SSC16-VI-4

3U CUBESAT "EAGLET-1": TOWARDS A FUNCTIONAL NANO-SAT LEO CONSTELLATION

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ABSTRACT

This paper presents the project named "EAGLET-1", a 3U+ CubeSat equipped with a 12 MP panchromatic optical payload and AIS bent-pipe capabilities. An X-Band hi-rate link allows the download of the acquired images while the platform communicates to ground with a VHF band uplink for telecommands (TC) and a UHF band downlink for telemetry (TM). The system, that will be launched in 2017, is designed to operate as a stand-alone spacecraft, although it is planned to operate in conjunction with other similar platforms, in a LEO constellation that will be able to provide complementary services to the ones provided now by much larger geostationary systems or low-orbit radar missions (e.g. Copernicus). The second step, which is scheduled to be concluded by the end of 2017, consists in the development and launch of an upgraded version of the satellite. This second version will feature active AIS elaborating system and a propulsion system. As an upgrade of the previous version, more commercial components will be replaced with self-developed specific parts. Finally, starting in 2018, the EAGLET Constellation will be realized: a system of 20 EAGLET-NG (New Generation) satellites for Earth Observation and maritime surveillance.

INTRODUCTION

The following sections describe the EAGLET-1 mission and its further developments that will lead to the deployment of an operational constellation for Earth Observation. First, our company and its background is briefly introduced, with a short overview of its main heritage. In the subsequent chapter, the EAGLET-1 system is presented. Its main characteristics and performances are discussed and, in the following sections, its future developments (EAGLET-NG) are described, together with an overview of the related constellation. The last section "Services and Products" finally contains a list and a description of the main services that can be provided by the EAGLET constellation.

THE COMPANY

CGS SpA – Compagnia Generale per lo Spazio is a leading company in Italy for the design, development and integration of Space Systems and has been operating in this field for over 30 years. CGS is part of a cluster of European firms owned by OHB SE, one of the three Large System integrators recognized by the European Space Agency. CGS main products include turnkey systems, satellites and instruments, for scientific and application missions for the Italian Space Agency (ASI) and the European Space Agency (ESA). The main recent and current ASI Programs where CGS has the system responsibility are AGILE, PRISMA and LARES. AGILE is a scientific mission for X and Gamma ray observation, launched in April 2007 and still operating, LARES is a LAser RElativity Satellite, launched in February 2012 with the qualification flight of the VEGA launcher and PRISMA is an Hyperspectral Earth Observation Mission currently under development. CGS also develops payloads for ESA on many European missions, among which the gravitational waves sensor for the LISA Pathfinder (Laser Interferometer Space Antenna) mission, the METIS (Multi Element Telescope for Imaging and Spectroscopy) coronagraph instrument for the Solar Orbiter mission and is prime contractor for various instruments on the EUCLID and Bepi Colombo missions. CGS is also the prime contractor of the Micro Wave Imager (MWI), a conical scan radiometer to be flown on board of the Metop Second Generation satellites. With this ambitious project, CGS aims to be one of the first following the trend that the space world is establishing in the frame of Earth Observation, i.e. the use of low-orbit nanosat constellations.

EAGLET-1

The current state-of-the-art of technology allows for the realization of real high performance missions with nanosatellites (mass lower than 5 kg). In Europe, there are many initiatives for the development of nanosats, but they are essentially academic initiatives with no serious industrial approach. CGS has the opportunity to be a world player in this segment. We expect in perspective an interest of new customers that never approached space but also old customers attracted by the use of large constellations.

For the development of a nanosat program, CGS has adopted the CubeSat standard because it is well known at international level, it presents frequent flight opportunities and equally important, its products are easily available on the market.

EAGLET-1 is a prototype of a CubeSat satellite 3U+ in size (10 cm x 10 cm x 34 cm) for Land and Maritime Surveillance, operating in a sun-synchronous orbit at 540-600 km of altitude. Since no propulsion system is mounted on board, the satellite is only able to perform attitude control. The actual orbit is determined by the launcher's precision in the release of EAGLET-1 as secondary payload.

The spacecraft will embark two payloads:

- a high resolution optical payload able to acquire panchromatic photos all over the world, while the Mediterranean area is considered as the Area of Interest;
- a payload, called AIS (Automatic Identification System), able to receive and transmit to the ground, through a transparent repeater, the messages emitted by ships, which include unique identification, position, course and speed, in the area covered by the satellite.

The development strategy of EAGLET-1 consists in the use of COTS whenever possible, retaining for CGS the development of the key technologies, namely the telescope, the focal plane and the AIS.

The optical payload mainly consists of three logically separate items: the telescope, the Focal Plane Assembly and the Payload Electronics (PLE). The selected optical layout allows for a compact longitudinal size with a good image quality all over the field of view. From the electronics point of view, the Focal Plane Assembly includes four parts. The first part is the focal plane board (detector board) with the detector, power supply filters and relevant regulators. The second component is the acquisition board (FPGS board) with the FPGA to manage the detector, the memory buffer and all the interfaces, the frame buffer memories (2 GB), the drivers for the interfaces to S/C On-Board Computer and to the X-band. The third part is the power board (PWR board) to manage all the requested power supply rails drawn by the satellite input main power of 12 V and the last item is the connector board (PC104 and X-band TX connectors). EAGLET-1 optical payload's main characteristics are reported in the following table.

Table 1: EAGLET-1 optical payload characteristics

Lens	Dimensions 116 mm long, 89 mm diameter
	Designed by CGS, manufactured by INAF-Osservatorio Astronomico di Brera
Image Sensor	Resolution 12 MP - 4096(H) x 3072(V)
	Pixel size 5.5 x 5.5 μm
	Frame rate up to 300 fps
Control Board	SmartFusion2 FPGA (system-on-chip)
	Frame grabber
	Data storage (2 GB SDRAM)
	Data recovery and pulse shaping

The second payload, AIS, is capable to receive and transmit to the ground, through a transparent repeater, the signals transmitted by ships in the area covered by the satellite.

It receives frequencies (either at 162 MHz or 156 MHz) and shifts them, with proper filtering, in a band adjacent to that selected for the TLM (Telemetry) of the satellite. The downlink frequency for AIS carrier is 435,8 MHz. Either one or the other of two signals are translated from VHF to UHF. The VHF frequencies are either 161,975 MHz or 156,775 MHz. A picture of the payload operational frequencies is shown in Figure 1.

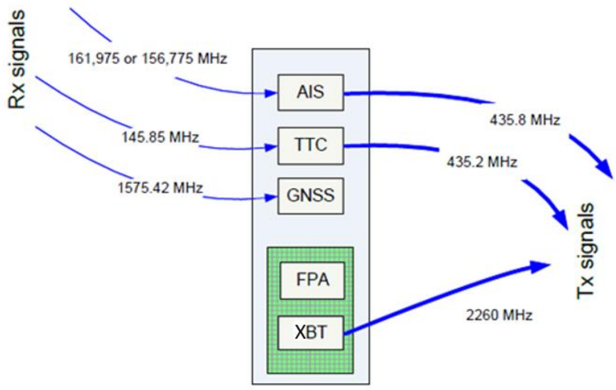

Figure 1: Payload frequencies

EAGLET-1 AIS' main characteristics are summarized in the following table.

Table 2: EAGLET-1 AIS payload characteristics

Power consumption	5 W
Operating temperature	-30°C to +50°C
Storage temperature	-40°C to +80°C
Input frequency	161,975 MHz; 162,025 MHz; 156,775 MHz
Output frequency	435,8 MHz

The development strategy of EAGLET-1 platform consists in the use of COTS selected from main European suppliers.
The power S/S is selected considering the satellite configuration and power requirements; it is composed by EPS, Battery Pack and two deployable solar panels.

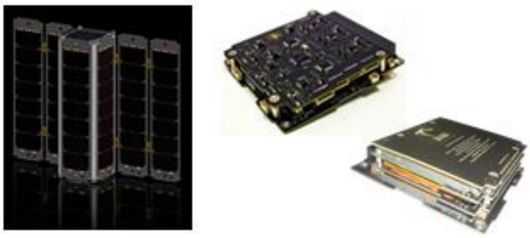

Figure 2: EAGLET-1 Power S/S

The ADCS S/S is selected considering the scope of the mission and the accuracy requirements. A 3-axis control that uses a combination of magnetometer, coarse sun sensor, fine sun sensor, nadir sensor, star tracker and MEMS rate sensor measurements to estimate the attitude of the satellite was selected. Magneto-torquers and reaction wheels are employed as actuators, to stabilize and control the attitude.
The On-Board Computer provides a large variety of interfacing options as well as processing capability while still being very power-efficient. At the same time, the ability to plug in a daughterboard allows for a great degree of flexibility.

Figure 3: EAGLET-1 OBC s/s

The TTC s/s is composed of a VHF/UHF transceiver and antenna.

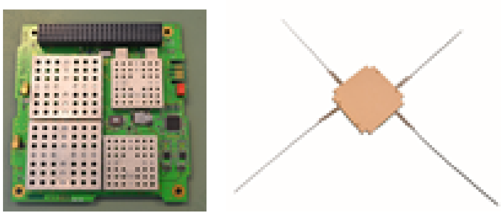

Figure 4: EAGLET-1 TTC s/s

Finally, the platform mounts a X-Band transmitter and antenna for the download to ground of the acquired images and a GPS transmitter and antenna chosen according to the ADCS s/s.

An overview of the entire system is shown in the following figure, while the main characteristics are presented in the table right after.

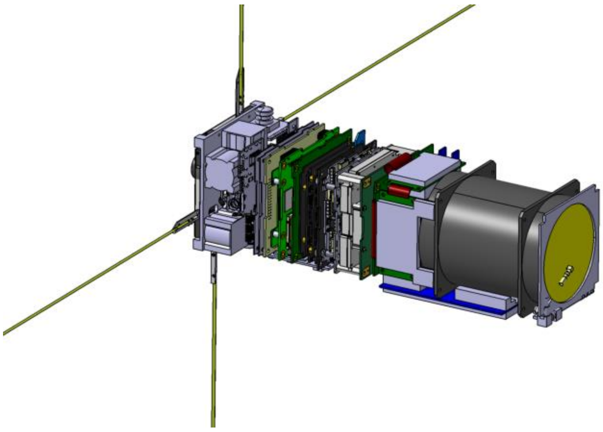

Figure 5: EAGLET-1

Table 3: EAGLET-1 main characteristics

Type	CubeSat satellite 3U+
Telecommand link (TLC)	VHF band
Telemetry link (TLM)	UHF band
Mass	5 Kg
ADCS type	Three axis
ADCS sensors	Earth sensor, Sun Sensor, Star tracker, GPS, Magnetometer
ADCS actuators	Magneto-torquer, Reaction Wheels
Batteries	30 Ah
Solar Panels	Deployable
Payloads	Optical and AIS

Mission

Mission requirements are focused on observation needs, geographical coverage, revisit time, spectral, radiometric and geometric performance.
A fundamental assumption behind this mission concept is the reverse design process concerning classical projects, where Customer/Stakeholders impose mission requirements. Adopting the CubeSat standard, the design starts from low-cost drivers (for bus and P/L), but it is always oriented to maximize the achievable performance, measured with regards to an hypothetical reference mission to demonstrate its commercial suitability. Scope of EAGLET-1 mission is to provide high-resolution Earth images through an Optical Observation System, of an Area of Interest that

encompasses all land areas between -56° and 84° latitude and longitude between –180° and +180°. This area also includes every major island greater than 100 km^2 in size, EU islands and all the other small islands located at less than 20 km from the coastline. The Area of Primary Interest for the mission covers mainly the Mediterranean Sea. It includes the waters between 30° and 46° N of latitude and between 5° W and 37° E of longitude.

Figure 6: EAGLET-1 Area of primary interest

The satellite will be injected into a sun-synchronous orbit between 540 and 600 km of altitude, with an eccentricity in the range of 0 ÷ 0,0043 and ascending node LTAN equal to 10:30. In these conditions, the main mission performance are show in Table 4.

Table 4: EAGLET-1 main mission performance

Ground Sampling Distance (GSD)	7 m	
Nominal Swath width	20 km cross track	
Revisit Time (days)		
Min	**Ave**	**Max**
1,01	2,23	4,99
Information Age for a single image data volume (min)		
Min	**Ave**	**Max**
0,03	8,11	9,00
Information Age for full load data volume (2 GB memory)		
Min	**Ave**	**Max**
1,27	9,66	10,91

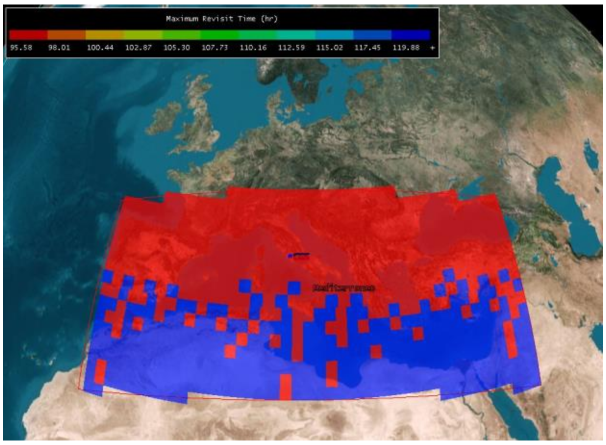

Figure 7: EAGLET-1 max revisit time

The following image is referred to information age for a single image data volume, the red area indicate an instantaneous data acquisition and download for the most of Mediterranean Sea; in orange is represented the area in which is need 1 orbit to download acquisitions; in blu is represented the area in which is need > 1orbit to download acquisitions.

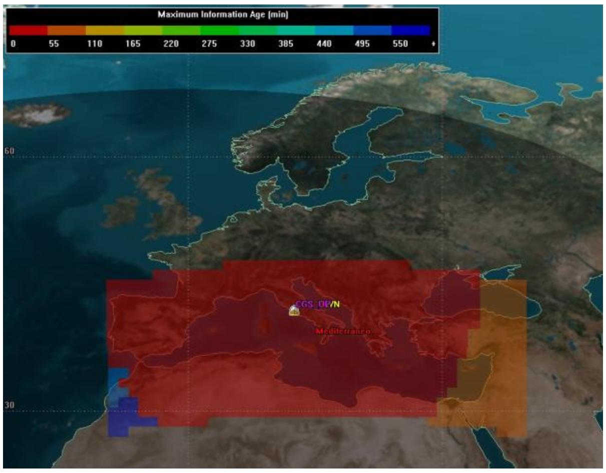

Figure 8: EAGLET-1 Information Age for a single image data volume

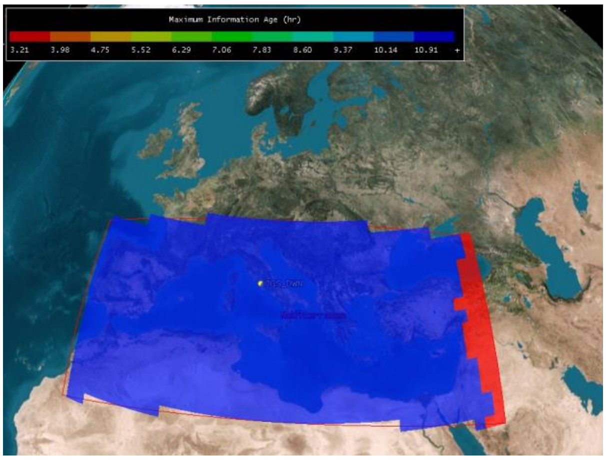

Figure 9: EAGLET-1 Information Age for full load data volume (2 GB memory)

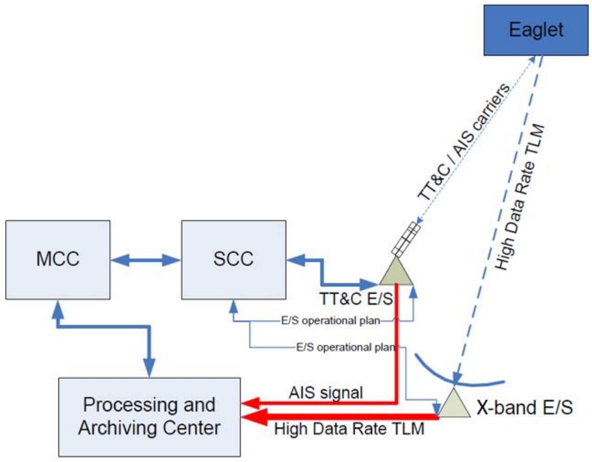

Figure 10: EAGLET-1 ground segment link network

Ground segment

Satellites need to be monitored and controlled in orbit. The telemetry and command subsystem performs several routine functions aboard the spacecraft in order to measure data on board and transfer them to Ground for interpretation, evaluation and reaction.
In case of EAGLET-1, the platform and payloads are simplified with respect to a large satellite and the amount of data to be transferred to Ground is limited. Considering the availability of dedicated HW developed for CubeSats, VHF and UHF bands have been adopted for TLC and TLM respectively.
As already discussed, the satellite is equipped with Telecommand link (TLC) in the VHF band while satellite telemetry (TLM) is downloaded in the UHF band.

The frequencies belong to the amateur radio band to support the TLM signal reception even in areas where a station TT&C is not present. The optical payload transmits High Data Rate Telemetry to ground in the X-band, allocated by the ITU to the Telemetry Downlink service for LEO satellites. Since this service is assigned in this band on a primary basis, this results in a better protection from interference. The receiving station X-band antenna diameter is expected to be greater than 10 m. The ground segment of EAGLET-1 is composed of a Mission Planning and Control Center (MCC), a Satellite Control Center (SCC) and a receiving, processing and archiving center. The link configuration between these different GS elements is summarized in Figure 10.

The Mission Planning and Control Center (MCC) has several tasks:

- Reception of Image Acquisition Request;
- Evaluation of GS and EAGLET-1 operation capability;
- Harmonization of Requests and conflict solving;
- Mission Planning;
- Communicating to the Satellite Control Centre for Operational Plan elaboration within the Eaglet resources;
- Reception of Message of correct EAGLET-1 on board image acquisition and transmission to Ground;
- Reception of Message from Ground Segment of correct satellite acquisition and data reception;
- Reception of Message from Processing and Archiving Center of correct processing and archiving of received data.

The SCC receives and elaborates the telemetry; also, it checks EAGLET-1's operational status (correctness of required operations, verification of performance or anomalies, etc.) and it assess any performance changes. The Receiving, Processing and Archiving Center receives data from the X-band, processes them according to the MCC requests and delivers data to the final users.

FUTURE DEVELOPMENTS

EAGLET-NG

EAGLET-1 represents the first prototype of the nanosat Constellation for maritime surveillance. After the successful deployment of the first batch, a new satellites generation will be developed, named EAGLET-NG (NewGeneration), with additional capabilities, including thermal and multispectral sensors. During this phase, the performance of the observation system will be upgraded, also in terms of number of available spectral channels. The introduction of the thermal infrared bands will provide several additional information exploitable for a great variety of purposes. For example, thermal infrared is useful when temperature control is critical, as in the monitoring of areas affected by wildfires and in the case of the mapping of ground temperatures for weather patterns.

With respect to EAGLET-1, this second version will likely install an active AIS elaborating system, an X-Band link for the downstream of hi-resolution (GSD of 3 meters) images and a propulsion system. As an upgrade and adjustment of the previous version, more commercial components will be replaced with self-developed specific parts, like the ADCS and the propulsion sub-system. One of the purposes of this system is to test the performance of the constellation in terms of inter-satellite link and in-orbit maintenance.

EAGLET CONSTELLATION

As described, the first satellite will be a technology demonstrator for the company's capabilities in the CubeSat field. EAGLET-NG, instead, will show design and realization maturity, while carrying important innovations in the radio communications field and in the propulsion sector, quite essential for a constellation construction. The following step is the building of a CubeSat constellation for remote sensing and AIS services. The satellites will be launched in a SSO orbit at an altitude of about 500 km to respect the requirement for 25 years maximum satellite in orbit lifetime. A communication satellite system is required for continuous coverage in case of interactive communication. The "store and forward" message system, such as the satellite AIS, do not require continuous coverage, but the quality of service (QoS) depends on the latency time. An efficient surveillance system should react in terms of minutes to service request. Figure 11 gives a comparison among circular constellations (the Walker and the Street-of-Coverage or SOC) based on the utilization of continuous bands of coverage, usually resulting in polar orbits.1

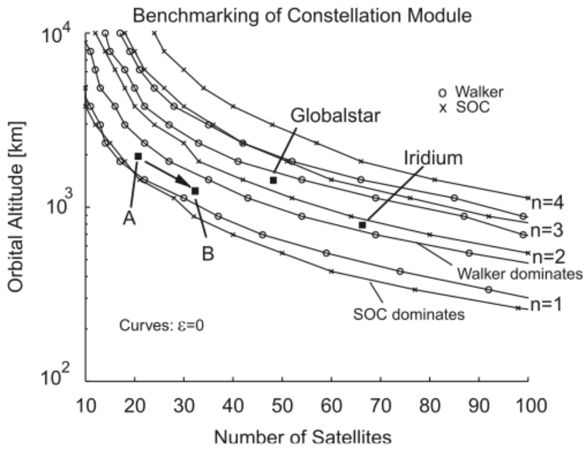

Figure 11: Comparison among circular constellations

Walker constellations are the most symmetric of the satellite patterns. The Walker Delta Pattern contains a set number of satellites distributed evenly within a set number of orbit planes at the same inclination. The ascending nodes of the orbital planes are uniformly distributed around the equator and the satellites are uniformly distributed within the orbital planes. Walker constellations are completely symmetrical in longitude, but perhaps their greatest advantage is that there are a finite number of them and they can all be identified and investigated. Figure 11 states that a continuous coverage, for communication purposes, can be obtained for satellites orbiting at about 500 km (hence with a visibility at 5° elevation of 2000 km) with the utilisation of 50-60 satellites. If we assume to accept 0° visibility, still for communication purposes, leading to less than 10 seconds latency, the number of required satellites can be reduced to about a half, i.e. 30-35 of them. In case of remote sensing, a global coverage of all terrestrial globe, with an inclination of about 45°, leads to the need of an enormous number of satellites (around 800), but accepting a latency of 45 minutes the number goes down to 30/40 satellites and a replenishment plan can be organized to substitute failed satellites or reduce the latency time to 30 minutes by launching 20 additional satellites. This latency time could allow getting the AIS data, to make up a store-and-forward message service and to allow a prompt response for an image anywhere on the Earth surface, within 15 minutes. For images we have obviously the time of the day problem, i.e. no optical images will be available during night.

SERVICES AND PRODUCTS

In a business case analysis for a CubeSat, the LEO based services have to be considered as mainstream. Since latency could be excessive for a single satellite system, a constellation of cooperating satellites should be considered. The first step is to consider the simultaneous presence in orbit of a group of satellites, not necessarily communicating with each other, in orbits that allow them a quasi-continuous coverage, such that a latency of one minute is the maximum tolerated. The following applications have already been considered matching this requirement, and have been or are being realized for telecommunications purposes.

AIS

AIS was developed as a high intensity, short-range identification and tracking network and, since 2008, companies such as ExactEarth, ORBCOMM, Luxspace and Spacequest have deployed AIS receivers on satellites. The TDMA radio access scheme used by the AIS system creates significant technical issues for a reliable reception of AIS messages from all types of transceivers: Class A, Class B, Identifier, AtoN and SART. The current technologies development will allow extending the satellite utilization beyond Class A messages to Class B and Identifier messages. The fundamental challenge for satellite AIS is the ability to receive very large numbers of AIS messages simultaneously from a satellite's large reception footprint. Companies are developing new technologies and CGS has received contracts to decode conflicting TDMA messages by utilizing proprietary schemes that should lead to a single chip decoder integration capable to be installed on-board a CubeSat. Mounting a bent-pipe AIS system, EAGLET-1 will transpose the received 156 and 162 MHz signal to UHF and transmit it to the G/S where proper decoding will be performed. Because of the satellite-based TDMA limitations, the reception performance will never match the terrestrial-based network, and satellites will augment rather than replace the terrestrial system.

ADS-B

ADS-B is a surveillance technology in which an aircraft determines its position via satellite navigation and periodically broadcasts it, enabling it to be tracked. Already proven and certified as a viable low cost replacement for conventional radar, ADS-B allows pilots and air traffic controllers to “see” and control aircraft with more precision, and over a far larger percentage of the earth's surface, than has ever been possible before.

- **Automatic** It is always ON and requires no operator intervention.
- **Dependent** It depends on an accurate GNSS signal for position data.
- **Surveillance** It provides "Radar-like" surveillance services, much like RADAR.
- **Broadcast** It continuously broadcasts aircraft position and other data to any aircraft, or ground station equipped to receive ADS-B.

A significant step forward for ADS-B is the reception, by space-based satellites, of the ADS-B signal. This is being deployed on the IRIDIUM satellite network, a LEO (Low Earth Orbit) satellite network that was created to deliver cell phone service anywhere on the planet. By capturing ADS-B position data from aircraft flying below the satellite, the network will give the following capabilities:

- Traffic – When using an ADS-B In system, a pilot is able to view traffic information about surrounding aircraft if those aircraft are equipped with ADS-B out. This information includes altitude, heading, speed, and distance to aircraft.
- Weather – Aircraft equipped with universal access transceiver ADS-B In will be able to receive weather reports, and weather radar through flight information service-broadcast (FIS-B).
- Flight information – Traffic information service-broadcast (TIS-B) transmits readable flight information such as temporary flight restrictions and NOTAMs.

Full air traffic control will be possible over water, in areas that radar does not currently cover. Receivers for ADS-B have already been installed by ESA on-board the ISS, in advance to possible services offerings.

Store-and-forward messaging

In general, this technique is used in networks with intermittent connectivity, especially in the wilderness or environments requiring high mobility. This technique originates the delay-tolerant networks. No real-time services are available for these kinds of networks. Store-and-forward messaging have been experimented via satellite by the OSCAR satellites of AMSAT, the radio amateur satellites, with the first one being Fuji, OSCAR12, in 1986. Many amateur-satellites receive an OSCAR designation, which is an acronym for Orbiting Satellite Carrying Amateur Radio. In 1992 UoSAT-OSCAR-14 was to provide non-amateur radio related store-and-forward digital communications for VITA and SatelLife, a non-profit, humanitarian organization, using VHF and UHF frequencies. Currently, over five fully operational amateur-satellites in orbit act as repeaters or store and forward digital relays.

Cargo Tracking

The tracking of cargo containers over the open ocean is highly valued since a current tracking system for cargo containers is capable of identifying the container within a mile from shore, but loses all contact for the majority of the open-water journey. This is a store-and-forward-like service and could be integrated with the previous one.

TV broadcasting by CubeSats in geostationary orbits

As more small satellites operate in space, a theoretical concept of their capabilities is useful not only for satellite designers, but also current spacecraft operators and space situational awareness observers. The study “Small Satellite Capability Analysis: Communications Subsystem”2 examines the maximum communication capability of a S-band geostationary small satellite as part of a larger Small Satellite Capability Analysis study. Link budgets show that a Geostationary satellite operating in C-Band can deliver 1-2 Mbps video signal DVB S2 encoded to a 2 m user dish-antenna on ground, if the satellite can deliver about 23 dBW EIRP i.e. 1 W RF power over the full visible globe.

Designed Services

Besides the aforementioned possible solutions, the EAGLET Constellation is designed to provide several additional services to a wide range of different users, both institutional and commercial. These services can cover three major areas of intervention, namely Security, Disaster Management and Natural Resources.

Regarding the first area, Security, the constellation will be able to provide services related to survey and surveillance. Thanks to its low revisit time and the capability of observing multiple areas at the same time, the constellation can monitor the evolution on a specific target location, granting enough information to determine, for example, the main characteristics and feature of a collaborative or non-collaborative ship or vessel. This, combined with the active AIS capabilities of the next EAGLET satellites and/or with the data about last known position/velocity, can provide valuable information to users and agencies interested in monitoring and preventing trafficking, smuggling and any possible illicit activity that involves maritime transportation. This includes, for example, national Navies, costal guards, immigration control, etc. Another interesting exploitation of these capabilities is the surveillance of archaeological sites along with the capability of discovering new ones. Using subsequent observation, the system is able to recognize any relevant change in the area, detecting for example illegal operations on these sites. Moreover, using pattern recognition algorithms combined with HR imaging, it will be possible to perform shape detection, allowing the identification of sand-covered or ground-covered structures and sites.

Concerning the Disaster Management activities, such a constellation can be extremely useful due to the responsiveness of its data. Highly frequent observation of multiple areas, in fact, can provide quick alerts when it comes to the early detection of disasters like flood or wildfires, as well as anthropogenic events like the diffusion of polluting agents. If used in synergy with traditional EO systems like COPERNICUS, the effectiveness of the observations rises drastically: the EAGLET Constellation can detect the event quickly, thanks to its revisit time and the multiple observable points, and a Sentinel can consequently monitor the event as long as it is needed, with higher performances. Institutional users potentially interested can include civil protection agencies, forestry corps, firefighters, police forces.

Finally, the constellation can successfully exploit support for what it concerns the management of Natural Resources. In this framework, EAGLET can provide services related, for example, to the so-called “precision farming”. Through the provided information, the user can evaluate the hydrological needs of the terrain, the actual conditions, like the levels of pollution or nutrients in the soil, its nature and any treatment that may be requested. Water consumption is another very important subject that can be appointed by such a service, binding the irrigation of the crops to the actual usage instead of determining it by shifts. Another use of this service is the identification of the conditions of forests and their situation (health, deforestation, fauna/flora species diversity, etc.). These operations can take extremely advantage from the provision of satellite data, causing an inversion of the trend and allowing intervention before the matter becomes an issue (prevention vs. intervention). Potential users for these services can include private companies or farmers as well as institutional user such as those interested in the development of the national agricultural system, local and regional agencies, and forestry corps.

CONCLUSIONS

This paper discussed the mission EAGLET-1, a nanosatellite designed as a 3U+ CubeSat, that will be launched at the beginning of the year 2017. This spacecraft will perform Earth Observation activities during its lifetime and it will set the base for the development of a LEO nanosat constellation that will provide EO services to different users. The main features of the system are hereunder collected and presented in Table 5.

Table 5: EAGLET-1 system characteristics

Type	CubeSat satellite 3U+
Orbit	Sun-synchronous at about 540 to 600 km altitude
Orbit eccentricity	0 ÷ 0,0043
Telecommand link (TLC)	VHF band
Telemetry link (TLM)	UHF band
Mass	5 kg
ADCS type	Three axis
ADCS sensors	Earth sensor, Sun Sensor, Star tracker, GPS, Magnetometer
ADCS actuators	Magneto-torquer, Reaction Wheels
Batteries	30 Ah
In flight thermal environment	-30 ÷ +80 °C
Area of primary interest (Mediterranean Sea)	Latitude between +30° and +46° N Longitude between -5° W and 37° E
Satellite effective revisit time	15 days (goal) 30 days maximum
Satellite geometrical revisit time	5 days (goal) 10 days maximum
Target pointing accuracy	5 km (goal 1 km)

References

1. Adams and Rider, "Circular polar constellations providing single or multiple coverage above a specified latitude", The Journal of the Astronautical Sciences, 35, 1987.
2. Jones S., "Small Satellite Capability Analysis: Communications Subsystem", Applied Technology Associates, Air Force Research Laboratory, RVSS/SSAIG.