN continues to be the scientist operational interface with the NOSYCA network system during the flight (see figure 8).

<u>General considerations about the SIREN concept</u>

This couple of equipment interfaces with the ground network which ensures the science data transmission to the board. So each scientist team can access to its payload which is either in preparation, in integration, or in-flight activities without having to change its configuration.

Using the SIREN interfaces the ground system allows the implementation on the science data link of all IP conventional protocols in single or multicast. mode (UDP, FTP, TELNET, HTTP, NTP, HTML, …).

Referral flow of science data between the different configurations is made by the operators directly from the balloon control centre.

In addition, the ground SIREN provides others services such as :

- Archiving of all science data.
- NTP for synchronisation of the payload control centre.
- Balloon localization data, technical parameters and system alarms provided by multicast protocol
- Internet access via the CNES web provider; depending on the mission campaign site ; independent access to the Internet could be implemented.

Note : The science data flows have not the priority over other network flows.

E. Ground RS232 Data transmission network principles

The Iridium or Inmarsat networks support command control and science data flows when the balloon is out of the S-band station visibility. They offer a bit rate of 2.4 Kbps. So in the Iridium and Inmarsat configuration flows operate alternately : the ground to board link transports either the command control flow or the science flow.

F. Control Centre (CICLOP) Software

The NOSYCA Control Centre software (CICLOP) developed by CapGemini operates ground and on-board systems for CNES balloons dedicated to specific on boarded scientific missions.

It comprehensively adjusts to each mission specific architecture. It allows the management of several balloons or fleet of balloons, using several occurrences of ground and on-board systems on various operational sites. It can be deployed on mobile shelters and can withstand frequent installations and de-installations.

The theater of operations enforces the use of Reliability, Availability and Maintainability (RAM) techniques to comply with safety requirements. It is classified as “Vital” due to the dropping of payload and the flying over inhabited areas.

Capgemini’s Control Centre fulfills these constraints and implements all the ground operations segment requirements of NOSYCA, i.e.:

The control centre operates remote monitoring of the balloon and send control commands to it. Up to three telemetry and control command double channels have to be managed for a critical balloon flight with an on board “intermittent high bit rate connection” architecture. The control centre can manage simultaneously two connected balloons and up to twenty balloons controlled in turn through connection sessions. Balloon’s control can be done in a real time way all along the flight with one or several SCILA ground stations. The control centre also get the modules telemetry recorded on board through a dump sessions planning.

A from start to finish IP Channel is established from the control centre to the ITAC Module via the ground station router, allowing thus the control centre to access directly to the board resources. This is really an original feature of the NOSYCA program. An IP Channel is also established by the control centre from the on board scientific payload to the ground remote monitoring and control system of the Scientifics users.

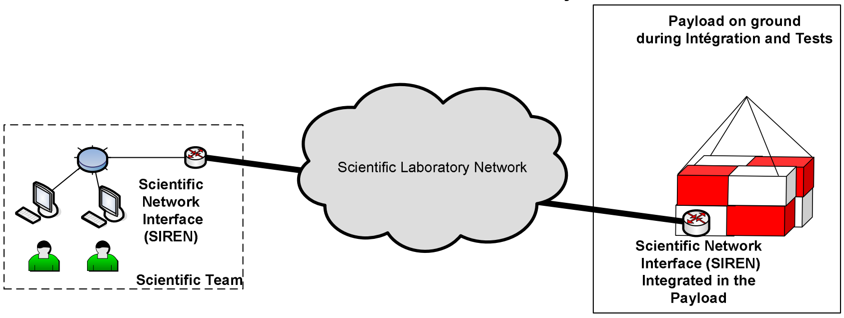

Figure 5. Payload in stand-alone configuration (Note : In bold line the science data transmission)

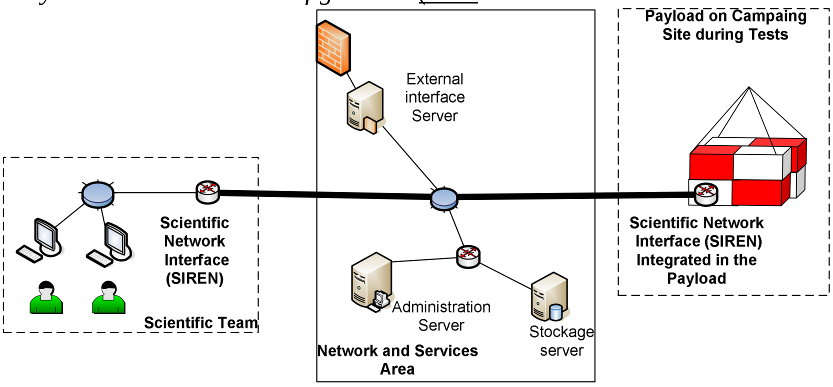

Figure 6. Payload in ground tests on campaign site
(payload connected to scientist team through IP NOSYCA ground network)

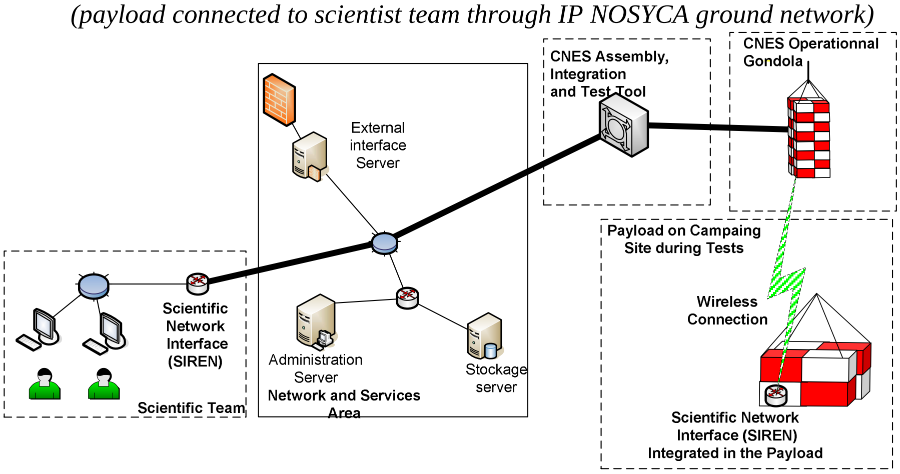

Figure 7. Payload in tests before launch
(Payload connected to payload control centre through IP ground network and CNES test bench including the OG)

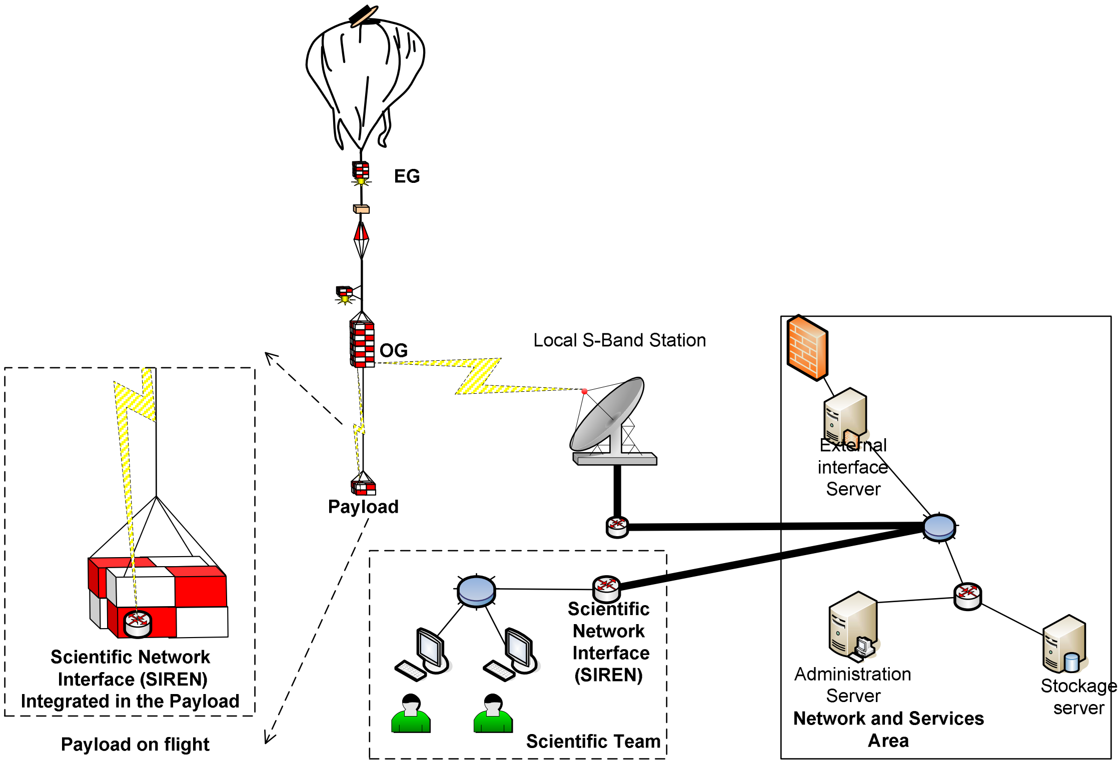

Figure 8. Payload in flight connected to payload control centre through the NOSYCA system

G. Reliable Architecture and COTS integration

In order to optimize the development cost and deadline, the NOSYCA Control Centre design is based on the reuse of components and on Commercial Off The Shelf (COTS) software integration. The NOSYCA ground segment takes technical advantage of CNES's investments made on other space projects :

- OCTAVE : The Control Centre uses the OCTAVE generic control centre developed by CNES;
- ESRI : The Control Centre integrates ESRI GIS to display cartographic representations
- NAGIOS : The Technical Supervisory Control is build on NAGIOS free software
- GIDE : The Exchanges Centre uses GIDE software for external secured data exchanges. This software was developed for Pléiades earth observation program
- COCPIT : The Control Centre reuses the COCPIT solution already implemented on satellite ground segment for the system database management.

Whatever the reliability level of an on-shelf software may be, it is quite difficult to demonstrate this reliability with tests. That's why the Control Centre architecture includes reliability modules to improve RAM level of the telemetry and remote control processing chain (see figure 10).

- A telemetry reliability module. It compares the highly critical telemetry received directly and through the OCTAVE telemetry management module.
- A remote command reliability module for highly critical remote commands transmission.

An MMI module to confirm the radiation of highly critical remote commands, and to display errors detected by the telemetry reliability module.

These reliability modules are developed at a specific high quality level and thus allow meeting the required RAM level for the ground system.

H. The ground segment configuration defined by the on board configuration

Each mission has its specificities ; so the on board architecture is modular and can be adapted to the specificity of each mission. The ground segment includes a system that can adapt the configuration of the ground from the on board and payload mission configurations.

This configuration is automatically distributed to all components of the ground segment at the beginning of a flight preparation.

I. Ground S Band Station

The Ground station SCILA is composed of a S-Band TT&C antenna, and a base band including the TCP/IP router used for the IP board to ground interface. The ground station has been designed by ELTA. The mean features of the station are as shown below :

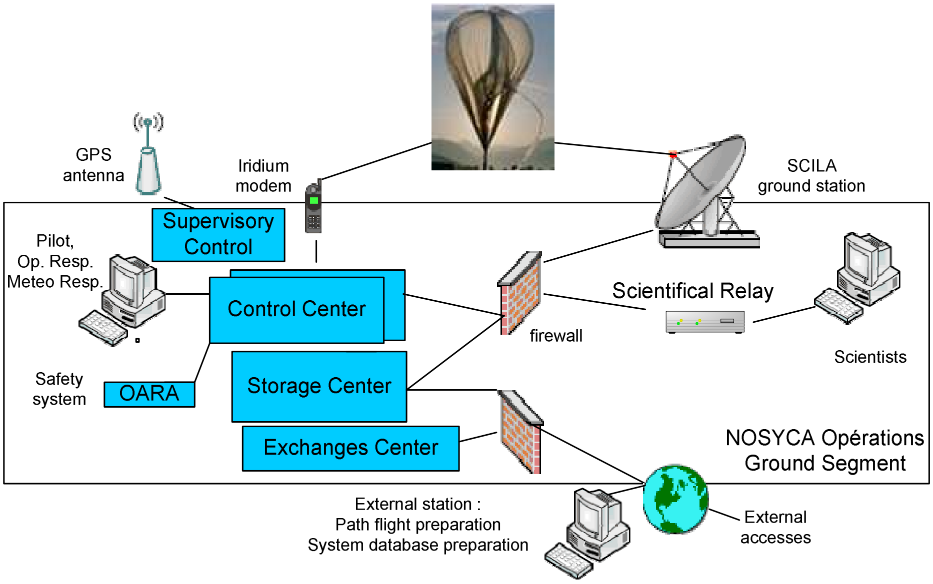

Figure 9. Functional architecture of CICLOP software

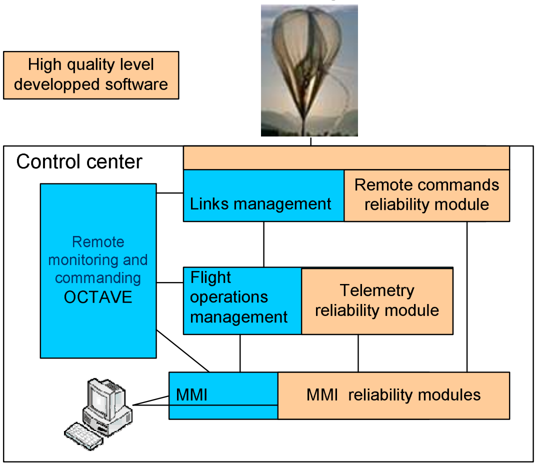

Figure 10. Architecture of CICLOP critical software

- G/T@ 5° : > 5 dB/°K ;
- Polarization : RHCP : Right Hand Circular Polarization ;
- EIRP : 17.2 dBW ;
- Frequency : S-Band ;
- Modulation / Demodulation : QPSK ;
- User Data Rate : 1.75 MBits/s ;
- Data Encoding & Decoding : Viterbi - Reed-Solomon

Tracking of the balloon at the S Band ground station is achieved by the Balloon Control Centre sending azimuth/elevation information to the ground station. This information is calculated at the Balloon Control Centre based on GPS data from the stratospheric balloon over S-Band, Iridium or Inmarsat links.

J. Ground Facilities for the Gondolas

Test benches are provided which allow revalidation of the gondolas before and after a flight : Pre-flight revalidation of the on-board electronics is essential in attaining the fail-safe and availability requirements by early detection of failures. This pre-flight validation effectively "resets" the "fail-rate counters" to zero.

These test benches allow configuring the OBC before a flight. Because of the versatility of the on board system, this configuration is transmitted to the CICLOP through the TM in order to configure the control centre.

So it is possible to guarantee the compliance of the interfaces (board and ground) with reduced validation tests in preparation of the operations. All the archived CNES gondola data is recovered via this test bench after the flight.

CONCLUSION

NOSYCA will use new concepts of command – control architecture, board to ground interface, management of the ground segment configuration, and payload data link interface. So the balloon activities will be as ever an interesting experiment area for the future space operations concepts.

Because of his modular architecture, it will be possible to adapt easily this new system for longer flights. Therefore NOSYCA is the first step on the long way to long duration ZPB (Zero Pressure Balloon) flight.