FLIGHT TELECOMMUNICATION SYSTEMS UNDER BALLOONS

Jean-Paul Lefèvre [(1)] , Nicolas Verdier [(1)]

[(1)] CNES (French Space Agency) Balloon Sub Directorate 18 avenue E. BELIN 31401 Toulouse CEDEX 09 France
Email: jean-paul.lefevre@cnes.fr , nicolas.verdier@cnes.fr

ABSTRACT

The CNES Balloon Sub Directorate must have the capacity to control the end to end flight of a balloon around the world with a maximum of safety. As different sizes of balloons are used for short or long duration flights, it must have many kind of TM/TC specific equipment associated.

The main goal of this document is the synthesis of the different systems used today. It must also inform on the new possibilities offered by the new technologies to design the future systems.

Successively, different ways are approached :

- Point to point dedicated links,
- Satellite communications,
- System based on the properties of the propagation in the ionosphere.

1. POINT TO POINT DEDICATED LINKS

Historically, it was the only one solution to pilot a balloon. But many ground stations must be used to control a flight on long distances.

However, a point to point dedicated link presents some advantages :

- Total control of the system,
- Low cost of the communications,
- Possibility to design a custom-made system adapted to the application
- …

1.1. UHF system

UHF (Ultra High Frequency) was used by CNES for long time to control the ZPB (Zero Pressure Balloons). This system is now obsolete.

1.2. ETNA 2 L Band system

ETNA 2 for “Equipment of TM/TC for Nacelle” is a point to point dedicated L band system used today to control for ZPB. The architecture is based on an on board TCP/IP router.

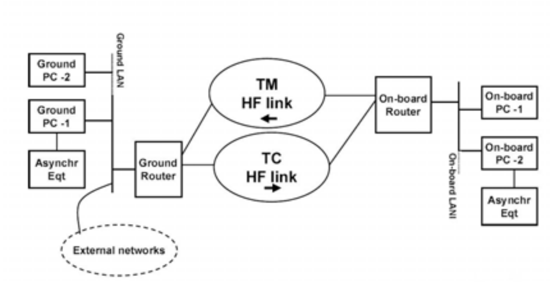

Figure 1. Principles for an IP architecture in the balloon context

RF main characteristics :

- Frequency : L band around 1500 MHz
- Modulation : QPSK (Quaternary Phase Shift Keying) with over modulation OOK (On/Off Keying) for discrete orders
- VITERBI coding and data scrambling
- On board Transmitted power (down link) : 250 mW (24 dBm) to 1 W (30 dBm) on 50 Ω
- Up link transmitted power : up to 10 W on 50 Ω (up to 40 dBm adjusted by software)
- TM data rate from 250 kbit/s to 2 Mbps/s and fixed TC data rate of 115 kbps/s

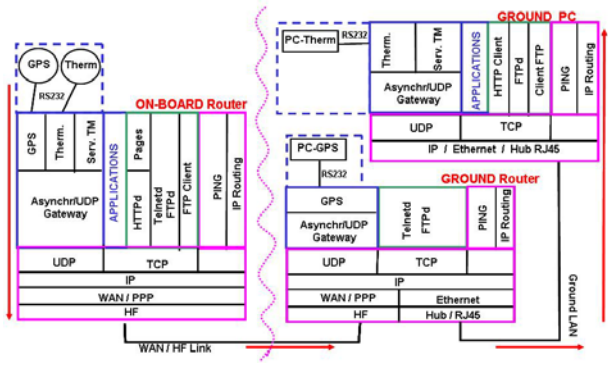

Figure 2. Overview of ETNA 2 TCP/IP architecture

1.3. NOSYCA

NOSYCA (New Operational SYstem for Control of Aerostat) is in development phase. It combines both an on board TCP/IP router working in S band, to carry house keeping data used to control the flight and scientific data from NCU (scientific gondola), and a

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

satellite low data rate bi directional link to pilot only in spare the aerostat (housekeeping TM and TC). A specific presentation of NOSYCA is scheduled during this Symposium.

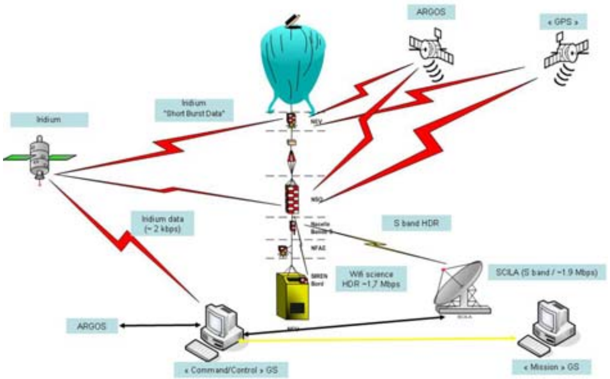

Figure 1. NOSYCA system overview

1.4. Original NANO system

It is used by the Boundary Layer Pressurized Balloons (BPCL) and nano aerostats.

<u>The NANO concept</u>

The concept of NANO (Nano Aerostat Network for Observations) proposed by the CNES consists in using every gondola as relay to transfer the information collected by his neighbours. For a significant number of aerostats, we can so cover a vast geographical zone.

Intrinsically, the system offers a better service to the scientists by proposing a new spatial and temporal fineness of sampling. To be relevant, this solution imposes nevertheless to reduce appreciably the recurring cost of balloons and to assure a fast implementation.

The domain of preference of these miniature aerostats is the study of the atmospheric limit layer (0 to 1000 m) in the synoptic scale (some thousand km).

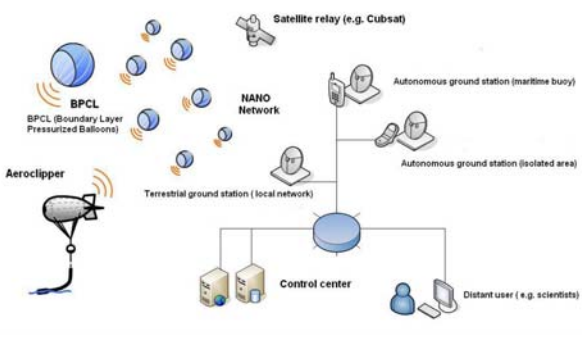

Figure 2. NANO architecture

<u>The NANO gondola</u>

The gondola has a weight of about 100 g. It contains the following elements : one pressure sensor, one temperature sensor, one 3D localization GPS receiver and one UHF digital transceiver (broadcasting and receiving).

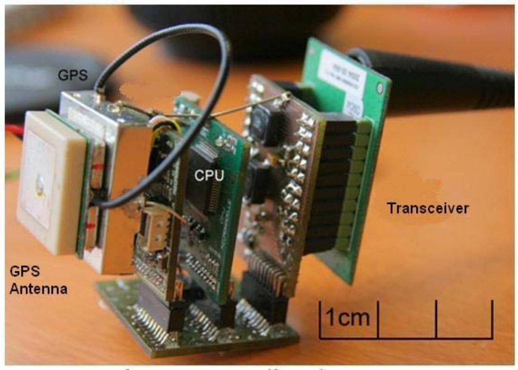

Figure 3. NANO gondola electronic equipment

<u>Principle of the information transfer</u>

The multitude of aerostats launching for every measurement campaign (typically 50 balloons by campaign) allows the creation of a dynamic network that supports the data transfer towards one or several ground stations.

A routing mechanism of the informative data packets must be implemented as well as a protocol offering the adequate services.

The main ground station sends regularly a frame, named “about shorter road”, to the whole network. A representative row of its nearness towards one or several collected station(s) is attributed to each gondola depending on visibility status from ground. At the end of this attribution, the data are sent to the nearest neighbour of lower rank. It results a progressive transfer of the measurement information of every aerostat towards the nearest ground stations in visibility.

2. SATELLITES COMMUNICATIONS

LEO (Low Earth Orbit) and GEO (Geostationary Earth Orbit) satellites are used to carry information from balloons to ground stations. In accordance with the different family of balloons, we can use either TM or TM/TC satellite services.

2.1. ARGOS LEO satellites

ARGOS constellation is the system used today to collect data. The ARGOS beacon transmits at a 400 bps (bit per second) data rate the information to a store and forward data satellite (TM). The OBD (On Board Computer) calculates the exact time of transmission with satellite visibility in order to save the energy on board. After post treatment and a little delay, data are available by the provider (CLS Company).

CNES is interested in the down link capabilities, but no application used them today. The future ARGOS-4 system could offer new capabilities to control in back up a flight under balloon or to improve the on board security with a double access to vital equipments.

2.2. IRIDIUM™ LEO satellites

CNES uses IRIDIUM™ since 2006 to pilot BPS (Stratospheric Pressurized Balloons). On the other hand, SBD (Short Burst Data) service is used by the BPCL (Atmospheric Boundary Layer Balloons) to manage the flight.

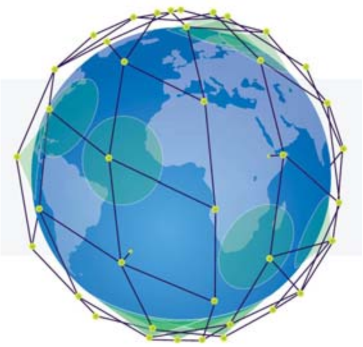

Figure 4. In orbit Iridium network

It is an "old" L band system but it offers many advantages to pilot a balloon :

- Low power consumption,
- Contact with any gondola everywhere and every time,
- Very easy to establish a dialog with the modem through AT commands,
- Possibility to manage simultaneously many aerostats with an only one dedicated control station,
- …

CNES is expected the new IRIDIUM NEXT™ to be used for the control of the new gondola generations (short and long duration). The all constellation must be operational for the first quarter of 2017.

The preliminary information known about this new system must allow the design of new architectures based on the TCP/IP environment.

The main characteristics for IRIDIUM NEXT™ data services in L band must be :

- Flexible delivery of bandwidth,
- From existing 2.4 kbps to 1.5 Mbps,
- Backward compatibility.

2.3. GEO satellites

Using GEO satellites is the second way to communicate by satellites with aerostats. Today, CNES division does not use this possibility to control the flights but must find a solution to complete the IRIDIUM solution while waiting for the starting of IRIDIUM next™. On the other hand, new constraints requested by the CNES safety rules impose the simultaneous using of two different telecommunication systems to improve the redundancy level.

Commercial solutions are existing today and CNES is studying a way based on particular services offered by the INMARSAT 4 satellite constellation and in particular through a Research & Development study labelled "Using of INMARSAT BGAN under balloons". BGAN is the acronym of Broadband Global Area Network.

2.3.1. INMARSAT BGAN services generalities

INMARSAT 4 constellation is operational since the end of February 2009. The incoming of ALPHASAT I-XL, expected in 2013 at the latest, must improve appreciably the quality of service over the European area (green or central area on figure 5).

For reminding, the main enhancements offered by this new system allow new capabilities to design energy-efficient on board equipments :

- EIRP (Equivalent isotropically radiated power) satellite : 67 dBW,
- Narrow spot G/T : 9.4 dB/K,
- 630 channels with 200 kHz RF band width,
- Data rate up to 432 Kbps,
- TCP/IP environment,
- Worldwide coverage on a latitude comprised between 80° N & S.

Figure 5. INMARSAT BGAN coverage

2.3.2. INMARSAT low speed data services

BGAN ISATPHONE data service is operational since the end of March 2011. It must be the solution to control the flight of the balloon with a 2400 bps data rate (house keeping application).

Figure 6. ISATPHONE Pro terminal

To use this COTS (Commercial Off The Shelf), CNES must have a sufficient knowledge of this equipment to customise it in the balloon harsh environment (flight pressure comprised between 1020 and 4 hPa, temperature comprised between -40° C and + 85 °C).

2.3.3. BGAN high data rate streaming services (up to 432 Kbps)

It is the second way interesting for the applications under balloon. The actual dedicated point to point systems used today or in phase of development (ETNA2 or NOSYCA), offer a data bite rate of 1.5 Mbps but with a visibility circle of about 500 Km.

The use of high data rate BGAN terminals must offer an answer for the pointed gondola applications : find a solution to carry information (sky pictures transmitted today with no onboard compression) on long distances (greater than 500 km).

Figure 7. OEM BGAN Core Module (Addvalue company)

2.3.4. Antenna problematic for using BGAN system at high latitude

The INMARSAT 4 satellites offer interesting characteristics of EIRP and G/T. To decrease the energy consumption of terminals and keep a sufficient margin on the link budget for a functioning in high latitudes, it is necessary to define an high gain antenna adapted to the need.

Different ways could be approached :

- Use an antenna pointed in the direction of the working satellite so as to align the respective lobes and obtain so the maximum gain. A GPS (Global Positioning System) receiver associated to an mini inertial central gives localisation and attitude information to the OBC (On Board Computer). This last one, after calculation, puts and tracks in real time the antenna in direction of the satellite.

- Use an ensemble of many directional antennas arranged all around the gondola. The most adapted antenna (best gain in direction of the working satellite) is switched by the OBC after calculation in the same way as for the previous paragraph,

- Use an omni directional antenna with an adapted radiation pattern to offer a sufficient margin on the link budget for all latitudes comprised between 80° N and S.

2.3.5. Example of global solution under balloon with INMARSAT BGAN

The combination using of two BGAN high data rate terminals, one installed on the NSO "Operational Housekeeping Gondola", the second on the NCU (Payload or scientific gondola) and the both linked with a TCP/IP wireless link (e.g. WiFi) could be an interesting solution for new designs. A data compression algorithm, chosen to have the best adaptation between the size of the picture to be transmitted and the maximum data rate permitted without pixel loss, could be implemented to offer the same possibilities that the dedicated point to point system but with a major advantage : no limitation on the distance.

3. SYSTEM BASED ON THE PROPERTY OF THE PROPAGATION IN THE IONOSPHERE

This system is the object of a second present Research and Development study. It consists to design an entire system based on the properties of the propagation in the ionosphere in short waves (frequencies comprised between 3.5 and 30 MHz).

Historically, a system named CHACAL used for twenty years from 1976 by CNES to carry the TM from long duration flight balloon under MIR (hot air balloon or Infra Red "Montgolfière"). The data were transmitted from the gondola to three ground stations located in different continents around the world. Generally, one station was installed on the launch pad (i.e. Equator), one in Asia (i.e. New Caledonia) and one in South Africa (i.e. near Cape Town). The mean distance between two stations was about 15000 Km using three bounces on the ionospheric layers (E or F). The efficiency was very good (most 90 % of transmitted frames received both by the three stations. But this system had no TC link, the ground stations were distinct from each others and only one two fixed frequencies were used, one in the low band and one in the upper band (i.e. 6.5 and 15 MHz). The exact frequencies were determined by using a math chart every weeks before launching. The analogical NBFM modulation (Narrow Band Frequency Modulation) was used with a few modulation ratio to minimize the width of the occupied channel and to have the better S/N (Signal over Noise) ratio. This modulation with constant envelop permitted the using of high efficiency non linear amplifier (C class amplification mode)

The propagation in the ionosphere permits transmissions between stations everywhere around the world in complement or in spare of the LEO constellation of satellites.

In 2007, the CNES had not information about the continuity of the IRIDIUM™ commercial communication system and decided the come back of this original TM/TC concept through a R&D study labelled "Numerical Short Wave (NSW) under balloon"

Technological progresses permit its new approach with utilization of :

- Numerical modulations at constant envelop to increase the transmission efficiency and to permit the design of non linear high efficiency amplifiers.
- Half duplex modem to permit the transmission in the two way (TM and TC)
- Adapted transmission protocols (i.e. DTN : Data Tolerant Network) that would permit to minimize the effect of the delay accumulated during the transmission through the ionosphere
- Dedicated software to predict the right frequency to use at a precise time. The calculation is made from different parameters as the position of the balloon and the operational ground station, the solar radiation ratio, the instant of transmission during the day or the night, the season, etc.

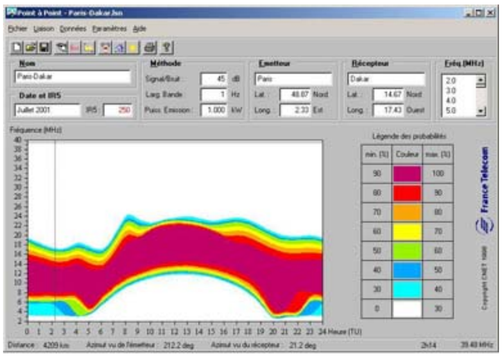

Figure 8. Example of hard copy of the dedicated software used to calculate the exact working frequency

- WAN (World Area Network) to allow a permanent connexion between the ground stations. This network architecture permits to capture and to distribute the information in quasi real time to the main ground control station or to the launch pad to prepare the next launching.

3.1. System definition

The NSW modem (see fig. 9) is installed at the base of the flight train so as to protect the vertical doublet antenna of any disruptive element (metallic cables, magnetic mass…) that could modify the radiation pattern. For the same reason, the link between the operational housekeeping gondola and the NSW modem use a low consumption powered ZigBee terminal (low data rate at 2.4 GHz).

The working frequencies are chosen in seven bands between 3.5 and 30 MHz. To minimize the difficulties to design the antenna and to optimize the SWR (Short Wave Ratio), the frequencies are chosen as harmonics. So, for example, the antenna can resonate at a frequency of 3.5, 7, 14, 21 or 28 MHz. So, with a simple wire dipole correctly shaped, the impedance adaptation is optimized and the maximal energy can be transmitted to the ionosphere.

The transmitted power to the antenna is up to 10 W with a possibility to an adjustment by software. GMSK

(Gaussian Minimum Shift Keying) envelop constant modulation with a 0.5 BT ratio permits the use of non linear amplifier to increase the global efficiency of the onboard segment.

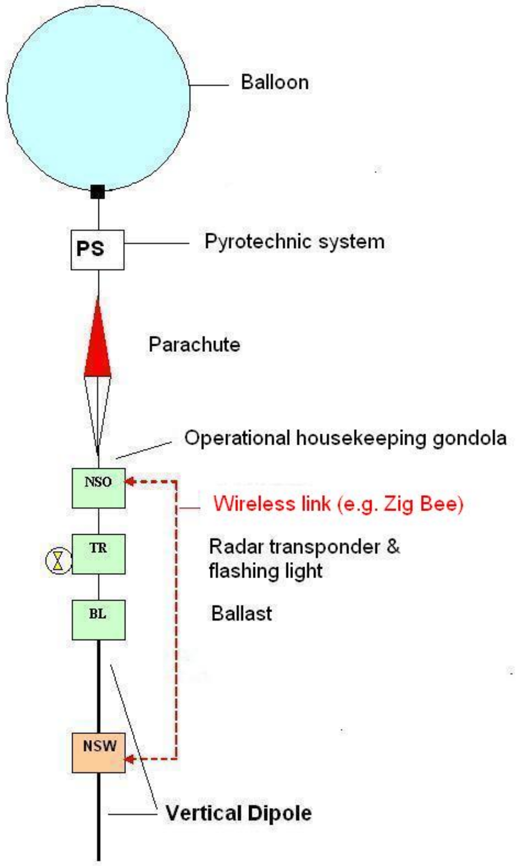

Figure 9. NSW flight train

The NSW prototype modem is displayed on the figure 10. It is about 16 cm long, 10 cm wide for 12 cm high.

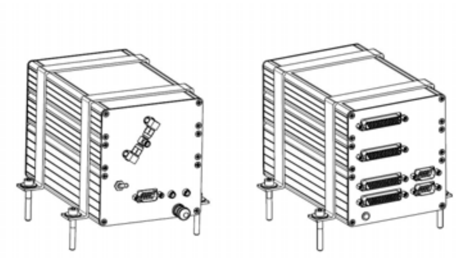

Figure 10. NSW transceiver overview

4. CONCLUSION

CNES Balloon Sub Directorate keeps going on to find new solutions to pilot all balloon flights around the world. The main objective is both the use of home designed systems to keep the entire control of the telecommunication network and to use satellite commercial systems.

Use of COTS designed to work with these commercial systems must be always realize with regards to have the total control of the used system.

For this reason, primary R&D studies must prepare the future and offer solutions for the new projects.

As we saw in this presentation, INMARSAT BGAN™ service could become one vector of transmission for an high data rate exchange with an opened stratospheric balloon everything around the world on latitudes included between 0 and 80 ° N and S. The coupling of several terminals on the same flight train by means of WiFi link associated to a light data compression could allow a solution to carry information around with no complementary ground stations.

On an other hand, the numerical short wave R&D study could offer an alternate solution to pilot a balloon everywhere around the world in the case of the not starting of the IRIDIUM next™ constellation.

CNES Balloon Sub Directorate is expected the first NOSYCA system flight scheduled for the beginning of 2013 to propose new capabilities to the scientific community and continue to assure its mission of scientific applications under balloons carrier.