BISS, a BI-DIRECTIONAL INTERNET of THINGS SATELLITE SERVICE: PRELIMINARY STUDIES and FUTURE PERSPECTIVES

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The use of CubeSat constellations in synergy with terrestrial networks, by allowing global connectivity with low cost and low power consumption, can provide an important contribution to the growth of Internet of Things services. In this framework, the BISS project, recently funded for phase A/B activities by the Italian Space Agency, aims at developing a CubeSat constellation, together with the relative ground and user infrastructures, to build up a worldwide competitive Internet of Things service. Peculiarity of the BISS project will be the two-way communication capability of its ground devices, enabling several promising services in remote zones. These services will cover, among others, applications for environmental monitoring, railways and roads transport, electricity transport, oil and gas, smart cities and agriculture, assets tracking. In the present paper, the first outcomes of BISS preliminary studies in regard of its space, ground and user segments definition, are provided beside a quick insight into the innovations introduced and the services potentially enabled by the project.

1 INTRODUCTION

ASI has recognized the need to put emphasis on a through and integrated strategy to maximize the benefits from the micro- and nano-satellite domain in advancing overall Agency objectives. In particular, ASI has established a new Operative Unit dedicated to the Development of Micro- and Nano-Satellites and has foreseen in its Plan of Activities 2021-2023 several initiatives aimed at placing Italy in a condition of consolidated leadership in the CubeSat sector, to be achieved with appropriate investments of value, wisely distributed between missions and the development of a national technological roadmap.
A dedicated call for tenders called "Future CubeSat missions" has been recently emanated to fund novel missions, either through ESA Global Support Technology Program (GSTP) or, when available, national resources. An incremental approach is adopted by funding the mission up to phase A/B and then, if promising results are achieved, for the following phases. Of fortynine received proposals, twenty have been selected as eligible to be funded and eleven can rely on already allocated funds. In particular, two of these missions are funded through ESA GSTP, while the remaining nine missions, are funded with national resources. The twenty selected missions cover a very diversified spectrum of topics, including among others: telecommunication for Internet of Things (IoT), optical and radar remote sensing for Earth observation, astrophysics for space weather, Universe, planetary and Near-Earth Object (NEO) exploration.

In this framework, the BISS (BI-directional IoT Satellite Service) proposal by IMT, which resulted as the first classified by the Agency technical evaluation, has been funded up to phase B completion. BISS, kicked-off in January 2022, is now ongoing the phase A and is approaching the Preliminary Requirements Review (PRR), where mission requirements and preliminary flow down at system level will be presented. Two other major key points are foreseen on the way forward, a System Requirements Review (SRR) at T0 + 6 months, aimed at consolidating the requirements at system, sub-system and component level, and a Preliminary Design Review (PDR) at T0 + 12 months, to freeze the preliminary design.
Beside IMT, prime contractor of the BISS project, D-Orbit, University of Bologna (CIRI-Aero), LeafSpace and Fincons are involved as partners, sharing expertise in the field of attitude determination and control, mission analysis and control, ground segment hardware and services, IoT payload and ground devices, IoT network and application servers. Such a team has the know how to assure an end-to-end solution, from the IoT hardware (both satellite and ground devices) to the IoT software (both network and application servers).
Currently, there are several worldwide satellite IoT projects by Astrocast, Myriota, Hiber, Eutelsat, OQ Technology, Lacuna Space, Sateliot, EchoStar Mobile, Swarm Technologies [1]. These projects are based on LoRaWAN, NB-IoT or Sigfox technologies, Ultra High Frequency (UHF), L or S bands and transferred data payload of few tens of bytes.
The BISS projects aims at covering the gap present in the current systems of satellite IoT, by making the system compatible with both the satellite and terrestrial networks and by implementing a bi-directional link with IoT ground devices.
In the following, the innovations introduced and the services enabled by BISS in the field of satellite IoT services are presented together with an overall system description in regard of its different segments, as depicted by the product tree in Figure 1 and as arise from first performed analysis and design activities.

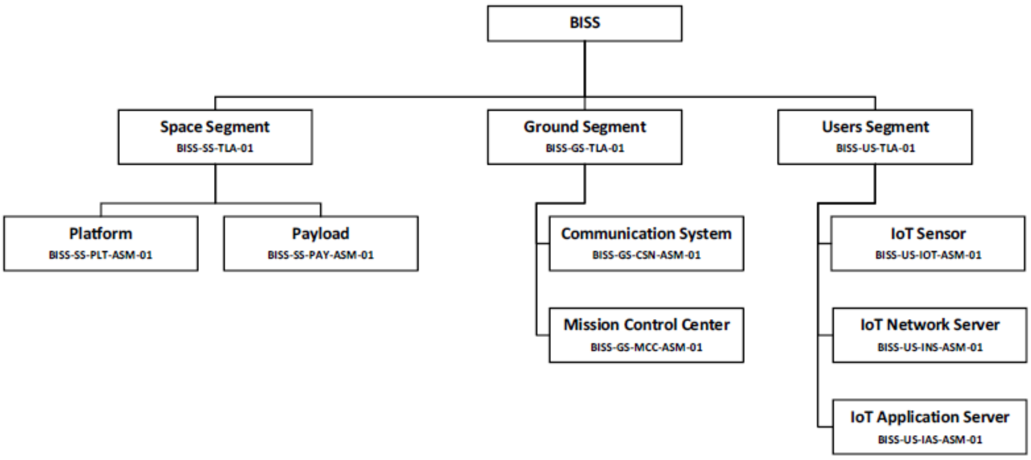

Figure 1. BISS product tree.

2 NOVEL IOT CONTRIBUTION from BISS PROJECT

The main purpose of the BISS project is to design the first Italian CubeSat for IoT mission in Low Earth Orbit (LEO) and to lay the foundations for the related IoT service infrastructure, from IoT ground devices to IoT network and application servers. This is considered the first steps towards the realization of an Italian CubeSat constellation able to provide a competitive IoT service, with global coverage, low cost and low power consumption.

The latter requirements are nowadays considered essential to allow a further growth of IoT services, in a market that is already experiencing a strong expansion. The IoT market is in fact showing an annual growth rate between 25% and 40%, with a prevision of global coverage in 2025.
Existing constellations, however, satisfy only part of the aforementioned requirements, by allowing a global coverage with solutions that do not satisfy the low cost and low power consumption criteria. Conversely, terrestrial networks guarantee low cost and low power consumption connectivity, but do not cover more than the 10% of the globe surface [2].
To overcome such limitations, the BISS project combines a satellite network, constituted by a constellation of CubeSats, which is intrinsically characterized by low cost and low power consumption, with a terrestrial network connectivity. This is allowed by the possibility of BISS IoT ground devices to connect using either the satellite network and the terrestrial one.
Such an important feature is envisaged only for few existing satellite IoT projects, which however do not have the possibility to perform a bi-directional communication between the satellite network and IoT ground devices. The bi-directional communication is peculiarly introduced by the BISS project, with its downlink allowing the satellite to provide ephemerides to the IoT ground devices. In such a way they can enter an idle mode when no satellite passage is foreseen and can turn on very close to the satellite passage in order to exchange the IoT data payload as usual. To have IoT ground devices in idle mode for a long part of their operational lifetime allows a significant power consumption saving, enabling the installation of IoT sensors in very remote zones for the monitoring of several parameters in very different fields of application.
The BISS service schematic is presented in Figure 2.

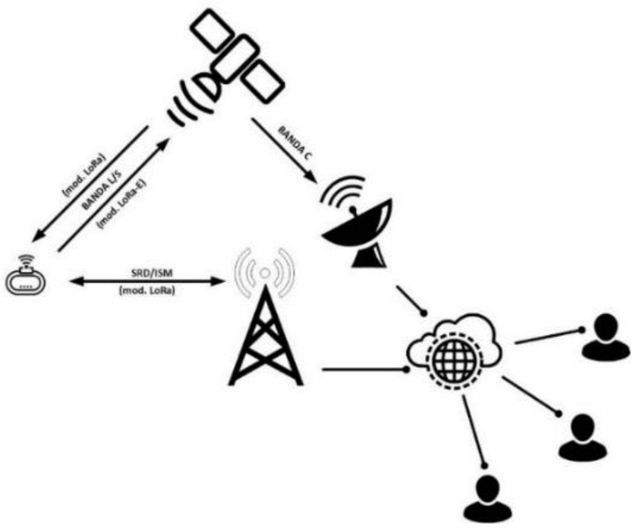

Figure 2. BISS service schematic.

3 ENABLED IOT SERVICES by BISS PROJECT

Several applications are enabled by the BISS service, allowing the environment monitoring, as well as the monitoring of mining infrastructures, oil and gas infrastructures, agriculture and livestock. Beside the previously discussed low power consumption and long life of IoT ground devices, they will be miniaturized to guarantee the application in remote zones, where the small dimension is also an important driver. In Table 1 some IoT services that will be enabled by the BISS project are presented, together with the relative monitored parameter and advantage with respect to the present used systems.

Table 1. BISS enabled services.

Field of application	Monitored parameter	Advantage with respect to the present used system
Electricity transport and distribution	Structural integrity of supports	Installations in inaccessible places, not covered by another network. Sensors very distant from each other to be reached by a concentrator equipped with a satellite modem. No power. Good visibility of the sky.
Electricity transport	Temperature, conductor elongation	Installations in inaccessible places, not covered by another network. Sensors very distant from each other to be reached by a concentrator equipped with a satellite modem. No power. Good visibility of the sky.
Transport - Railways	Long-term structural analysis of works of art (bridges, etc)	Installations in mountain areas not covered by another network. No power. Partial visibility of the sky.
Transport - Railways	Structural integrity of rail joints	Very small sensors with tight spaces for antenna and battery. No power. Ground level mounting with poor visibility of land concentrators. Good visibility of the sky.
Transport - Railways	Rail temperature	Very small sensors with tight spaces for antenna and battery. No power. Ground level mounting with poor visibility of land concentrators. Good visibility of the sky.
Transport - Railways	Long-term monitoring of landslides	Installations in inaccessible places, not covered by another network. Sensors very distant from each other to be reached by a concentrator equipped with a satellite modem. No power. Good visibility of the sky.
Transport - Roads	Long-term structural analysis of works of art (bridges, etc)	Installations in mountain areas not covered by another network. No power. Partial visibility of the sky.
Transport - Roads	Long-term monitoring of landslides	Installations in inaccessible places, not covered by another network. Sensors very distant from each other to be reached by a concentrator equipped with a satellite modem. No power. Good visibility of the sky.
Oil & Gas	Pressure measurement in isolated pressure points	Installations in inaccessible places, not covered by another network. Sensors very distant from each other to be reached by a concentrator equipped with a satellite modem. No power. Good visibility of the sky.
Oil & Gas	Cathodic protection: measurement of voltage and current at points arranged along the tube	Installations in inaccessible places, not covered by another network. Sensors very distant from each other to be reached by a concentrator equipped with a satellite modem. No power. Good visibility of the sky.
Environment	Level of rivers and lakes	Installations in inaccessible places, not covered by another network. Sensors very distant from each other to be reached by a concentrator equipped with a satellite modem. No power. Good visibility of the sky.
Environment	Oceanographic buoys with parameters such as water temperature, pH, salinity, wave motion, etc	The only available carrier is the satellite.
Environment	Measurements of gas concentration in the atmosphere, background radiation, etc	Installations in inaccessible places, not covered by another network. Sensors very distant from each other to be reached by a concentrator equipped with a satellite modem. No power. Good visibility of the sky.
Asset tracking	Tracking of containers at sea	The only available carrier is the satellite.

Smart city	Cathodic protection: measurement of voltage and current at points arranged along the tube	Installations in inaccessible places, not covered by another network. Sensors very distant from each other to be reached by a concentrator equipped with a satellite modem. No power. Good visibility of the sky.
Smart agriculture	Measurements of moisture, soil conductivity to optimize irrigation	Installations in inaccessible places, not covered by another network. Sensors very distant from each other to be reached by a concentrator equipped with a satellite modem. No power. Good visibility of the sky.

4 SPACE SEGMENT OVERVIEW

The constellation design and the mission architectural design, performed by University of Bologna (CIRI-Aero), are made sufficiently flexible to allow future increases of the number of satellites in the constellation. The first goal of the service implementation is to assure a maximum latency time of 24 h and then, by incrementing the number of satellites in the constellation, to decrease the latency time up to few hours.

The space segment will be composed by 6U CubeSats developed by IMT, whose platform will be based on both Commercial Of The Shelf (COTS) sub-systems and custom ones. Among the latter, for example, the Attitude Determination and Control System (ADCS), including the Global Navigation Satellite System (GNSS) receiver, will be developed by D-Orbit.

The IoT payload, in charge to IMT, will be operative for the whole orbit segment both in transmitter and receiver operational modes. It will be composed by a deployable Quadrifilar Helix Antenna (QHA) in S band and a Radio Frequency (RF) processing unit. They will assure a bi-directional link with the End User (EU) devices, to transmit service data and receive payload ones. Thanks to this bi-directional link, it will be possible to improve the performance of the EU lifetime and the link stability. The payload data length will be variable as a function of the volume of acquired data and the space segment status. With the first satellite deployment the amount of payload data is expected to be around 50 byte, which is sufficient to cover several services in rural areas.

To assure the required payload power consumption, the µSADA [3], a solar array drive mechanism suitable for 6U and 12U CubeSats, is planned to be used. The µSADA, developed by IMT under an ESA GSTP contract, is now under validation, with end of testing activities expected for Q2 2022. Thanks to the Sun pointing mechanism of the µSADA, it will be possible to increase the maximum on-board generated power up to 120 W, thus to reach an Orbit Average Power (OAP) greater than with traditional solar array deployment systems.

When the satellite is in contact with the ground segment, the IoT data collected and stored during the orbital motion are transmitted to the ground station through a feeder link transmission channel. Depending on the volume of data, a high data rate communication sub-system in C band called SCAT could be implemented. The SCAT [4], developed by Sitael, IMT and University of Bologna under an ESA Advanced Research in Telecommunication Systems (ARTES) contract, can reach throughput up to 50 Mbps in the 5091-5216 MHz band, suitable for feeder link services.

In Figure 3 the preliminary layout of the BISS satellite is shown.

At the end of the phase A/B, the platform preliminary design will be defined and suitable breadboards for both the payload and antenna systems will be developed. Thanks to these breadboards, it will be possible to start preliminary functional tests in order to verify the main performances of the system such as data rates, modulation and robustness to the Doppler effects like Doppler shift and Doppler rate.

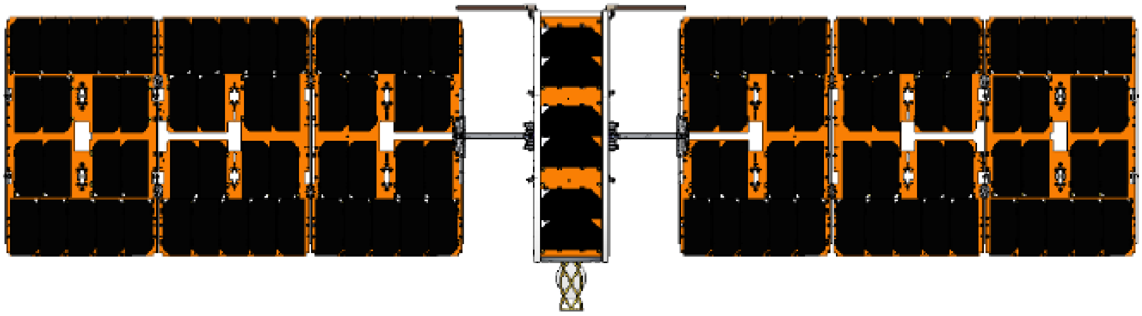

Figure 3. BISS satellite preliminary layout (credit by IMT).

5 GROUND SEGMENT OVERVIEW

The ground segment will be composed by a network of ground stations and a mission control centre. The first is in charge to the company Leaf Space, the second one to the company D-Orbit.
Thanks to Leaf Space solutions called Leaf Key (dedicated ground segment service) and LeafLine (shared ground station network) it will be possible to communicate with the BISS constellation for a long time in several different locations of the globe. The LeafSpace ground stations are compliant with the UHF, S and X bands to assure the maximum compatibility with the BISS platforms. Thanks to more than fifteen ground stations located worldwide, it will be possible to perform the most convenient satellite communication in order to reduce the service latency time. The LeafSpace ground stations are equipped with large aperture antennas, up to 4 m, and an Effective Isotropic Radiated Power (EIRP) over 50 dBW that assures high data rates.
In Figure 4 LeafSpace ground stations picture and functional diagram are presented.

Figure 4. LeafSpace ground stations picture and functional diagram (credit by LeafSpace).

The constellation satellites will be controlled by a mission control software of D-Orbit, called Aurora. Aurora is a powerful cloud-based mission control software suite with an user-friendly, fully customizable, control interface. Thanks to its flexibility and modularity, the Aurora software architecture will be tailored to support the BISS mission in all definition phases, from the service deployment, with one or few satellites, to the full service operation, with several satellites in orbit.
In addition, the Aurora software is installed in a private cloud instance with AES256 encryption 2FA token user authentication, to ensure a state-of-art cyber security protection.
In Figure 5 D-Orbit mission control centre and Aurora functional diagram are presented.

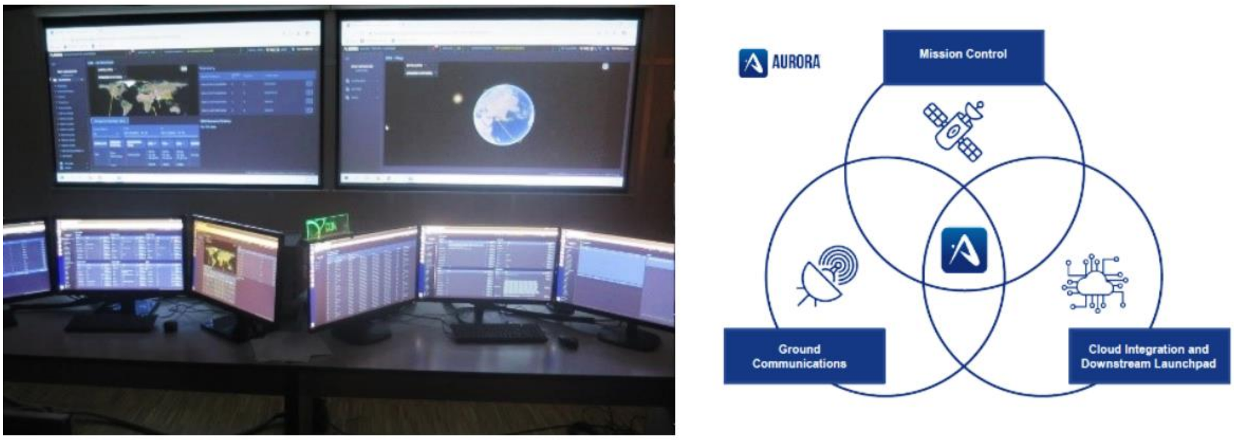

Figure 5. D-Orbit mission control centre and Aurora functional diagram (credit by D-Orbit).

6 USER SEGMENT OVERVIEW

The user segment is composed by the following main blocks:

- EU device
- Terrestrial gateway (optional)
- Network server
- Application server

The EU devices, terrestrial gateway and network server are in charge to IMT with the support of WiLab, a spin-off of the University of Bologna, and Axatel. The application server is in charge to Fincons.

The EU devices will be compact, low cost and low power consumption modules suitable for satellite IoT service in rural areas. The module will implement both terrestrial and satellite communications to perform different services based on operational and service cost needs. The module will be able to use either the terrestrial network, if implemented, like a conventional IoT device, or the satellite link as a primary or backup communication, when the terrestrial network is not operative, in order to improve the service availability. The EU device will be composed by a LoRa transceiver and a dedicated RF front-end. The latter will assure both terrestrial and satellite links, by using the amplification stage needed for long range communications. Obviously, the EU device will allow the connection with two antennas for both links. In order to assure compatibility with already available IoT sensors, the EU device will implement UART or SPI data interface, with 3.3 V bus voltage.

The terrestrial gateway will be made compatible with the LoRa/LoRaWAN technology, in order to improve the compatibility with already existing IoT networks.

The main role of the network server will be to manage the endpoints and gateways that are dispersed throughout the terrestrial network or the satellite constellation. In addition, the network server will coordinate data routing to EU applications, ensuring that information reaches its final destination secretly and intact. Moreover, the network server will allow scalability, from small to large scale deployment as a function of the number of EU devices and constellation satellites.

Finally, the application server will handle the LoRaWAN application layer, including the payload data decoding and decryption.

7 CONCLUSIONS

The phase A/B of the BISS project by the Italian Space Agency has been recently kicked off and is now approaching the PRR. The overall definition of BISS space, ground and user segment is on track, with the goals to have fundamental breadboards tested and the preliminary design well defined within Q1 2023. If promising results will be achieved, this will be the first step towards the realization of a competitive satellite IoT service, relying on global coverage, low cost and low power consumption, thanks to the use of CubeSat platforms. Crucial technologies to this aim will be the dual connectivity, with both satellite and terrestrial networks, as well as the ability of bi-directional communication between satellites and IoT ground devices, enabling several promising IoT services in remote zones.

8 REFERENCES

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