

A Low-Data-Rate Connectivity Architecture for Earth Observation (EO) in Low Earth Orbit (LEO)

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ESA CSC x EOP Cross-directorate Initiative

1. IoT4EO Vision

- Introduction & Background
- IoT4EO Objectives

2. IoT4EO Service Definition & Stakeholders

- Service & System Overview
- Service A: Bi-Directional low-data-rate TT&C
- Service B: Bi-Directional low-data-rate interaction with in-situ sensors

3. IoT4EO Provider-agnostic system architecture

- Requirements Translation & Traceability
- Standardisation & Interoperability Action Plan

IoT4EO Vision



Earth Observation has very **heterogenous sources** of data

→ Need to **federate** those sources

Earth Observation is **not yet** making use of the **potential of timely observations**

→ **Connectivity to LEO** is **very expensive** (especially if at very high speed)

→ Need to find a connectivity service

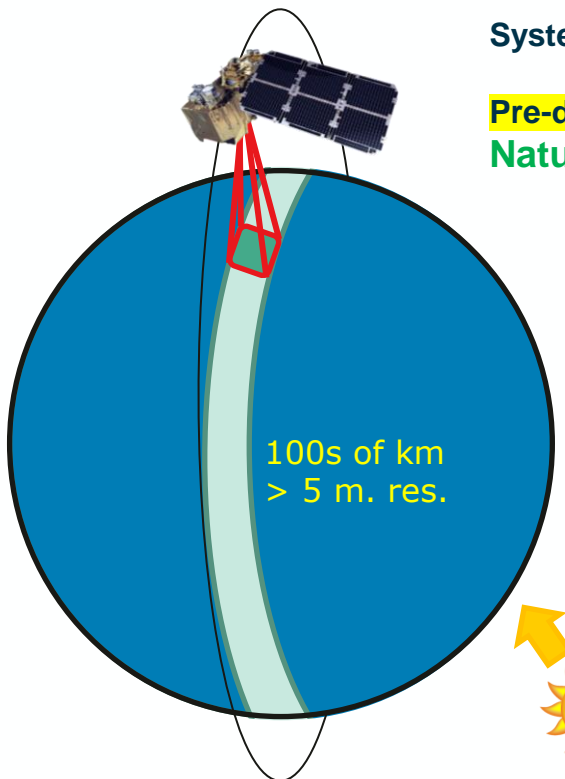
→ cost-effective

→ near-permanent (even if it is only at 1 kb/s)

Widespread adoption of cellular and non-cellular **Low-Power Wide-Area Network (LPWAN)**

→ Internet of Things (IoT)

Systematic / Carpet mapping

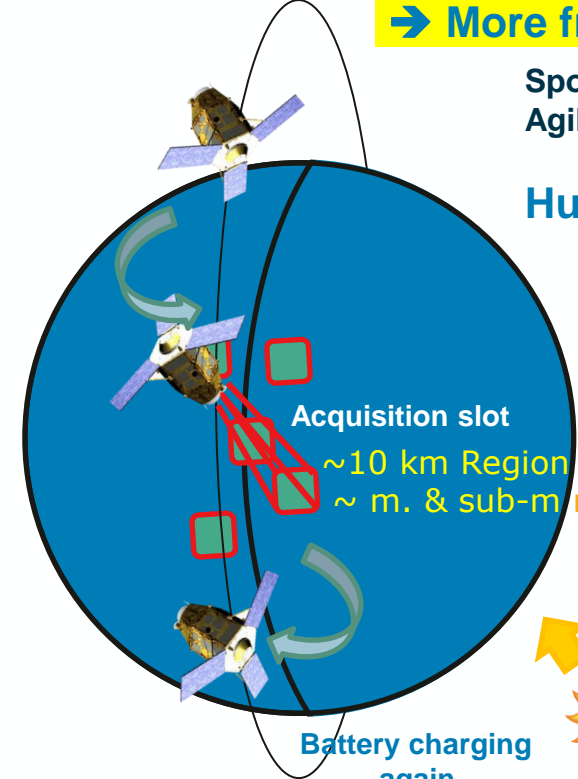


Systematic coverage – mid-resolution
Pre-determined acquisitions (1x /day)
Natural phenomena

100s of km
> 5 m. res.

On-demand acquisition with SmallSat

→ More frequent tasking – High Resolution



Spotlight / focused acquisition
Agility → Quick re-planning

Human Activity (near real-time)

Acquisition slot
~10 km Region Interest
~ m. & sub-m resolution.

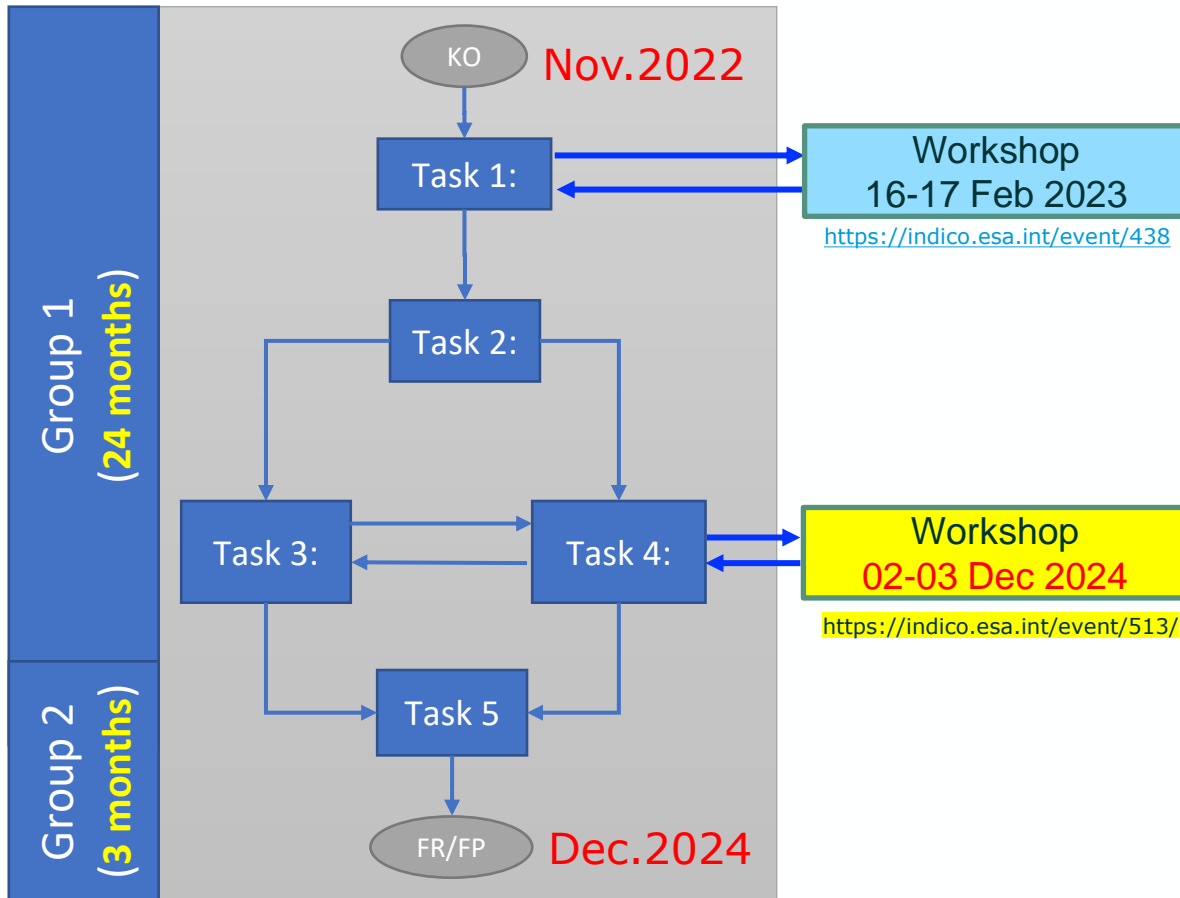
Battery charging again

- Many New applications combining Traditional & SmallSats**
- Agriculture: VHR complement to Sent.2
 - GHG (CO2,CH4,NO2): specific plant perpetrator ?
 - Event: fire, ships, gas leaks, ...
 - Others (e.g. security)

Timeliness → new market (human activity)
Simplicity (IoT) → enabler + affordable

SoW ([link](#)) – 2 Studies granted

- x1 OHB (DE)
- x1 Airbus (FR)



Work descriptions

T1: Use cases, Market Survey and Requirements review

- Workshop on 16th Feb. 2023

T2: ConOps and Architecture Definition:

- 3-year scenario – Evaluate existing systems
- 7-year scenario – Potential optimization

T3: Detailed architectural design, including simulations

- Link budgets → System Feasibility
- Orbit propagators (system)

T4: Technology/Standardization Roadmap

- **Workshop on 2-3 Dec. 2024**
- Identify Pre-development (for future activities)
- WRC-2027 for freq. ?

T5: Support to ESA for international exchange

- With IOAG Agencies + NewSpace (via Workshop or other)

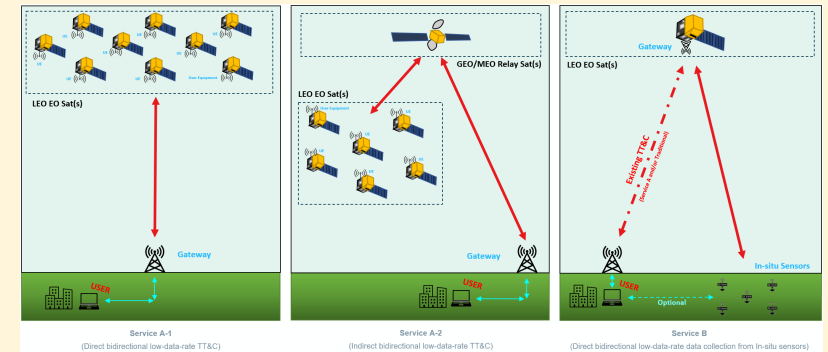
1. Facilitate the utilization of near-permanent IoT comms for future LEO EO missions

- Direct & Bi-Directional (Space – Earth)
- In-Direct & Bi-Directional (via ISL - mainly GEO/MEO)

2. Develop High Level ConOps & Preliminary Architecture - associated services

3. Develop the business case for cross support / federating:

- Institutional actors
- Commercial NewSpace actors



Two key drivers

→ Ubiquitous :

- Timeliness: near 24/7
- scale-ability & standards → Provider agnostic

→ Affordable & Simple:

- Fit for Narrow Band & low data rates (kb/s range)
- Excluded: high data rate communications (complementary)



SERVICES

- EO users: where to subscribe ?
- Providers: what to offer ?

1

To **establish** and **develop** an **interoperable framework** for **low-data-rate** connectivity with Earth Observation (EO) Satellites in Low Earth Orbit (LEO)

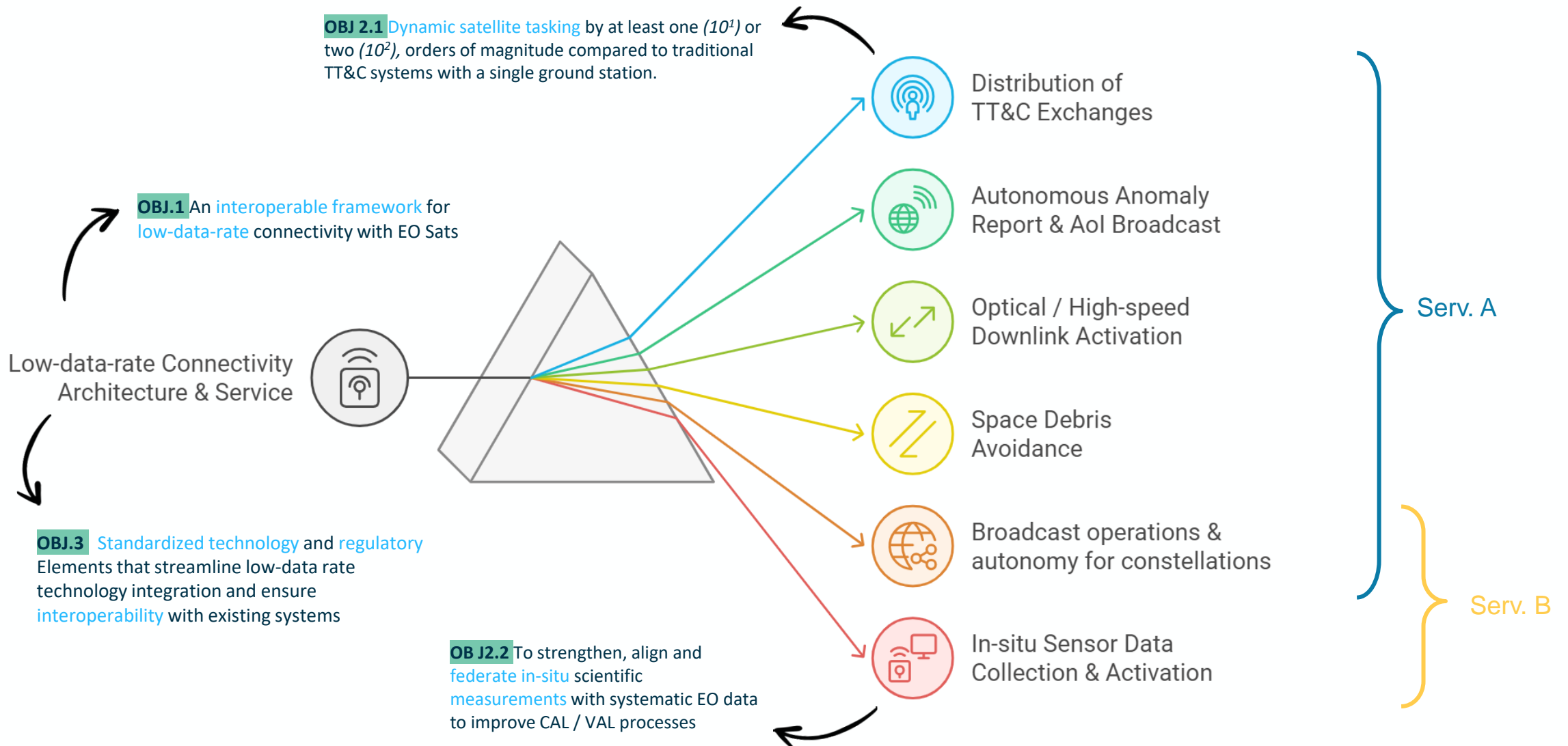
2

To enable and **operationalize** new services, applications, and use cases that add value to satellite **operations** and facilitate the integration and **co-location** of satellite and non-satellite measurements

3

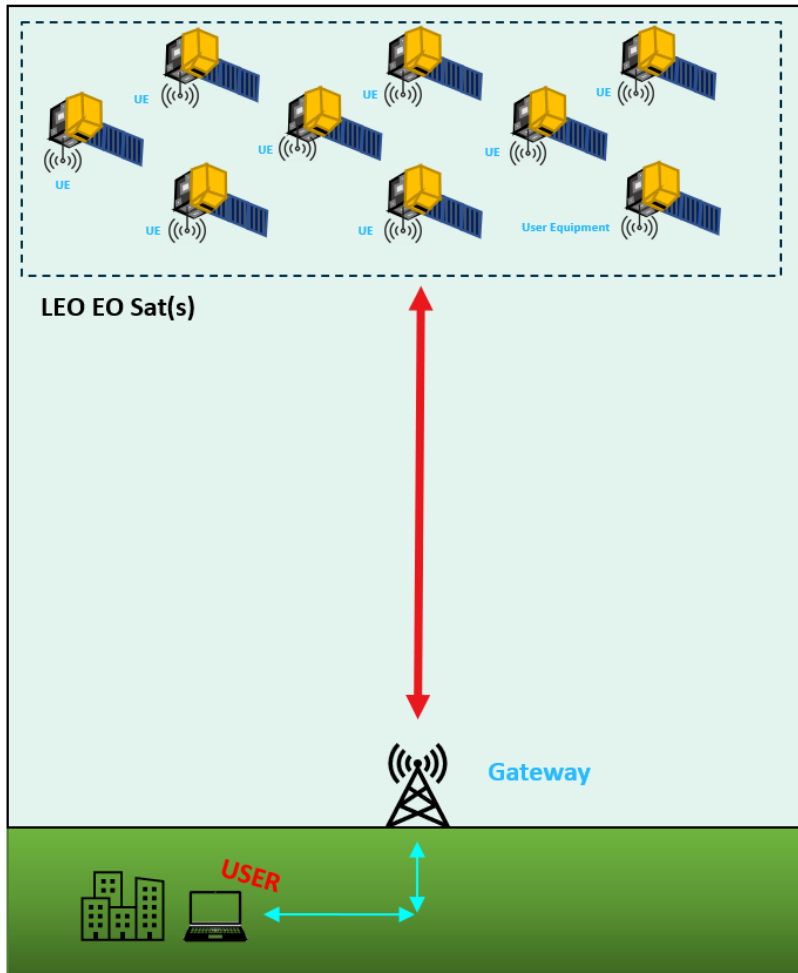
To develop **standardized technology** and **regulatory** elements that streamline low-data-rate technology integration and ensure **interoperability** with existing systems

IoT4EO Use Cases & Applications

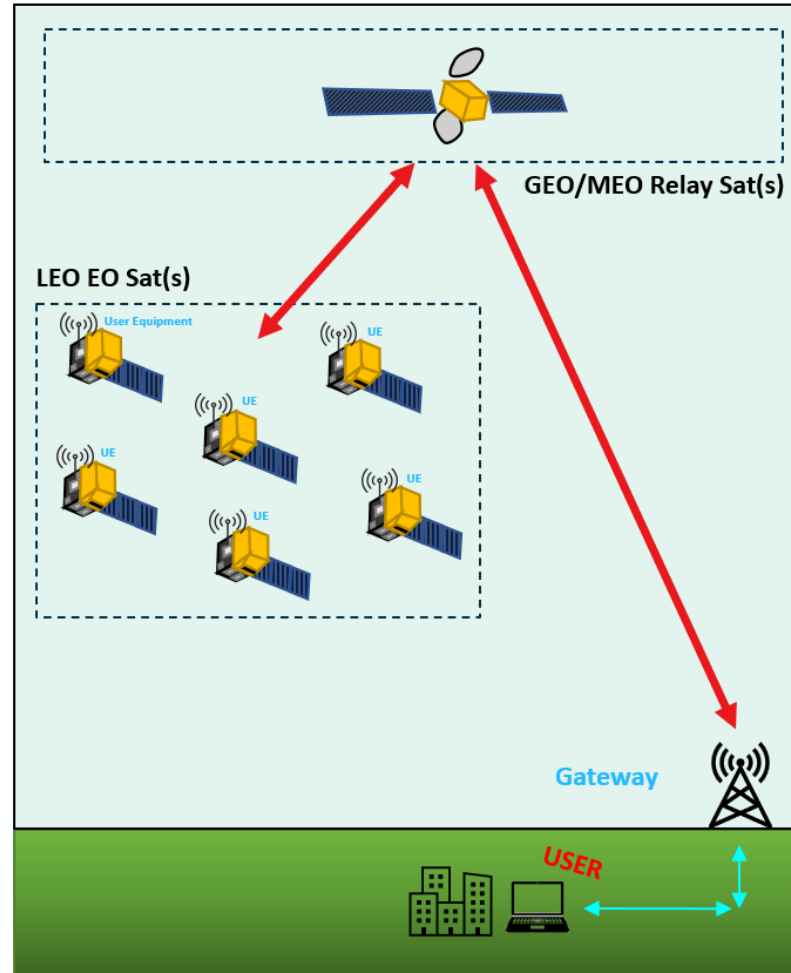


IoT4EO Service Definition & Stakeholders

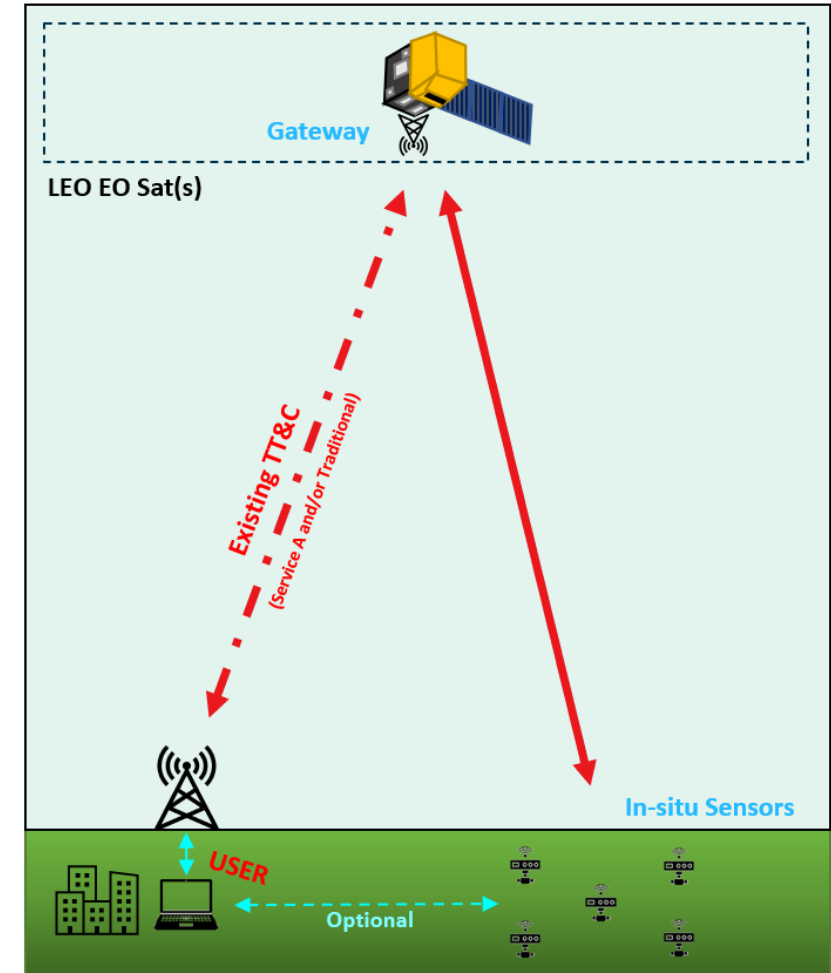
IoT4EO: Two CORE Services (A&B)



Service A-1
(Direct bidirectional low-data-rate TT&C)



Service A-2
(Indirect bidirectional low-data-rate TT&C)



Service B
(Direct bidirectional low-data-rate data collection from In-situ sensors)

IoT4EO Service & System Overview

- At least **one (10^1)** or **two (10^2)**, orders of magnitude **compared** to traditional TT&C systems with **a single ground station**
- In-situ & satellite **co-located** measurements, in spatial and temporal dimensions

	Service A-1	Service A-2	Service B
Data Type	TT&C	TT&C	Data & Messaging
Communication Direction	Bi-directional	Bi-directional	Bi-directional
Coverage	Terrestrial & Coastal (Limited at open ocean)	Terrestrial & Oceanic (Limited at Poles)	Terrestrial & Oceanic
Visibility Latency	< 10 Minutes	Near-zero	N/A
Daily Data Allowance	≥30kB or ≥300kB*	≥30kB or ≥300kB*	≥3kB
Upload/Download Speeds	≥2kbps	≥2kbps	≥2kbps
Message Length	Variable (Ave 0.2kB, Max 1kB)	Variable (Ave 0.2kB, Max 1kB)	Variable (Ave 0.1kB, Max 1kB)
Capacity	>500 Satellites	>500 Satellites	<20,000 Sensors

*Subject to user requirements, the improvement must be at least an order of magnitude, which means a minimum increase by a factor of 10 or 100

Service A-1 (Direct bidirectional low-data-rate TT&C)

Bi-directional TT&C Exchanges

Supports standard telemetry, tracking, and command (TT&C) data types, and offers both uplink and downlink communications.

Global Terrestrial & Coastal Coverage

Continuous and uninterrupted global coverage over terrestrial and coastal areas, capable of extending to a latitude range of $\pm 90^\circ$.

< 10 Minute Visibility Latency

Less than a 10 Minute visibility latency over terrestrial and coastal areas, by leveraging a well-distributed gateway infrastructure.

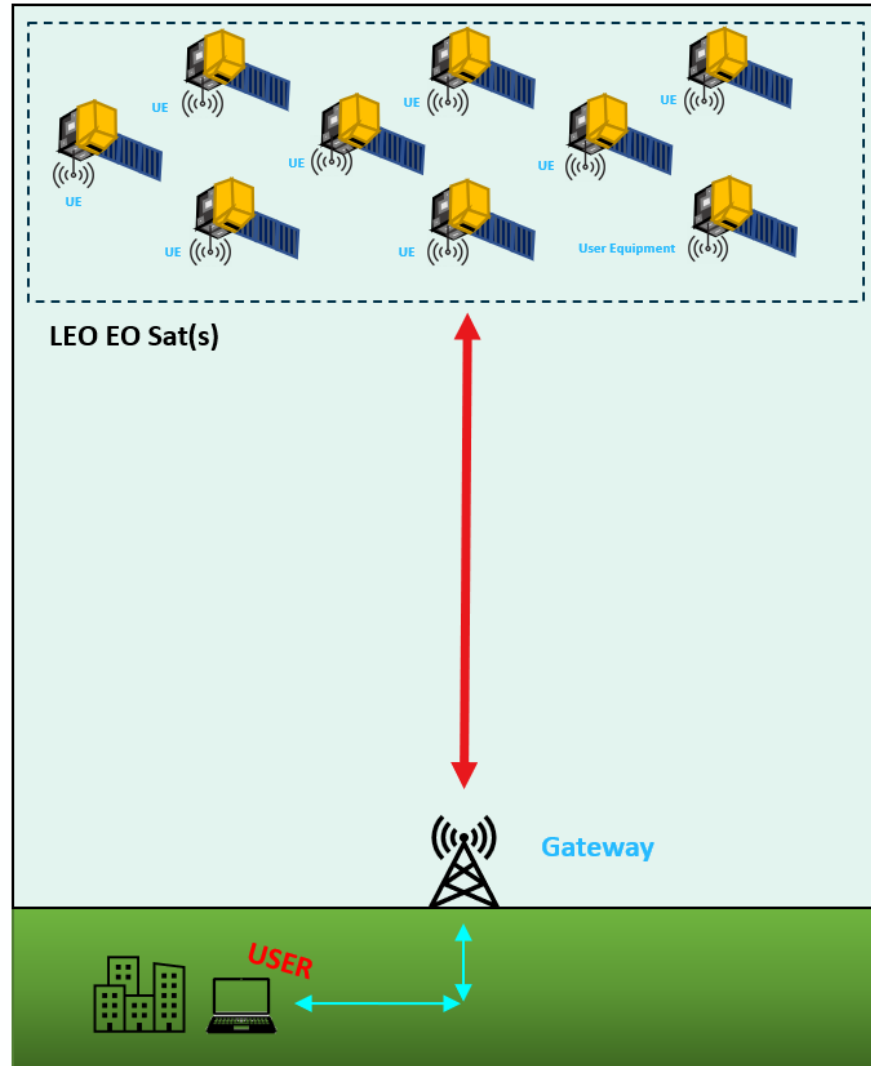
$\geq 30\text{KB}$ or $\geq 300\text{KB}$ Daily Data Allowance*

Send/receive ≥ 150 or ≥ 1500 messages/day/satellite (~0.2kB each, on average) with a cumulative total daily data allowance of $\geq 30\text{KB}$ or $\geq 300\text{KB}$.

*Subject to user requirements, the improvement must be at least an order of magnitude, which means a minimum increase by a factor of 10 or 100

$\geq 2\text{kbps}$ Upload and Download Speeds

Data upload/download speeds start at 2 kbps, with priority given to higher-speed transmissions for mission-critical operations



Service description

TT&C exchanges (Ground \leftrightarrow LEO EO sats):

1. Enable dynamic satellite tasking
2. Near-permanent link

Attractive to:

- EO Satellite Providers
- EO Satellite Operators
- EO Data Providers
- EO Data Users

Applications/Use Cases

- Distribution of TT&C Exchanges
- Broadcast Payload operations
- Autonomous Anomaly Report
- Optical / High-speed Downlink Activation
- Space Debris Avoidance
- Broadcasting Area of Interest
- On-board autonomy support for constellations

Service A-2 (Indirect bidirectional low-data-rate TT&C)

Bi-directional TT&C Exchanges

Supports standard telemetry, tracking, and command (TT&C) data types, and offers both uplink and downlink communications.

Global Terrestrial & Oceanic Coverage

Continuous and uninterrupted global coverage over terrestrial & oceanic areas, capable of extending to a latitude range of $\pm 70^\circ$.

Near-zero Visibility Latency

Near-zero Visibility latency over terrestrial & oceanic areas, by leveraging beam coverage of GEO communication providers

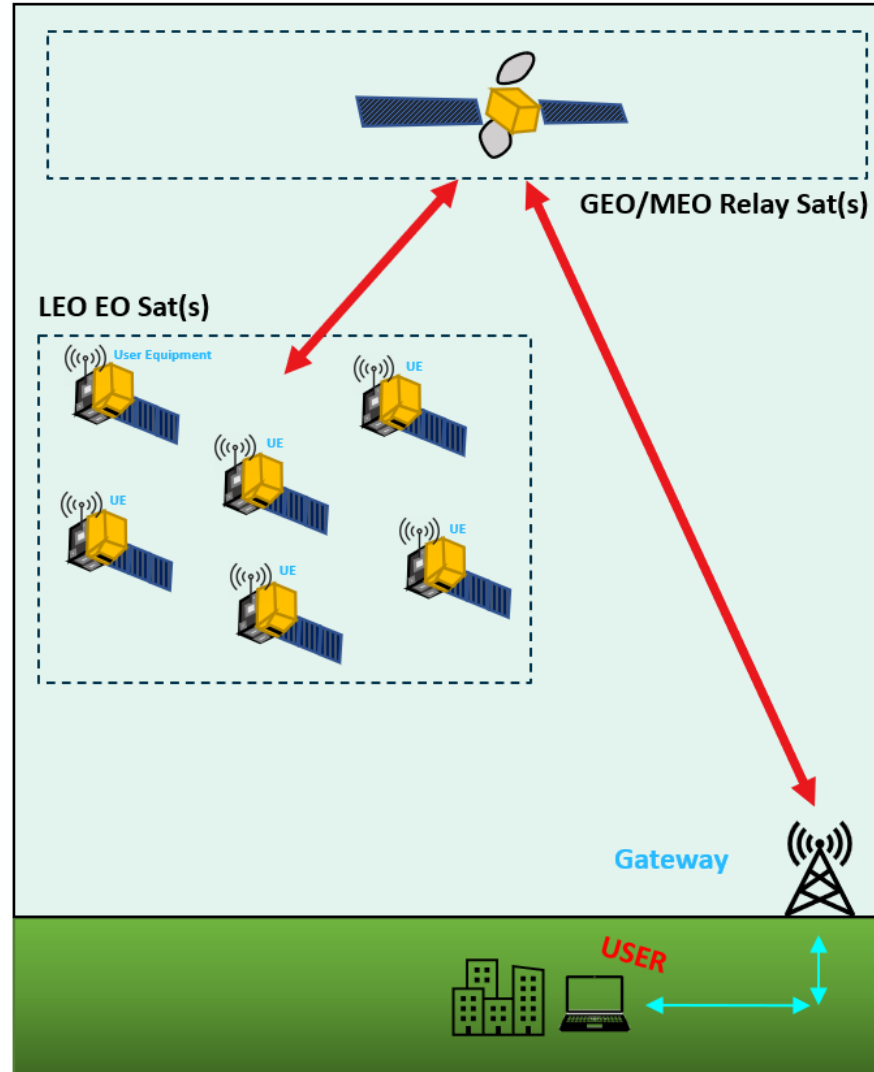
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- EO Satellite Operators
- EO Data Providers
- EO Data Users

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- Distribution of TT&C Exchanges
- Broadcast Payload operations
- Autonomous Anomaly Report
- Optical / High-speed Downlink Activation
- Space Debris Avoidance
- Broadcasting Area of Interest
- On-board autonomy support for constellations

Bi-directional Scientific Data Exchanges

Supports scientific data and messaging data types, and offers both uplink and downlink communications.

Global Terrestrial & Oceanic Coverage

Continuous and uninterrupted global coverage over terrestrial & oceanic areas, capable of extending to a latitude range of $\pm 90^\circ$.

Variable Visibility Latency

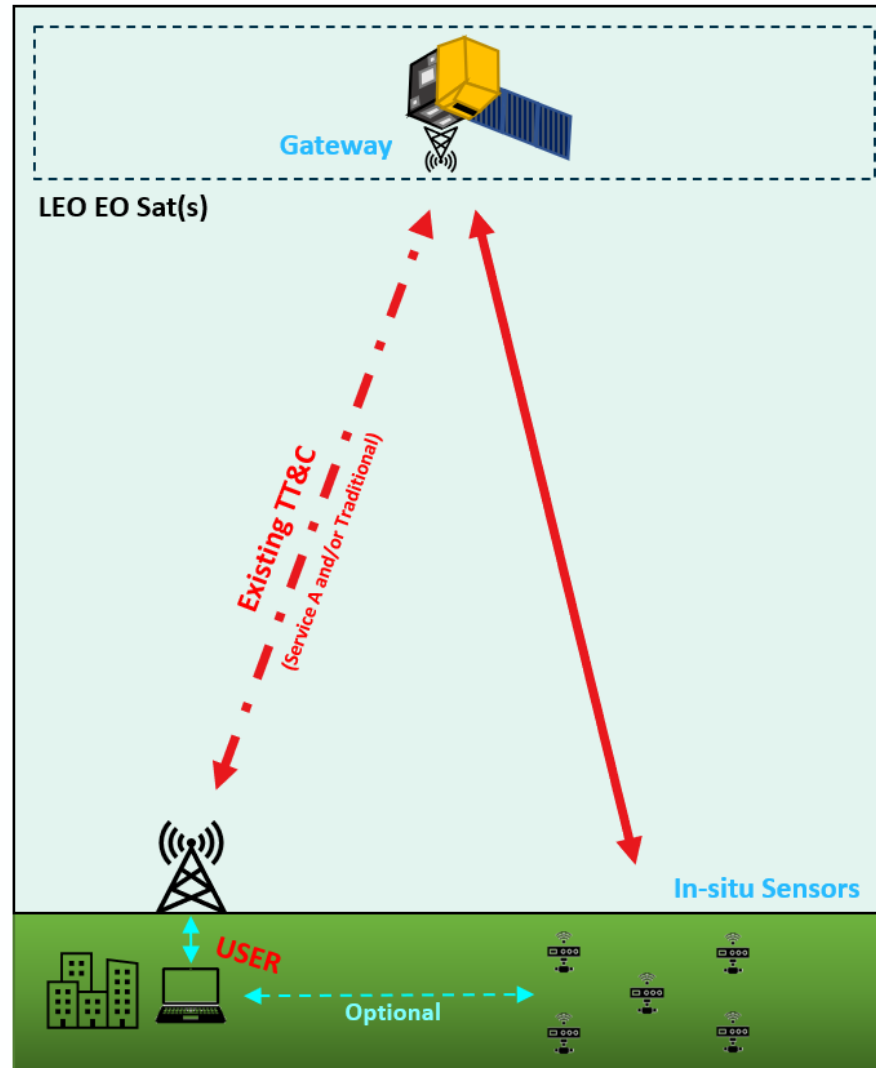
Variable Visibility latency over terrestrial & oceanic areas, highly dependent on number and distribution of in-situ sensors.

$\geq 3\text{kB}$ Daily Data Allowance

Send/receive ≥ 30 messages/day/sensor ($\sim 0.1\text{kB}$ each, on average) with a cumulative total daily data allowance of $\geq 3\text{kB}$.

$\geq 2\text{kbps}$ Upload and Download Speeds

Data upload/download speeds start at 2 kbps, with priority given to higher-speed transmissions for mission-critical operations



Service description:

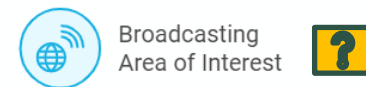
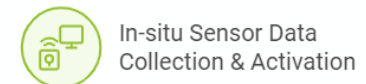
In-situ sensors \leftrightarrow LEO EO satellites:

1. In-situ sensor data collection
2. In-situ sensor triggering for **co-located** in-situ and remote sensing measurements, across **spatial** and **temporal** dimensions.

Attractive to:

- EO Data Providers
- EO Data Users
- In-situ Sensor Users / Operators

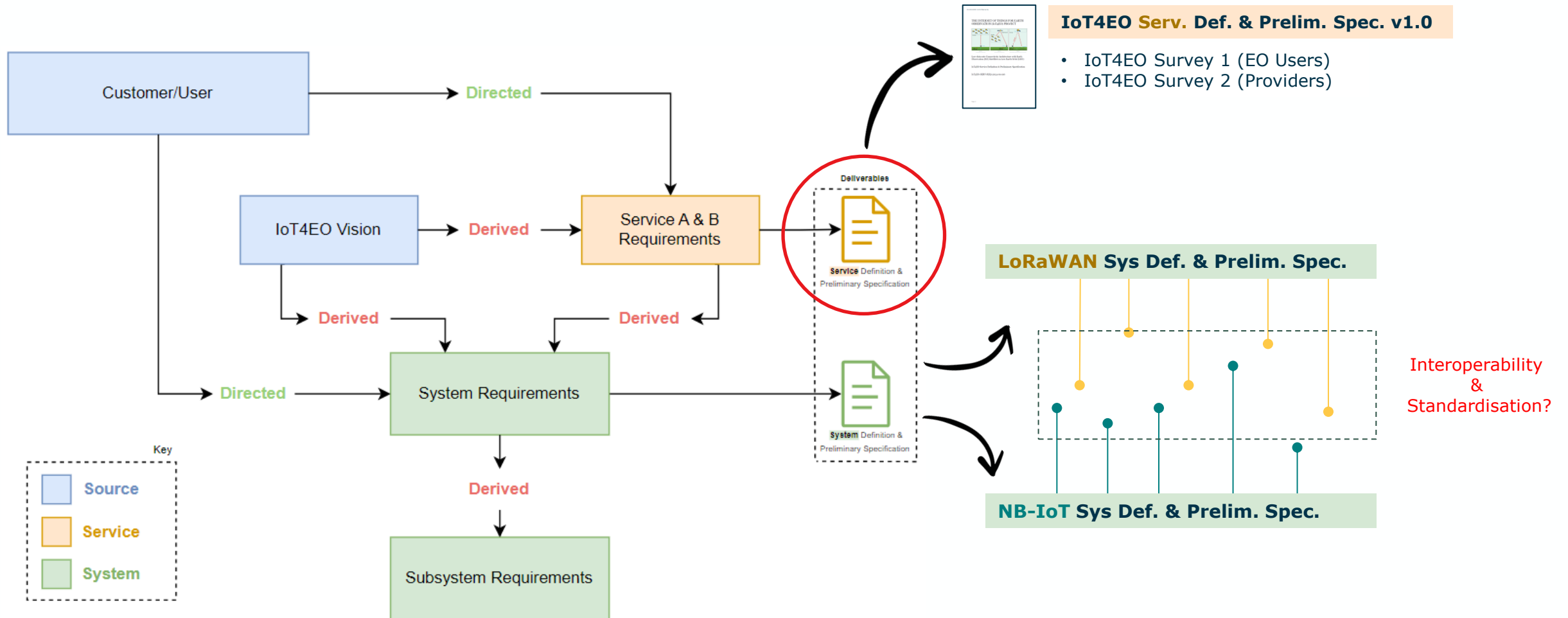
Applications/Use Cases:



IoT4EO Provider-Agnostic System Architecture

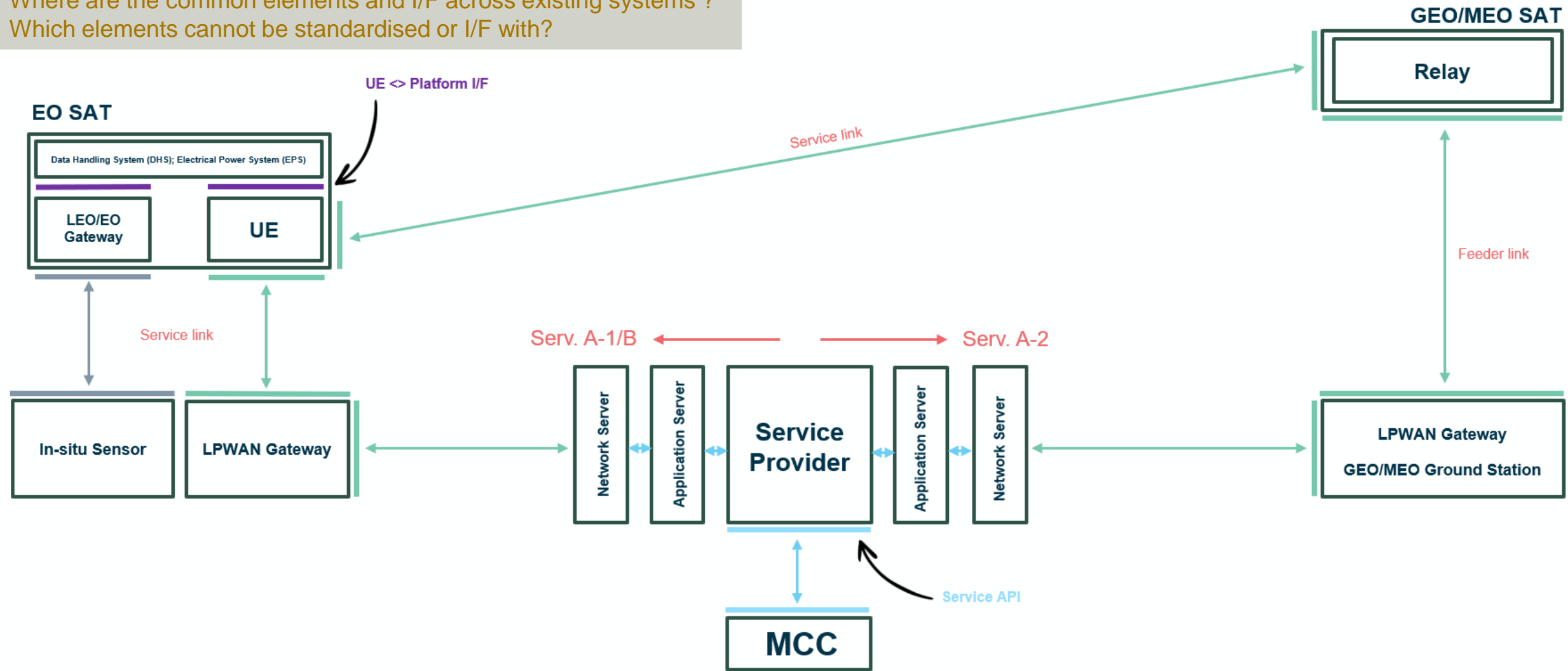
Vision/User Req. → Service → System

(Requirements Translation & Traceability)

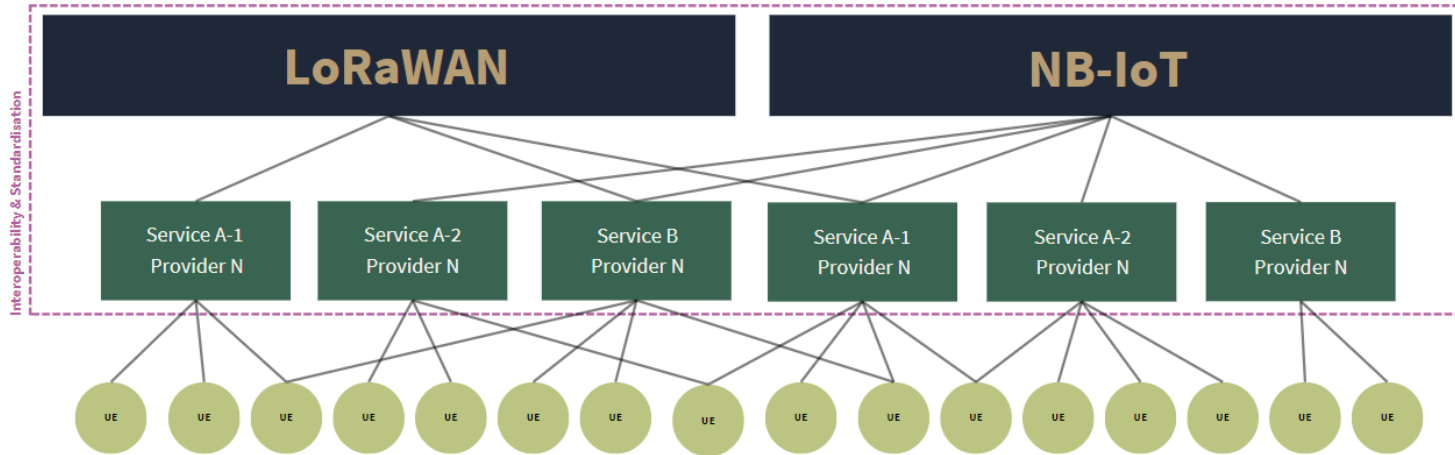


IoT4EO Provider-Agnostic System Architecture (Simplified)

Where are the common elements and I/F across existing systems ?
Which elements cannot be standardised or I/F with?



IoT4EO Service Definition & Preliminary Specification

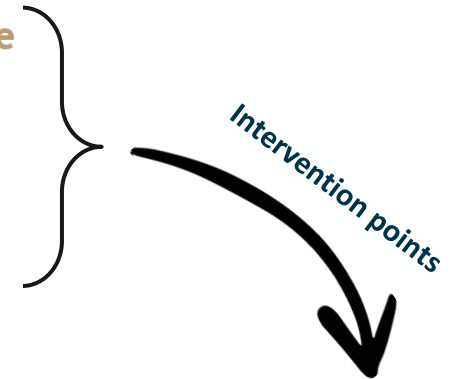


IoT4EO Vision
User requirements

System Architecture
Multi-solution options

Service Provision
Provider Agnostic

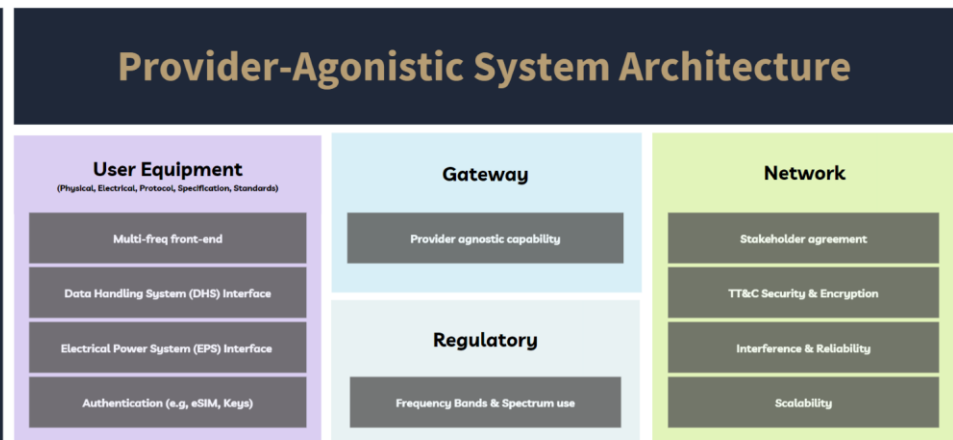
User base



- safety / security to route TT&C messages through public I/F ?
- capital cost of standardisation justified ? wrt capabilities
- core functionalities & objectives ?
- systems & interfaces & providers needed ?
- interfaces & APIs already available?
- data formats, protocols, and standards ?

Provider-Agnostic System Architecture

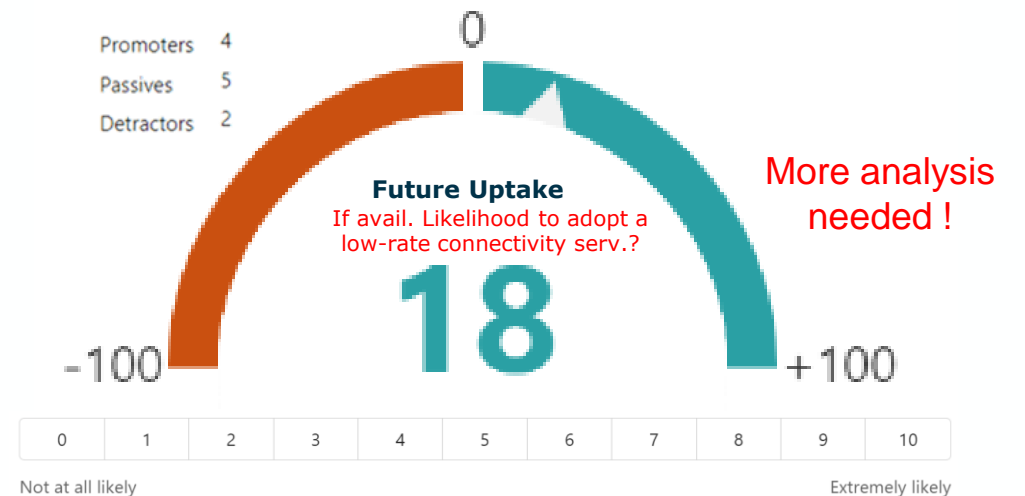
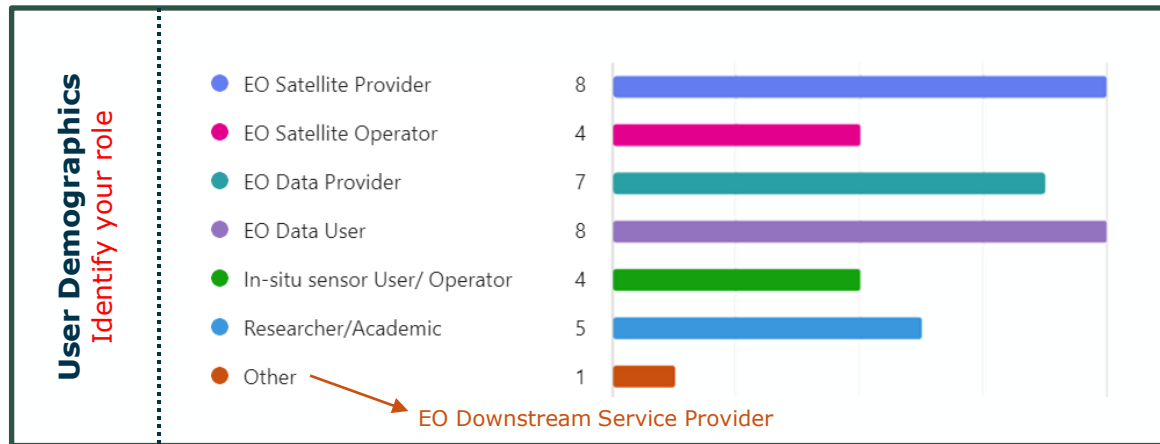
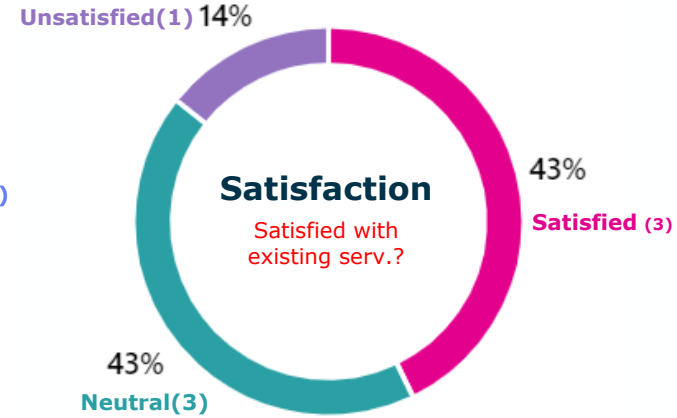
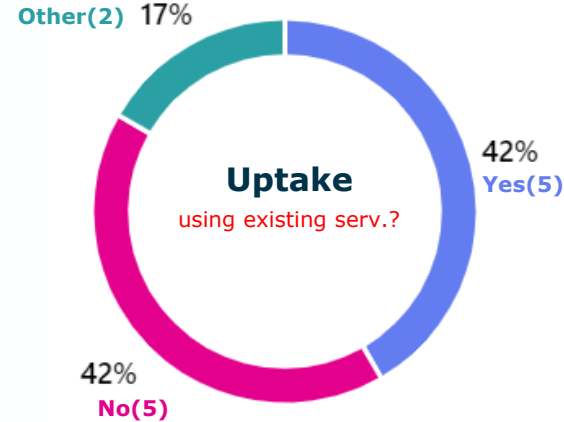
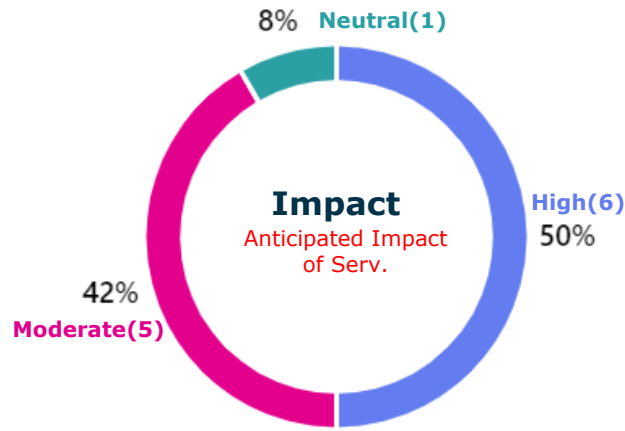
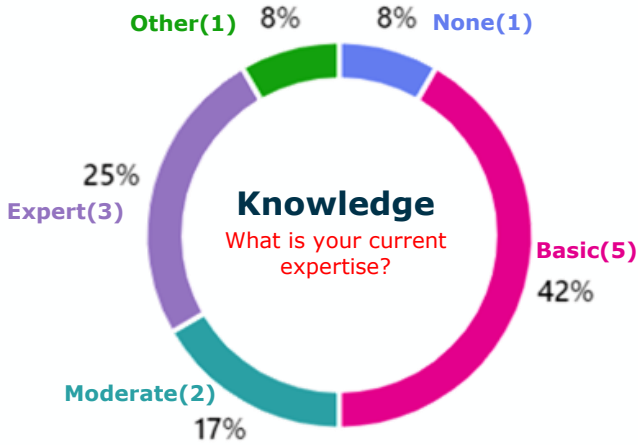
Interoperability & Standardisation



IoT4EO Survey Results – Sneak Preview



USER Survey Results – Stakeholder Demographics & Interest



PROVIDER Survey Results – Stakeholder Demographics & Interest

