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CONCEPTS FOR THE USE OF IOT IN EARTH OBSERVATION SYSTEM - EXPRO+
ESA EXPRESS PROCUREMENT [PLUS] – EXPRO [+]

CONCEPTS FOR THE USE OF IOT IN EARTH OBSERVATION

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Table of Contents

1. Introduction

1.1. Scope of the Document

This document describes the activity to be executed and the deliverables required by the European Space Agency in relation to “Concepts for the use of IoT in Earth Observation system”.

It will be part of the Contract and shall serve as an applicable document throughout the execution of the work.

1.2. Applicable and Reference Documents

The reference documents are available under following ESA box url:

https://esabox.esa.int/owncloud/index.php/s/7KNQMOGy01gNLX0

Password: 1OT_for_E0

1.2.1. Applicable Documents (ADs)

The following documents, listed in order of precedence, contain requirements applicable to the activity:

Not Applicable

1.2.2. Reference Documents (RDs)

The following documents can be consulted by the Contractor as they contain relevant information:

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RD	Reference	Name
RD[1]		The Matosinhos Manifesto: Accelerating the Use of Space in Europe
RD[2]		Radio Regulations, 2020. It includes Vol.1/Articles, Vol.2/Appendices, Vol.3/Resolutions, Vol.4/Recommendations.
RD[3]	SA.1273-0 (10/97)	Power flux-density levels from the space research, space operation and Earth exploration-satellite services at the surface of the Earth required to protect the fixed service in the bands 2 025-2 110 MHz and 2 200-2 290 MHz
RD[4]	SFCG 6-1R5	Interference from Space-to-Space Links between Non-Geostationary Satellites to other Space Systems in the 2025-2110 and 2200-2290 MHz Bands
RD[5]	ITU-R S.1591	Sharing of inter-satellite link bands around 23, 32.5 and 64.5 GHz between non-geostationary/geostationary inter-satellite links and geostationary/geostationary inter-satellite links
RD[6]	Resolution 773 (WRC-19)	Study of technical and operational issues and regulatory provisions for satellite-to-satellite links in the frequency bands 11.7-12.7 GHz, 18.1-18.6 GHz, 18.8-20.2 GHz and 27.5-30 GHz
RD[7]	ISO/IEC 7498	OSI Model
RD[8]	IOAG Home Page	InterAgency Operations Advisory Group –
RD[9]	IOAG.T.LEO26SG.2019	IOAG 26 GHz SG report – Feb. 2019, (example of IOAG Study Group) – Word Template will be provided (for convenience) at KO, and can be adapted for this IoT work
RD[10]		6th FFSS Workshop – Federated and Fractionated Space Systems (https://golkar.scripts.mit.edu/fss/)
RD[11]		Advanced Information Systems Technology (AIST) New Observing Strategies (NOS) Workshop Summary Report (https://esto.nasa.gov/nos-workshop/)
RD[12]		LoRaWAN® 1.0.4 Specification Package (https://lora-alliance.org/resource_hub/lorawan-104-specification-package/)
RD[13]		Designing a 3GPP NB-IoT NTN service for CubeSats in low density constellation, M. Guadalupi et al, CubeSat

		Developers Workshop, "Working Together", Virtual Conference, April 27-29 2021
RD[14]	AO/1-10220	SoW for "Satellite telemetry and control using space IoT networks for small satellites" Became two parallel ESA Contracts (Nb. 4000135323 led by TAS-I, Nb. 4000135324 led by Kepler Communications Inc. in CA)
RD[15]	AO/1-10204	SoW for "Radio with Identity and Location Data for Operations and Space Situational Awareness (RILDOS) based operations for telecom missions"
RD[16]	AO/1-11269	Statement of Work on "Rapid and resilient crisis response system study"

1.3. Acronyms and Abbreviations (alphabetical order)

Acronym	
ConOps	Concept of Operation
EESS	Earth Exploration-Satellite Service
EO	Earth Observation
FSS	Fixed-satellite service
GEO	Geostationary Orbit
HAPS	High Altitude Pseudo Satellite
IOAG	Interagency Operations Advisory Group
IoT	Internet of Things
ISL	Intersatellite Link
ISS	Inter-satellite service
ITU	International Telecommunication Union
LEO	Low Earth Orbit
M2M	Machine-to-Machine
MSS	Mobile-satellite service
RILDOS	Radio with Identity and Location Data for Operations and space Situational awareness
RR -	Radio Regulations
SG	Study Group (in IOAG)
SoS	System of Systems
SOS	Space Operational Service
SRS	Space Research Services
TC	Telecommand
TM	Telemetry
WRC	World Radiocommunication conference

1.4. Background and Objective(s)

1.4.1. Background

The current generation of institutional Earth Observation (EO) satellites is typically using defined ground station passes to downlink telemetry and science data every orbit, but the upload of telecommands typically occurs only once a day. This is fine for satellites with well pre-planned systematic observations (e.g. over land, or 24/7), but insufficient for urgent tasking in order to react to unforeseen events such as environmental disasters and emergency cases.

Bringing today's world of seamless integrated networks with near instant connectivity to the EO spacecrafts creates an opportunity to enable new applications such as dynamic satellite tasking, on-board event detection and near-real time distribution of information to and from both ground and space nodes in the network. It would also enable higher levels of autonomy, especially for constellations of satellites that need higher interaction and with the objective to reduce their operational costs. The concept of seamless implies the avoidance of complex antenna pointing approaches in the spacecraft, which in turn results in **low signal levels and low, but hopefully sufficient, data rates**. Where higher data rates are needed, the seamless communication system should help establish the communication through complementary and more directional systems.

The currently ongoing acceleration in the deployment **of "Internet of Things" (IoT)** should provide the framework (regulatory, physical, data, network layers and protocols) to establish the envisaged seamless networks in space. Figure 1 shows the interaction between different elements both in space and on ground, with each element representing one or more nodes in the system of system, which includes LEO and GEO relay assets.

It is also assumed the use of global (not limited to Europe) seamless IoT networks, hence the need to be coordinated with commercial actors providing the relevant IoT services, and also with institutional ones in the frame of a dedicated Study Group (SG) that is being created in the frame of the Interagency Operations Advisory Group (IOAG,RD[8]) in order to ensure cross compatibility and avoidance of proprietary standards, where possible. A successful example done in this IOAG collaboration is shown in the 26GHz data downlink report RD[9] .

For the context of this study, both, dedicated IoT relay constellations or in the form of hosted payloads on megaconstellations, should be considered as a service, rather than a dedicated system. Also internal routing in the IoT network is considered to be out of scope in the frame of this activity. The focus of the activity is on the overall IoT network and the links between different IoT nodes.

A detailed set of definitions (e.g. IoT, IoT node, IoT network, EO satellite, Relay satellite, IoT Ground node, Low Latency, seamless, etc.) is provided in Appendix A of this SoW. The reader is advised to have a look at these definitions before continuing. Appendix A of this SoW. The reader is advised to have a look at these definitions before continuing.

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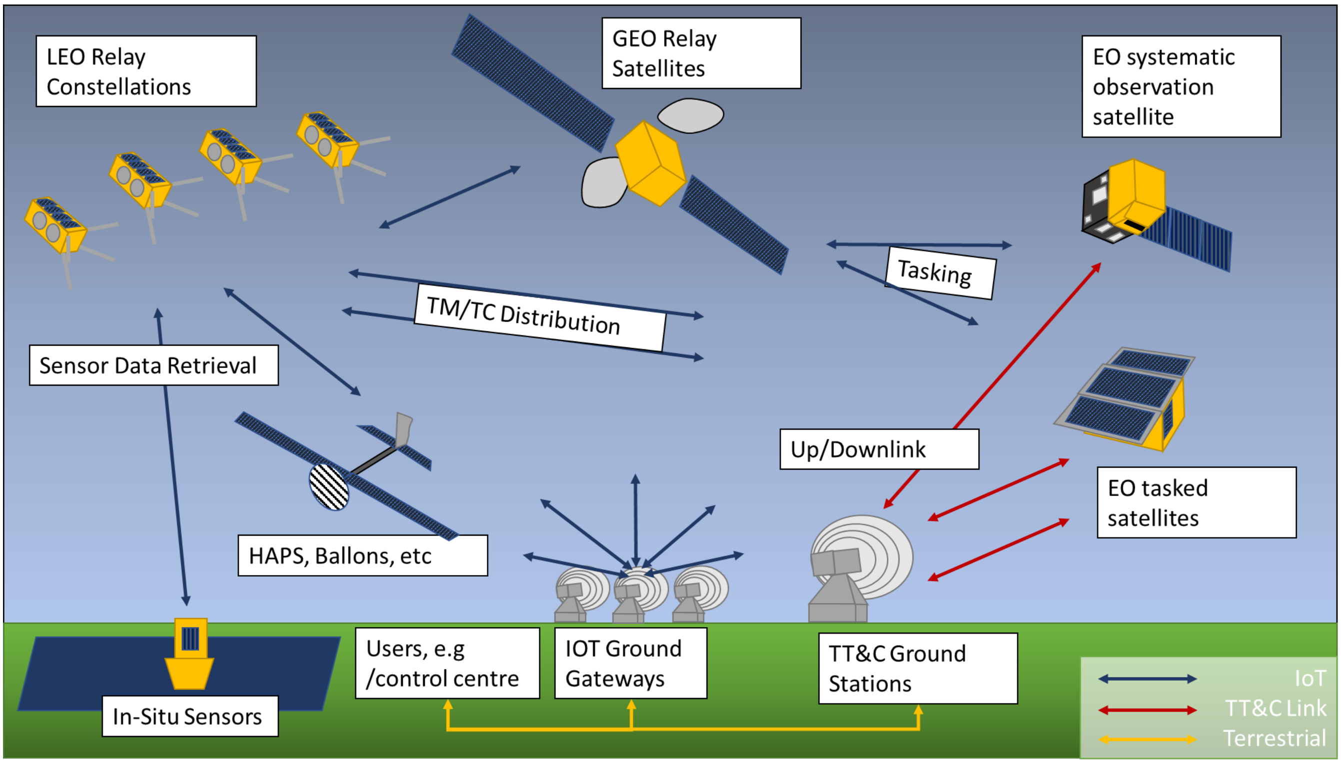

Figure 1: Seamless Network for ground to space

A more expanded list of initial uses cases is provided in Appendix B.

1.4.2. Objective(s) of the Activity

The first objective of this activity is to establish a Concept of Operations and architecture for the ubiquitous interconnectivity of institutional and commercial Earth Observation (EO) through an IoT seamless network which includes other space and ground IoT nodes. This includes:

- a refinement of EO use cases and related requirements (in Appendices of this SoW),
- a number of trade-offs (e.g. regarding Radio Regulations RD[2] and selection of frequencies, as well as protocols including security and services).
- supporting the Agency in discussions with international partners in the frame of IOAG and-or other fora (e.g. workshops with other stakeholders).
- consolidation of the architecture will require some simulations at system level duly supported by Link Budgets to demonstrate its feasibility.

The second objective is to elaborate a plan of work for future work, in terms of radio regulations, technology developments as well as in terms of possible updates of IoT and CCSDS standards for cross support.

In more detail, the main objectives of the activity are:

OBJ 1: Identification of EO use cases, their mapping to data rates, and review of the initial set of requirements in the Appendices of this SoW for these EO use cases

OBJ 2: Performing a world-wide market survey and review for IoT in terms of available services, security, network architecture, regulatory framework and implemented standards, including preliminary analysis of expected data rates and identification of gaps and critical areas for further trade-off and system simulations.

OBJ 3: Establishment of a ConOps for the System of System, including the definition of all actors, interfaces, protocols including security and services, in general and also with respect to representative EO use cases.

OBJ 4: Establishment of the system architecture(s) required to implement the envisaged ConOps and its IoT network, and detailed analysis of critical issues supported by relevant simulations and updated link budgets.

OBJ 5: Development of a roadmap for regulatory and technology and further standardization.

OBJ 6: Generation of a public IoT-SG DRAFT document, and supporting the Agency in discussions with international partners in the frame of IOAG and-or other fora (e.g. workshops with institutional and commercial stakeholders).

Timeline

Two scenarios shall be considered:

- which commercial IoT services will be available in the next 3 years, with minor upgrades of standards and technology, as well as with existing international radio regulatory framework (also considering the possible new one to exist after WRC-23);

- what could be achieved in a more ideal case in 7 years, if the technology, services, and the standards recommended in this activity are developed and become deployed in IoT relay initiatives.

1.4.3. Relation to other activities

The activity is related to two of ESA's accelerators RD[1] to speed up the use of space, in particular for "Green Future" (the endpoint users are EO satellites) addressing the need to develop a "Rapid and Resilient Crisis Response" (through ubiquitous IoT interconnectivity).

Unlike the ITT called "Rapid and Resilient crisis response system study" RD[16] , the present ITT focuses more on the EO end-user cases and on "seamless narrow-band" connectivity.

There is extensive literature and workshops held in relatively similar topics (e.g. RD[10] on Federated Systems, RD[11] on New Observing Strategies (NOS) which can be relevant for the EO use cases.

Some of the regulatory and standardization issues are addressed in for example the NB-IoT presentation by SatelIoT RD[14] , but it is left to the Contractor to extend this kind of survey. Radio frequency regulations (RD[2] and related recommendations (refer RD[3] to RD[6]) are inputs to the study.

There are other ESA ARTES complementary activities that are worth taking note: the "Satellite TM and control using space IoT networks for small satellites" RD[14] is particularly related to the development of a low-latency, global and independent telemetry and control communication system utilizing existing space-based M2M/IoT networks, and includes a system testbed and the development of a prototype satellite IoT user terminal to be launched and tested in orbit using a flight opportunity. RD[15] is called "RILDOS" and its objective is first to accelerate the identification of small satellites after deployment, and second to explore the feasibility for localisation of the satellites. Regarding RILDOS, the use of beacons read from a space asset might be of interest as an EO use case.

2. Work to be performed

2.1. Work Logic

The work logic for the study is organised into two groups comprising each of 12 months or in total 24 months (2 years). The flow of activities is shown in Figure 2

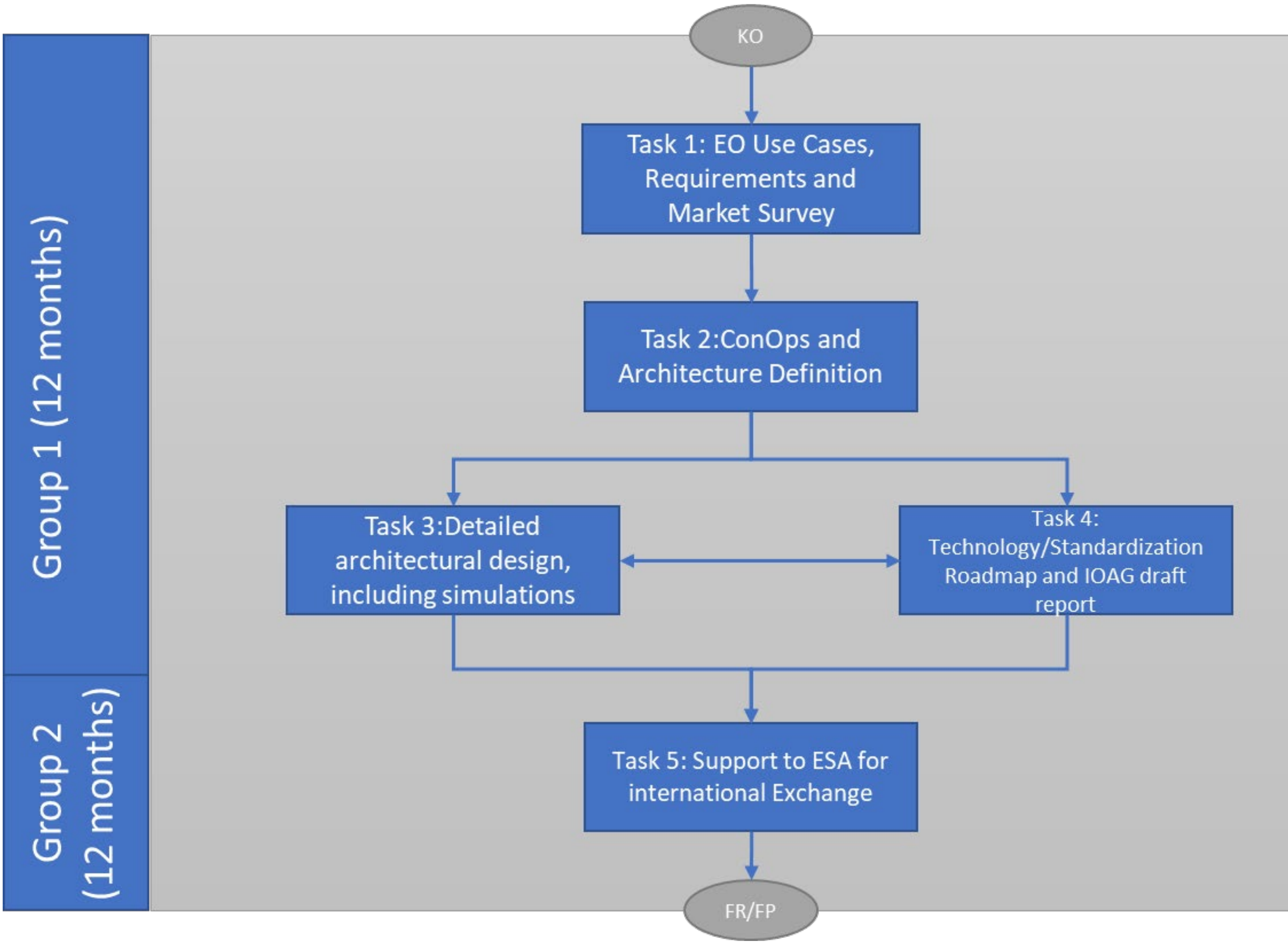

Figure 2: Proposed work logic

Group 1: Study Execution

The first group of study shall be focused on performing the required analysis for preparation of the input documents for IOAG and is proposed in the following sequential steps. This part of the study shall run from Kick-off until PM3.

- Part 1: Linking use cases with requirements and established technical capabilities on the market. The output shall be a mapping of requirements to existing capabilities and how these meet the envisaged use cases in the context of Earth Observation (EO). The results shall be reported at PM1 and the Agency will constrain the requirements and use cases to be considered further in the study based on the results. The results will be discussed in the form of a public workshop.

- Part 2: The development of a ConOps and associated Architecture shall be in focus in this part of the study. The selected EO use cases in part 1 shall be further developed and the impact on all system elements assessed. PM2 shall be used to discuss the results and further constrain the number of use cases based on the results.
- Part 3: This part shall be focused on the development of a regulatory, technology and standardization roadmap based on the selected EO uses cases. In addition, a public report is prepared for the Agency input to the IoT Study Group (SG) in IOAG and/or other fora, including a workshop.

Group 2: Support to ESA for international discussions

The second group shall be the support to the discussions with international partners via IOAG and help to prepare a second workshop with other stakeholders. The phase is closed with the final review.

2.2. Task 1: Use cases, Market and Requirements review

Input:

- Appendix A: High Level Definition;
- Appendix B: Initial EO Use Cases;
- Appendix C: High-level Requirements;
- Appendix D: Minimum set of scenarios to simulate at System Level;
- Proposal from Contractor and Negotiation agreements.

Task description

The contractor shall:

- Review, refine and expand the preliminary list of use case provided in Appendix C, and:
    - Identify all relevant stakeholders (e.g. IoT network providers, both in space and on-ground and EO users), including development for each use case of the user story;
    - Asses the required range of data rate(s) for each identified EO use case and provide the relevant grouping, to be aligned with the radio regulatory framework, ConOps and other relevant aspects, for further assessment in later tasks (e.g. with Link Budgets LEO-LEO, LEO-GEO, LEO ground, etc);
    - Perform an assessment, including mission and business considerations, for use of IoT in EO applications.
- Perform a market survey for existing IoT capabilities in terms of existing and future radio spectrum and orbit regulatory provisions, standards, constellations, and systems and technologies (for both ground and space nodes);Based on the identified EO use cases and IoT survey, identify gaps and critical areas (e.g. spectrum and orbit regulatory provisions, comprising the identification of possible radio services, frequency-bands and associated regulatory opportunities and challenges, , routing, loss of contacts, proprietary and public protocols or security in such a heterogeneous system) for further trade-off and system simulations in later Tasks;
- Develop a preliminary ConOps concept, to be agreed by the Agency, based on the EO use cases, and:
    - Identify the radio services and respective regulatory framework for the operation of each radio component of the system for each use case;
    - Identify and further define the high-level functions of its constituents, including graphical representation(s) as needed;
    - Propose a strategy to elaborate the Architecture to be simulated in the following tasks;
    - For all this, consider two scenarios about what could be achieved:
        - in the next 3 years with minor upgrades of existing infrastructure;
        - in 7 years, with optimal standardisation and new technology developments.

- Review, refine and expand the preliminary list of requirements provided Appendix C and:
    - Review, refine and expand the list of definition provided in Appendix A;
    - provide their applicability matrix, assumptions and implications depending on the use case, i.e. which requirements are applicable for which data rates and/or use case
- Report the work performed in this task.
- Support the Agency to prepare the first workshop on IoT for EO users and with other stakeholders

Output:

- D1: Chapter-1: EO Use cases, Market and Requirements review, including all aspects above.

2.3. Task 2: ConOps and Architecture Definition

Input:

- Outputs and agreements from Task 1.

Task description

The contractor shall:

- Refine the ConOps for the System of System for the identified and agreed upon use cases. This should include, but not limited to, the following:
    - Define all entities relevant to a EO use case;
    - Establish the interfaces and interactions between the different entities;
    - Report the ConOps using appropriate diagrams;
    - Refine the spectrum requirements and constraints in terms of radio services and frequency allocations for the operation of the envisaged use cases, detail the respective regulatory framework for the operation of the identified services, as well as other regulatory aspects relevant for the deployment of the system;
    - Elaborate an initial set of end-to-end link budgets (e.g. in Excel), including LEO-LEO, LEO-GEO and LEO-Ground cases, in order to confirm the initial assumptions regarding, for example, antenna performance and range of data rates.
- Detail the system architecture to be modelled for the agreed EO use cases in Task-1 with respect to Minimum set of scenarios to simulate at System LevelAppendix D. Multiple aspects need to be considered, such as:
    - At system and End-to-End level:

        - Complete the trade-offs identified in Task-1 (e.g. radio service, frequency-band, available bandwidth per channel, etc.), including also:
            - Regulatory provisions (e.g. international radio regulations and recommendation at the ITU level, as well as regional regulatory provisions, actions and initiatives, e.g. at CEPT level), protocols including Security and type of Service agreements required to achieve interoperability between systems;
            - Radio wave propagation channel characteristics and models, footprints of antennas at receiving end (GEO, LEO, ground) in order to establish connectivity statistics vs requirements with the envisaged cases to be simulated;
            - Switching mechanisms and algorithms, and path-prioritisation when EO satellite has access to other EO IoT compatible sats, with relay satellites and with IoT ground gateways (see also System requirement in Appendix C);
            - Mechanisms to deal with the cases where the LEO satellites does not have contact with the IoT network for a few seconds;
    - For the EO satellites, including large institutional satellites and also Small / Cube Sats:
        - envisaged SWAP budgets and location of the IoT equipment (electronics and antenna-s), as well as required performance (patterns) of those antennas, in relation to data rates and use case
        - Interfaces (HW and SW) to other subsystems of the spacecraft,
        - Considerations on autonomy and impact of commanding parts of the EO satellites via third-party (relay) satellites
    - For ground, perform assessment differentiating interaction:
        - between EO satellites and in-situ EO sensor (e.g. buoys)
        - between EO and/or relay satellite with IoT gateways
        - between IoT gateways and IoT control of the EO satellite

Note: The contractor is invited to propose STK-like configurations, to perform the Architecture simulation in Task-3, as well as MBSE methodologies if adequate.

- Anticipate an initial set of recommendations (e.g. regarding further spectrum needs, proprietary standards or gaps or optimisable performances), and identify alternatives to achieve the interoperability, especially for the 7 year scenario.
- Propose the Simulator architecture to be used in Task-3 and elaborate a high-Level Test Plan.
- Based on the detailed analysis update the results of Task 1 and in specific:
    - Use cases and related data rates;
    - Formulation of requirements and complete regulatory framework(s) for operation;
    - Security aspects;

- Report the ConOps and architecture definition, including trade-off, assumptions, initial recommendations, and Simulator architecture plus Test plan for Task-3.

Output:

- Updates of outputs from Task 1, if necessary;
- D1, Chapter 2: ConOps and Architecture Definition;
- SW-UM: Preliminary Simulator Manual, including Simulator Architecture, and preliminary Test Plan;
- SW-1: Link budget tool (e.g. in Excel or Matlab-like).

2.4. Task 3: Detailed architectural design, including simulations

Input:

- Output from Task 1 and 2

Task description

Based on the agreements in Task 2, the contractor shall:

- Consolidate the architecture of the flight segment (EO and relay satellites) and the ground segment (in situ-EO, IoT gateways and EO control center, IoT operators) for the identified scenarios (in 3 and 7 years), both:
  - from a conceptual view point;
  - Integrating the simulator with the configuration parameters agreed in Task-2.
- Perform full simulation of the agreed scenarios to confirm the expected system performance (data volumes, latencies, coverage or contact time and contact gaps, etc);
- Analyse the results of the simulations and derive relevant recommendations.

Output:

- Updates of outputs Task 1 and 2, if necessary;
- SW-UM, Update of Simulator Manual;
- D1, Chapter 3: Analysis of simulations and recommendations;
- SW-2: Simulator, including STK-like scripts with space and ground nodes.

2.5. Task 4: Technology/Standardization Roadmap and IOAG draft report

Input:

- Output of Task 1 to 3

Task description

The contractor shall:

- Develop a regulatory roadmap and a technology roadmap to address the identified use cases, differentiating between the "3 years" and the "7 years" scenarios, and for what part of the system (EO nodes, relay satellites, ground). This shall include but not limited to:
    - Current regulatory framework, in Europe and away, and timeline for further regulatory framework development where necessary;
    - Current technology status and TRL, in Europe and away, and timeline for technology development where necessary;
    - Identification of priorities to address the most use cases;
    - Preliminary requirements for those developments, so that the Agency can use them as Annexes to future ITTs;
- Recommend standardization updates to address the identified needs and ensure the intercompatibility between systems, not limited to Europe, and giving priority to non-proprietary solutions
    - Detail the missing standardization, including technical details from the physical layer to the network and transport layers, both in the context of IoT for users in space, as well as CCSDS;
    - Including detailed connections to specific terrestrial standards, as necessary.
- Improvements to the existing regulatory conditions shall be considered and identified in the regulatory roadmap preparation for the future
- Report the regulatory, technology and standardization roadmap;
- Summarise the work performed in the IOAG Template provided by the Agency, which shall be very similar to the IOAG one used for the 26GHz Study Group RD[9]);
- Perform updates to the documentation (e.g. for requirements), if necessary.

Output:

- Updates of output from task 1 to 3, if necessary;
- D1 Chapter-4: "Technology Roadmaps" (specifications to be public);
- D1 Chapter-5: "Recommendations for further Standardisation";
- D2: IOAG IoT draft Report (public)

2.6. Task 5: Support to ESA for international exchange

Input:

- All preceding Tasks.

Task description

The contractor shall:

- Run one more iteration of simulations (e.g. with new parameters) and their analysis, without changing the simulator, and in case the interaction with other Agencies results in the need to have that new simulation;
- Support the agency in discussion with international Member States in IOAG (e.g. NASA) by providing ad-hoc support to prepare meetings;
- Support the Agency to prepare the second workshop on IoT for EO users and with other stakeholders
- Prepare a Final Report summarising the work done in this activity.

Output:

- D1 – update with the result of new simulations;
- Executive Summary
- Final Report.

3. Requirements for Management, Reporting, Meetings and Deliverables

The following are the requirements for Management, Reporting, Meetings and Deliverables applicable to the present activity.

3.1. Management

3.1.1. General

The Contractor shall implement effective and economical management for the project.

The Contractor's nominated Project Manager shall be responsible for the management and execution of the work to be performed and, in the case of a consortium, for the coordination and control of the consortium's work.

3.1.2. Communications

All communications to the Agency, affecting technical terms and conditions of the activity, shall be addressed in writing to the Agency's representatives nominated in the Contract.

3.2. Access

During the course of the Contract the Agency shall be afforded free access to any plan, procedure, specification or other documentation relevant to the programme of work.

3.3. Reporting

3.3.1. Minutes of Meeting

The Contractor is responsible for the preparation and distribution of Minutes of Meetings held in connection with the Contract. Electronic versions shall be issued and distributed to all participants, to the Agency's Technical Officer and to the Agency's Contracts Officer, not later than ten (10) days after the meeting concerned.

The minutes shall clearly identify all agreements made and actions accepted at the meeting.

3.3.2. Bar-chart Schedule

The Contractor shall be responsible for maintaining the bar chart for work carried out under the Contract, as agreed with the Agency.

The Contractor shall present an up-to-date chart for review at all subsequent meetings, indicating the current status of the Contract activity (WP's completed, documents delivered, etc.).

3.3.3. Progress Reports

Every month, the Contractor shall provide a Progress Report in electronic format to the Agency's representatives, covering the activities carried out under the Contract. This report shall refer to the current activities shown on the latest issued bar chart and shall give:

- Action items completed during the reporting period;
- Description of progress: actual vs schedule, milestones and events accomplished;
- Reasons for slippages and/or problem areas, if any, and corrective actions planned and/or taken, with revised completion date per activity;
- Events anticipated during the next reporting period (e.g. milestones reached);
- Milestone payment status.

3.3.4. Problem Notification

The Contractor shall notify the Agency's representatives (Technical Officer and Contracts Officer) of any problem likely to have a major effect on the time schedule of the work or to significantly impact the scope of the work to be performed.

3.3.5. Technical Documentation

As they become available and not later than the dates in the delivery plan, the Contractor shall submit for the Agency's approval Technical Notes, Task/WP Reports, etc.

Technical documentation to be discussed at a meeting with the Agency shall be submitted electronically two (2) weeks prior to the meeting.

Technical documents from Subcontractors shall be submitted to the Agency only after review and acceptance by the Contractor and shall be passed to the Agency via the Contractor's formal interface to the Agency.

3.4. Meetings

The kick-off meeting shall take place by video- or tele-conference.

Progress Meetings shall be held at approximately two 2-monthly intervals, by video- or teleconference.

Two workshops shall be organised in the course of the study, refer Task 1 and Task 5, and will take place in a hybrid format (Physical presence at the Agency's premises + Online participation).

The final presentation shall take place online, to a public audience, within twelve (12) months of Contract closure. During the course of the activity the Agency will decide on the format for the final presentation (e.g. dedicated meeting, conference, specific event). Preference shall be given to a specific event where technologies related to a specific technology domain or technology theme are presented together.

Additional meetings may be requested either by the Agency or the Contractor.

With due notice to the Contractor the Agency reserves the right to invite Third Party(ies) to meetings to facilitate information exchange.

For each meeting the Contractor shall propose an agenda in electronic form and shall compile and distribute hand-outs of any presentation given at the meeting. Should the Contractor wish to invite Third Party(ies) to meetings, the prior approval of the Agency shall be sought.

3.5. Deliverable Items

In addition to the documents to be delivered according to section 3.3 here above, the following items shall also be delivered.

All documentation deliverables mentioned hereunder (including all their constituent parts) shall be delivered in electronic form in a format agreed by the Agency (PDF format, the native format and in other exchange formats where relevant).

Upon explicit request of the Agency, all the documentation shall also be delivered on computer readable media (e.g. USB key).

The draft version of the documentation shall be sent to the Agency’s Technical Officer in electronic format not later than two (2) weeks before the documentation is to be presented. The final version shall be provided in a number of copies specified hereunder.

All documents shall bear the appropriate copyright notice. In all cases, this shall include the title, ESA Contract number, deliverable number, date, status (draft), version and/or revision number. The information shall be repeated consistently in the header or footer of every page.

Documentation

Doc ID	Title	Milestone	No. of copies/format to be delivered to
D1	*Concepts for the use of IoT in EO system (multiple chapter) –* *The Requirements for Technology shall be public*	*Chapter as defined in tasks*	*Electronic searchable, indexed and not encrypted PDF and native (WORD) file to be delivered to the ESA Technical Officer.*
D2	*IOAG template filled by contractor (public)*	*end of Task 4*	*Electronic searchable, indexed and not encrypted PDF and native (WORD) file to be delivered to the ESA Technical Officer.*
SW-UM	*SW User Manual*	*end of Task 3*	*Electronic searchable, indexed and not encrypted PDF and native (WORD) file to be delivered to the ESA Technical Officer.*
FP	*Final Presentation*	*Final Review*	*Electronic file in the form of a slide editor tool file (e.g. PowerPoint or compatible) to be delivered to the ESA Technical Officer.*
ESR	*Executive Summary Report (**)*	*Final Review*	*Electronic searchable, indexed and not encrypted PDF and native (WORD) file to be delivered to the ESA Technical Officer and Contracts Officer.* *In addition to the above, one (1) electronic searchable, indexed and not encrypted PDF and native (WORD) file shall be sent to the ESA Information and Documentation Centre – ESTEC Library (email: esa.ids@esa.int).*
FR	*Final Report (**)*	*Final Review*	*Electronic searchable, indexed and not encrypted PDF and native (WORD) file to be delivered to the ESA Technical Officer and Contracts Officer.* *In addition to the above, one (1) electronic searchable, indexed and not encrypted PDF and native (WORD) file shall be sent to the ESA Information and Documentation Centre – ESTEC Library (email: esa.ids@esa.int).*
CCD	*Contract Closure Documentation (**)*	*Final Review*	*Signed electronic copy to be delivered to the ESA Technical Officer with copy to the ESA Contracts Officer.*

Definitions of Deliverable Documents

ESR EXECUTIVE SUMMARY REPORT

The Executive Summary Report shall concisely summarise the findings of the Contract. It shall be suitable for non-experts in the field and should also be appropriate for publication. For this reason, it shall not exceed five (5) pages of text and ten (10) pages in total (one thousand five hundred (1500) to three thousand (3000) words).

FR FINAL REPORT

The Final Report shall provide a complete description of all the work done during the activity and shall be self-standing, not requiring to be read in conjunction with reports previously issued. It shall cover the whole scope of the activity, i.e. a comprehensive introduction of the context, a description of the programme of work and report on the activities performed and the main results achieved.

The Final Report is a mandatory deliverable, due upon completion of the work performed under the Contract. For the avoidance of doubt, “completion of the work performed under the Contract” shall mean the finalisation of a series of tasks as defined in a self-contained Statement of Work.

The Final Report shall not contain any proprietary information or confidentiality statement.

CCD CONTRACT CLOSURE DOCUMENTATION

The Contract Closure Documentation is a mandatory deliverable, due at the end of the Contract. Work performed under Contract Change Notices adding new tasks with respect to the original Contract shall require separate Contract Closure Documentation. The contents of the Contract Closure Documentation shall conform to the layout provided in Annex A hereto.

Other Deliverables (Hardware, Software, Models, Data, Algorithms, etc.)

All software developed in the frame of the activity shall be delivered to the agency.

Item Identifier	Title	Milestone	Quantity to be delivered / Delivery Media	Remarks
SW-1	Link budget tool (e.g. in Excel or Matlab-like).	end of Task 2 and 3		All files needed for independent execution.
SW-2	Simulator, including STK-like scripts with space and ground nodes	end of Task 2 and 3		All files needed for independent execution.

4. Schedule and Milestones

4.1. Duration

The duration of the work ***shall not exceed 24 months*** from kick-off to end of the activity (delivery of the draft Final Report).

The proposed duration is:

- Group 1 = 12 months
- Group 2 = 12 months

The effort for group 2 should be 10% of the overall effort for the activity. Deviations shall be justified.

The kick-off is tentatively foreseen for June 2022.

4.2. Milestones

The following milestones shall apply:

- …End of task 2
- …End of task 4
- …Final Review

Appendix A. High Level Definitions

This Appendix contains the high-level definition and requirements derived for this activity. Both are to be considered as starting point and need to be further iterated, expanded, and detailed as per the corresponding task definition.

Not all requirements will be applicable to all EO use cases in Appendix B.

High Level Definitions (all still TBC)

Table 1: High-level Definitions

Term	Definition
System of System (SoS)	The System of Systems is composed of heterogeneous ground and space assets, each with one or more IoT nodes that are inter-connected via IoT links within the IoT network and possibly via complementary non-IoT communications too (e.g. higher speed directional links or other technologies on ground).
ConOps	The IoT ConOps describes how to operate the envisaged IoT SoS.
IoT	Low-power, low-data rate communications techniques used to exchange data between devices and systems.
IoT Node	A Node is either a redistribution point (e.g. in LEO or GEO Relay satellites) or a communication endpoint (e.g. in the EO satellite). An IoT node makes use of IoT communication links (typically aerial, and supported by interoperable protocol layers) to communicate with other IoT nodes. An IoT node is an abstraction of different elements (interface to host, transmitter/receiver electronics, and protocols, as well as low directivity antenna), without considering their location or physical aspects
IoT Network	An IoT network is a group of IoT nodes interconnected via IoT links that are used to exchange messages between nodes. The interconnection, if not done point-to-point, includes switching/routing capabilities on-ground or in relay satellites.
EO satellite	Earth Observation Satellite typically in LEO orbit acquiring remote sensing measurements. It can be in a variety of forms: • in large institutional satellites, as well as for Small Sats in the NewSpace context

	• in stand alone sats with systematic data acquisitions, as well as in in constellations with the need to be tasked and quickly react to emergency cases. EO satellite with IoT nodes should be able to communicate with other EO satellites via IoT compatible links.
Relay Satellites	LEO or GEO satellites with IoT compatible nodes capable to interface EO satellites, and with the capability to route the signals (not necessarily using IoT) to Relay Satellites and ground gateways.
IoT Ground node	IoT node on the ground using IoT links compatible with EO satellites. It can be in • EO in-situ ground sensor in e.g. buoys, aircrafts, HAPS, • IoT Gateways communicating to EO in-situ nodes or IoT space nodes (e.g. EO Sat or IoT relay sats).
Very Low latency	Latency of data limited by transfer duration and required computing not by orbital mechanics and ground station location. In the context of this activity, it is in the order of milliseconds to seconds (depending on the use cases), rather than one full LEO orbit before revisiting a polar station.
Seamless	Connecting IoT nodes though different connections independent on the provider (i.e. it can be directly to Space-Earth, or Space-Space to other EO satellites or via Relay Satellites).
Endpoint User	The user which after receiving/sending of data is not in further need of the connectivity for this instance of the data.
IoT Network	An IoT network is a group of IoT nodes interconnected via IoT links that are used to exchange messages between nodes. The interconnection, if not done point-to-point, includes switching/routing capabilities on-ground or in relay satellites.

Appendix B. Initial EO Use Cases

The following use cases have been identified in preparation based on assuming a seamless connection between ground and space nodes with low data rates. Within the study this list needs to be expanded and the uses cases further analysed. The initial list is provided in Table 2.

Table 2: Initial list of EO uses cases

Use case	Description
Distribution of Telecommands to EO sat	A set of telecommands is sent by an operations centre and transmitted via IoT nodes (and ground links) to the EO receiving satellite. This needs further elaboration and in particular regarding security (e.g. for critical tasking commands in NewSpace satellites, or for hosted payloads that operate fairly independent from the rest of the large satellites, as long as they comply with power budget allocations)
Distribution of Telemetry	A EO satellite transmits telemetry (e.g. coordinates of detected events) via IoT nodes (and ground links) to the receiving operations centre.
Satellite autonomously calling home in case of on-board anomalies	Instead of the flight operations constantly pinging the spacecraft for its health status via prescheduled ground station passes, the Satellites could initiate the contact to mission operations in case of unforeseen issues enabling a faster response time to anomalies and increase autonomy.
Collecting data from in-situ EO ground sensor or beacon	An IoT node in space receives information from an in-situ EO ground sensor via an IoT link. Assuming further on-board intelligence, this might imply immediate and autonomous activation of new measurements by the EO sat or the availability of new ground-truth data to complement on-board calibration.
Triggering in-situ EO ground sensors	An in-situ EO ground sensor is triggered to perform a collocated observation (e.g. for vicarious calibration) or measurement via an IoT link when the EO satellite is flying by.

	The in-situ measurement can be transmitted to the EO Data Center via other means than via the EO satellite.
Reading of deployment sensors / deorbit kit	A deorbit kit, i.e. a system embarked providing independent deorbiting capabilities, contains an IoT node which provides information independently about the it status and enables receiving activation commands
Broadcasting of payload operations (incl. radar synchronization) between EO sats	An IoT node as part of the payload of a spacecraft broadcasts relevant information to companion satellites.
Optical ground station downlink of opportunity	A ground (gateway) or relay IP node informs (only minutes ahead) the EO satellite that an optical ground station in the coming path of the EO sat will have clear skies for the dedicated (non-IP) high data rate optical downlink to be used.
Triggering other sats to acquire new observations in specific areas	A EO sat with systematic acquisitions identifies an alarm case with on-board DSP/AI and informs (directly or via IoT network) another EO sat (e.g. in a NewSpace constellation) to take action and task new observations (e.g. zoom in a specific area).
Support to on-board autonomy in constellations	In addition to other above cases, constellations can benefit in terms of autonomy (e.g. less ground stations in non-cooperative countries) and tasking for emergency cases. This needs further elaboration.

It has been recognized that the use cases imply the following connections

- Space to Space: this applies EO to EO satellite in LEO orbits, as well as via IoT links to relay satellites in LEO and in GEO orbits

- Space to Ground: this also applies direct EO to ground (in-situ IoT sensors, IoT gateways) or via IoT relay satellites and then to ground
- Ground to Space: this applies directly (in-situ IoT sensors, IoT gateways) to space or via ioT compatible relay satellites
- Ground to Ground: this includes cases where data is transferred on-ground using terrestrial (IoT and non-IoT) interfaces between different entities, i.e. FOS(ESOC) and IoT Provider.

The different connection can be combined for the different use cases.

Appendix C. High-level Requirements

These high-level requirements are derived from initial set of use cases provided in Appendix A.

All definitions and requirements are to be considered TBC.
Not all requirements will be applicable to all use cases.

User Requirements

ID	Requirement
USR-01	The system shall enable a seamless network (as per Appendix A) between IoT nodes in EO satellites and ground, leading to new concepts for the use of IoT in Earth Observation (e.g. higher autonomy and enabling higher interaction for tasking).

USR-02	The system shall consider the following users:
	- Satellite Operators for all space nodes:
	  ○ For EO sats: institutional large satellites, as well as constellations of NewSpace small satellites
	  ○ For relay satellites, both in LEO and MEO/GEO
	- Emergency Responders – i.e. users that could benefit from information (E.g. coordinates of an alarm) broadcasted immediately via the IoT network
	- IoT service providers, interfacing the space IoT network, directly with the EO sat or via relay sats
	- Academia, (e.g. willing to interface directly their payload)
	- Ground station operators
	- In-situ EO Ground sensor operators.

USR-03	The system shall consider the following stakeholders: - Space Agencies - Regulatory bodies, including ITU - Spacecraft manufacturer and operators (both Institutional and NewSpace) - suppliers of IoT compatible equipment - Existing satellite IoT providers

System Requirements

ID	Requirement
SYS-01	The system of systems shall be defined as the connection of different nodes using IoT devices for connectivity.
SYS-02	The connectivity shall be seamless to provide very-low latency connections between the different nodes. *Note: it is assumed that the LEO satellite has near permanent visibility of relay (LEO, MEO, GEO) IoT satellites and high visibility of ground IoT nodes over land.*
SYS-03	The system shall consist of both space and ground nodes using IoT links. *Note: For space assets Earth orbits are to be considered. For EO satellites, they can be limited to LEO orbits.* *Note2: Ground nodes could be Operation Centres, In-situ EO Sensors, Ground stations,* *Note3: Allocation of HAPS or airplanes to either ground (most likely) or space is to be assessed.*
SYS-04	The system shall consider at least the following space nodes: - EO satellites and constellations in LEO - Telecommunication satellites and constellations in LEO, MEO and GEO - IoT constellations in LEO and MEO - TBD
SYS-05	The system shall consider at least the following IoT ground nodes: - In-situ IoT Sensors (Buoys, Temperature Sensors, etc) - HAPS or Airplanes (TBC) - Beacons - TBD
SYS-06 (7 yr scenario only)	The IoT network shall have a TBD algorithm, including Network and Transport layers, to route and prioritise in the most efficient way the traffic between end-points: i.e. EO sat and the EO Data and Control Center.

	Note: The IoT network also includes IoT nodes in relay satellites and IoT ground gateways. This might have serious implications in terms of future standardisation and simulations beyond this activity.
SYS-07	The overall system shall be compatible with multiple and global (not just European) communication providers.
SYS-09	The system shall consider ground connections terrestrial networks where applicable *Note: This relates to where an operation centre is connecting to a communication provider. This connection is expected to established using other networks than IoT.*
SYS-10	The system shall operate, for each use case, in accordance with appropriate radio and orbit regulatory framework(s) to be identified by the contractor, considering possible opportunities and constraints (existing and future) at international (ITU) and regional (e.g. CEPT) levels. The required regulatory review shall include, but not be limited to, the investigation of suitable radio services (e.g. EESS, FSS, MSS, SRS, SOS, etc.), respective spectrum availability, coordination requirements and technical and operational opportunities and constraints for the envisaged technological deployment as considered in relevant regulatory literature (e.g. the ITU-R RR , recommendations, reports, etc).
SYS-11	The system shall have a data throughput of TBD.
SYS-12	The system shall be scalable in terms of amount of nodes.
SYS-13	The system shall be scalable in terms of data throughput.

Security

ID	Requirement
SEC-01	The system shall provide the necessary security not to allow unauthorized access to any of its constituents.
SEC-02	The IoT device shall only accept transmissions which are authenticated.
SEC-03	The IoT device shall be able to broadcast data either encrypted or unencrypted to other devices.

SEC-04	The system shall not allow intermediate IoT nodes (e.g. in relay satellites) to read content of transferred encrypted user data.
SEC-05	The system shall allow for end-to-end encryption between the originating and final node.

Service

ID	Requirement
SRV-01	The IoT connectivity shall be provided to the end EO user as a service. *Note: For example a IoT constellation will be in the middle of a satellite operator and the satellite for the case of transfer TCs. The satellite operator will use the IoT constellation in the frame of a service agreement*
SRV-02	The service shall be defined in the frame of a service level agreement (SLA) and service level definitions (SLD). *Note: The SLA and SLD parameters should be considering performance indicators of the system , i.e. nr. Of nodes, latency, data volume, etc.*
SRV-03	The SLA shall define at least: - TBD
SRV-04	The SLD shall contain at least: - TBD

Design Requirements

Design – EO Satellite (Endpoint)

ID	Requirement
EOSAT-01	The set of IoT antenna(s) and their accomodation shall provide maximum coverage to connect to relay satellites and to ground IoT nodes.

	Note: Several cases can be considered: e.g two hemispherical, or isoflux to maximise radiation to Earth Disk and a second one for zenith similar to GPS antennas.
EOSAT-02	The IoT antenna shall be miniaturised and have no moving parts. *Note: This requirement serves the purpose to exclude mechanically steerable*. It also aligns with the concept of simple, seamless, narrow-band and being the IoT node not the nominal communication means to the S/C.
EOSAT-03	The IoT electronics shall be miniaturised. *Note: It is expected the use of Solid State Power Amplifiers, rather than Travel Wave Tubes (TWTs) given the rather low frequencies envisaged.*
EOSAT-05	The IoT node shall be able to operate on demand and/or in broadcasting mode.
EOSAT-06	The IoT node shall be able to be operated independently of the OBC. *Note: this assumes that it should allow end-users to interact with hosted payloads, as long as they comply with some pre-defined requirements (e.g. power budgets)*
EOSAT-07	The IoT node shall be able to be interface with the Data Handling System (DHS) of the spacecraft. *Note: The DHS includes OBC, Mass Memory, and a number of interfaces to GNSS Receiver, Payloads, sensors, etc.*
EOSAT-08	The IoT nodes shall not cause harmful interference to nominal RF communication systems installed on-board. *Note: Frequency allocations used for EO TTC and science data downlink. In principle it should not be a problem due to the low IoT power. Different coding and modulation schemes might be envisaged.* *On the other side, the high speed/ high power comms from the nominal system might interfere the IoT node in the vicinity of the Earth station, except for the frequency-bands used by direct broadcasting systems for data delivery.*

Band	Frequencies [MHz[	Bandwidth [MHz]
S-Band – Up	2025-2110	85
S-Band – Down	2200-2290	90
X-Band-Up	7190-7250	60

	X-band	8025-8400	375
	K-band	25500-27000	1500
EOSAT-09	The IoT nodes shall not cause harmful interference to nominal RF communication systems installed on-board.		
EOSAT-10	The nominal RF communication system installed on-board shall not cause harmful interence to the IoT node on-board.		

Design – IoT Relay Satellite

ID	Requirement
RELSAT-01	The Relay sats shall have IoT nodes compatible (e.g. frequencies, coding, protocols) with the IoT nodes of the EO Sat (endpoints).

Design - Ground

ID	Requirement
GS-01	The IoT device shall be independent of a sensor. Note: This requirement is intended
GS-02	The system shall be compatible with be able to be integrated into existing operations centre infrastructure.

Appendix D. Minimum set of scenarios to simulate at System Level

This system study shall be supported by a minimum amount of simulations based on the above Appendixes on Use cases and Requirements.

All definitions and requirements are to be considered TBC.

Not all requirements will be applicable to all use cases.

Link Budgets

ID	Requirement
LKBDG-01	Link Budgets shall be established for the connections: • EO sat in LEO with other sats in LEO orbit (other EO sats or relay) • EO sat in LEO with relay sats in GEO (and perhaps MEO too) • EO sat in LEO with IoT ground nodes (gateways or in-situ EO observers) • Relay to Relay *(7 yr scenario only)* • Ground with relay sats in case IoT links are used
LKBDG-02	Link Budgets shall be flexible to allow for different input parameters such as: • Frequency-band • EIRP • Radiowave propagation channel characteristics and possible associated propagation impairment mitigation techniques • Antenna gain characteristics • Coding and Modulation • Orbit altitude • Elevation angle (specially on-ground or if antenna pattern affects) • TBD others

Contact Time and non-availability

ID	Requirement
STATS-01	An IoT network scenario with a TBD number of the following IoT nodes shall be established and configured in a STK-type of system tool complemented by relevant Python-type of scripts: • > 1 EO sat(s) • TBD number of IoT Gateways accessing the EO sat(s) and Relay sats • TBD number of Relay Sats in LEO • at least one GEO Sat *Note: The number of nodes is to be defined within the study, taking into account available computing power and need for representative plans for deployment of IoT relay constellations..*
STATS-02	The tool shall be able to derive a number of outputs, such as, but not limited to: • Contact or geometric visibility of the EO Sat by the other element of the IoT network, as a function of a number of input or derived parameters (e.g. antenna footprints based on antenna patterns, propagation model parameters if necessary, etc); • System availability statistics (e.g. interruptions, scalability with other IoT users) of the IoT communication with the EO Sat; • SNR etc.

Note: Protocol analysis is not going to be simulated in the study, but it shall be possible to extrapolate higher level protocol performances from these results (e.g. from SNR)

Appendix E. LAYOUT FOR CONTRACT CLOSURE DOCUMENTATION

Contract Closure Documentation
for
ESA Contract No. 4000XXXXXX/xx/XX/XXX/xxx
"[Title of Activity]",
hereinafter referred as the "Contract"

Section 1 – Parties, Contract Duration and Financial Information

<table>
<tr><td colspan="2">Contractor</td><td colspan="2">[CONTRACTOR NAME AND COUNTRY]</td></tr>
<tr><td colspan="2">Subcontractor(s)
(state if not applicable)</td><td colspan="2">[NAME AND COUNTRY]</td></tr>
<tr><td colspan="2">Contract Duration
(insert the dates agreed for kick-off and end of Contract)</td><td colspan="2">From:

To:</td></tr>
<tr><td colspan="2">Total Contract Price
(including all CCNs, Work Orders, Call of Orders)

and Total Contract Value
(in case of co-funding; state if not applicable)</td><td colspan="2">EUR

EUR</td></tr>
<tr><td rowspan="4">Broken down as follows:</td><td>Original Contract Price

and original Contract Value
(in case of co-funding; state if not applicable)</td><td colspan="2">XXX EUR (XXX EUR)

EUR</td></tr>
<tr><td>CCN x to n</td><td>EUR</td><td>in total</td></tr>
<tr><td>Work Order x to n</td><td>EUR</td><td>in total</td></tr>
<tr><td>Call-Off Order x to n</td><td>EUR</td><td>in total</td></tr>
</table>

Section 2 – Recapitulation of Deliverable Items

2.1 Items deliverable under the Contract

If any of the columns do not apply to the item in question, please indicate “n/a”.

Table 2.1.1 - Items deliverable according to the Statement of Work and Article 2 of the Contract

Type	Ref. No.	Name / Title	Description	Replacement Value (EUR)/ Other	Location ([1])	Property of	Rights granted / Specific IPR Conditions ([2])
Documentation							
Hardware							
Software			*(Delivery in Object code / Source code?)*				
Other							

Table 2.1.2 – Items deliverable under Article 7 of the Contract (*if applicable*)

The Contractor, after agreement with the Agency with respect to the disposal/transfer of Inventory Items/Fixed Assets under the Contract, shall submit the Inventory/Fixed Asset Record as attachment to the CCD. For each Item/Fixed Asset, the information as requested by Appendix 3 to the Contract shall be provided in the Record.

There was no Customer Furnished Items or Items made available by the Agency.

[1] *In case the item is not delivered to ESA, please indicate the location of the deliverable and the reason for non-delivery (e.g. loan agreement, waiver, future delivery, etc.)*
[2] *e.g. IPR constraints, deliverable containing proprietary background information (see also Table 2.1.3 below)*

Table 2.1.4 - Background information used and delivered under the Contract (see Article 6.3 of the Contract)

The following background information has been incorporated in the deliverable(s):

Proprietary Information (*title, description*)	**Owner** (*Contractor / Subcontractor(s)/ Third Party(ies)*)	**Affected deliverable** (*which documents, hardware, software, etc.*)	**Description impact on ESA's rights to the deliverable** ([3])	**Other comments**

[3] *if not explicitly stated otherwise, the contractual stipulations shall prevail in case of conflict with the description provided in this table*

Section 3 – Statement on Intellectual Property Rights generated under the Contract

[OPTION 1: NO INVENTION]
In accordance with the provisions of the Contract …………… [Contract Number], …………… [Company] hereby certifies both on its own behalf and that of its consortium/Subcontractor(s), that no Intellectual Property Right(s) (as defined in the Contract, under the section 'Definitions') has(ve) been generated in the course of or resulting from work undertaken for the purpose of this Contract.**[END OPTION 1]**

[OPTION 2: INVENTION]
In accordance with the provisions of the Contract …………… [Contract Number], …………… [Company] hereby certifies both on its own behalf and that of its consortium/Subcontractor(s) that the following Intellectual Property Right(s) (as defined in the Contract, under the section 'Definitions') has(ve) been generated in the course of or resulting from work undertaken for the purpose of this Contract:

- Intellectual Property Rights ("IPR") suitable for registration (i.e. "Registered Intellectual Property Rights" as per definition in the Contract) and their current status (Registered – In the process of being registered – Foreseen for registration – Not foreseen for registration)

  ……………………..

  Should any Intellectual Property Rights be indicated as being foreseen for registration or in the process of registration, the Contractor undertakes to notify the Agency's Technical Officer when:
  - registration of any such IPR(s) is rejected
  - registration of any such IPR(s) is obtained (and will provide the registration details)

- Intellectual Property Rights ("IPR") not suitable for registration (i.e. not being "Registered Intellectual Property Rights" as per definition in the Contract)

  ……………………..

The Agency's rights in the Intellectual Property Rights listed above shall be in accordance with the Contract.**[END OPTION 2]**

Section 4 – Output from / Achievements under the Contract

4.1 Technology Readiness Level (TRL)

Indicate the TRL of the technology developed under the Contract using the classification given below (for additional information on definitions, please refer to ECSS-E-AS-11C):

Initial TRL	Planned TRL as activity outcome	Actual TRL at end of activity

1	Basic principles observed and reported
2	Technology concept and/ or application formulated
3	Analytical and experimental critical function and/ or characteristic proof of concept
4	Component and /or breadboard validation in laboratory environment
5	Component and /or breadboard critical function verification in a relevant environment
6	Model demonstrating the critical functions of the element in a relevant environment
7	Model demonstrating the element performance for the operational environment
8	Actual system completed and accepted for flight ‘flight qualified’
9	Actual system ‘flight proven’ through successful mission operations

Note: The TRL shall be assessed by ESA. The Agency’s responsible Technical Officer shall verify TRLs 1-4 while TRLs 5-9 shall be assessed through an ESA-internal formal procedure.

4.2 Achievements and Technology Domain

…………………………………………………..
Provide a concise description (max two hundred (200) words) of the achievements of the Contract and its explicit outcome (including main performances achieved): please refer to the final documentation (e.g. Final Report).

Please indicate the Technology Domain (TD 1 to 25) of the development (*please tick off*):

	1	On-Board Data Systems		14	Life & Physical Sciences
	2	Space System Software		15	Mechanisms & Tribology
	3	Spacecraft Electrical Power		16	Optics
	4	Spacecraft Environment & Effects		17	Optoelectronics
	5	Space System Control		18	Aerothermodynamics
	6	RF Payload and Systems		19	Propulsion
	7	Electromagnetic Technologies and Techniques		20	Structures & Pyrotechnics
	8	System Design & Verification		21	Thermal
	9	Mission Operations and Ground Data Systems		22	Environmental Control Life Support
	10	Flight Dynamics and GNSS		23	EEE Components and Quality
	11	Space Debris		24	Materials and Processes
	12	Ground Station System & Networking		25	Quality, Dependability and Safety
	13	Automation, Telepresence & Robotics			

4.3 Application of the Output/Achievements

Please tick off as appropriate:

☐ Possible use in programme:

…………………………………………………………..
Please indicate the service domain (see table) relevant to a possible application

	1	Earth Observation
	2	Science
	3	Human Spaceflight and Exploration
	4	Space Transportation
	5	Telecommunications
	6	Navigation
	7	Generic Technologies and Techniques
	8	Security
	9	Robotic Exploration

☐ Actual use in programme:

…………………………………………………………..
Please describe the specific programme and application or mission for which the output of this Contract is or will be used.

4.4 Further Steps/Expected Duration

Please tick off as appropriate:

☐ No further development envisaged.

☐ Further development needed:

…………………………………………………………..
Please describe further development activities needed, if any, to reach TRL 5/6 including an estimate of the expected duration and cost.

4.5 Potential Non-Space Applications

…………………………………………………………..
Describe any potential non-space applications or products that may benefit from the technology that has been developed. Emphasize potential markets and customers where known.

…………………………………………………………..
Describe the principle features of technology that would be required in a technology demonstrator for any identified non-space application. Include an estimate of the resources in time and money that would be required.

The above statements provided in the various sections of this Annex A "Layout for Contract Closure Documentation" for ESA Contract No. **4000xxxxxx/xx/XX/XXX/xxx *[insert the corresponding contract number*]** have been made after due verifications. The Contractor furthermore certifies that all its obligations with regard to Fixed Assets, if any, have been fulfilled. If required by ESA, an updated version shall be provided for incorporating amendments requested by ESA.	
Name of Contractor: *[insert Contractor name]*	
Authorised signatory: *[insert Authorised signatory full name]*	*[signature of the Authorised signatory*]
Date: [insert date]	