February 26th
ASMS/SPSC 2025
Sitges, Spain

Feb 26th, 2025

Session Plan (16:30 - 18:30)
- 4 x 20-minute talks
- 1 x 40-minute panel

Space-Terrestrial Integrated IoT

Juan A. Fraire

Inria

Marco Guadalupi

SATELIOT

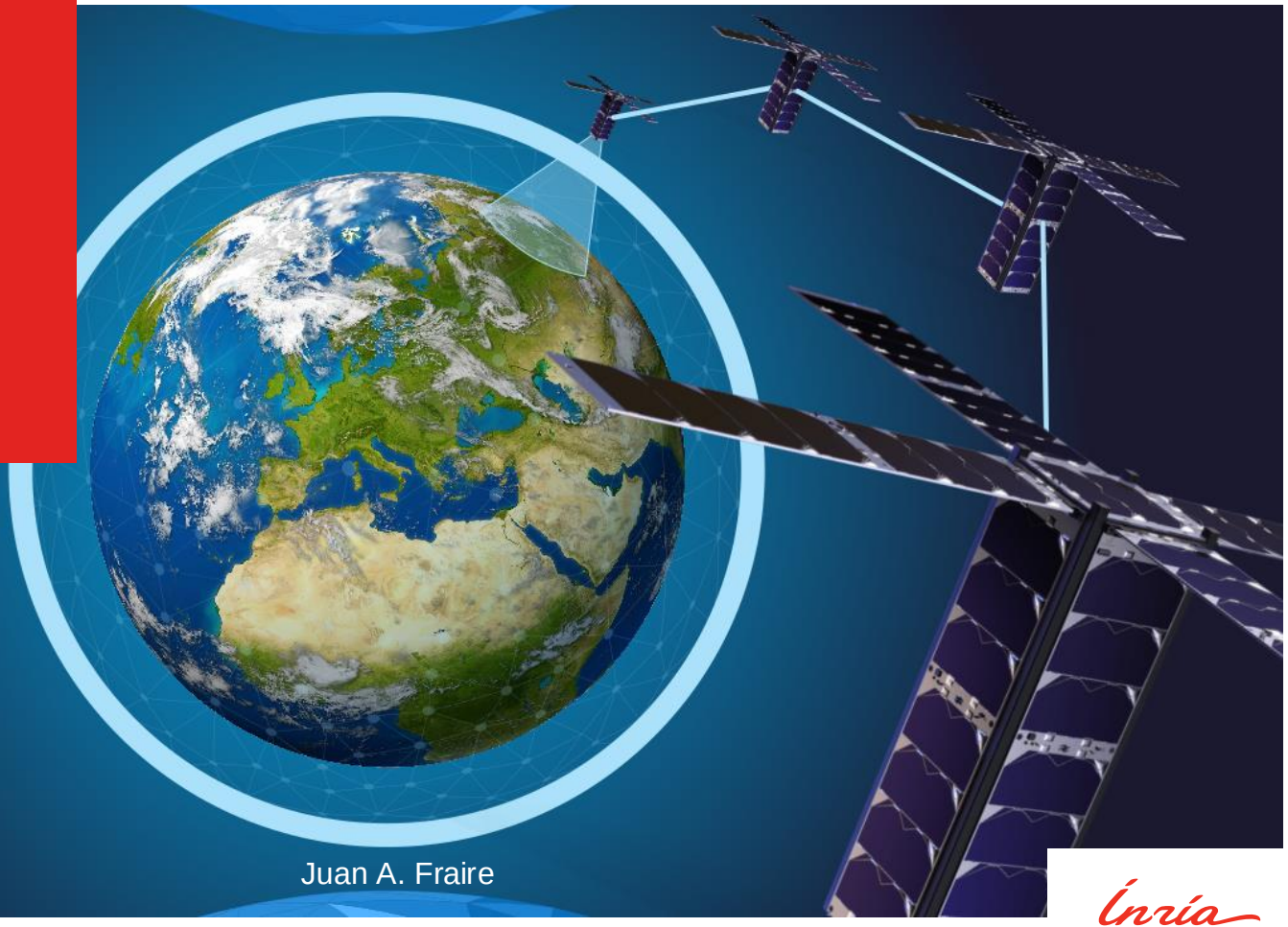
Vincent Deslandes

kinéis

Sergio Sarasola

FOSSA

Challenges and Opportunities in Space-Terrestrial Integrated IoT



ASMS/SPSC 2025

Juan A. Fraire


Only
of the world's surface has
terrestrial connectivity
10%
Space-Terrestrial
Integration
Bidirectional
Communication
Dense/Sparse
Constellations
Low-cost
Connectivity
Space-Terrestrial
Integrated IoT
(STEREO)
anr agence nationale de la recherche
Agriculture
Utilities
Tracking
Logistics
Maritime

A Low-Power, Low-Rate, and Low-Cost Worldwide Satellite IoT Service

Exploitation of **cost-performance** ratio from terrestrial technologies.

New Space

In-orbit gateways

LPWAN

On-ground devices

Classical Satellite IoT Protocols

Argos, AIS, ADS-B

(but not terrestrial)

N=3U

CubeSats

N units of 10x10x10 cm

20-to-200 kg satellites

Space-Terrestrial Integrated IoT (STEREO)

Space-Terrestrial Satellite IoT Protocols

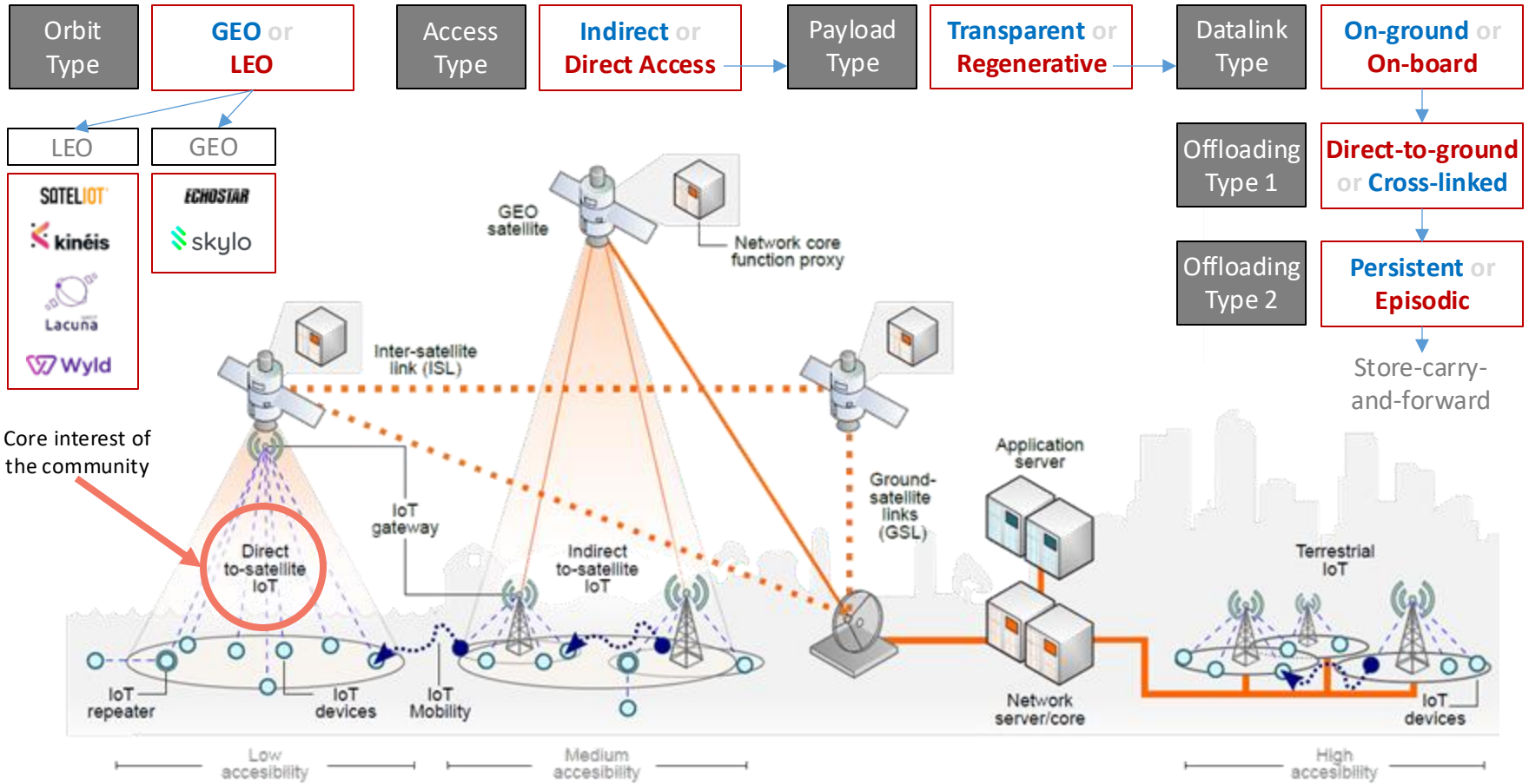
LPWAN

kinéis, Lacuna, FLEET, KEPLER, SATELIOT, ECHOSTAR, Wyld, skylo, Myriota

Non-Cellular	Cellular
	
LoRaWAN **LoRa** (Mioty, SigFox)	**mMTC** **NB-IoT**
LoRa Alliance **NTN** **LoRa** (↓), **LR-FHSS** (↑) (un)licensed bands	3GPP 5G **NTN** **NB-IoT** (Rel-17) licensed bands
Adaptable	**Adoptable**
LoRa Alliance	3GPP A GLOBAL INITIATIVE

[1] Centenaro, Marco, et al. "A survey on technologies, standards and open challenges in satellite IoT." IEEE Communications Surveys & Tutorials 23.3 (2021): 1693-1720..

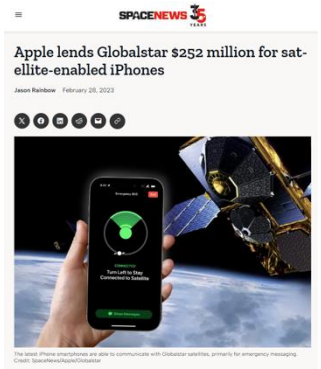
Satellite IoT Taxonomy



[1] Fraire, Juan A., Oana Iova, and Fabrice Valois. "Space-terrestrial integrated Internet of Things: Challenges and opportunities." IEEE Communications Magazine 60.12 (2022): 64-70.

Direct-to-Device (D2D) Communications

Old Actors



Globalstar
Teamed with Apple

48 DTS satellites in orbit

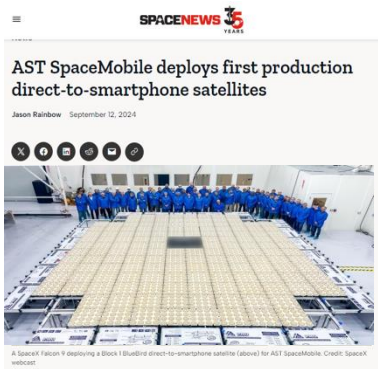
Dual-mode with dedicated chipset

Iridium
Leading NTN standards

66 DTS satellites in orbit

Focused on 3GPP-based open interfaces

New Actors (Dedicated Constellations)



AST SpaceMobile
Teamed with AT&T/Verizon

5 DTS satellites in orbit

Unmodified smartphone, but 64.4 m2 antenna

Lynk Global
Solomon and Cook islands

5 DTS satellites in orbit

Small satellites but +5k are needed for global service

SpaceX

Starlink
Teamed with T-Mobile.

100 DTS satellites in orbit

Starlink V2 satellite with 25 m2 antenna

Organizational: MNO and SNO Integration

Standardization: NTN Definition and Adoption

Challenge: Unclear how the overall sector will evolve and integrate IoT.

- 2/23 https://spacenews.com/apple-loans-globalstar-252-million-for-satellite-enabled-iphones/
- 1/24 https://spacenews.com/spacex-deploys-direct-to-smartphone-satellites-in-first-launch-of-2024
- 1/24 https://spacenews.com/lynk-global-plans-to-go-public-to-fund-direct-to-smartphone-satellites/
- 1/24 https://spacenews.com/iridium-pivots-to-standardized-direct-to-device-satellite-services/
- 4/24 https://spacenews.com/taking-the-next-steps-for-satellite-to-smartphone-services/
- 4/24 https://spacenews.com/banding-together-for-direct-to-smartphone-satellite-services/
- 5/24 https://spacenews.com/verizon-plots-100-million-direct-to-smartphone-satellite-investment/
- 9/24 https://spacenews.com/ast-spacemobile-deploys-first-production-direct-to-smartphone-satellites/

Telecoms.

Opportunity: Computer Science Research in Satellite IoT.

Astrodynamics

Modelling, **Optimization** (Exact/Heuristics), **Learning** (RL, SL), **Simulation/Experimentation**

Protocols

LoRa Enhancements

Headerless LR-FHSS decoding [1].

LoRa demodulator assignation [2].

LoRa/LR-FHSS co-existence [3].

Custom protocol Design

LoRa-based reservation methods (e.g., RESS [4], MSDQ [5])

Design

Constellation Design

Global and regional gap-aware constellation design [6].

LR-FHSS hopping sequence design [2].

Analytical Models

Analytical LoRaWAN Class A Throughput Model [7].

Operations

End-Device Operations

Transmission policies [8, 9].

Satellite visibility prediction [10].

Network size estimation [11, 12].

Satellite Operations

Task scheduling [13, 14].

Cross-link and routing [15].

Evaluation

Simulation Tools

End-to-end discrete-event simulators (e.g., FLoRaSat [16, 17]).

Experimental Characterization

LoRa and LR-FHSS performance in urban and balloon scenarios [18].

Satellite validation [19, 20].

[1] Fraire, Juan A., Alexandre Guitton, and Oana Iova. "Recovering Headerless Frames in LR-FHSS." *EWSN 2023*.
[2] Diego Maldonado, M. Kaneko, et. al., "Enhancing LR-FHSS Scalability Through Advanced Sequence Design and Demodulator Allocation", IEEE TGCN, under review.
[3] Diego Maldonado, M. Kaneko, et. al., "LoRa and LR-FHSS Resource Allocation and Scheduling in Direct-to-Satellite IoT Scenarios" ongoing work.
[4] Ortigueira, Raydel, et al. "RESS-IoT: A scalable energy-efficient MAC protocol for direct-to-satellite IoT." IEEE Access 9 (2021): 164440-164453.
[5] Gerard, Jason, Juan A. Fraire, et al.. "Unlocking DtS-IoT Medium Access Through the Massively Scalable Distributed Queuing Protocol." *2024 IEEE WF-IoT*.
[6] Capez, Gabriel Maiolini, et al. "Sparse satellite constellation design for global and regional direct-to-satellite IoT services." IEEE TAES 58.5 (2022): 3786-3801.
[7] S. Henn, J. Fraire, et al.. "Multi-Gateway LoRaWAN Throughput Modeling in Direct-to-Satellite IoT Constellations", IEEE TNET, under review.
[8] Álvarez, Guido, et al. "Uplink transmission policies for LoRa-based direct-to-satellite IoT." IEEE Access 10 (2022): 72687-72701.
[9] Vogelgesang, Kai, et al. "Uplink transmission probability functions for LoRa-based direct-to-satellite IoT: A case study." 2021 IEEE GLOBECOM.
[10] Ortigueira, Raydel, et al. "Satellite visibility prediction for constrained devices in direct-to-satellite IoT systems." IEEE Sensors Journal (2024).
[11] Parra, Pablo Ilabaca, et al. "Network size estimation for direct-to-satellite IoT." IEEE Internet of Things Journal 10.7 (2022): 6111-6125.
[12] Maldonado, Diego, et al. "Network Size Estimation for LoRa-Based Direct-to-Satellite IoT." 2023 IEEE CCAAW.
[13] Singla, Arnau, et al. "Enhancing satellite NTN through advanced constellation management: Optimizing in-orbit resources for NB-IoT." IEEE OJCOMS (2024).
[14] Stock, Gregory, et al. "Managing fleets of LEO satellites: Nonlinear, optimal, efficient, scalable, usable, and robust." IEEE TCAD (2020).
[15] Montoya, Sebastián I., et al. "On the Role of Delay Tolerant Networks and Contact Graph Routing in Direct-to-Satellite IoT." 2024 IEEE SMC-IT.
[16] Fraire, Juan A., et al. "Simulating Lora-Based Direct-to-Satellite IoT Networks with Florasat." 2022 IEEE WoWMoM. IEEE, 2022.
[17] Alexander Y. Choquenaira-Florez, et al. "FLoRaSat 2: Simulating Cross-Linked Direct-to-Satellite IoT LEO Constellations" ASMS/SPSC 2025.
[18] Marcos Rojas Mardones, et al. "From the City to the Clouds: An Experimental Performance Evaluation of LR-FHSS" DCOSS-IoT 2015, under review.
[19] Feldmann, Marius, et al. "Ring road networks: Access for anyone." IEEE Communications Magazine 60.4 (2022): 38-44.
[20] Stock, Gregory, et al. "On the automation, optimization, and in-orbit validation of intelligent satellite constellation operations." SmallSate Conference 2022.

Some funding sources:

MISSION

STEREO anr

Thank you!

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Sitges, 26-28 February 2025

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Presentations from Industrials

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Moderator

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Panelist

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Panel Discussion