LoRaWAN for Direct-to-Satellite IoT

Simulation Tools and Open Challenges

Journées LPWAN
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Toulouse, France

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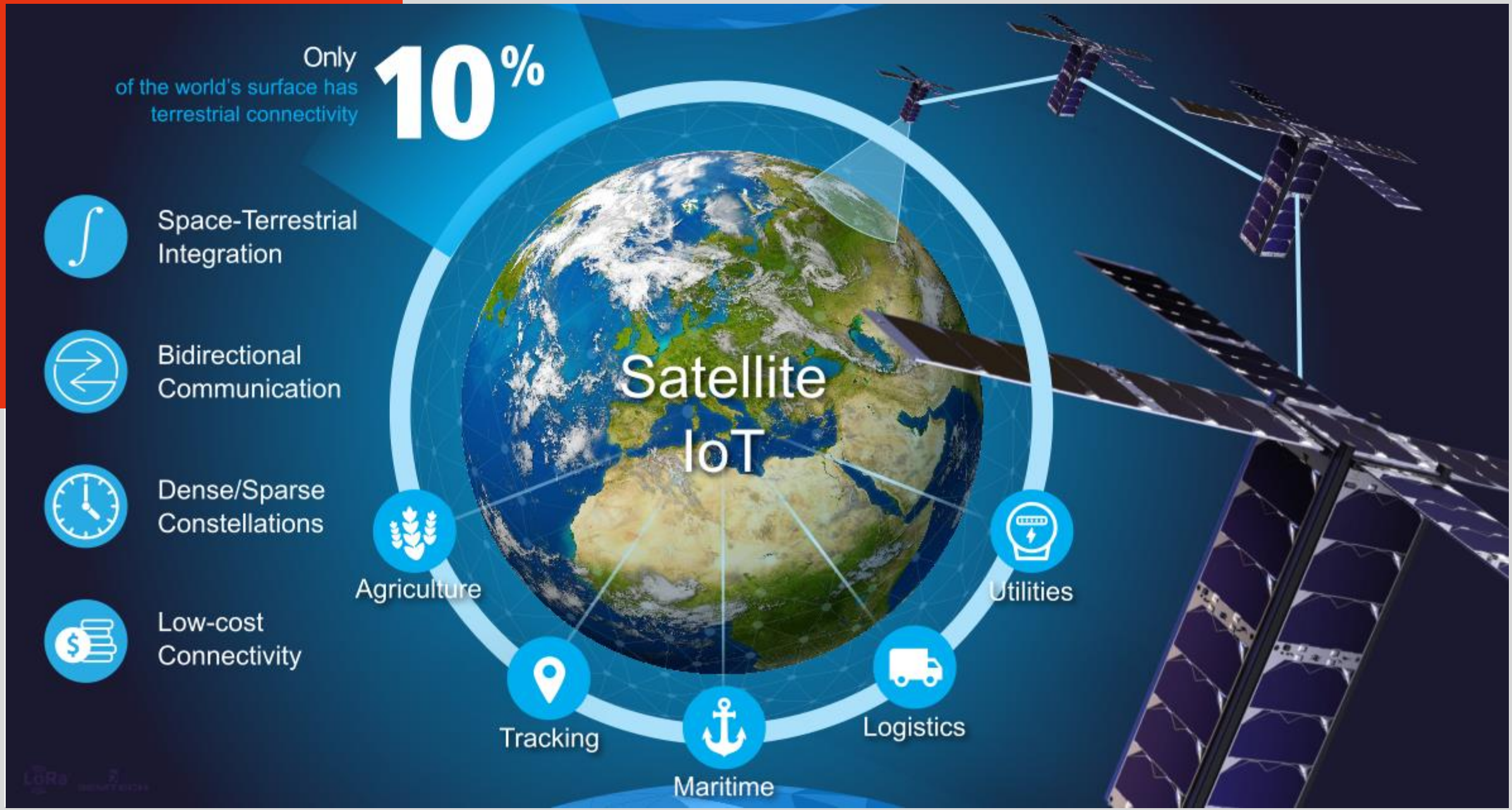
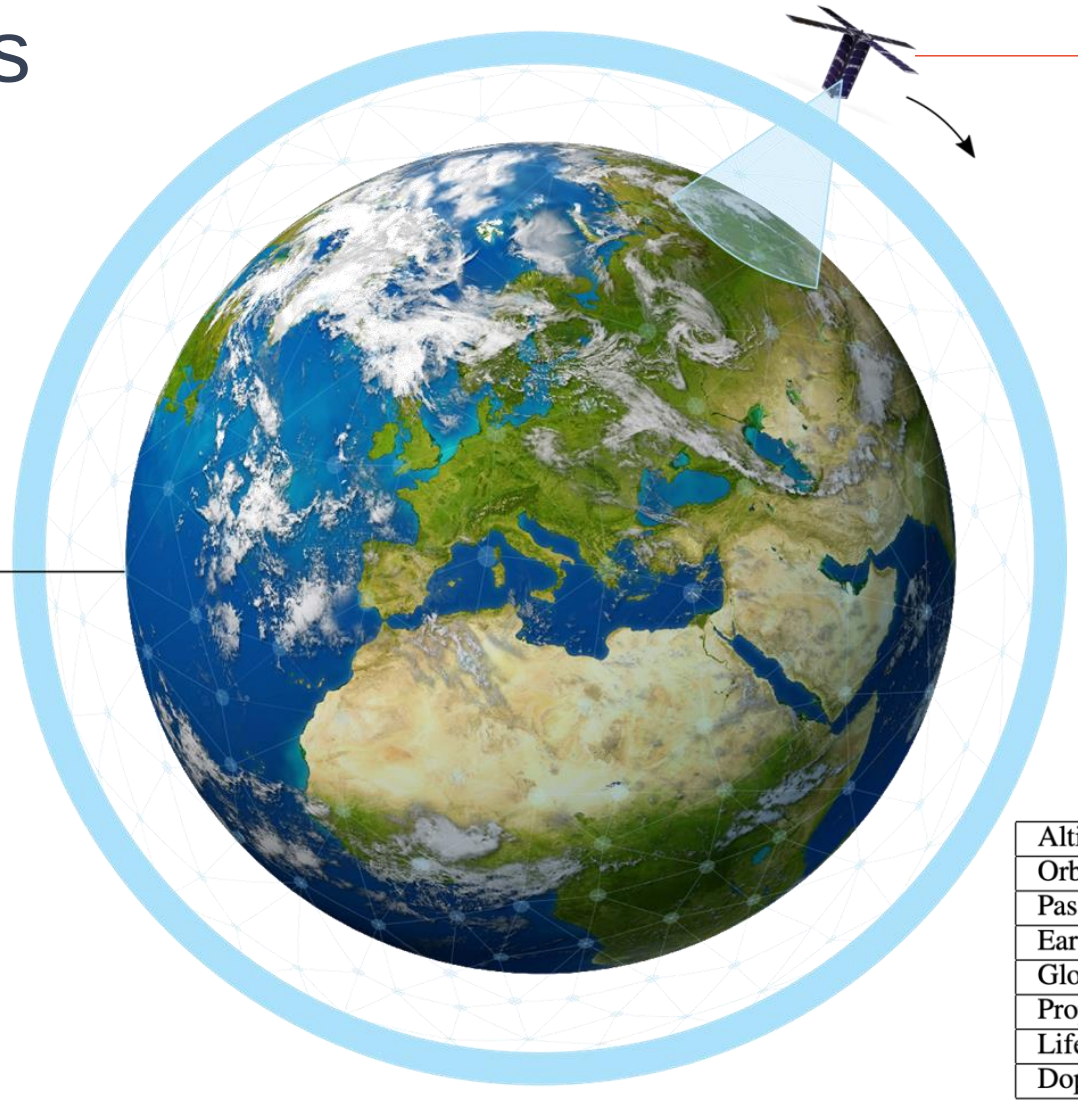

Only
of the world's surface has
terrestrial connectivity
10%
Space-Terrestrial
Integration
Bidirectional
Communication
Dense/Sparse
Constellations
Low-cost
Connectivity
Satellite
IoT
Agriculture
Utilities
Tracking
Logistics
Maritime

Orbit Basics

GEO

h: 35,786 km
v: 3 km/s

Equal to Earth rotational speed



LEO

h: < 1,000 km
v: 7 km/s

Passes over a region in <10 minutes

Constellations (cross-linked)

LEO AND GEO ORBIT CHARACTERISTICS

	LEO	GEO
Altitude	160-1000 km	35786 km
Orbital Period	~90 minutes	24 hours
Pass duration	<10 minutes	Permanent
Earth surface coverage	<1.5%	~30%
Global coverage	60+ needed	3+ needed
Propagation delay	7 ms	120 ms
Lifetime	<5 years	15 years
Doppler	Yes	No

Satellite IoT

In-orbit gateways

(**LEO**: Lacuna, Sateliot, Wyld)
(**GEO**: Echostar)

Traditional IoT-Like satellite protocols:
Argos, AIS

Space-Terrestrial Integrated IoT

hiber, FLEET, Lacuna, SQTELIOT, Myriota, KEPLER, kinéis

LoRaWAN: NB-IoT, SigFox

On-ground devices

LoRa [1]

Semtech LR1120 devices with **LR-FHSS** in Sub-GHz and 2.4 GHz ISM

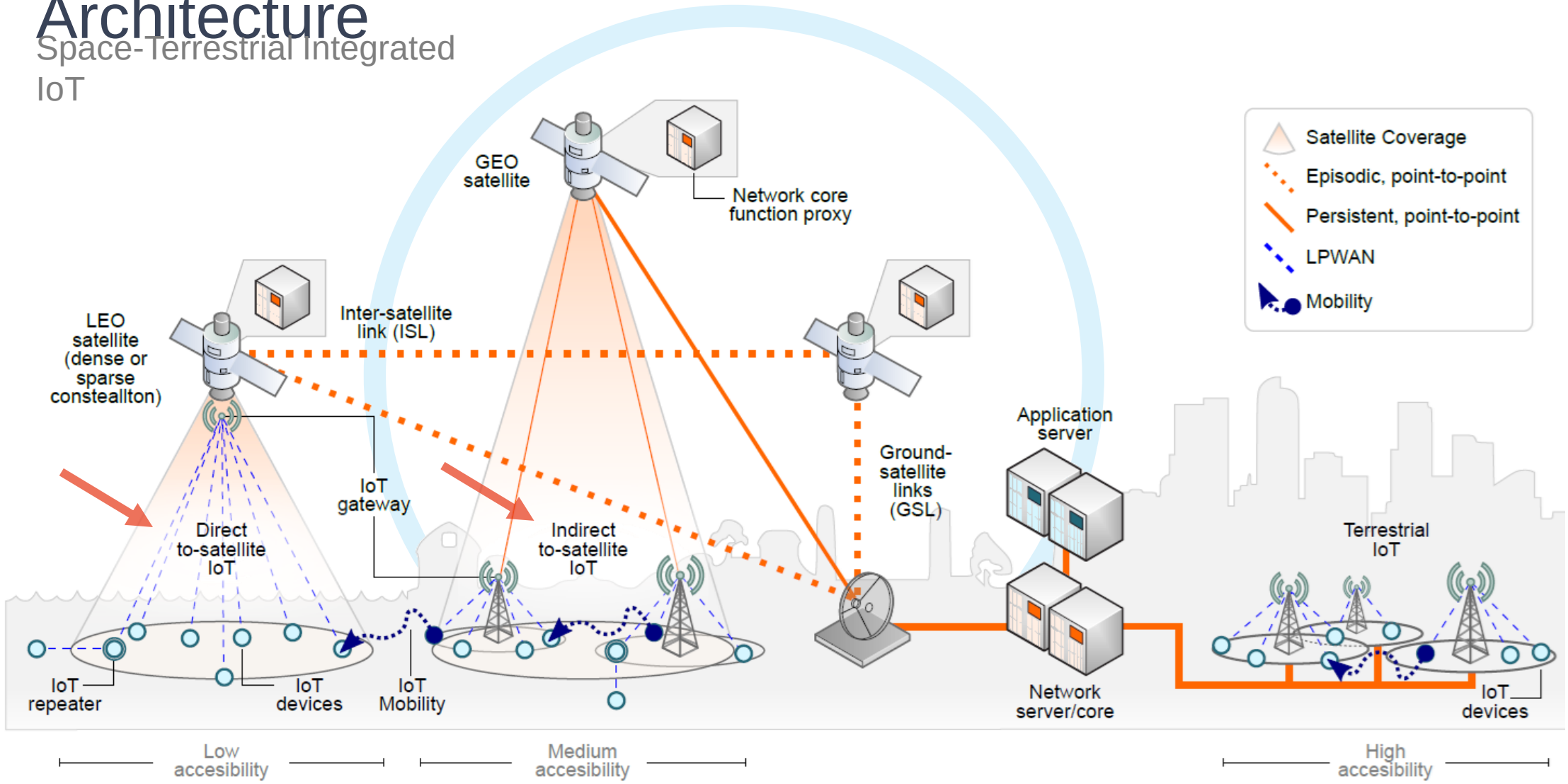
[2] NB-IoT

[1] N. Sornin (Semtech), Extending LoRaWAN Reach (https://youtu.be/pHq7_rgDyFA); Thomas Telkamp (Lacuna) Open satellite LoRaWAN at scale (https://youtu.be/vWkuqVJL1Sg)

[2] L. Ouvry, et al, "An Ultra-Low-Power 4.7mA-Rx 22.4mA-Tx Transceiver Circuit in 65-nm CMOS for M2M Satellite Coms," in IEEE Transactions on Circuits and Systems, May 2018

Architecture

Space-Terrestrial Integrated IoT



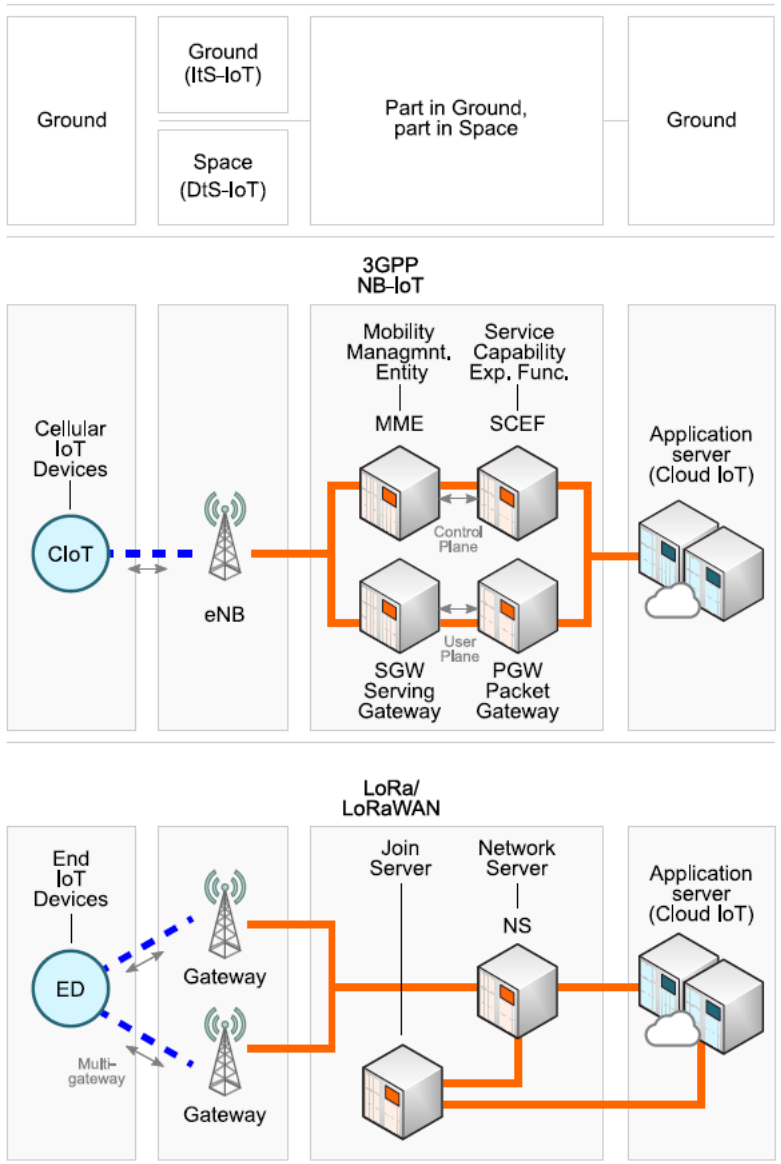
Challenges

Space-Terrestrial Integrated IoT

STEREO ANR

- **Architecture adaptations**
  - Radio-Access - frequency/protocols
  - Core-Network - sparse/dense
- **Software and hardware elements**
  - Synchronization and Localization
  - Mobility and Routing
  - Transmission and Reception Policies
  - Function Localization
- **Management and support**
  - Design and Operation
  - Evaluation

Inria (*Lyon*), LIG (*Grenoble*), IRIT, LAAS, Kineis (*Toulouse*)



Challenges

Space-Terrestrial Integrated IoT

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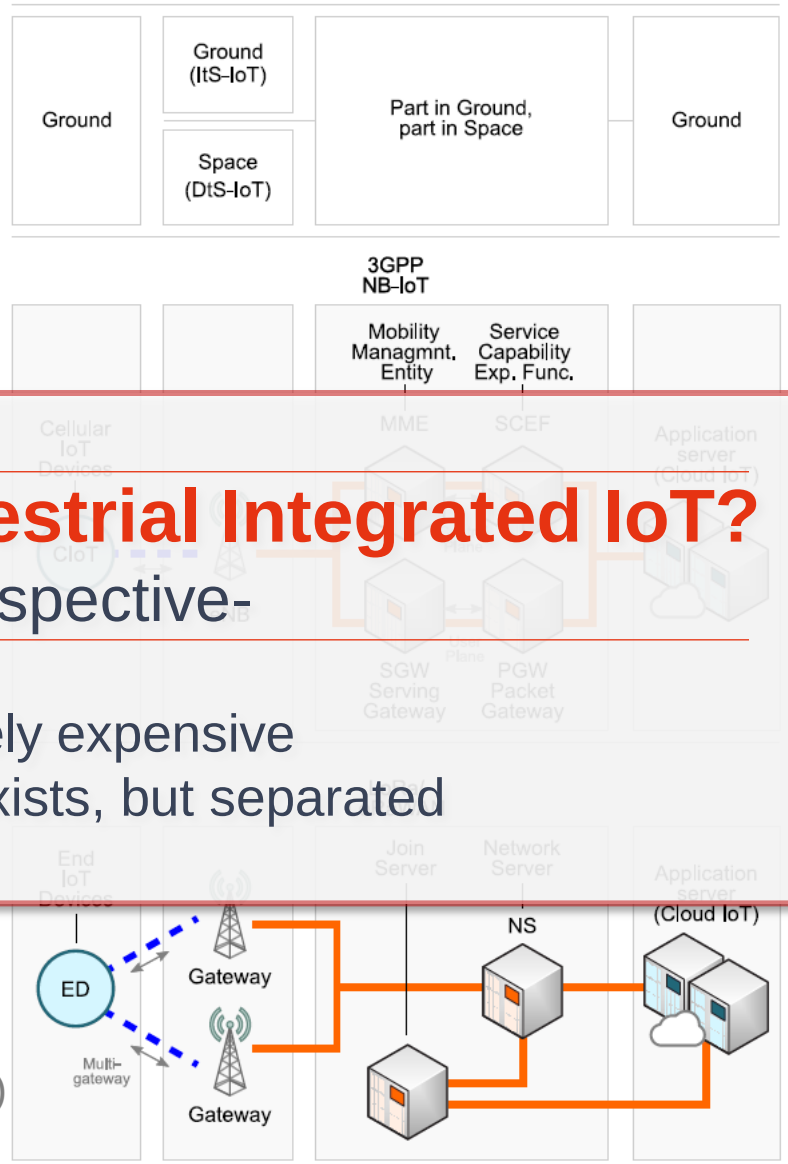


How can we evaluate Space-Terrestrial Integrated IoT?

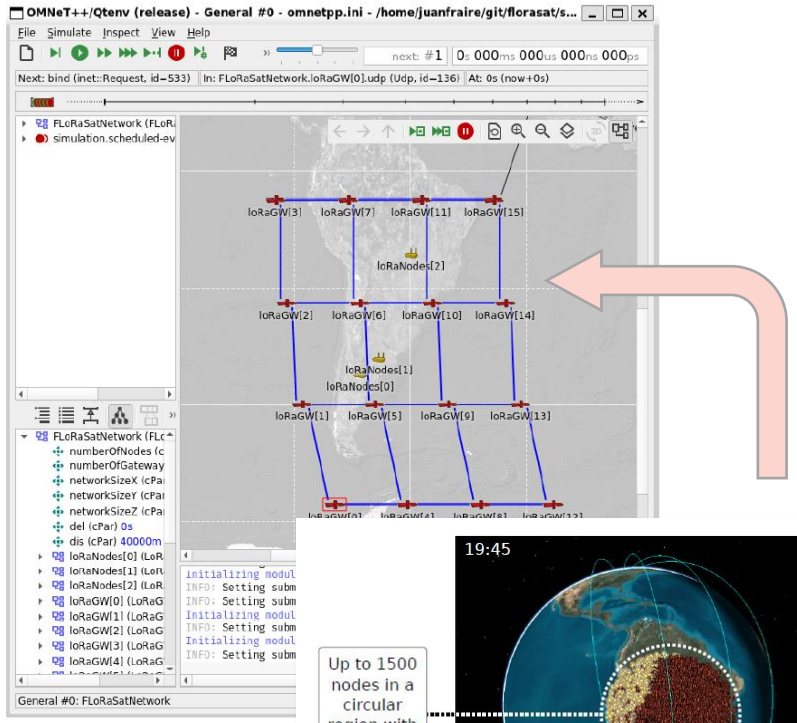
-with an end-to-end perspective-

Real experiments are extremely expensive

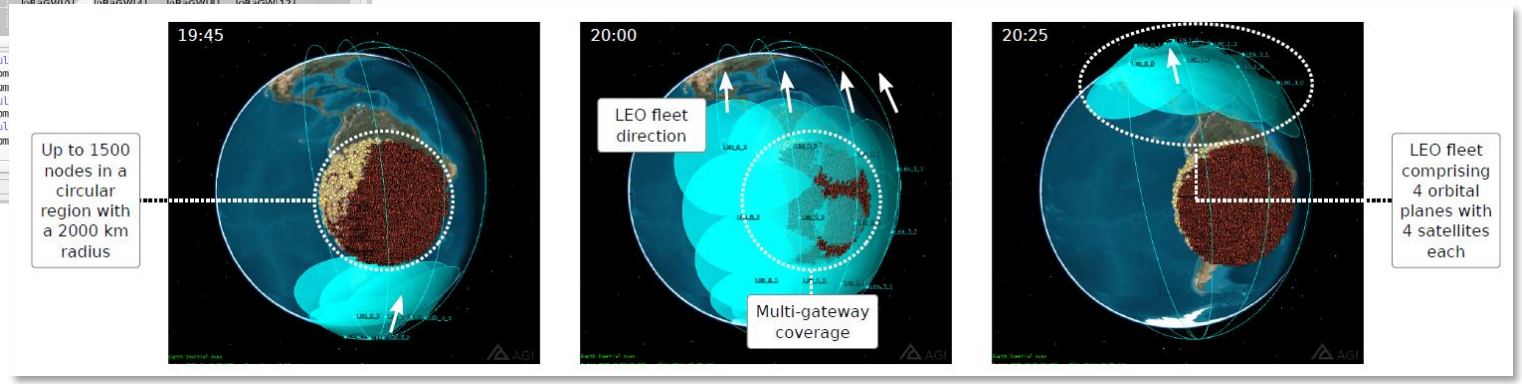
Good **satellite** and **IoT** simulators exists, but separated

FLoRaSat

Space-Terrestrial Integrated IoT

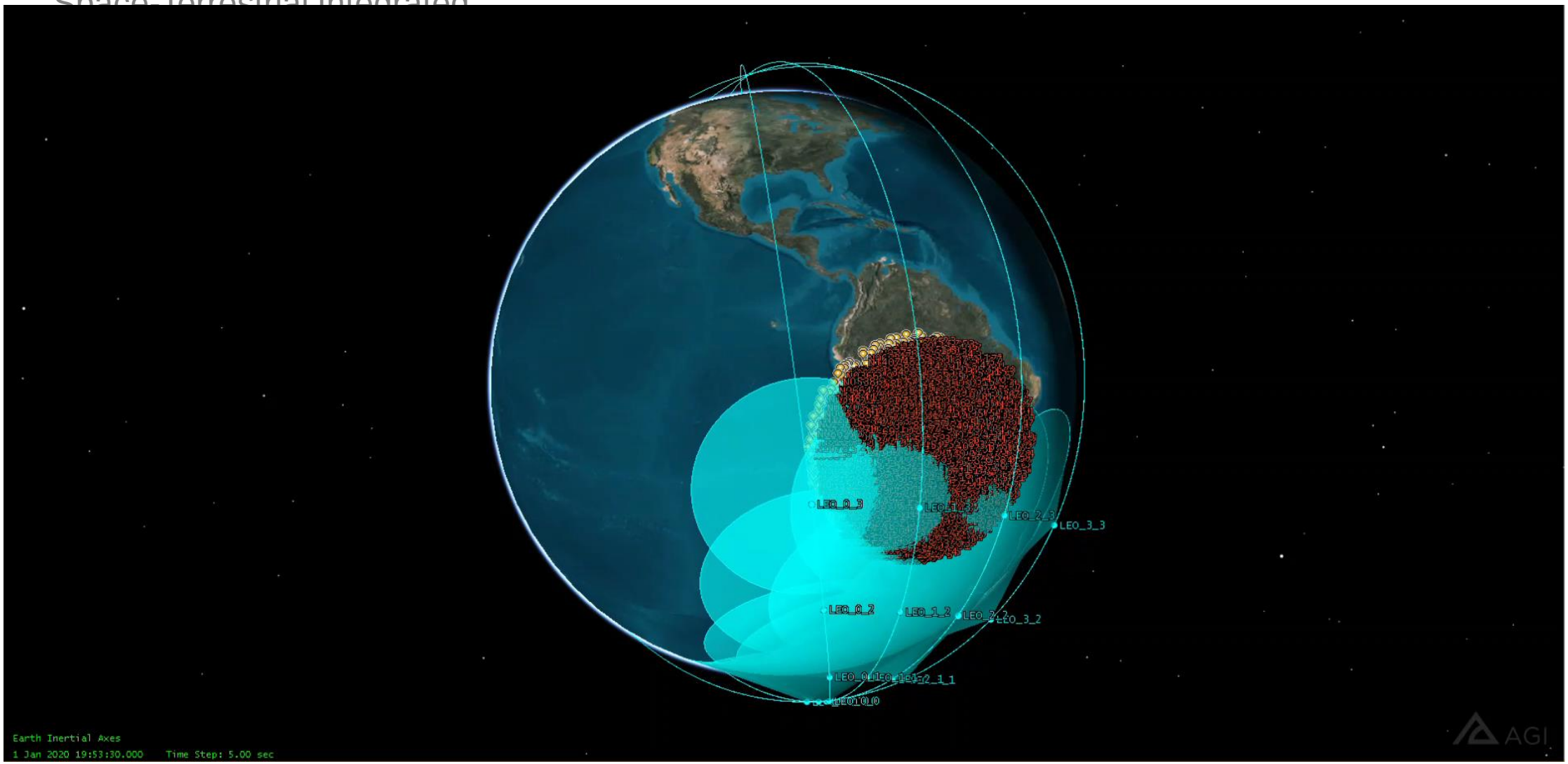


- **Omnet++ Framework**
  - **Event-driven** C++ (accelerated sims) (INET, OS3...)
  - Extends from **FLoRa** (https://flora.aalto.fi/)
- **Key features**
  - Orbital mechanics (**SGP4**: LEO, GEO)
  - Inter-Satellite Linking (**ISL**)
  - Beacon-based **LoRaWAN** (Class A and B)
  - **Application** and **Channel** models (INET)



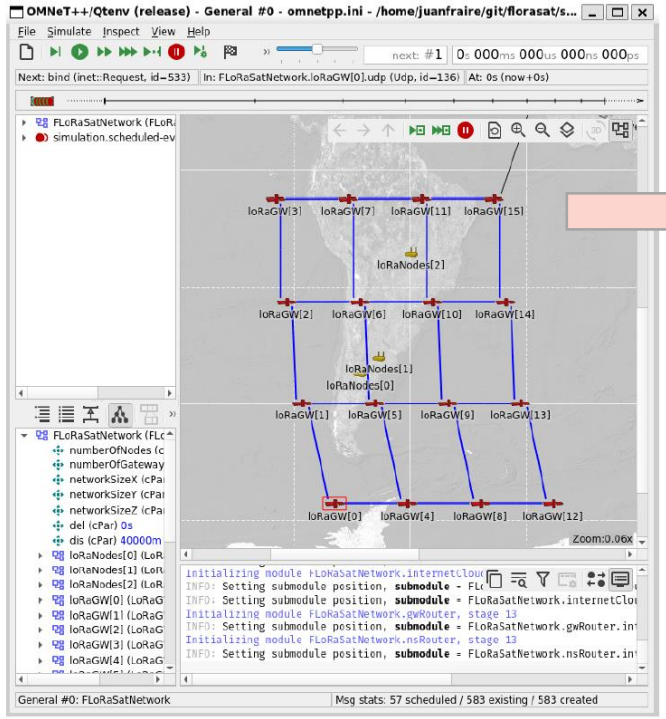
FLoRaSat

Space-Terrestrial Integrated

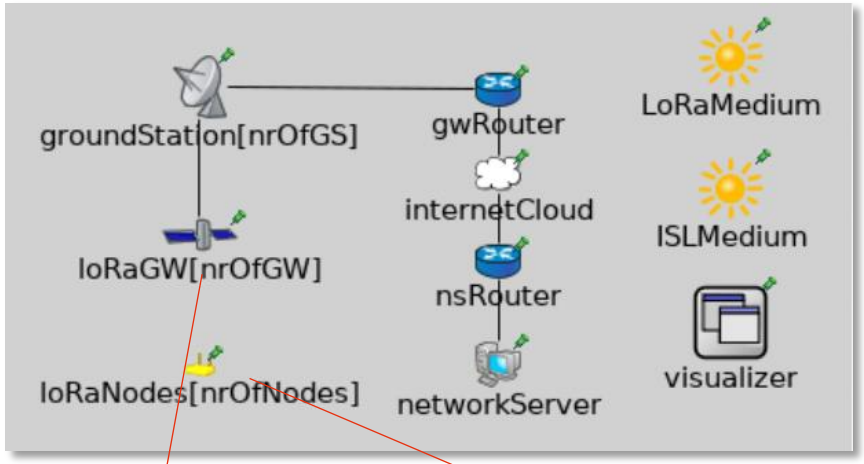


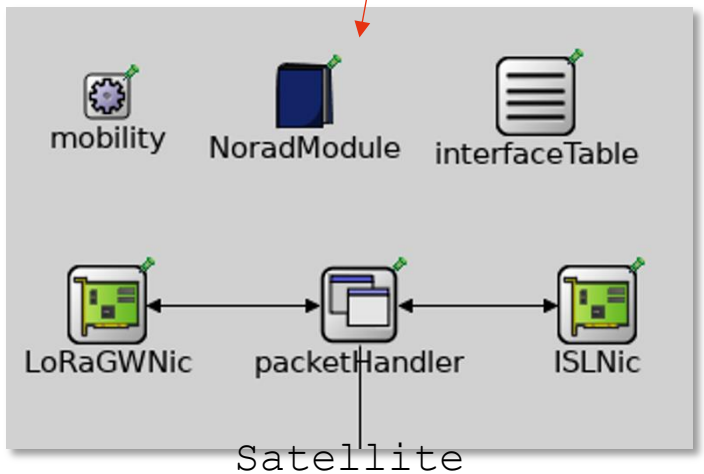
FLoRaSat Architecture

Space-Terrestrial Integrated IoT

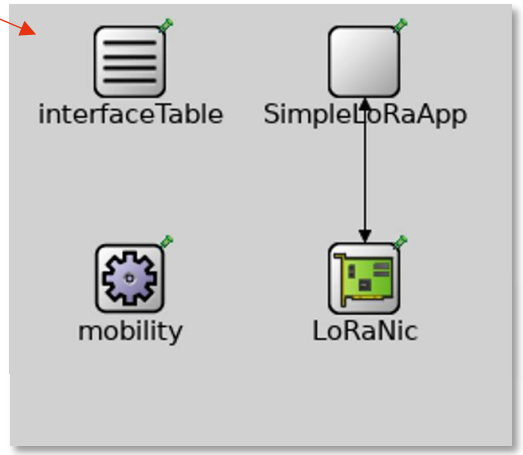


Network part



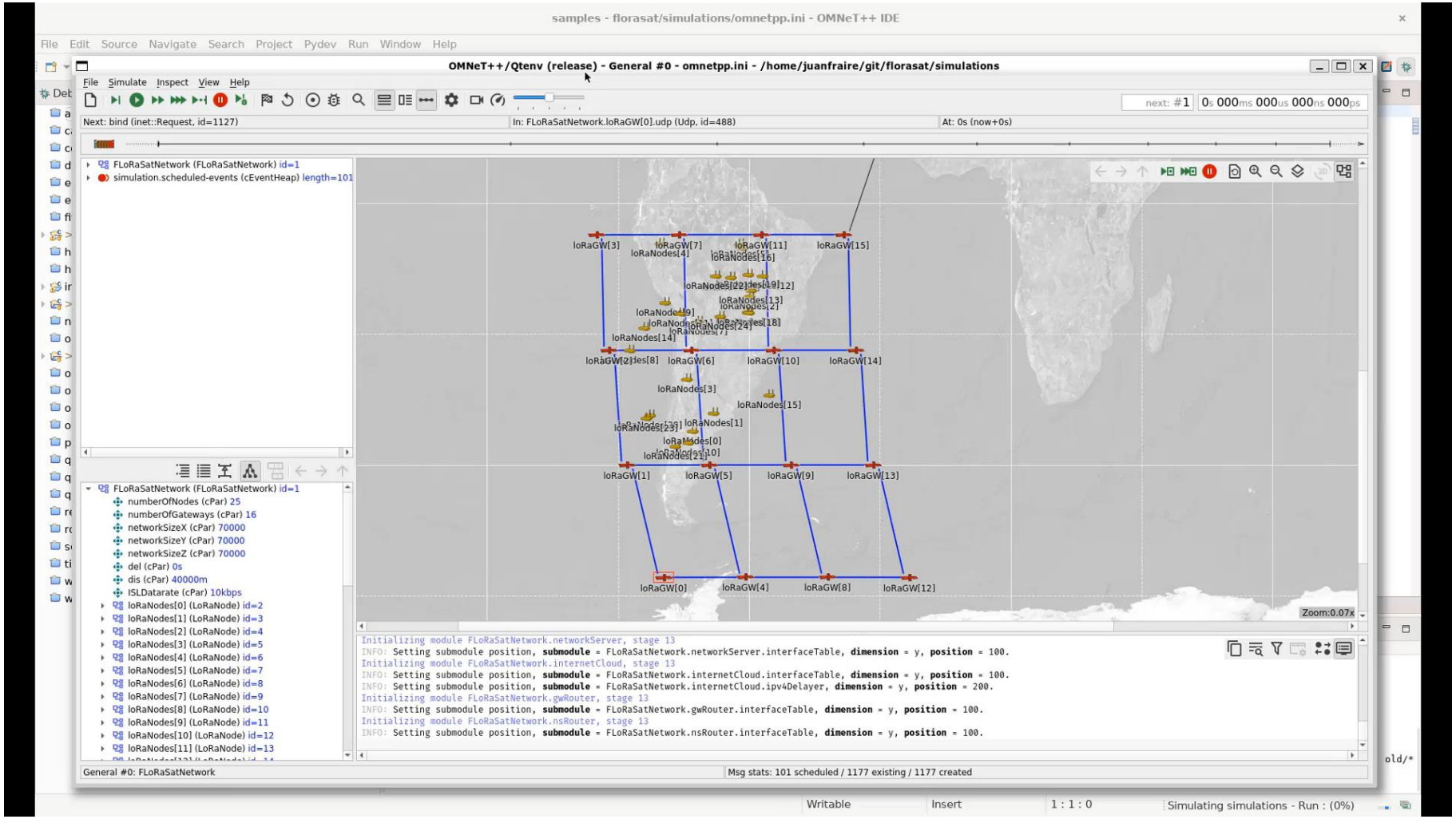


Satellite part



Device part

FLoRaSat Demo

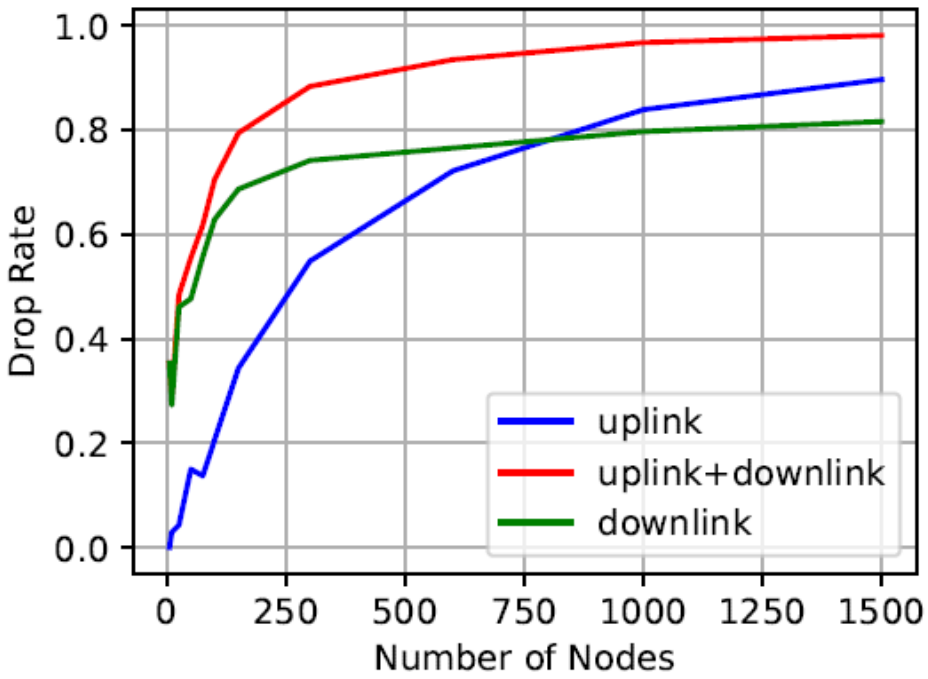


FLoRaSat Metrics

- **PHY metrics**
  - Received SINR, BER, ToA, prop. Delay…
    (in device-LEO, LEO-LEO, LEO-GND)
  - Energy consumption metrics
- **MAC metrics**
  - Tx/Rx frames, PER, dropped frames, collisions…
  - LoRaWAN: SF, Re-Tx metrics, ADR, DPAD…
- **NET metrics**
  - Queue occupation, hop-count, route latency…
    (spanning device-LEO-GND-Server)

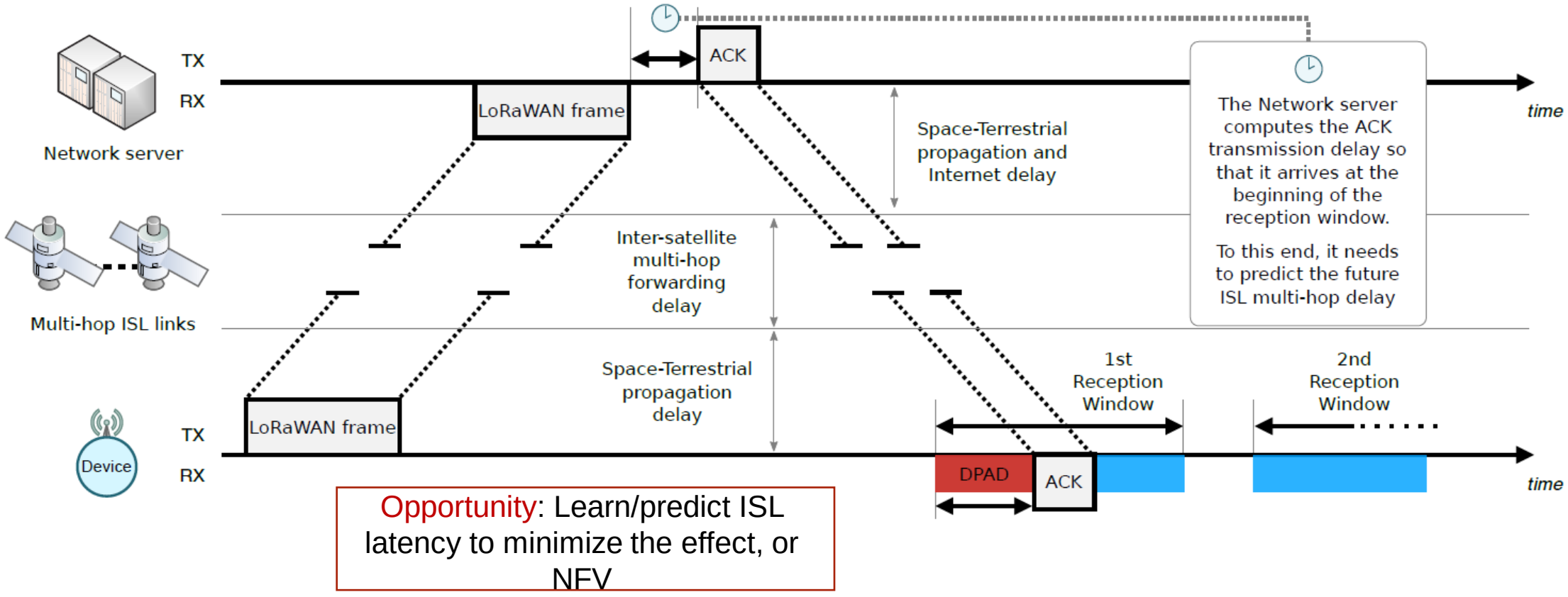
Time-evolving!

Drop rate for 1 Tx every 40-120 seconds (SF12): just at the edge of the duty-cycle



Downlinking via ISLs with Rx Windows

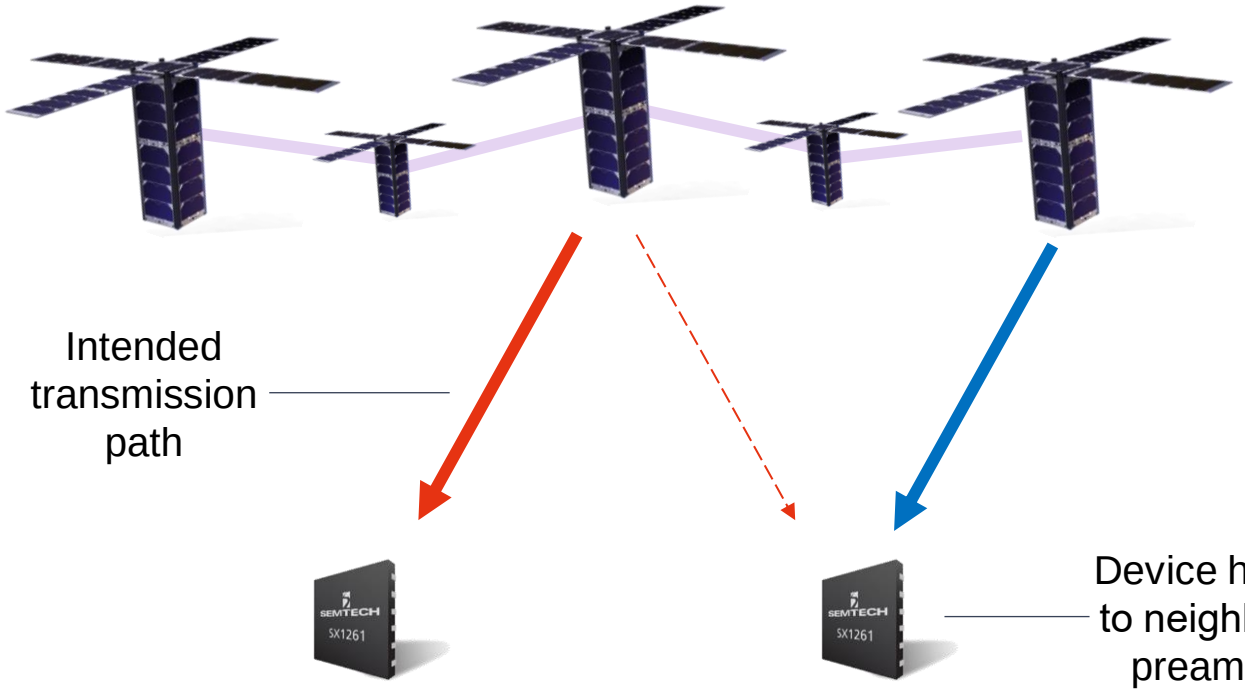
- Downlink Packet Arrival Delay Since Beginning of the Rx Window (DPAD)



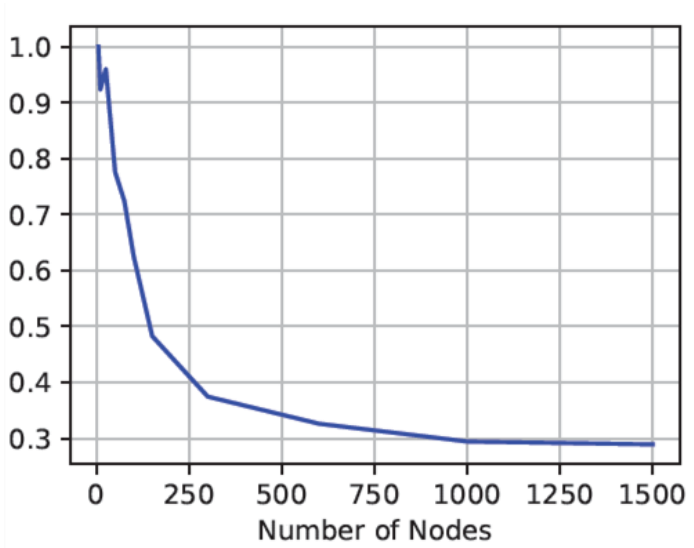
Opportunity: Learn/predict ISL latency to minimize the effect, or NFV

Decoding Downlink Frames in Massive Multi-Gateway

An orbital dynamics situations (e.g., high latitudes)



Correct Downlink Decoding Rate



Opportunity: Coordinate gateway selection from mission control

Happens in terrestrial LoRaWAN?

Takeaways

- Space-Terrestrial Integrated IoT (**STEREO**) is both
  - **Attractive**: extend the coverage of LPWAN to new domains
  - **Feasible**: under consideration by new/old enterprises
- FLoRaSat is a simulation tool to evaluate **STEREO** with an end-to-end focus
  - **Status**: a preliminary but working version with LoRaWAN is now ready to use [1]
  - **Findings**: we presented some non-intuitive issues of LoRaWAN
- **Perspectives**
  - **Features**: Access: LR-FHSS, NB-IoT, channel models; Core: GEO, ItS-IoT, ISL routing, NFV
  - **Science**: synthetic data sets for ML, resource optimization, topology design
  - **Funding**: STEREO ANR

[1] https://gitlab.inria.fr/jfraire/florasat

Thank you!

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