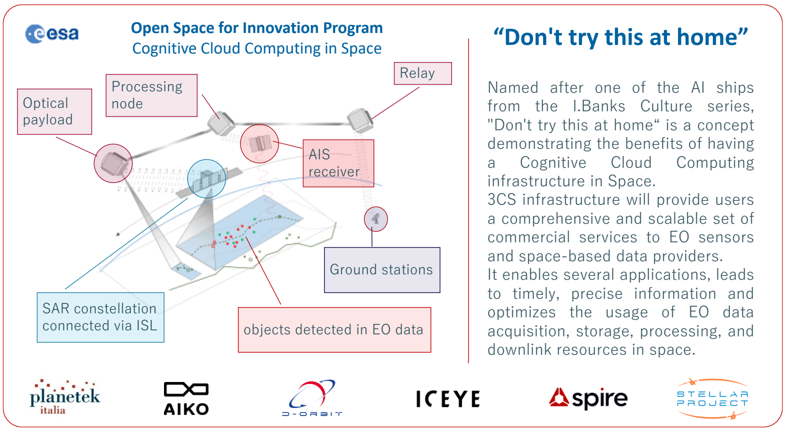

Don't try this at home

Executive summary

<u>IDEA: I-2022-00366</u>

Channel: EISI - Studies Proposals

Affiliation(s): <Planetek Italia srl (Prime), AIKO s.r.l (Sub 1), D-Orbit SpA (Sub 2), ICEYE (Sub 3), Spire Global (Sub 4), Stellar Project (Sub 5)>

Activity summary:
In ESA's vision "Cognitive Cloud Computing in Space (3CS)" is the future edge and cloud computing infrastructure in space for the next generation of AI-powered space missions. "Don't try this at home" is a concept demonstrating the capabilities of such a 3CS architecture, integrating AIS and EO(SAR) and providing comprehensive and scalable commercial services to final users that span any EO sensor platform. 3CS enables the efficient fusion of information at a variety of wavelengths, and times, and can provide timely, information that optimizes EO downlinking, storage, and processing. A 3CS-enhanced workflow brings advantages in terms of lowering latency, accuracy and improving coverage and responsiveness.

DISCOVERY

Executive summary

Don’t try this at home
(Cognitive Cloud Computing in Space)

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Planetek Italia S.r.l.
Società certificata in conformità alle norma ISO 9001, ISO 14001, SA 8000, ISO 27001 e EMAS III.

<Public>

Document History

List of reviews			
Version	**Authors**	**Date**	**Note**
1.0	Integrated tech. and BDev teams	30/11/2022	The first issue for FR

Table of Contents

1. Summary

1.1. Purpose of the document

This document is the ***executive summary*** (ES) for the “EISI - Studies Proposals, ***Don’t Try This at Home*** [***DTTaH***][Agreement/PO number: 4000138076]. It is meant to provide an ***overview of the core technical and key business modeling*** activities performed by the consortium during the study.

1.2. Structure and organization of the document

This document is structured as follows:

- ✓ **Chapter 1**: this chapter;
- ✓ **Chapter 2**: presents ***main items and outcomes*** of the activities;
- ✓ **Chapter 3**: provides an ***assessment*** of the ***application scenarios***;
- ✓ **Chapter 4:** a **mapping of 3CS functionalities** applied on **specific use case;**
- ✓ **Chapter 5: an overview** of application workflow design and final consideration;
- ✓ **Chapter 6:** highlights commercialization aspects by reporting a summary of the intended business model.

1.3. Applicable documents

[AD 1] Discovery_EISI_Agreement_I-2022-00366_ESA, purchase number 4000138076
P22S1957-02-v1

1.4. Reference documents

[RD 01] Don’t Try This At Home Final report
P22S1957-15-v1_FR

[RD 02] https://www-wired-com.cdn.ampproject.org/c/s/www.wired.com/story/nord-stream-pipeline-explosion-dark-ships/amp

[RD 03] Spire Constellation data

[RD 04] https://www.eoportal.org/satellite-missions/copernicus-sentinel-1#mission-capabilities

[RD 05] SPIRE AIS DATA INFORMATION: https://documentation.spire.com/

[RD 06] ESA - Data products

1.5. Acronyms

3CS:	Cognitive Cloud Computing Infrastructure in Space
AIS:	Automatic Identification System
CEOS:	Committee on Earth Observation Satellites
CEP90:	Circle of Error Probability 90%
DB:	Data Base
EO:	Earth Observation
ESA:	European Space Agency
ION:	InOrbit Now
HPC:	High-Performance Computing
HPCP:	High-Performance Computing Platform
HSL:	High-Speed Link
HW:	Hardware
MSSI:	Maritime Mobile Service Identity
OBC:	OnBoard Computer
OD:	Object Detection
OTV:	Orbital Transfer Vehicle
PN:	Processing Node
SAR:	Synthetic Aperture Radar
S/C:	Spacecraft
S/S:	Sub-system
SS:	Space Segment
SW:	Software
TBC:	To Be Confirmed
TBD:	To Be Defined
TC:	Telecommand
TIR:	Thermal Infrared
TS:	Technical Specification
VIS:	Visible
VDES:	VHF Data Exchange System

1.6. Definitions

CEP90

Common metric used to describe performances in geolocation accuracy for Earth Observation data. It corresponds to the radius of a circle encompassing 90% of errors, i.e., 90th percentile.

2. The activity in a nutshell

"***Don't try this at home***" (named after one of the AI ships from the I.Banks Culture series) is a ***concept demonstrating the benefits of having a Cognitive Cloud Computing infrastructure in Space (i.e., the 3CS)***. Such infrastructure shall provide users with a comprehensive and scalable set of ***commercial services to Earth Observation (EO) sensors and Space-based data providers***. It enables several applications by ***efficiently collecting and fusing*** information on target objects from observations of different platforms at various wavelengths, resolutions, and times. As a result, it leads to ***timely, precise information***. In addition, it ***optimizes*** the usage of EO data acquisition, storage, processing, and downlink ***resources*** in space.

A ***pilot application*** is proposed to demonstrate the power of the concept. This pilot is based on the ***critical maritime domain's need for EO data-derived information to detect and characterize artificial, natural, and anomalous floating objects and their behaviors***. These results are achieved by ***fusing synthetic aperture radar data, with Automatic Identification System (AIS) and Maritime Mobile Service Identity (MSSI) data and weather forecasts*** to provide ***near-real-time reports/ alerts for non-collaborative objects*** on their route to ships or anomalous behaviors ***to*** the appropriate ***local authorities***. This application scenario aims at the ***consolidation of the design*** of the infrastructure that leverages the technologies required for ***edge computing, tip and cue, and data fusion*** between different satellite systems. The final goal is to optimize information gathered from various platforms, with different resolution sensors, and at different frequencies.

The achievements of this study are a ***preliminary 3CS architecture***, the ***identification of its technological nodes,*** and the ***quantitative evaluation of the value*** it provides to users. As a final result, this activity will define the ***model for the commercial services*** 3CS would enable and the path of a possible technically and commercially viable ***implementation roadmap***.

3. Application scenario assessment

3.1. Overview

The pilot application proposed to demonstrate the power of having a Cognitive Cloud Computing Infrastructure in Space, is framed in the domain of maritime situational awareness, considering those systems and services aimed at using EO data-derived information to detect and characterize artificial, natural, and anomalous floating objects and their behaviors. Ideally, the best outcomes are achieved by fusing synthetic aperture radar data, with AIS and MSSI data and weather forecasts to provide near-real-time reports/alerts for non-collaborative objects on their route to ships or anomalous behaviors to the appropriate local authorities.
Among the most important aspects to be considered going towards the design of a user-valuable and effective system, are the following:

- **Timely-effective detection** & **reaction** to possible hazards help in mitigating navigation risks, improving safety assessment;
- **Complementary-derived information** based on the **synergic** use of EO data + AIS/MSSI data + weather forecast;

Cooperating space-based data providers & services demonstrates the benefits of having a Cognitive Cloud Computing infrastructure in Space

4. Mapping of functionalities to 3CS node(s) and component(s)

To define and develop a basic 3CS mission scenario, three main nodes (Figure 4-1) are defined:

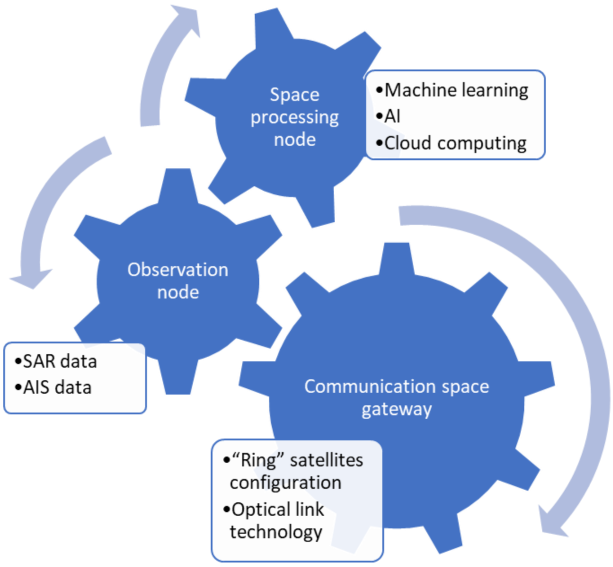


Figure 4-1. 3CS: Main nodes

- **OBSERVATION NODE:** includes all terminals involved in the observation phase (optical satellites, SAR satellites, ground support, etc…)
  The main observation category is divided into three main sub-categories:
  - **Earth Observation (EO) Node:** Optical and SAR satellites for AoI observation
  - **NO-EO Node**: AIS data acquisition provided by SPIRE company
  - **Weather Node:** Provided by AIS services, provided by other sources (EUMETcast, METEOsat,..)

- **PROCESSING NODE:** includes all satellites, space, and ground terminals involved in the processing phase (Satellites, OBC, storage capacity, ground support).
  Two main sub-groups are considered:
  - **Space Processing Node:** it shall be able to process SAR data starting from the raw data to the focusing and running algorithm for object detection and classification. It shall be able to merge SAR data with AIS and third-party data such as Sentinel-1 images or weather data to elaborate final reports and alarm signals.
  - **Ground Processing Node:** The ground processing node allows making complete elaboration of AIS data to create a complete set of vessel position data. Other services as vessel route prediction and weather data are provided by the ground.

- **COMMUNICATION NODE:** includes all technologies related to the communication (from the communication subsystem to the satellite configuration and general mission analysis).
  Two main sub-categories are analyzed :
  - **Space -Space Gateway**
  - **Space-Ground-Space Gateway**

4.1. Northstream disaster: What if we had 3CS?

On Sept. 26, 400,000 tons of methane are escaping from the North Stream pipeline. In a few hours, the idea of suspected sabotage was consolidated. Further analysis carried out in the following days confirmed the presence of two large vessels, with their trackers switched off, which had appeared around the leak sites in the days leading up to the disaster. To detect the vessels, 90 days of obtained satellite images of AoI are processed. [RD 02]
The total process to check the Northstream area, collect images, and AIS data, and process them, takes up to 20-30 days for final processing.
The main objective of the 3CS concept is to alert about obscure vessels and risk situations within 15 minutes of detection until reporting to end users such as local authorities. SAR images, AIS data, a machine learning algorithm, and a fast, reliable, and available communication gateway are the protagonists of the analyzed mission scenario. The general design proposed in this document aims to observe each oceanic/marine area with global coverage by collecting and processing SAR images to detect an alert situation.

4.1.1. North Stream case: observation node

The AIS segment: The AIS data are collected by the SPIRE company, pioneers of the vessel's traffic surveillance. Their 112 terminals placed on mixed orbit scenario allows them to observe constantly every sea area, recovering AIS data from vessels observed. The AIS data collected and elaborated by SPIRE segments are[RD 05]:

- **Vessels API data**
- **Vessels particulars**
- **Last known position**
- **Predicted position**
- **Matched port**
- **Weather data services**

All data collected by the satellite is decoded and sent to one of 30 SPIRE ground stations for processing. Data processing makes it possible to define alert situations depicting vessels with the AIS terminal switched off, as Northstream case. When the data is processed, it are sent back to the processing node for the creation of the final report. Following the autonomous routing concept, the other mission segments are tipped to send data to the space processing node in order to merge them with other information for final report elaboration.
The EO segment: The SAR technology is the best candidate for the 3CS concept. The radar capabilities allow observing every zone in every weather and light condition. The ICEYE company provides the SAR terminals for the mission.
When the EO segment is tipped, the SAR satellites observe the depicted area of interest, as they fly over it, collecting image data within minutes.
The time required to reach the Area of Interest, the Northstream zone, depends on the configuration of the constellation. The new mission analysis configurations are being studied to cover each zone in minutes and reduce revisit times.
The raw data is stored on board the terminals and sent to the processing node through the inter-satellite space gateway constituted by the ION satellites equipped with the optical terminals.
Current SAR satellites are equipped with RF communication subsystem, so it is possible to exchange information with the space gateway using the existing X-Band subsystem. The possibility of installing an optical terminal on board SAR satellites is being studied. With OISL technology, ICEYE terminals would be able to send up to 2 Gbps in seconds.

4.1.2. North Stream case: processing node

The Processing Node enables the storage and processing of data retrieved from the AIS, EO, and Weather segments. The node consists of D-Orbit hardware equipped with software designed by AIKO and Planetek.
The processing node is the central part of the DoTTaH mission scenario. It manages data provided by different mission segments such as Earth observation satellites (SAR data), third-party data such as SENTINEL-1, AIS data, and peak signals. The basic data needed to prepare the final report with the risk assessment are described below.

Processing node (base) workflow

The main key points that need to be achieved by the processing node are:
- **To perform** range compression on the raw SAR data retrieved from the SAR segment. Compression is one of the first steps in obtaining the final image products (amplitude and complex products);
- **To resize and divide** the compressed products into small *tiles* for the focusing process;
- **To execute the** *focus algorithm* on all tiles produced by the previous step. This format is critical for applying the machine learning algorithm to track;
- **To execute Machine Learning** algorithm for **object detection;**
- **To elaborate on the final report/alarm** messages;
- **To manage** the autonomous data workflow

the node is divided into the Ground Segment and the Space segment.

Computing HW characterization

The hardware is the basis of the 3CS concept. It represents the physical part where the primary operations are performed. In this section, the focus is on space processing hardware. The main component consist of[RD 01]:

- **Computing cluster:**
  the core of the processing node. It allows the management of all telemetry and data retrieved from the ground and other satellites. Integrates 4 FPGAs used for basic elaboration and for other processes(as **range compression and tile division** products). The High-Performance Computing Box (e.g. CORE3) aims the link with external accelerators.

- **Accelerator:**
  The myriad is the accelerator considered in the DoTTaH configuration. The myriad allows running the fundamental process as the focusing and the detection of object machine learning algorithms. It is possible to run at the same time two different processes. Each FPGA can manage two tiles per time.

SAR Data focusing process

The focusing algorithm aims to process the SAR data to obtain the quality necessary for the application of the object algorithm.
For the configuration analyzed, the focusing process is performed on the accelerator component. The analyzed image is based on SENTINEL-1 products and it is divided into 64 tiles.
The external FPGA component can process two tiles at a time Considering the data rate of data exchanges between the core and the external accelerator and the focusing process duration(Figure 4-2), the single tile inference study is completed in almost 777 ms and the main steps are:

- The time required to exchange data from the central computer cluster and the FPGA is around 3,35 ms. (**7 ms in total**)
- The inference process of a single tile ends at **770 ms.**

Considering the external FPGA limit to process two tiles per time, it can be deduced that focusing the entire image requires 32 Myriadx setups to achieve production in almost **880 ms**. These configurations are analyzed for trade-off analysis.

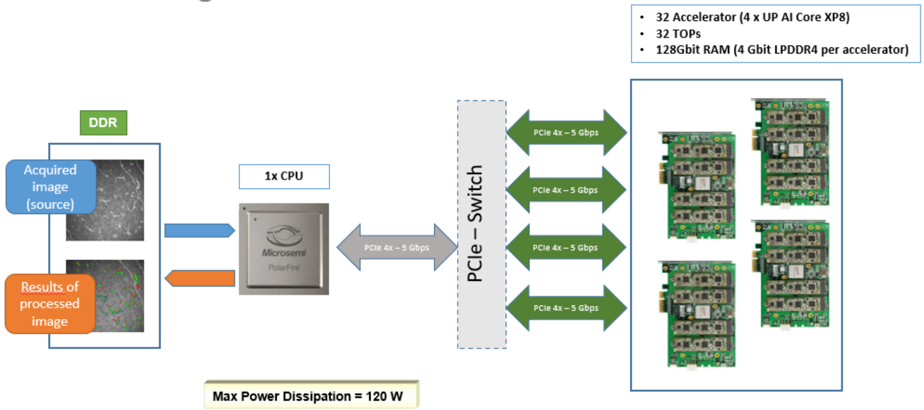


Figure 4-2. space processing node: Hardware configuration
Credits: D-Orbit

Object Detection algorithm: workflows proposed

Object detection (OD) can be applied on the same tile directly after focusing without problems, three possible configurations (based on trade-off w.r.t. accelerator model switch and data transfer time) are analyzed:

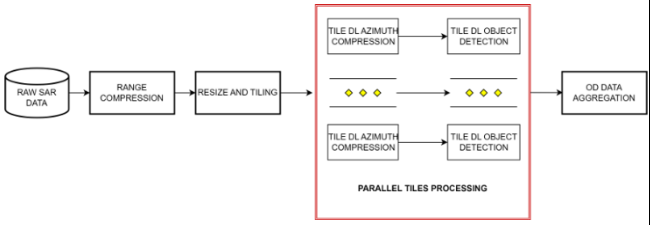
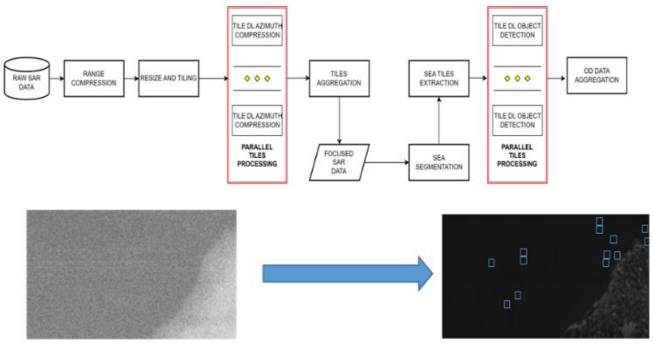
<table>
<tr><th>Configurations (credits: AIKO)</th><th></th></tr>
<tr><td>OD Switch: each tile is focused, then the model instantiated on the accelerator component is switched from SAR focusing to OD one, and object detection is performed on the same tile without the need to recreate the entire image.(Figure 4-3)</td><td rowspan="2">

Figure 4-3. Onboard algorithm workflow: configuration1 proposed. Credits: AIKO

the “blue” indicates the central computer cluster, and the “red” the operation performed on the accelerator</td></tr>
<tr><td>Pipeline: same as previous, but exploiting the parallel model execution on the accelerator device, we can have both models already instantiated and launch OD on a tile while starting focusing on the following one. (Figure 4-3)</td></tr>
</table>

2-steps: focusing is done on all the tiles using all the available resources (all accelerators on both “lanes”), after that the OD model is uploaded on all the devices and a second OD step is performed on all the tiles. This configuration can be enhanced by adding a pre-processing function before OD (done on the main computer cluster) to discard tiles without the sea. (Figure 4-4)	 *Figure 4-4.Onboard algorithm workflow: 2 steps configuration*

Autonomous data routing workflow

Autonomous data routing is another central point of the DoTTaH mission scenario. The data routing is fundamental to divide the different main workflow steps along the Ground segment and Space segment.
It is fundamental to define the processes and to distribute software (ground + space segment) to optimize data packets exchange across the nodes.
The main autonomous data routing path design for the missions scenario consists of:

On-ground SW modules	**Multiple Optimization Strategies** • Fairly maximize entire network throughput • Maximize satellite (or cluster) throughput
Onboard SW modules	**Satellite Autonomous capabilities** • Selecting the best route to forward an incoming data packet • Assessing node-to-node link availability • Assigning priorities to balance overall traffic • Re-routing high-priority data packets

4.1.3. North Stream case: Communication node

The main requirement of the DoTTaH mission scenario is the “ near real-time” concept in terms of collecting, processing data, and exchanging it between different terminals. A faster and more available communication system is fundamental for the 3CS concept. The existing configuration and technologies and does not fit in the best way in the near real-time scenario. To accomplish the mission target, new technologies based on the Optical InterSatellite link are analyzed.
To reduce the latency time from detection, elaboration, and sending the final report, an inter-satellite communication gateway to link all satellites of a different node is required.
The core part of the space gateway is figured out by rings of **D-Orbit ION satellites** equipped with **Optical terminals (“LaserCube”)** provided by **STELLAR company**.
The "ring" configuration (Figure 4-5) can provide a continuously available intersatellite↔Earth communication system offering up to 2 Gbps of data rate allowing large amounts of data to be exchanged in minutes in any global zone. With this service, DoTTaH could have warned local authorities in the disaster area (Northstream damaged zone) within minutes.

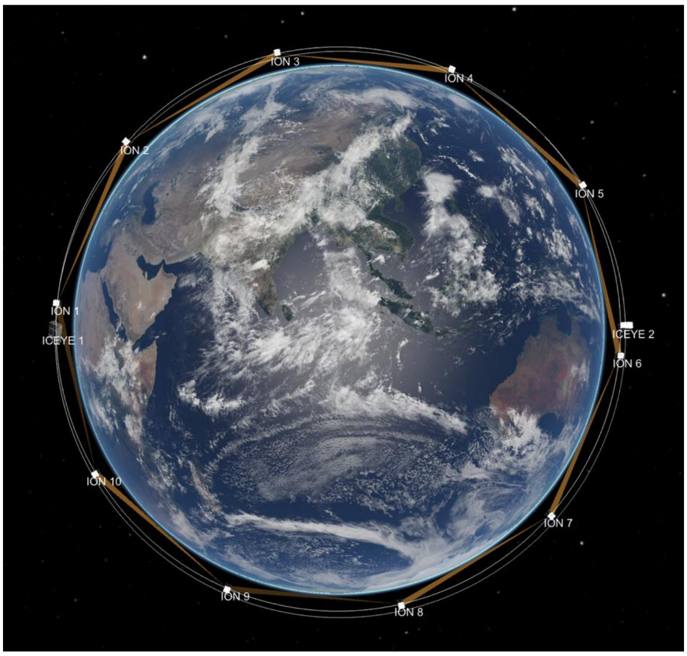


Figure 4-5. Illustration of Communication "Ring" configuration. credits: Planetek with Basilisk software

Three main configurations are analyzed in order to achive first results in terms of number of satellites, ground stations and orbits[RD 01]:

Case 1

Multiplanes: Satellites on the same orbital plane

Considering different constellations with 10 satellites for each orbital plane, an analysis of latency time, i.e. time between a passage of the satellite over a user and following ground stations, disposed randomly all around the world, was conducted. The ideal best configuration is figured out by the case with 50 ground stations available and 50 satellites placed on 5 orbital planes. With this scenario, it is possible to exchange data within 1 minute.

Case 2

Multiplanes: Satellites on different orbital planes

In this case, one satellite per orbit is analyzed. The study is focusing on cases with 5,8,10 satellites.

The ideal best configuration is figured out by the case with 50 ground stations available and 5 satellites. With this scenario, it is possible to exchange data within 9 minutes.

Case 3

Satellites on the same orbital plane + SAR constellation

The visibility time between **ION 7** and **ICEYE 19** endures around 700 seconds. The time to connect two terminals is around 60 seconds. Therefore, the real connection depends on the ability of the platforms to rotate with each other to communicate.

5. Application workflow design

5.1. Trade-off process and expected results

The maritime surveillance application is the pilot case study for the analysis and the definition of the possible 3CS system infrastructure and for evaluating measurable key performance indicators. The indicators will then quantitatively measure the advantages such an infrastructure brings to the application scenario. The performance indicators will also allow for identifying the 3CS infrastructure's key nodes (and technologies) either already ready-to-use or need an enhancement step, and consolidating the key points for the whole class of 3CS-enabled applications. The initial performance parameters are based on the improvement of latency, accuracy, coverage (spatial/time) and responsiveness, sustainability. The study aims to identify further performance parameters as appropriate to be translated into key performance indicators. The concept allows to measure the improvement of the application workflow in terms of:

▪Information latency,
▪Information accuracy,
▪Geographical coverage,
▪System responsiveness to information,
▪Engineering, storage, & compute requirements on orbit,
▪Workflow sustainability

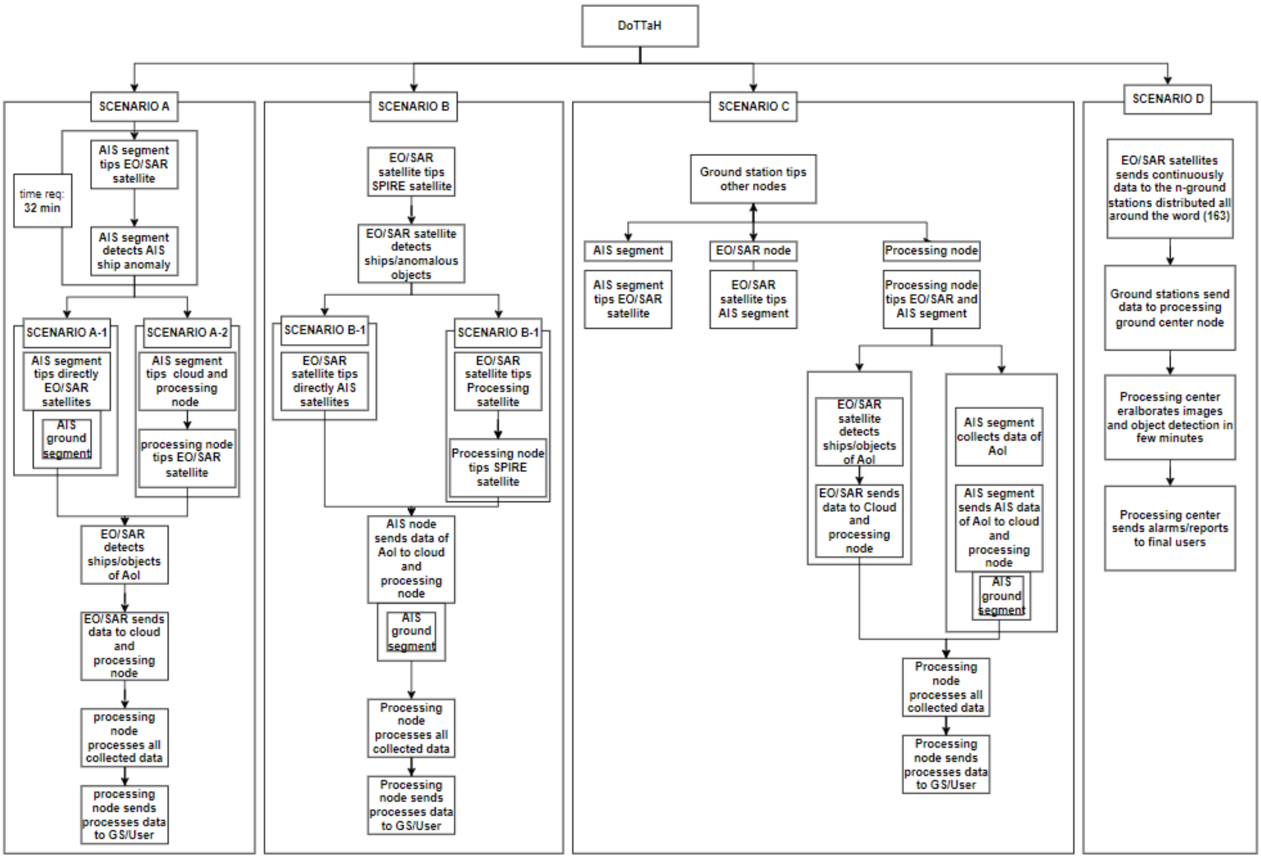


Figure 5-1. 3CS scenario(s) proposed

5.2. Mission scenarios: Final considerations

In the study, a ***wide range of scenarios have been analyzed*** to fulfill the main mission requirements based on the ***optimization of the information collected by various platforms, with sensors of different resolutions and at different frequencies***. The ***most-promising setup*** showing results close to concept definition in real-time is based on a single observation satellite acquiring images of the area of interest as it is tipped by the AIS segment. ***This scenario allows us to detect, process, and send data to the final user within 15 minutes***, against the 45-60 minutes required today. However, there are several critical points to be investigated to deploy this scenario and to consider the other design. These items deserving to be further investigated in detail are:

- A more ***quantitative feasibility analysis*** for trading-off core systems components in terms of power, satellite architecture, and other aspects to get the processing capabilities directly on Earth observation satellites, allow for reduced workflow latency times.
- The optical communication terminal is to be equipped by all partner satellites involved to exchange up to 2 Gbps between different satellites and ground segments.
- Onboard satellite AIS data processing to reduce the number of workflow steps and total time required.

5.3. Summary on basic KPIs

It can take considerable time to fuse and extract actionable insights from space-derived data streams, which are often enormous. Just one image tile of Earth from ESA's Sentinel-1 spacecraft, covering a 100 km by 100 km square, is 4 GB – the same size as a movie download. [RD 06]

Flood information for emergency response is a prime example of where updated satellite-derived insights are indispensable for directing relief efforts, but bottlenecks in the downloading and analysis of images can lead to delays of several hours or even days in making actionable insights available.

With the key points of 3CS described in this document, it is possible to respond to this challenge by offering a communication gateway that allows exchanging a large amount of data (up to 1-2 Gbps) in a very short time, a processing node of lo space that allows the processing of SAR data, the detection of objects and the preparation of final reports by managing the data retrieved from the various sources.

With these services and Earth Observation services, it is possible to monitor the entire ocean area and detect and report risk situations within 15 minutes against the large time required today.

6. Commercialization aspects

6.1. Business model

Digital business models disrupt 100-year-old billion-dollar companies in telecommunications, transportation, advertising, e-commerce, automotive, insurance, agriculture, finance, and the whole lot. ***Capitalizing on the developed technical skill within DoTTaH, we shall build an ecosystem in Space delivering value to different actors***: the way we deliver and capture value will be different for each element of the Space business. For example, in the DoTTaH pilot for Earth Observation, we can share revenues with Space App developers and data providers, offering users subscriptions to our platform. Another line of income would be the sales of onboard devices that enable access to the named as ***SPACEDGE™*** (a Planetek Italia Proprietary Brand), ecosystem. The following schematic depicts the value flows of different elements of the SPACEDGE ecosystem. Value is generated and extracted from all the users. The value of SPACEDGE is in the number of stakeholders that animate the platform. More precisely the Metcalfe's law1 states that this value is proportional to the square of the number of connected "compatible communicating devices"[RD 01].

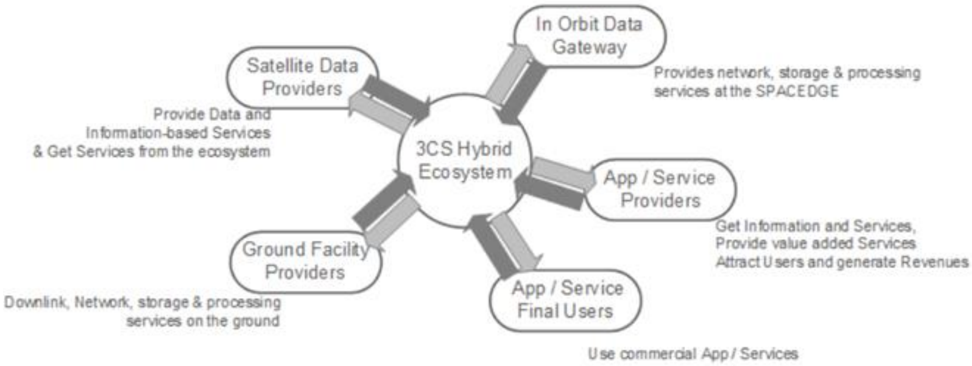


Figure 6-1. identifying the touched ecosystem: the actors of this ecosystem and the traded values (both provided and got) are highlighted
Credits: Planetek

In Figure 6-1, we sketch the foreseen SPACEDGE ecosystem: the actors of this ecosystem, as well as the traded values, are highlighted. The amount and contents of the trade value will be part of the detailed business plan. For some of these, the goal will be to build positive cash-flows for other indirect benefits to general costs, such as the platform operations.

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[1] https://www.thegeniusworks.com/2020/02/metcalfes-law-explains-how-the-value-of-networks-grow-exponentially-there-are-5-types-of-network-effects/