Concepts for the use of IOT in Earth Observation System

Workshop 2

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Agenda

- **Study overview**
- **Studied protocols overview**

- **Service A-1: ground gateways**
- **Service A-2: GEO relays**
- **Service B: data collection from ground sensors**

- **Conclusions and perspectives**

Study overview

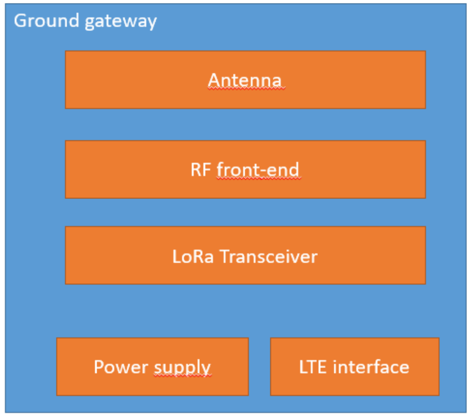
- Study started beg of November 2022
- Assessed potential use cases of a seamless connectivity for LEO EO satellites though low-data-rate omnidirectional comms
- Review of requirements
- Proposed different “Services” architectures
  - Service A-1: connection from “ground gateways”
  - Service A-2: connection from GEO relays
  - Service B: activation & collection of in-situ ground sensors data
- Conducted simulation performances to evaluate latency, coverage, capacity of the system

Protocols overview

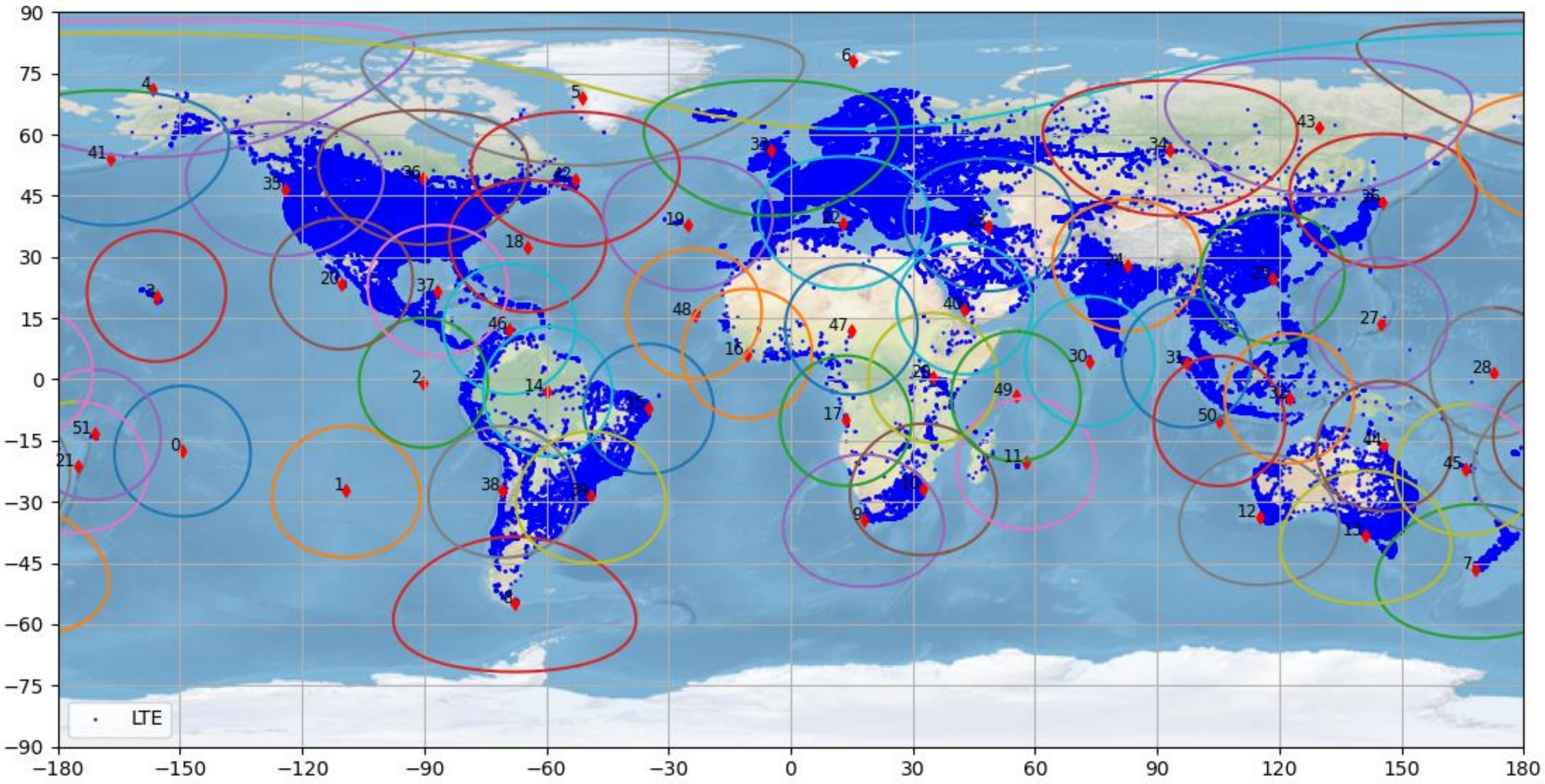
- Most popular protocols assessed: LoRa & NB-IoT

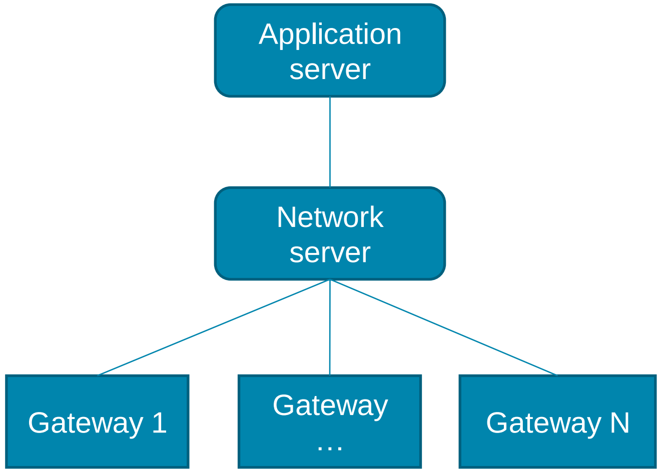
	LoRa	NB-IoT
Type	Spread Spectrum	Frequency Division
Bandwidth	> 125 kHz	3.8 (UL) / 180 (DL) kHz
Spectrum	Shared / dedicated	dedicated
Channel access	Random	Controlled
Packet Collision	Possible	None
Number of users per cell	< 100	10 000+
Required SNR	> -20 dB	> -1dB
Gateway-user pairing	None	Yes
Doppler robustness	Good	Need GPS information
Data rates	1-30 kbps (for 200kHz BW)	1-4 (UL) / 50-150 (DL) kbps

Service A-1: ground gateways



- Distributed worldwide network(s) of LoRa “ground gateways” looking upwards
- Passive, autonomous devices (no mechanism, no human intervention), WiFi-box-like
- All gateways of a same network connected via internet to a Network Server





Service A-1: ground gateways

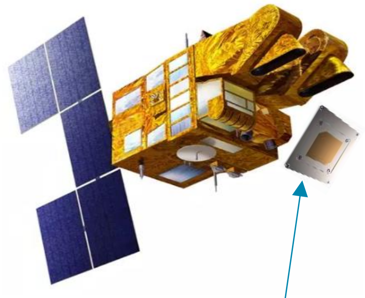
- Architecture

Altitude: 400 to 800km

Distance up to 2400km

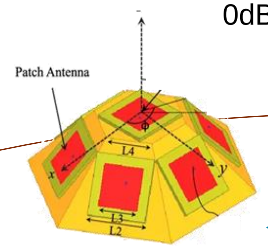
Link budget margin >= 3dB

Targeted packet collision rate 1%



Patch antenna
0 dBi 140° beam

Ground gateway
0dBi 160° beam



Minimum elevation angle:
at least 10° above
gateway horizon

internet

Mission
Control
Center

images credits: EnduroSat, Airbus DS

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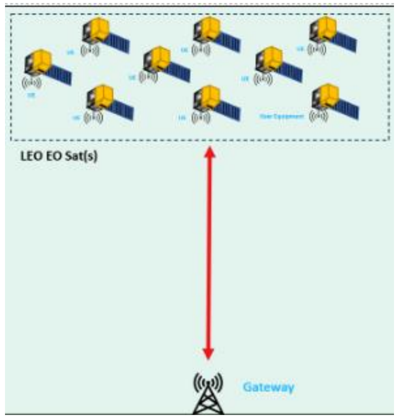
Service A-1: ground gateways

Legend:
- ground side
- satellite side
- RF



- Typical request life cycle for downlink* (Gateway → User or ground → satellite):

ground side | satellite side

Request via Application Server API → Transmission to Network Server → Scheduling and transmission to closest Gateway → Transmission to LEO satellite → Decoding

- Typical request life cycle for uplink* (User → Gateway or satellite → ground):

satellite side | ground side

Wait for gateway visibility → Random selection of a channel → Transmission to all gateways in view → Transmission to Network Server → Deduplication and decoding → Transmission to Application Server → Data accessible via Application server API

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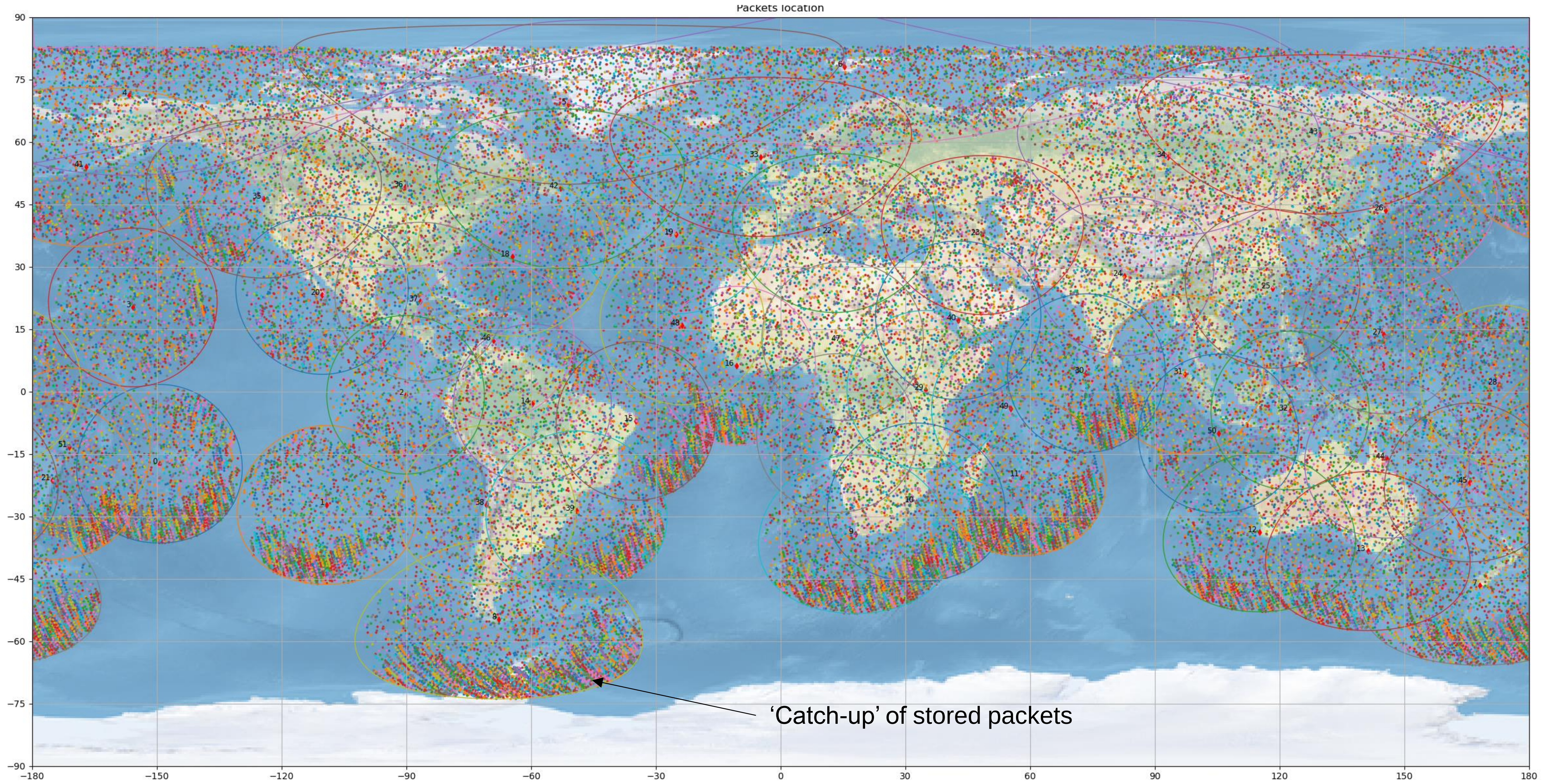
Service A-1: ground gateways

- Points = location of EO sat during packet emission
- 500 EO sats, each sending 1 packet every 9min
- 52 ground gateways with 10° minimum elevation angle



Service A-1: ground gateways

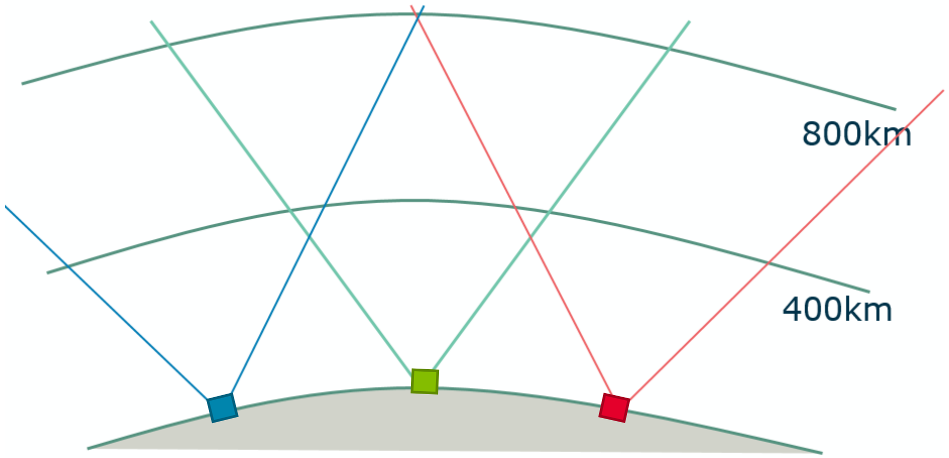
- Link budget: sizing case is 800km altitude satellites at 10° minimum elevation angle
  we use IoT terminology

	Uplink (sat to ground)	Downlink (ground to sat)
TX power	10 W	10 W
TX gain	0 dBi	0 dBi
Bandwidth	200 kHz @ 2GHz carrier	
Max distance	2400 km	
Losses (propagation, atmospheric, polarization/adaptation…)	-173 dB	
RX G/T	-27 dB/K	
SNR	-14.2 dB	
Worst-case data rate	1 kbps	

Service A-1: ground gateways

- LoRaWAN protocol selected:
  - Standardised since 2015
  - Service Provider agnostic: large number of LoRaWAN networks operators (27 in LoRa Alliance)
  - Dedicated Spectrum opportunity : Agenda Item AI 1.12 for WRC27 regarding low-data-rate non-geostationary mobile-satellite systems in 1-2 GHz band – burst-like protocols only
  - Inexpensive HW and low operation complexity (no “gateway selection” required)

- Other candidates assessed: NB-IoT, but
  - No dedicated frequency opportunity: negotiate with license owners -> costly
  - Complexity due to overlap between ground gateways service area
    - Frequency reuse needed to avoid interferences: larger spectrum needs
    - No Handover management in NB-IoT
  - Higher Stack complexity (usually deployed along with LTE/5G core)



Neighbouring ground gateways overlap but handover not managed in NB-IoT !

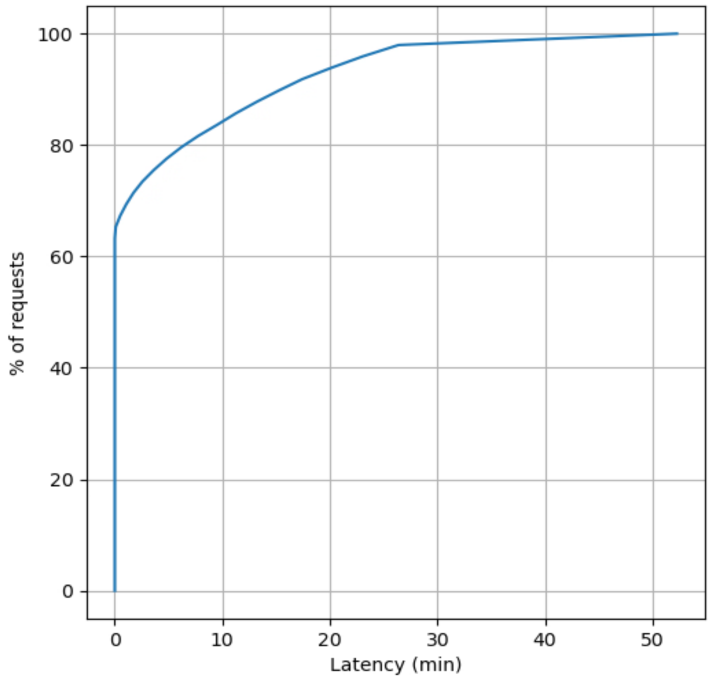
Service A-1: ground gateways

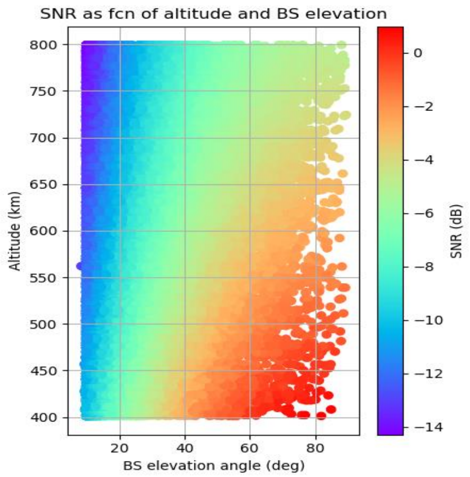
- Overall performances simulations for uplink
  - 500 LEO satellites, SSO orbits, 400-800km altitude
  - One 200Bytes packet sent every 9min by each EO satellite
  - 10 channels, 200kHz each
  - Targeted primary packet collision ratio 1%

- Results
  - Latency < 10min : 85% of the time for 10° MEA
  - Sensitivity to MEA performed:

% of orbit covered	MEA 10deg	MEA 20deg
'Zero' latency	66%	40%
<10min latency	85%	75%

  - Trade-off to be performed between number of ground gateways and MEA
  - "Adaptative Data Rate" approach to benefit from better SNR as satellites get closer to a gateway zenith





Service A-1: ground gateways

- Scalability is driven by the spectrum availability (to keep packet collisions low)
  - LR-FHSS to be studied for a x100 reduction in spectrum needs / increase in system capacity

	LoRa	LR-FHSS (uplink only)
Type	Spread Spectrum	Spread spectrum + Frequency Hopping
Bandwidth	200 kHz	137 kHz
Spectrum	Shared / dedicated	Shared / dedicated
Channel access	Random	Random
Packet Collision	Possible	Very unlikely
Number of users per cell	< 100	**< 10 000**
Required SNR	> -20 dB	> -20 dB
Gateway-user pairing	None	None
Doppler robustness	Good	High
Data rates	1-30 kbps	0.5 kbps

- In LR-FHSS, gateways can also collaborate to improve SNR

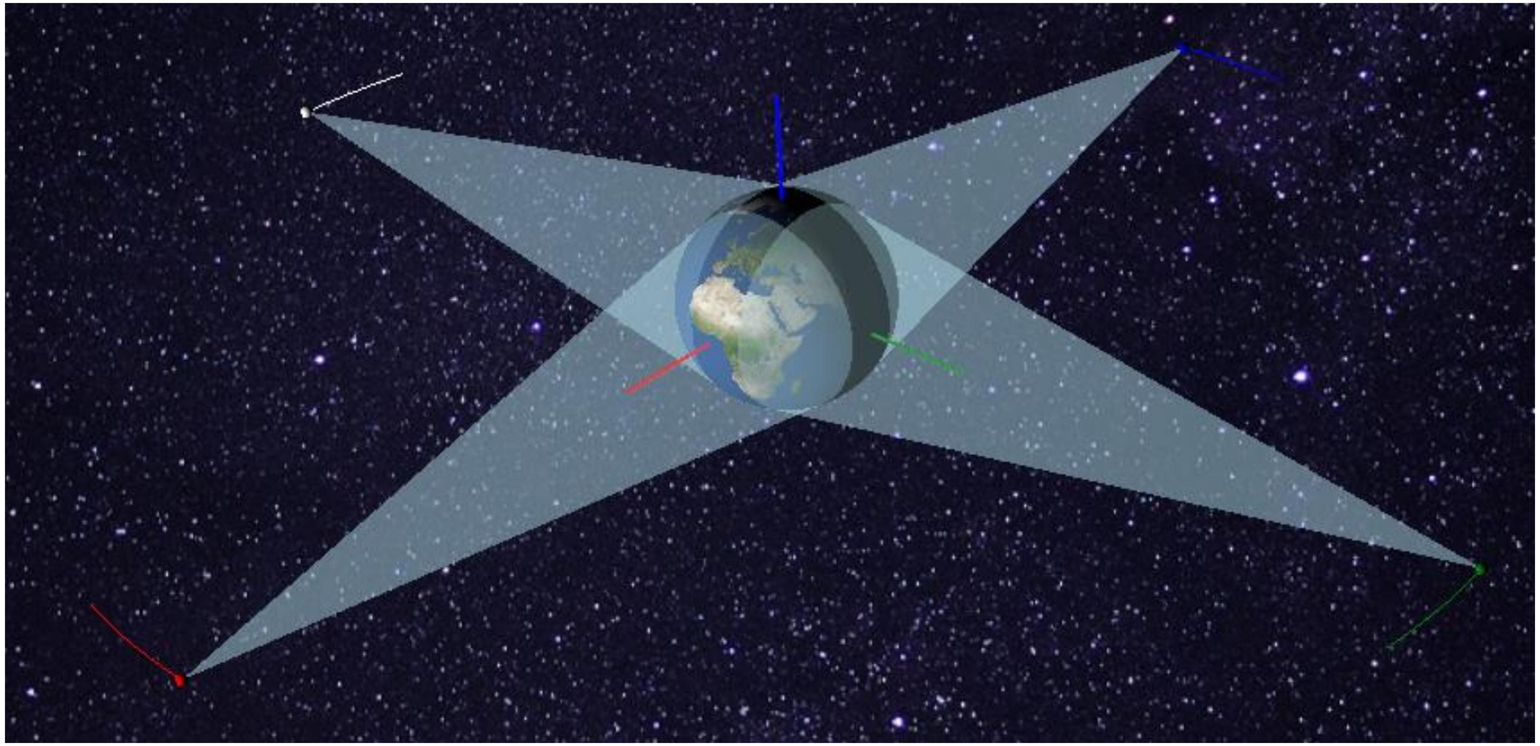
Service A-1: ground gateways

- Pros
  - Low initial CAPEX
  - Low entrance ticket for service providers
  - Good opportunity for spectrum availability
  - Multi-steps deployment / scalability
  - LR-FHSS opportunity for scalability

- Cons
  - Partial coverage (land + coastal zones extent depending on minimum elevation angle)
  - Lower data rates than NB-IoT
    - Compensated by longer time-on-air

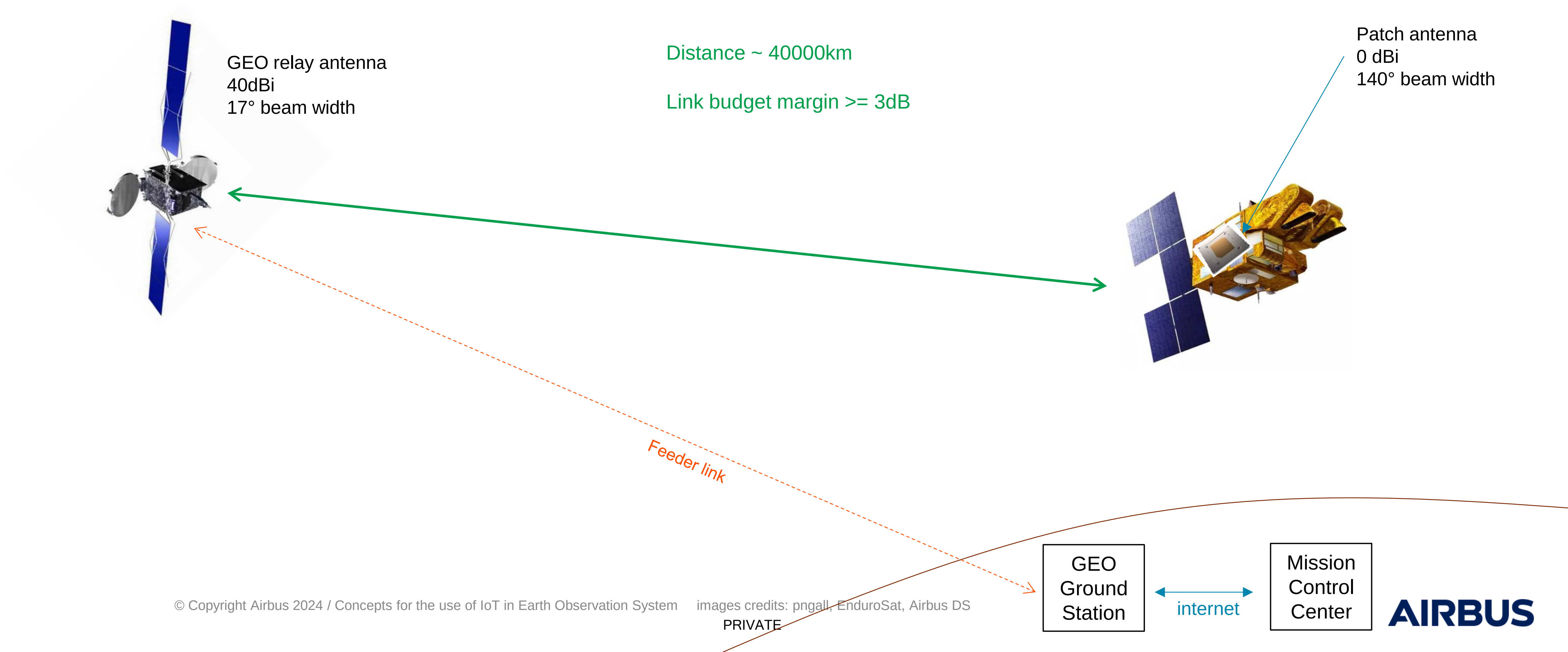
Service A-2: GEO relays

- 4 GEO satellites providing connectivity to LEO satellites



Service A-2: GEO relays

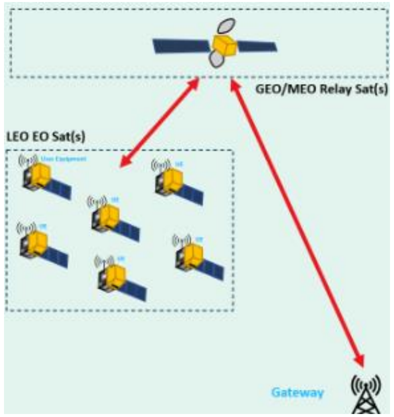
- Architecture



images credits: pngall, EnduroSat, Airbus DS

Service A-2: GEO relays

Legend:
- ground side
- GEO relay side
- LEO satellite side
- RF



- Typical request life cycle for downlink (Gateway → User or ground → LEO satellite):

ground side | Relay side | satellite side

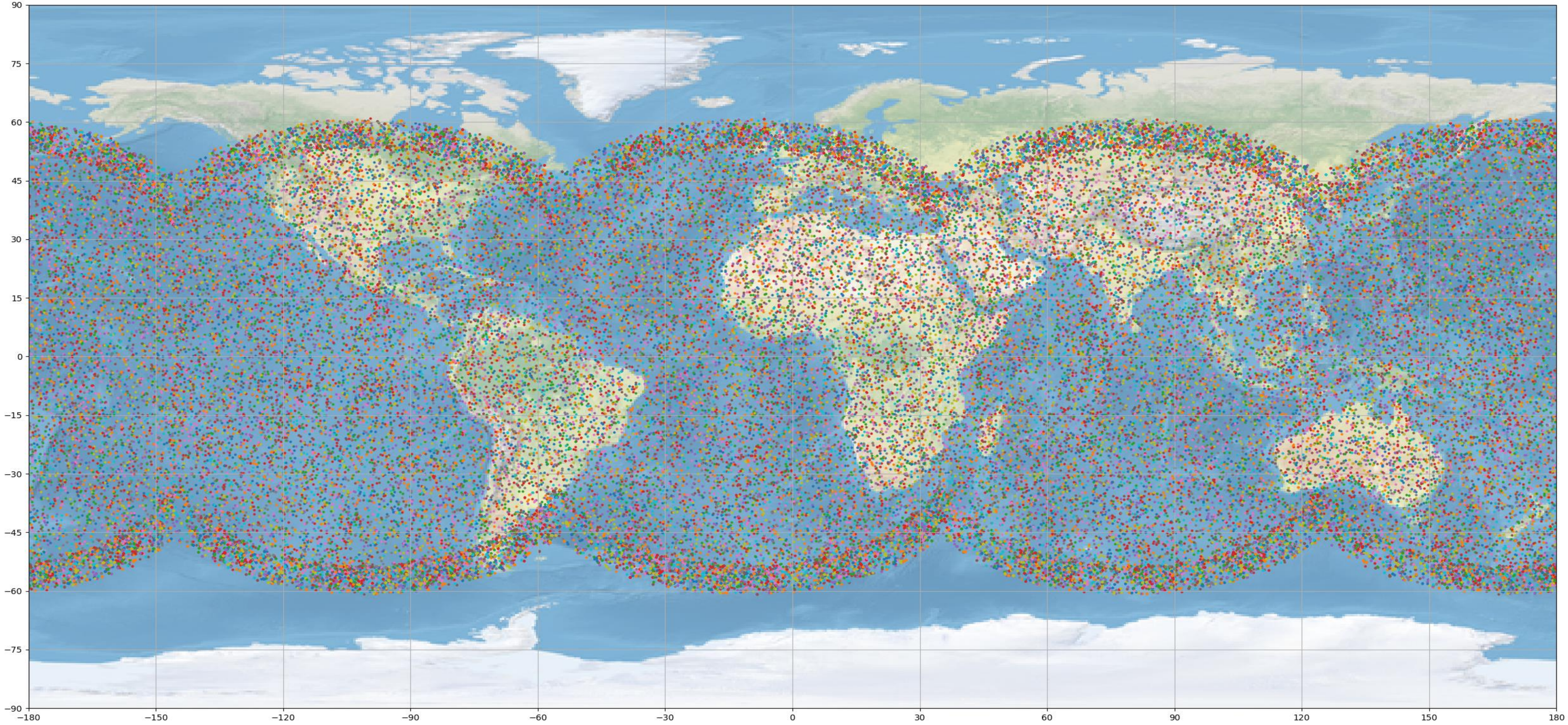
Request to GEO relay Control Centre → Transmission to GEO relay via feeder link → Modulation to NB-IoT carrier frequency → Transmission to LEO satellite → Decoding

- Typical request life cycle for uplink (User → Gateway or LEO satellite → ground):

Cell search → Cell reselection if needed → Transmission to GEO relay → Modulation to feeder link frequency → Transmission to GEO relay Control Centre → Data accessible via API

Service A-2: GEO relays

- Points = location of EO sats during packets emission
- 500 EO sats, each sending 1 packet every 9min
- 4 GEO relay satellites



Service A-2: GEO relays

- Link budget: sizing case is 400km-altitude satellites

	Uplink (sat to GEO)	Downlink (GEO to sat)
TX power	0.15 W	2.5 W
TX gain	0 dBi	40 dBi
Bandwidth	3.75 kHz	180 kHz
Max distance	39600 km	
Losses (propagation, polarization/adaptation…)	-194 dB	
RX G/T	13 dB/K	-27 dB/K
SNR	3.6 dB	-1.2 dB
Worst-case data rate	1 kbps	50 kbps

Service A-2: GEO relays

- NB-IoT protocol selected:
  - Limited number of overlaps between GEO relays service cones: limits the number of cell reselections
  - Capability to handle very high density of devices in uplink and downlink
  - Dedicated Spectrum opportunity :
    - Agenda Item AI 1.11 for WRC27 regarding use of L/S band between GEO and non-GEO satellites
    - Use of Ka band (resolution 679 of WRC 23)
    - In any case, TBD for omnidirectional comms (likely not possible in Ka band)

- Other candidates assessed: LoRa/LR-FHSS, but too many LEO satellites in view: issue for downlink traffic
    - LR-FHSS would be fit for uplink, but downlink would require several frequency channels -> not efficient

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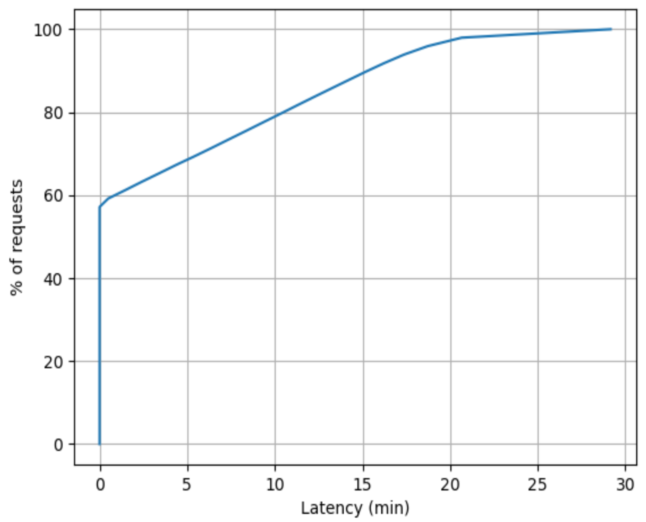
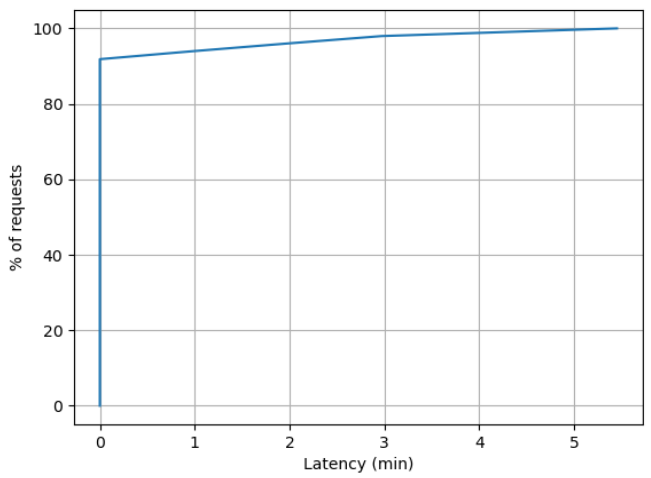
Service A-2: GEO relays

- Overall performances simulations
  - 500 LEO satellites, SSO orbits, 400-800km
  - One 200Bytes packet every 9min
  - 4 GEO satellites, 17° beam width (up to 80° latitude on ground)
  - Patch antenna on LEO user sat (140° beam width)
  - Frequency needs: one 180kHz channel per GEO relay



- Results
  - Latency < 10min 80% of the time
  - up to 100% coverage with <6min latency with larger GEO beam (20°) and full-hemispherical antenna (180°) on LEO satellite



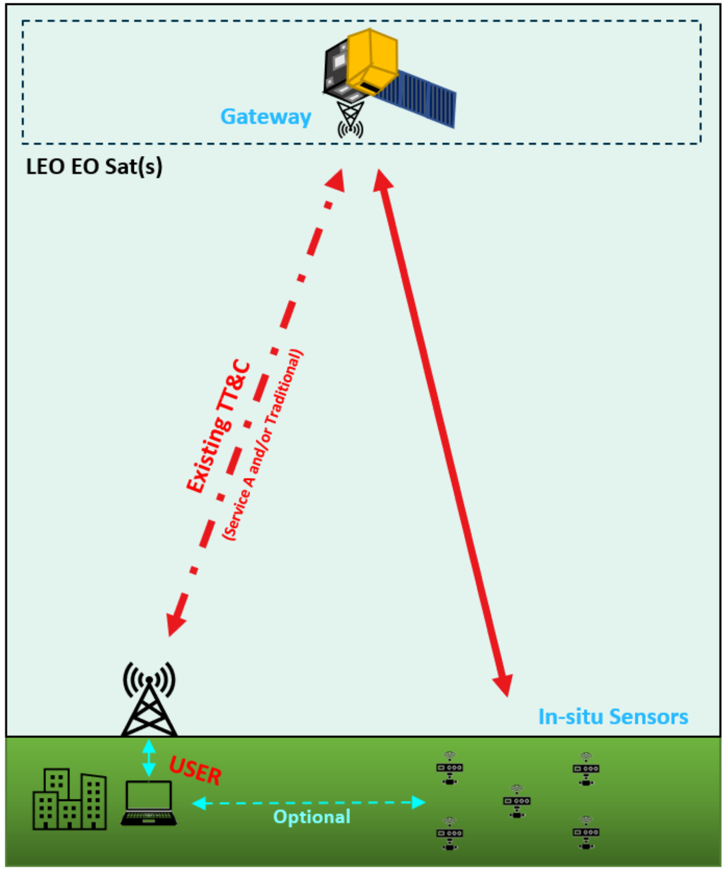
% of orbit covered	140deg beam width on EO sat	180deg beam width on EO sat
'Zero' latency	57%	92%
<10min latency	80%	100%

Service A-2: GEO relays

- Pros
  - Similar or better coverage than Service A-1 (depends on GEO & LEO antennas beam width)
  - Better data rates compared to Service A-1

- Cons
  - Larger initial CAPEX (rent/launch GEO satellites with large antenna)
  - Larger entrance ticket (standalone NB-IoT stack)
  - Uncertainty on spectrum availability conditions/cost of the service

Service B: interaction between LEO satellite and in-situ ground sensors



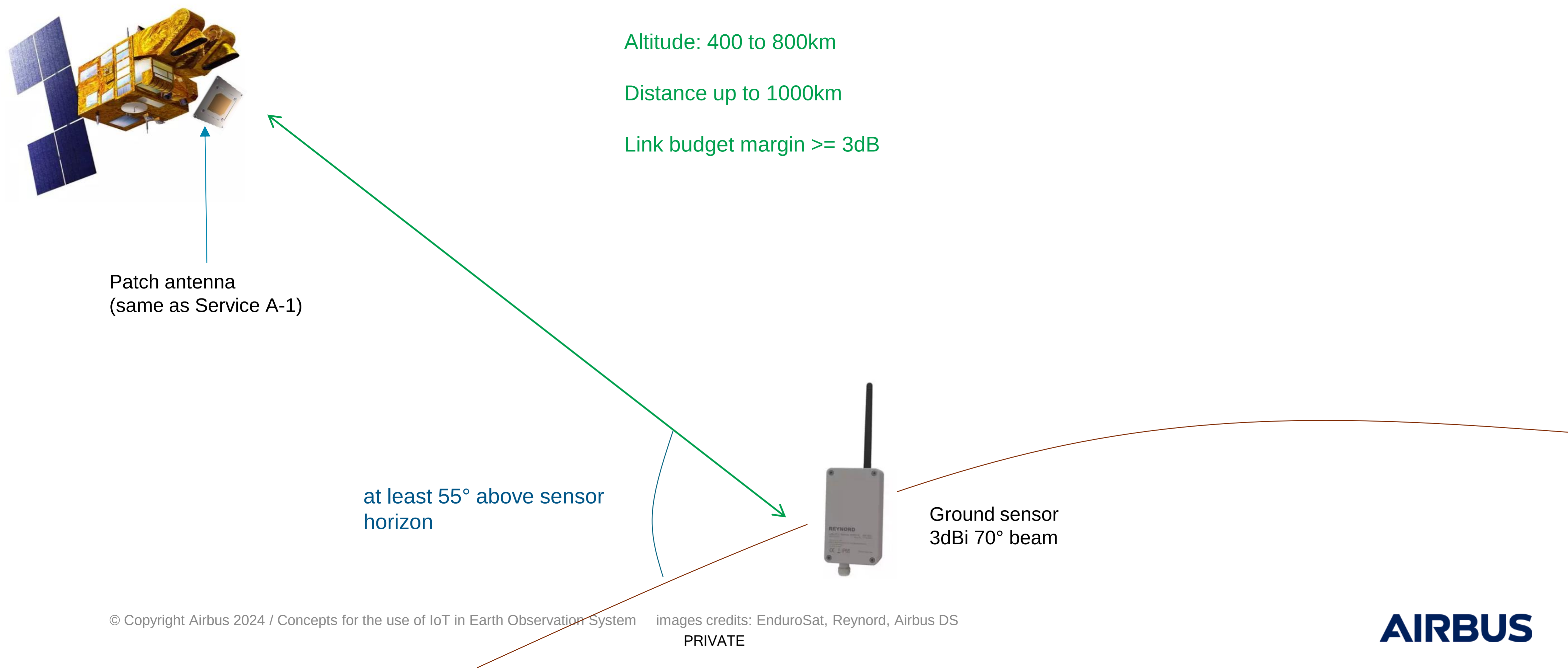
- LoRa/LR-FHSS Protocol
- The LEO EO satellite acts as a gateway
- The in-situ sensor acts as an end device
- LEO EO satellites transmit requests to sensors and collect data from them

Downlink : Gateway → User or Satellite → ground

Uplink : User → Gateway or Satellite → ground

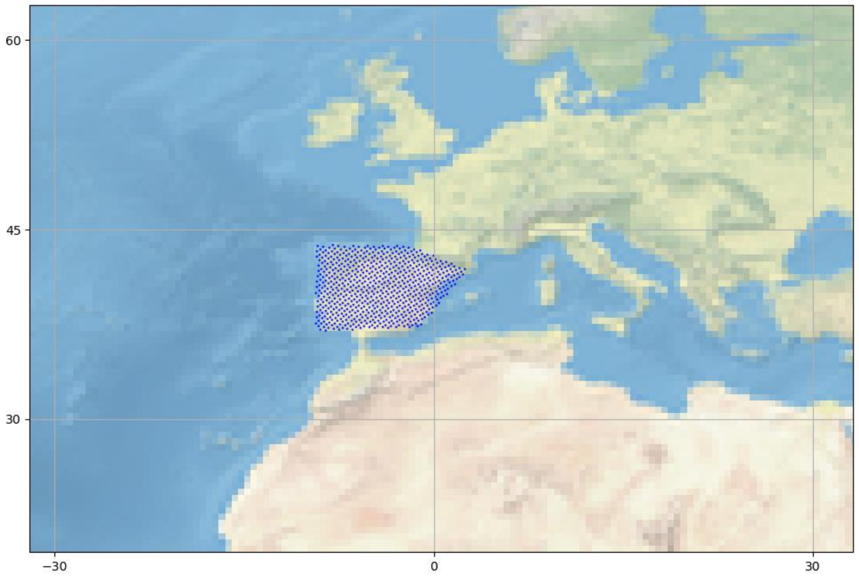
Service B: interaction between LEO satellite and in-situ ground sensors

- Architecture

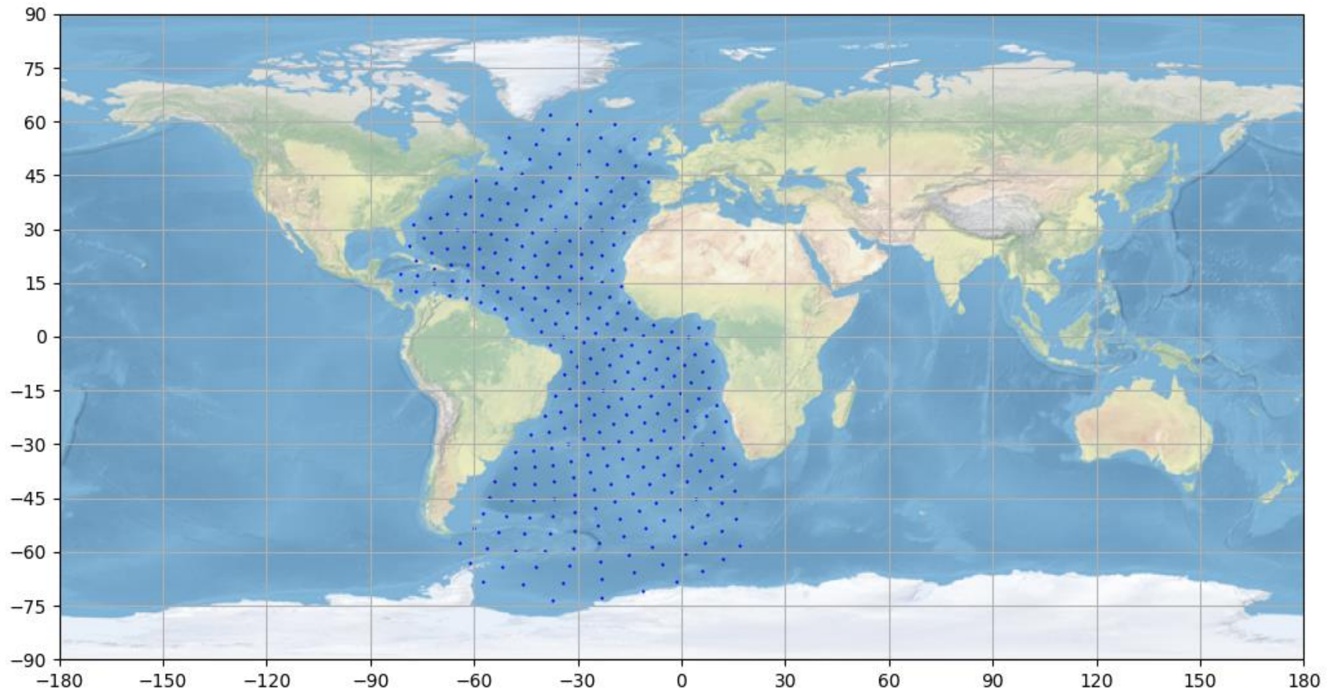


Service B: interaction between LEO satellite and in-situ ground sensors

- Ground sensors/actuators layout on Earth Surface can be varied



Moisture sensors in Spain/Portugal: dense mesh 30x30km



Surface temperature buoys in Atlantic Ocean: sparse mesh 500x500km

Service B: interaction between LEO satellite and in-situ ground sensors

- Link budget: sizing case is 800km altitude satellites at 55° minimum elevation angle

	Uplink (sensor to satellite) LR-FHSS	Downlink (satellite to sensor) LoRa
TX power	1 W	5 W
TX gain	3 dBi	0 dBi
Bandwidth	137 kHz @ 2GHz	125 kHz @ 2GHz
Max distance	1000 km	
Losses (propagation, atmospheric, polarization/adaptation…)	-162 dB	
RX G/T	-27 dB/K	-30 dB/K (no LNA)
SNR	-11 dB	
Worst-case data rate	0.5 kbps	1 kbps

Service B: interaction between LEO satellite and in-situ ground sensors

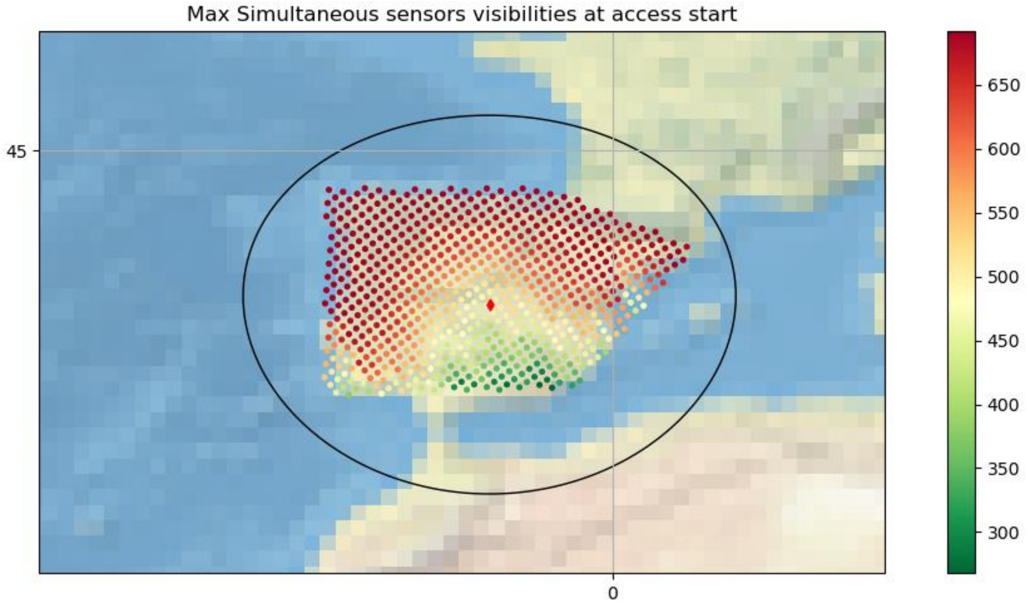
- LoRa protocol selected:
  - Large capacity (LR-FHSS for uplink)
  - Simple
  - Spectrum allocation opportunities (same as Service A-1)
  - Reuse LEO EO satellite HW (same as Service A-1)

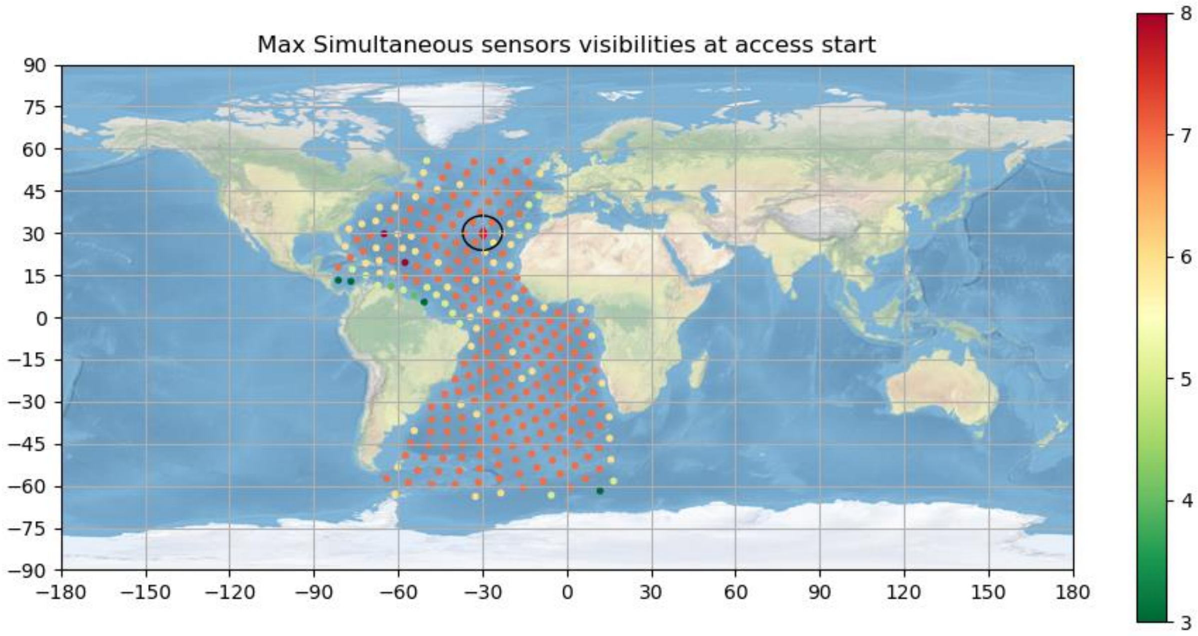
- Other candidates assessed: NB-IoT, but too complicated since LEO EO satellites layout is not controllable
  - frequency overlap -> interferences. Mitigation = more spectrum = costly

Service B: interaction between LEO satellite and in-situ ground sensors

Number of sensors visible by LEO satellite can be quite large !

Minimum elevation angle of 55° for sensors
Simulations with 500 EO sats
One point = one insitu sensor





Black circle: satellite visibility area

Driver | Important | Low criticity

Analysis of System Requirements – 1/2

Performance

Data volume per orbit/day | Packet length | Data rate | Latency | Coverage

Latency/Coverage directly drive.

- Service A1/B: nb of gateways & link budget
- Service A2: antenna pattern on EO satellite

10min max latency is deemed reasonable (latency mainly introduced because of poles/ocean)

- uniform packet rate to be refined with more realistic requests profile (e.g. mainly over landmass)

For service A1/B: The actual driver is a mix of data volume and nb of entities

Scalability

Nb of ground sensors | Nb of LEO satellites | Scalable architecture | Expansion of spectrum | Provider agnostic

Service A2: scalability ensured by NB-IoT

Service A1/B: the actual driver is a mix of data volume and nb of entities

Provider agnosticity is paramount, but low CAPEX/technological entrance ticket is a prerequisite given the IOT4EO market will remain small in volume

Driver | Important | Low criticity

Analysis of System Requirements – 2/2

Interoperability

International standards | Governance | Streamlined data flow | Documentation Maturity

International standards governance is influenced by 'major players'
Market size for IOT4EO will remain small in volume (<< 1 million chips)
-> Minimization of delta wrt existing standards is thus important !

Quality Of Service

Reliability | Resilience | Data accuracy

Reliability will drive qualification & redundancy.
Data accuracy could be expressed in terms of packet error rate. Packet Acknowledgement should be mentioned
Resilience req needs to be more concrete: % of system performance loss wrt % of inop. gateways for example

Data security and Privacy requirements

End-to-end encryption | Access control | Data protection

Stealthness: burst-like communications are harder to detect/localize
Discretion: ponctual RF emissions

Legal and Regulatory

ITU | Environmental | Data sovereignty

Frequency regulation / spectrum availability is THE main driver
Both in terms of business model (cost) and feasibility

Conclusion and perspectives - General

- Worldwide spectrum availability at reasonable cost is the main driver for Satellite IoT

- A few additional technical challenges compared to existing space based IoT
  - Omnidirectional antenna at LEO satellite level = more EIRP required + radiates everywhere
  - Symmetry between uplink traffic and downlink traffic

- A few challenges for industrial scalability
  - Spectrum availability
  - Networks cooperation for roaming

- Low-data-rate burst (LoRa-like) communications currently use unlicensed spectrum
  - Unclear existing regulatory framework for space-to-Earth emissions in current spectrum
  - Regulatory trend to restrict ‘new’ usages of these unlicensed bands for specific applications
  - New allocations to be discussed at WRC27 in 1-2GHz band (AI 1.12): best opportunity for Service A-1 & B !

Conclusion and perspectives – Regulatory roadmap

- For Service A-1 & B:
  - Need to be ready for working groups on AI 1.12 (new frequency allocation for low-datarate space <> earth comms)
    - most of business will be in ground sensors data collection, which have slightly different needs
  - Join LoRa Alliance right now to start influence work

- For Service A-2:
  - Assess cost of spectrum in L/S MSS band
  - Follow up regulatory evolution on AI 1.11

Conclusion and perspectives – Technological roadmap

- For Service A-1 & B:
  - Assessment of LR-FHSS with SemTech for minimisation of spectrum needs and improved scalability
    - Already used by a number of satellite IoT players
  - Antenna design for ground gateways: drives the EIRP envelope hence coverage and regulation
  - Refine simulations with more in-depth modelization of signal processing (gateway cooperation)

- For Service A-2:
  - Implementation of NB-IoT in (existing?) GEO satellites & handover management

Conclusion and perspectives – System studies

- For Service A-1:
  - Roaming across different LoRa networks (existing, but TBC if suitable for our use case)
  - Interconnexion & data flow between EO satellites operations & service providers
  - Frequency allocation/spectrum sharing across different LoRa networks
  - Downlink traffic management / spectrum optimization

Thank you