



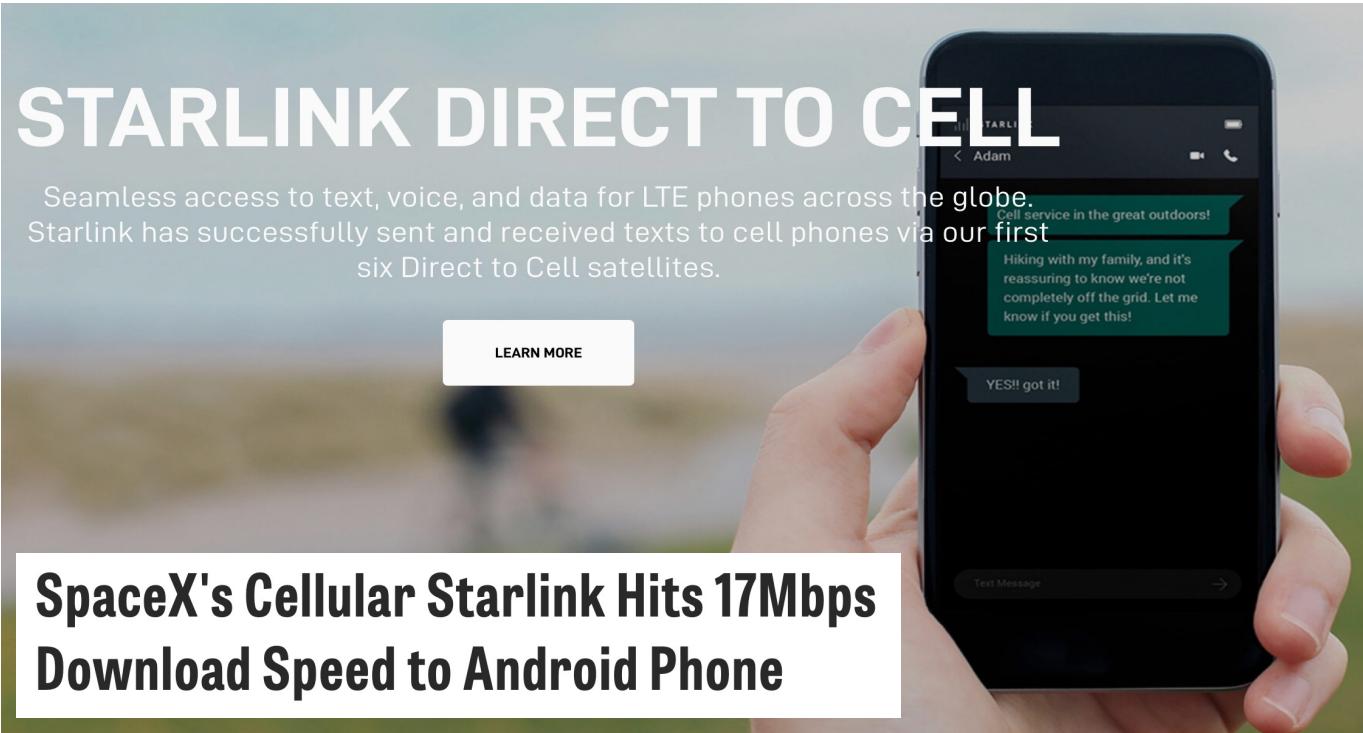
清华大学
Tsinghua University

Democratizing Direct-to-Cell Low Earth Orbit Satellite Networks

Lixin Liu

Yuanjie Li, Hewu Li, Jiabo Yang, Wei Liu, Jingyi Lan,
Yufeng Wang, Jiarui Li, Jianping Wu, Qian Wu, Jun Liu, Zeqi Lai

➤ Direct-to-Cell Satellites



STARLINK DIRECT TO CELL

Seamless access to text, voice, and data for LTE phones across the globe. Starlink has successfully sent and received texts to cell phones via our first six Direct to Cell satellites.

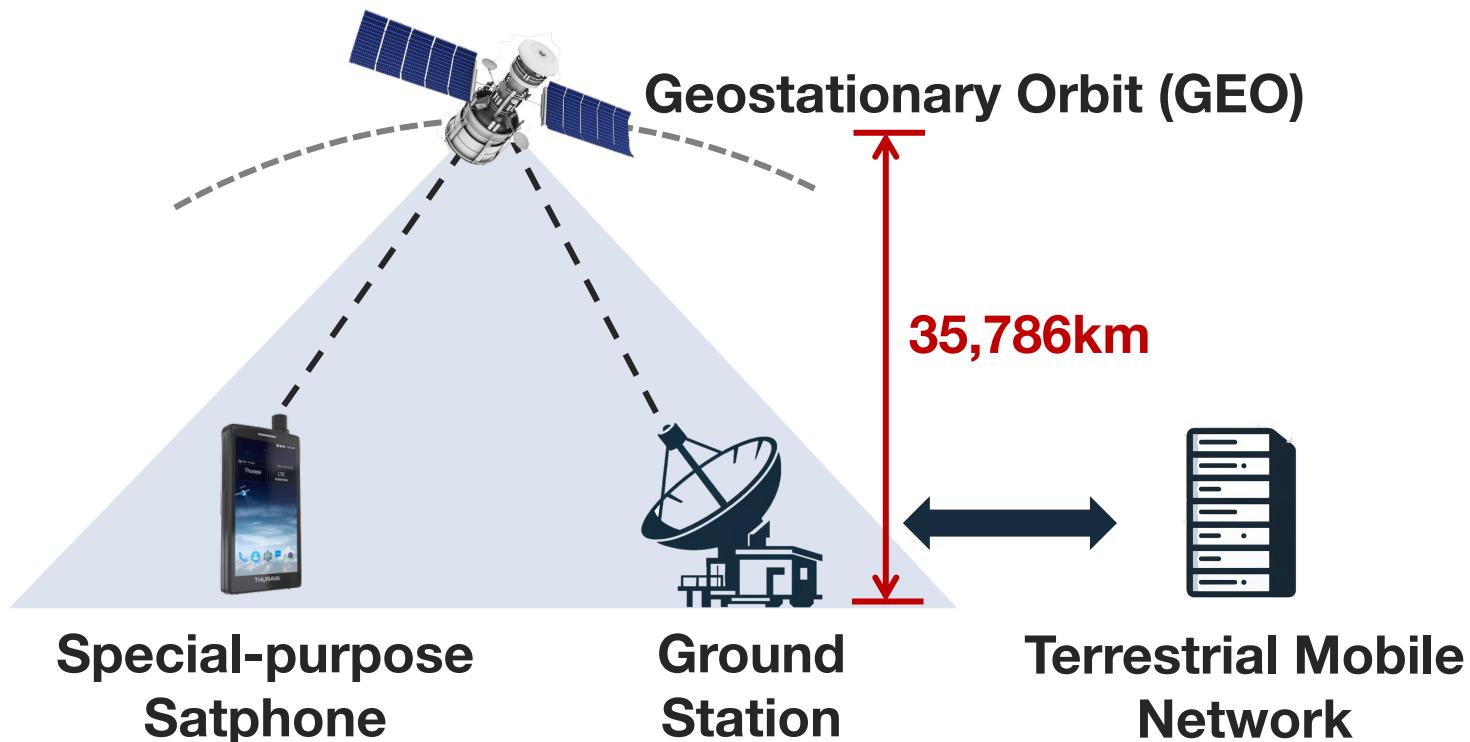
[LEARN MORE](#)

SpaceX's Cellular Starlink Hits 17Mbps Download Speed to Android Phone



➤ Why Direct-to-Cell Satellites?

Affordable ubiquitous connectivity for our regular phones

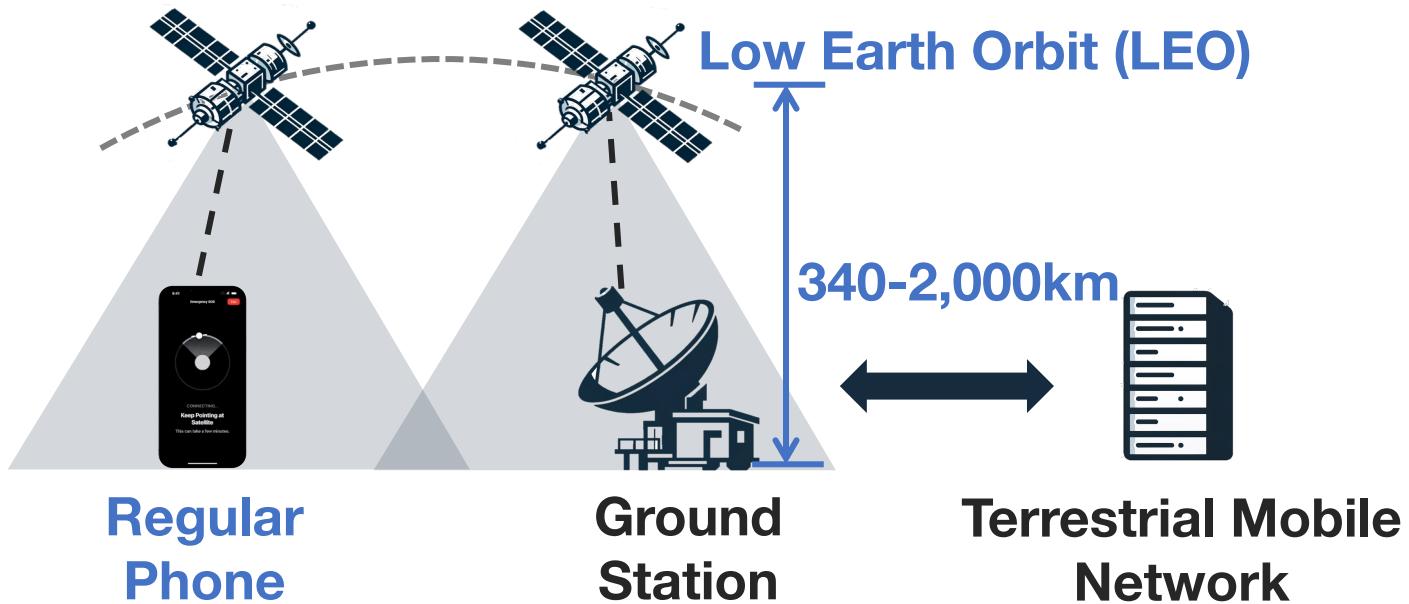


➤ Why Direct-to-Cell Satellites?

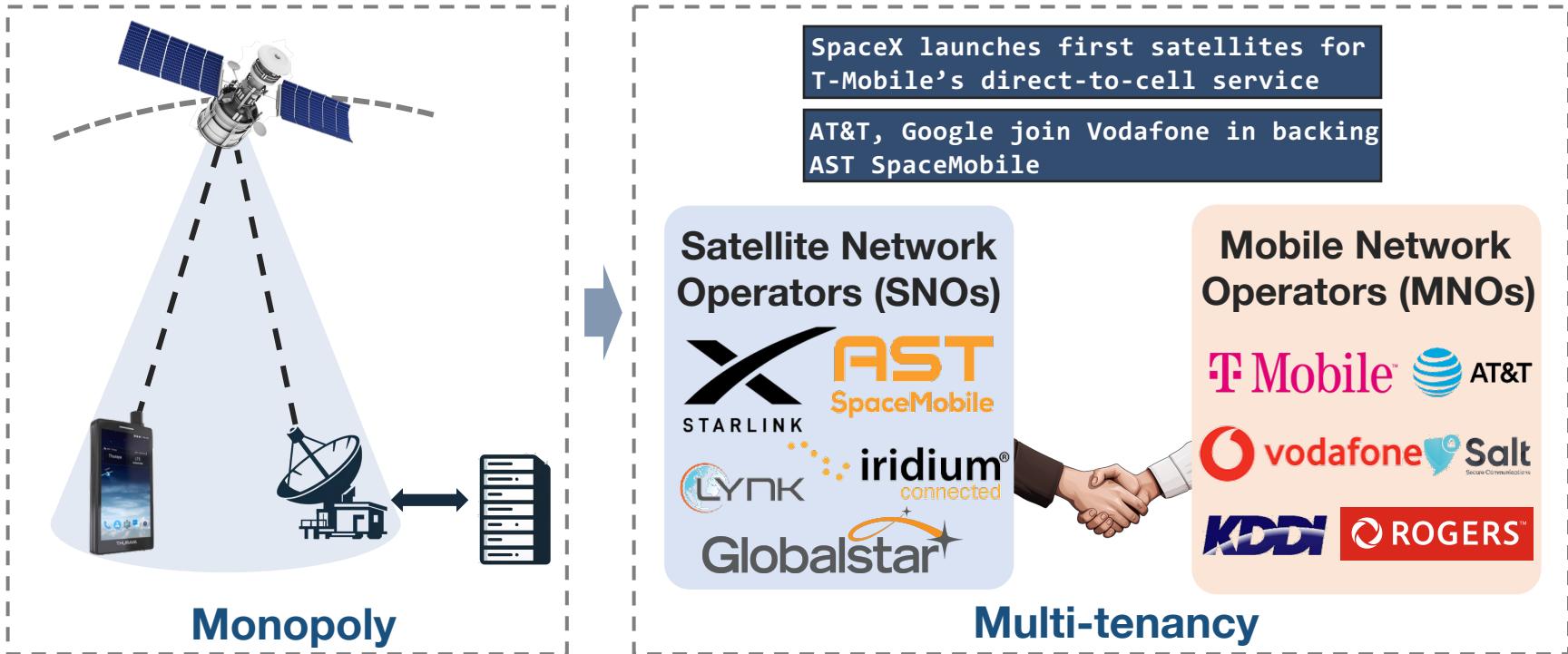
Affordable ubiquitous connectivity for our regular phones

Lower energy cost

More affordable hardware



➤ From Monopoly to Multi-Tenancy



➤ Why LEO Satellite Multi-Tenancy?



Mobile Network Operators (MNOs)

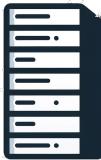
T Mobile™

AT&T

Scarce satellite resources



➤ Why LEO Satellite Multi-Tenancy?



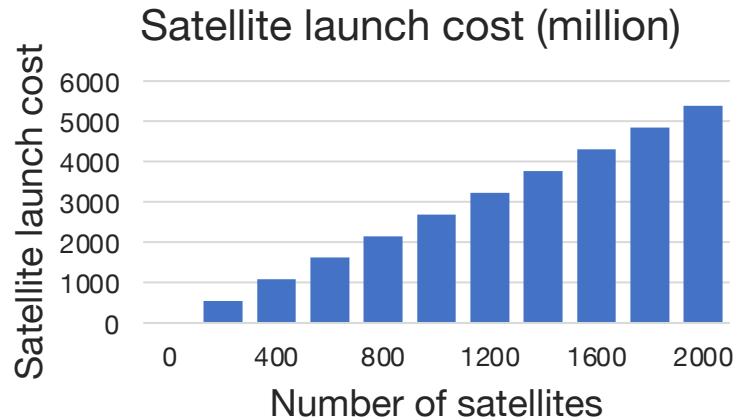
Mobile Network Operators (MNOs)

T Mobile™



Scarce satellite resources

Prohibitive capital expenses



Why LEO Satellite Multi-Tenancy?



Mobile Network Operators (MNOs)  

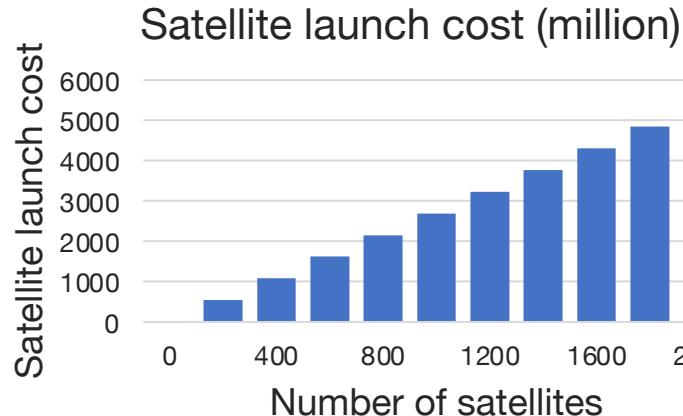
Scarce satellite resources

Prohibitive capital expenses

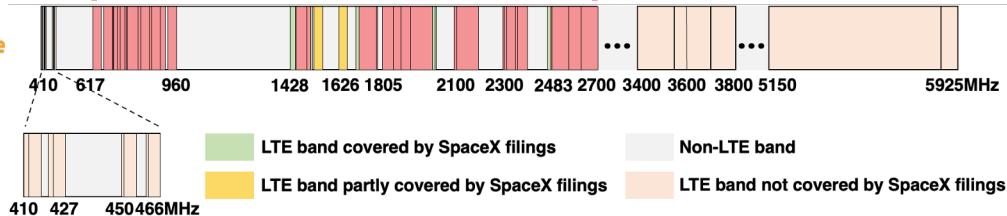


Satellite Network Operators (SNOs)  

Lack of licensed spectrums



Occupied by MNOs



➤ Why LEO Satellite Multi-Tenancy?



Mobile Network Operators (MNOs)  

Scarce satellite resources

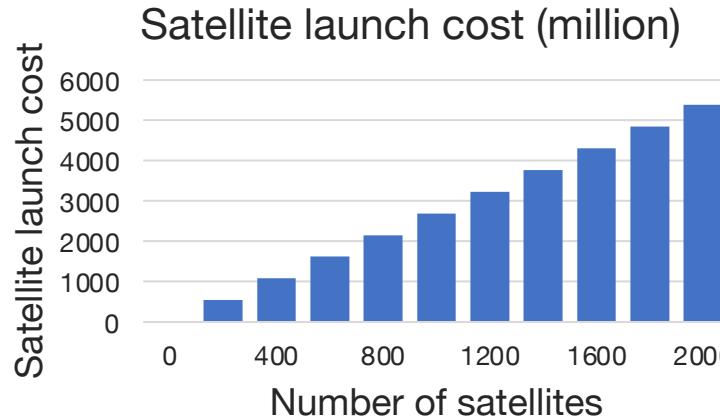
Prohibitive capital expenses



Satellite Network Operators (SNOs)  

Lack of licensed spectrums

Increased Revenues and ROI



Starlink's GLOBAL CUSTOMERS

- > T-MOBILE (USA)
- > OPTUS (AUSTRALIA)
- > ROGERS (CANADA)
- > ONE NZ (NEW ZEALAND)
- > KDDI (JAPAN)
- > SALT (SWITZERLAND)
- > ENTEL (CHILE, PERU)
- > . . .

➤ Why LEO Satellite Multi-Tenancy?

Home / EDOCS / Commission Documents

FCC Proposes Framework to Facilitate Supplemental Coverage From Space

Full Title: Single Network Future: Supplemental Coverage from Space, Space Innovation, Notice of Proposed Rulemaking

Document Type: Notice of Proposed Rulemaking

Bureau(s): International Affairs, Wireless Telecommunications

Description:

The FCC proposes a new regulatory framework for Supplemental Coverage from Space to facilitate the integration of satellite and terrestrial networks.

Docu
Relea
Adop
Issue
Tags:

February 22, 2024

FCC FACT SHEET*

Single Network Future: Supplemental Coverage from Space

Report and Order and Further Notice of Proposed Rulemaking

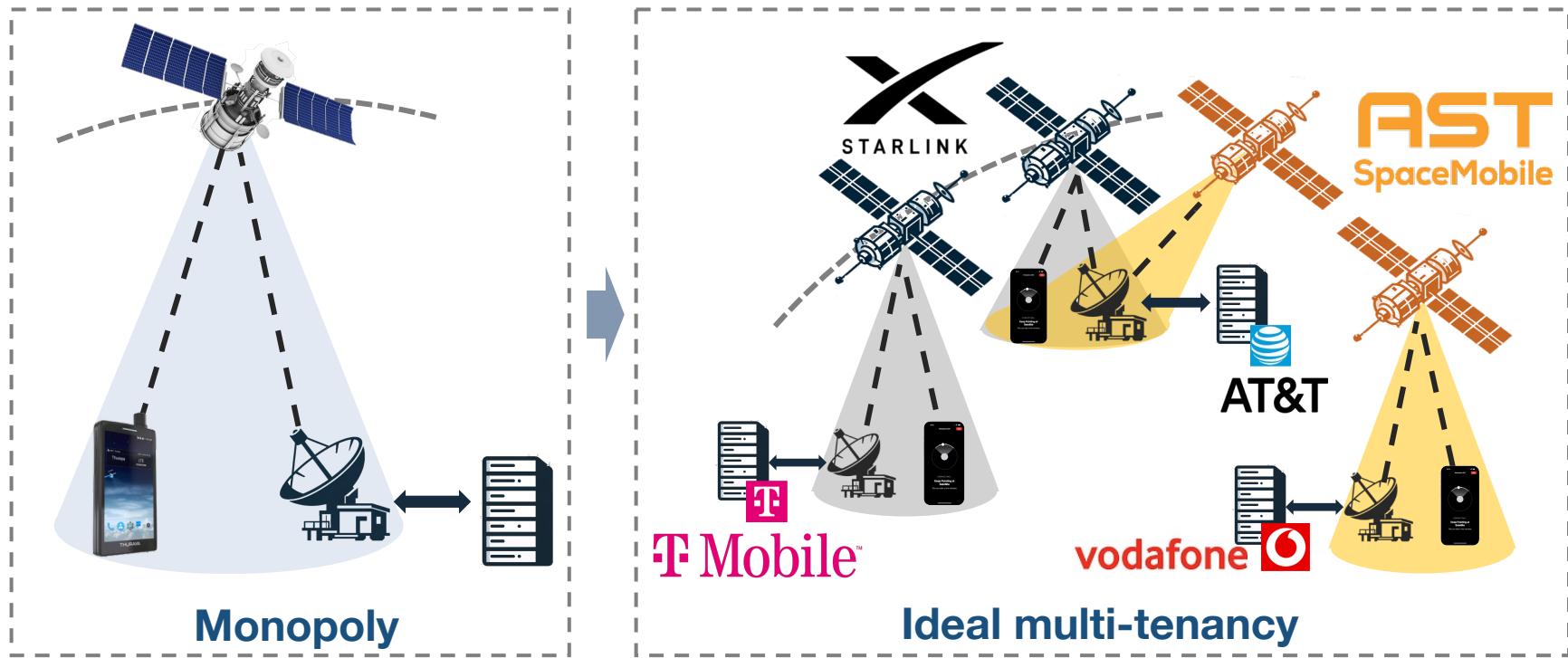
GN Docket No. 23-65 and IB Docket No. 22-271

Background: This *Report and Order* would establish a domestic regulatory framework—the first of its kind in the world—to enable collaborations between satellite operators and terrestrial service providers to offer ubiquitous connectivity, directly to consumer handsets using spectrum previously allocated only to terrestrial service. Supplemental Coverage from Space, or SCS, would enable expanded coverage to a terrestrial licensee's subscribers, especially in remote, unserved, and underserved areas, and would increase the availability of emergency communications.

FCC enables collaborations between SNOs and MNOs

A **win-win** solution for everyone

➤ How Should Multi-Tenancy Work?



➤ How to Enable LEO Satellite Multi-Tenancy?

Option 1: Infrastructure-as-a-Service Model



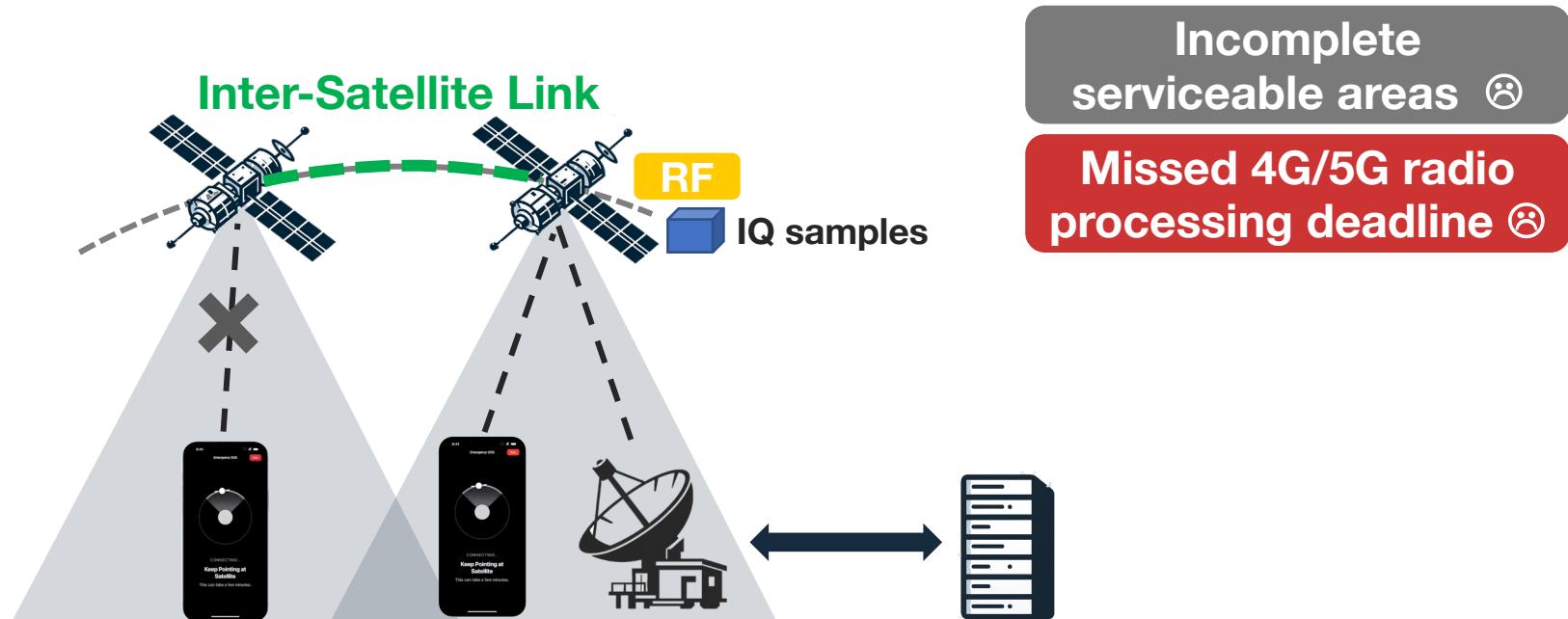
➤ How to Enable LEO Satellite Multi-Tenancy?

Option 1: Infrastructure-as-a-Service Model



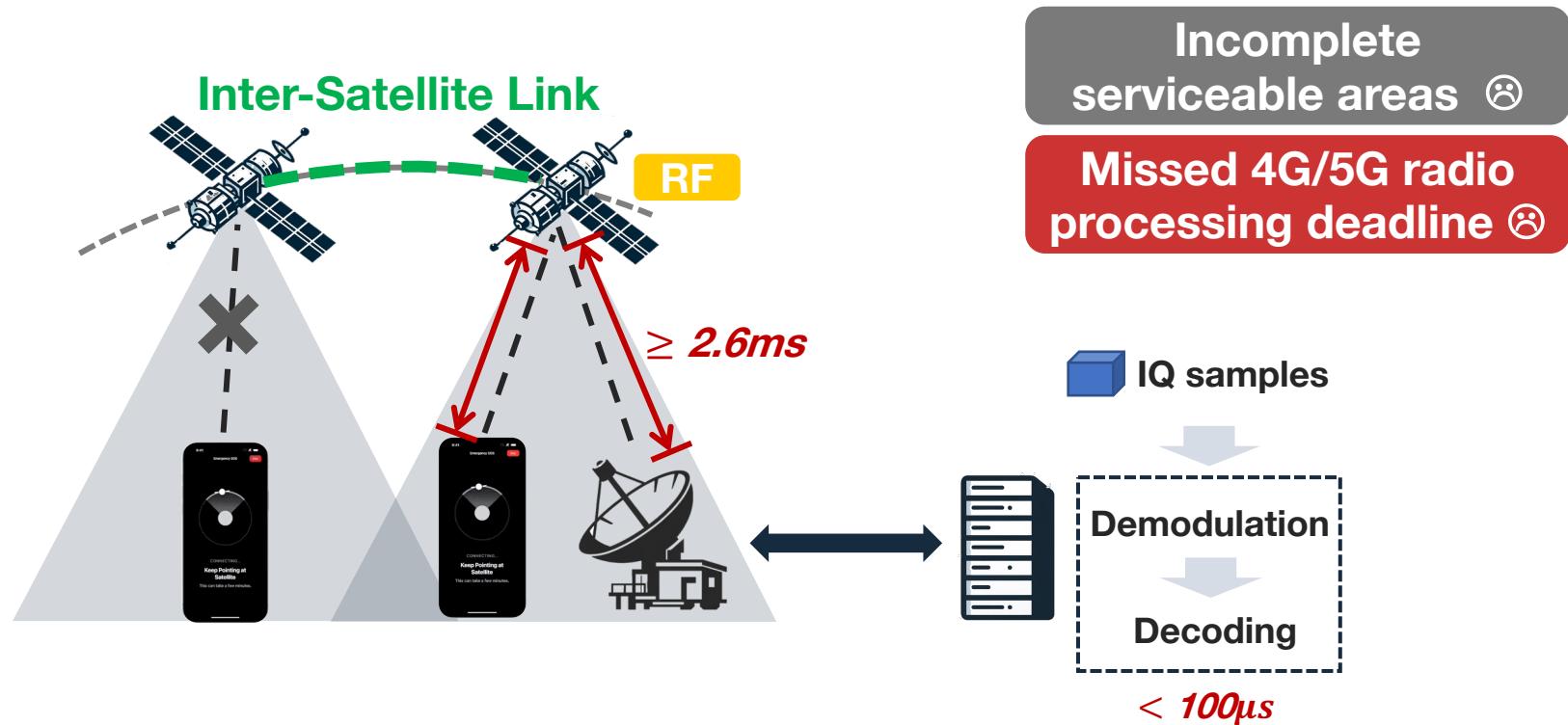
➤ How to Enable LEO Satellite Multi-Tenancy?

Option 1: Infrastructure-as-a-Service Model



➤ How to Enable LEO Satellite Multi-Tenancy?

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➤ How to Enable LEO Satellite Multi-Tenancy?

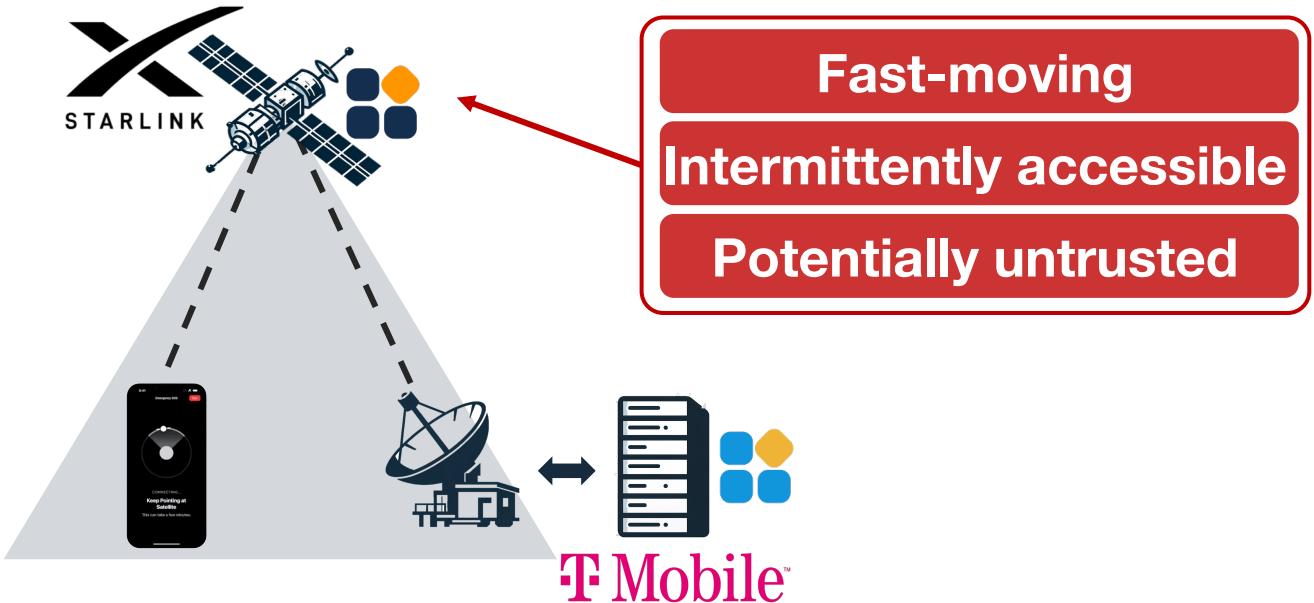
Option 2: Function-as-a-Service Model



Can this model enable multi-tenancy?

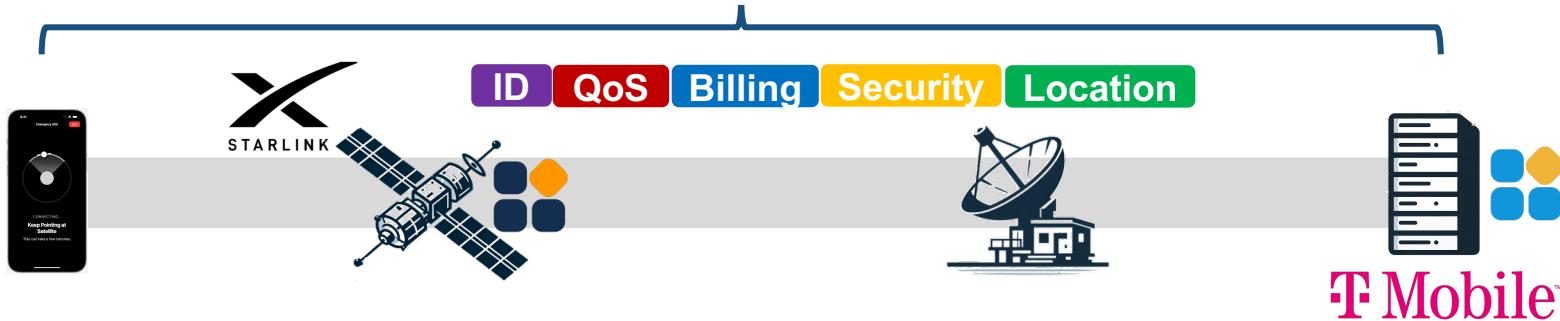
➤ Function-as-a-Service Model in Space?

MNO's cellular functions are offloaded to SNOs' satellites



➤ Function-as-a-Service Model in Space?

Hop-by-hop stateful session



Tight functional coupling

➤ Function-as-a-Service Model in Space?

Inflexible use of SNOs 😞

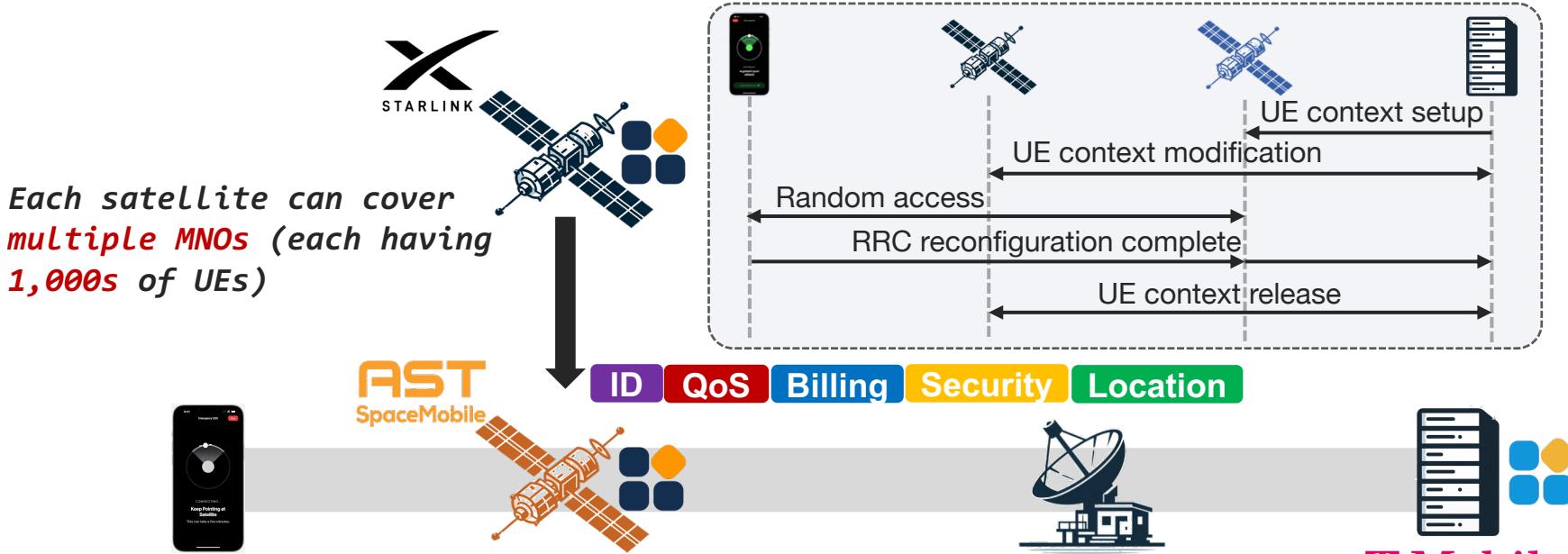


Tight functional coupling

➤ Function-as-a-Service Model in Space?

Inflexible use of SNOs 😞

Signaling storms due to huge coverage 😞



Tight functional coupling

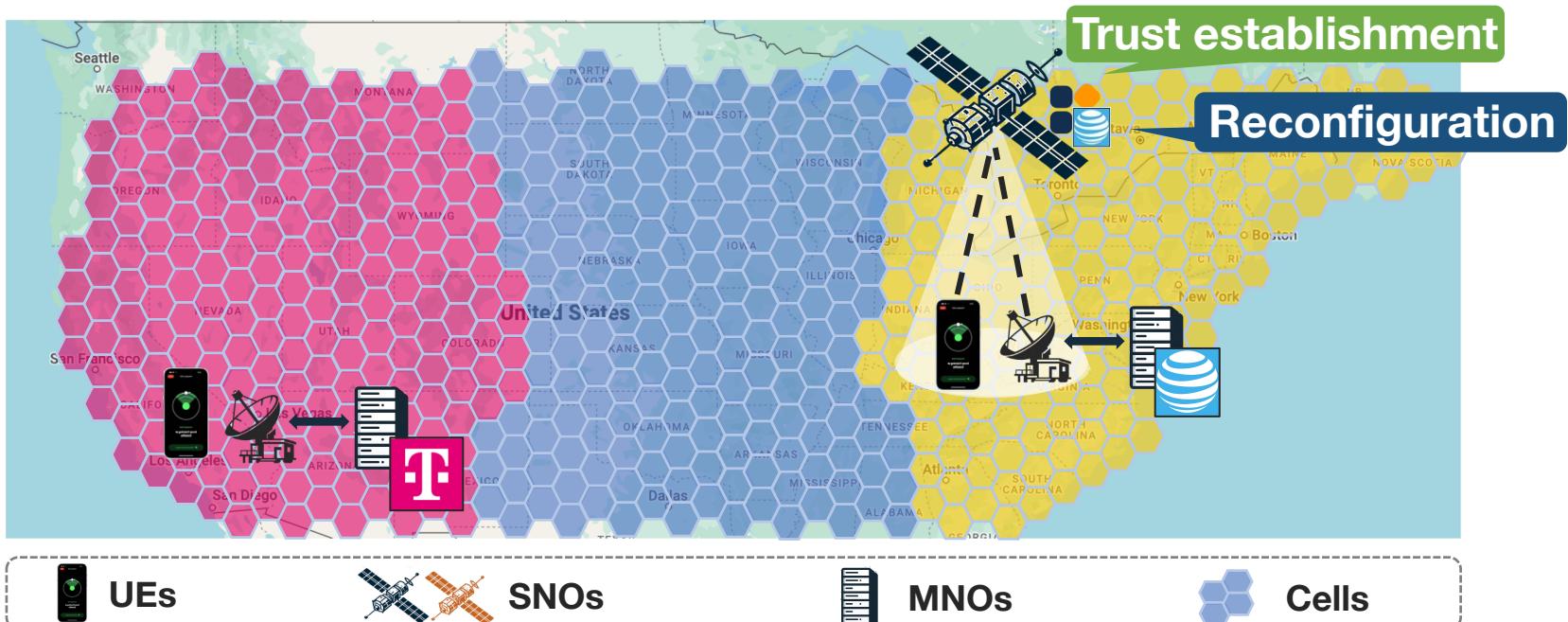
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Dynamic SNO-MNO-UE service relationship



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Dynamic SNO-MNO-UE service relationship

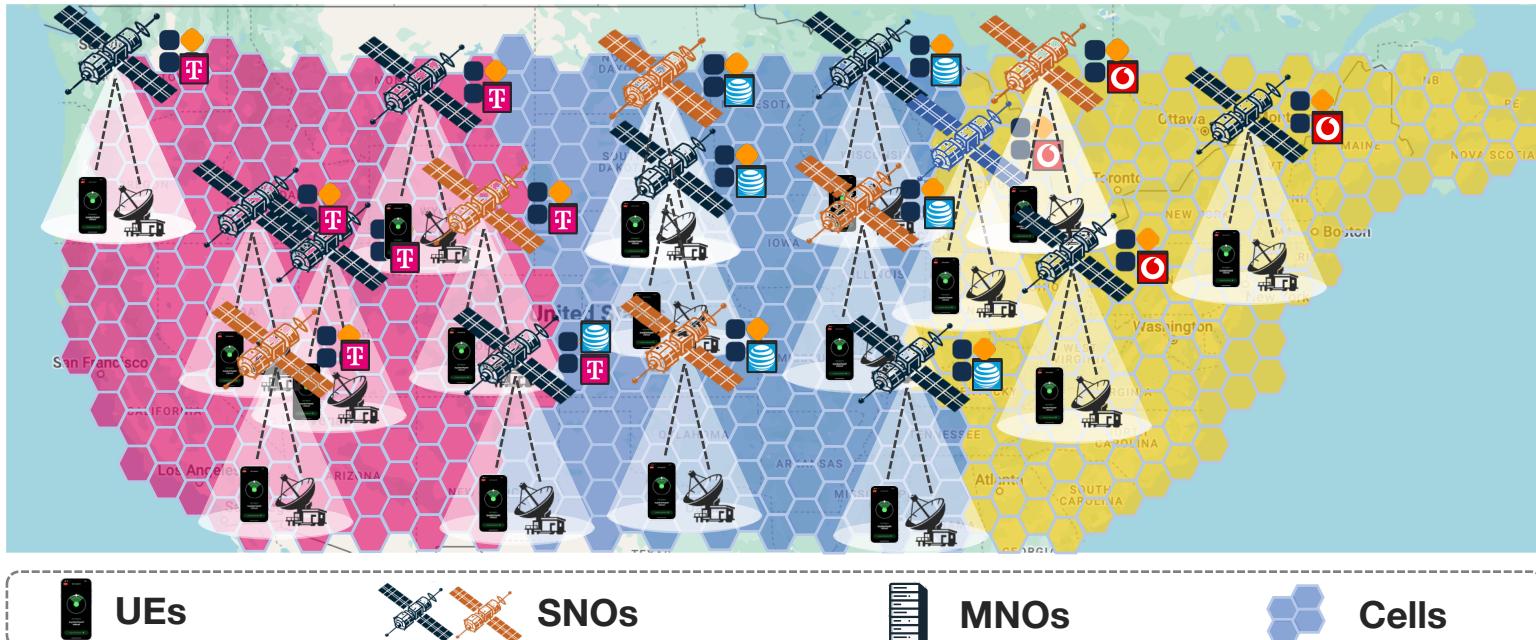


➤ Function-as-a-Service Model in Space?

Dynamic SNO-MNO-UE service relationship

Exhaustive MNO reconfigurations ☹

Dynamic trust establishment ☹



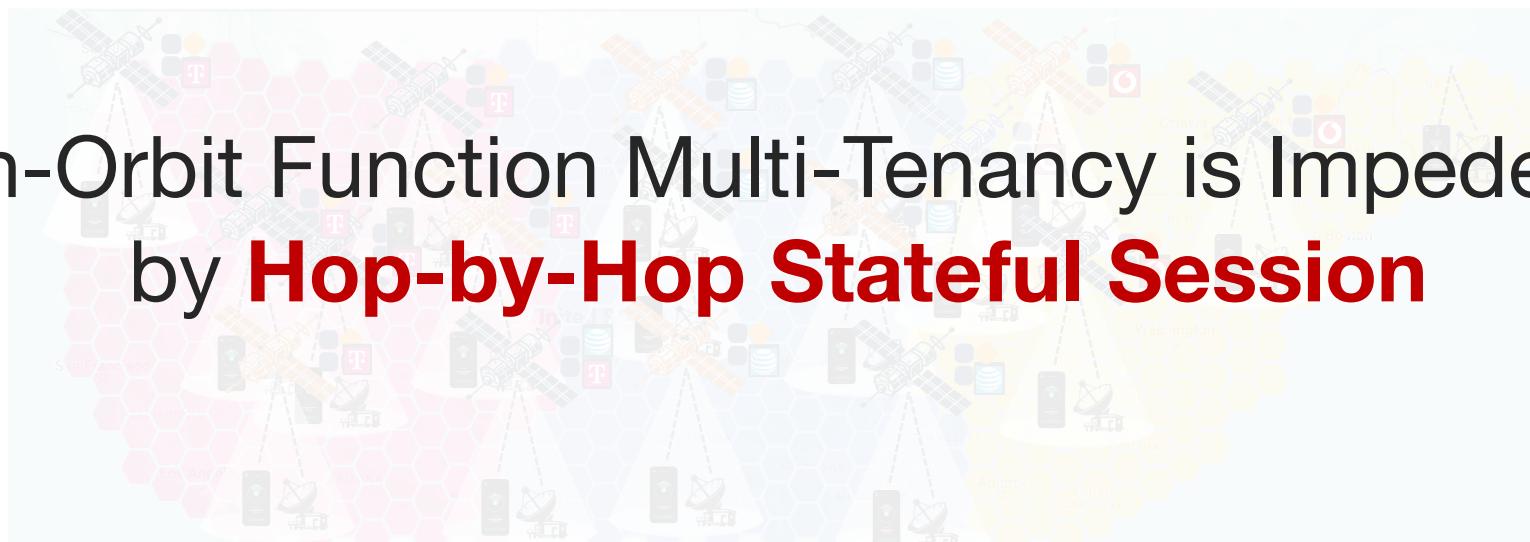
➤ Function-as-a-Service Model in Space?

Dynamic SNO-MNO-UE service relationship

Exhaustive MNO reconfigurations 😞

Dynamic trust establishment 😞

In-Orbit Function Multi-Tenancy is Impeded
by **Hop-by-Hop Stateful Session**



UEs



SNOs



MNOs



Cells

➤ How to Enable LEO Satellite Multi-Tenancy?

How do we share mobile infrastructure in life?



**Pay for the travel and
don't care which car**



Pay-as-you-go self-service

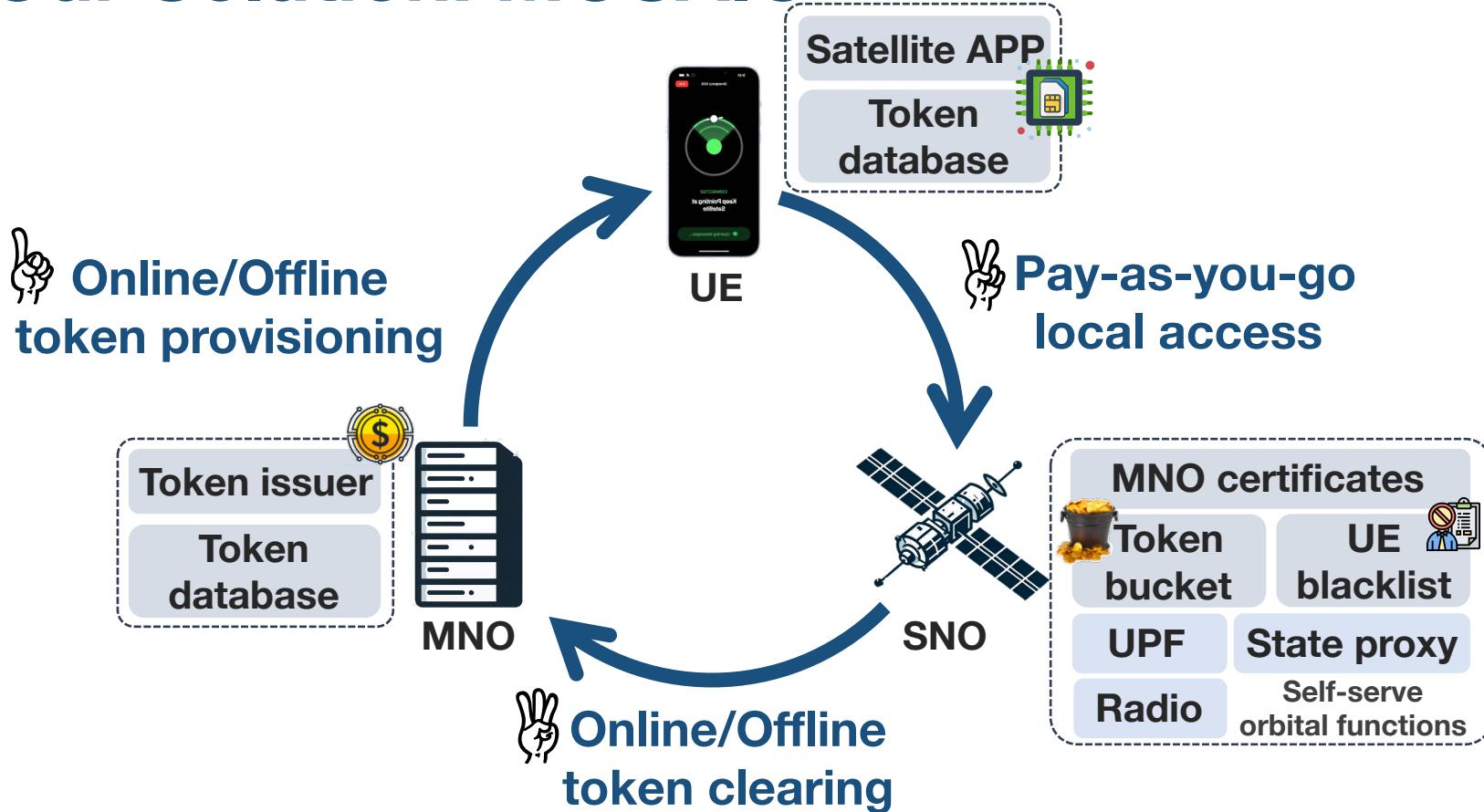
➤ How to Enable LEO Satellite Multi-Tenancy?

Pay-as-you-go satellite self-service

**Pay for the service and
don't care which SNO**



➤ Our Solution: MOSAIC



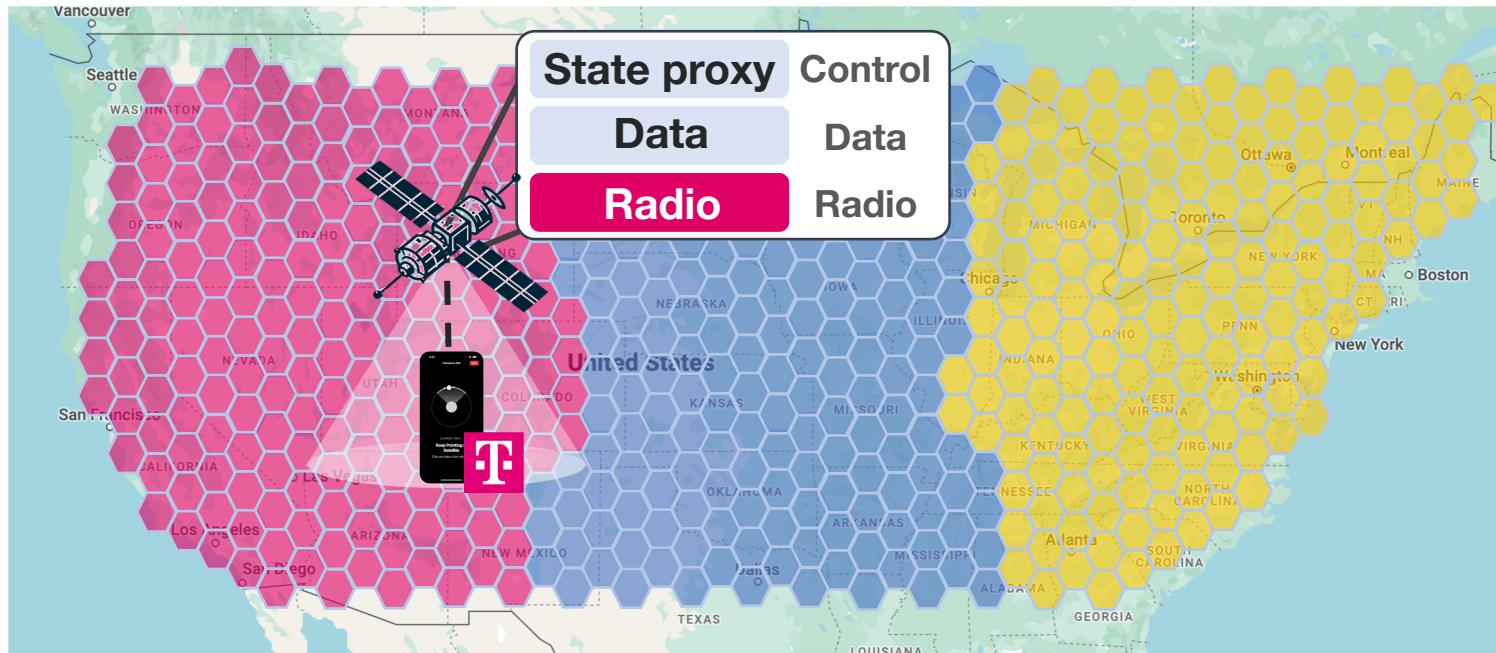
➤ How to Realize MOSAIC?

- ? How can SNOs enable self-service?
- ? How can MNOs enable pay-as-you-go tokens?
- ? How can UEs access satellite with tokens?

➤ How can SNOs Enable Multi-Tenant Self-Service?

Self-service

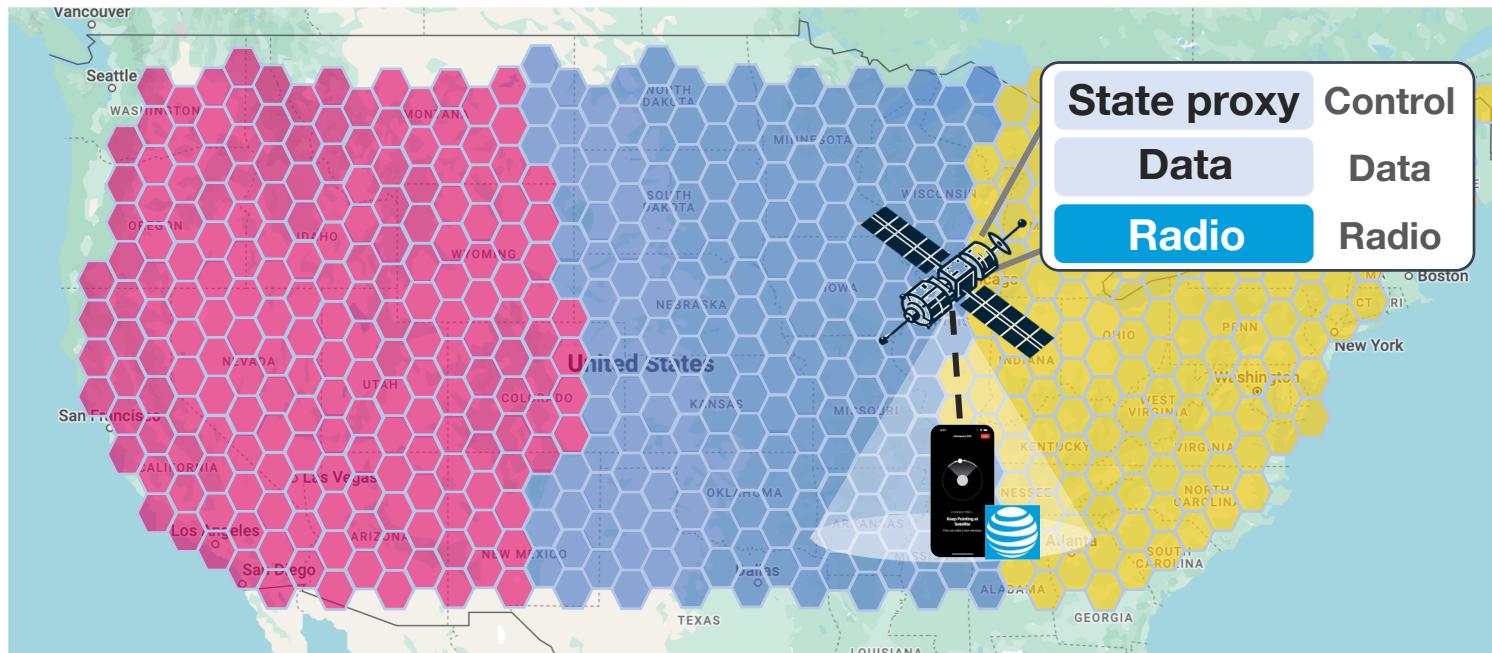
Full-fledged cellular functions



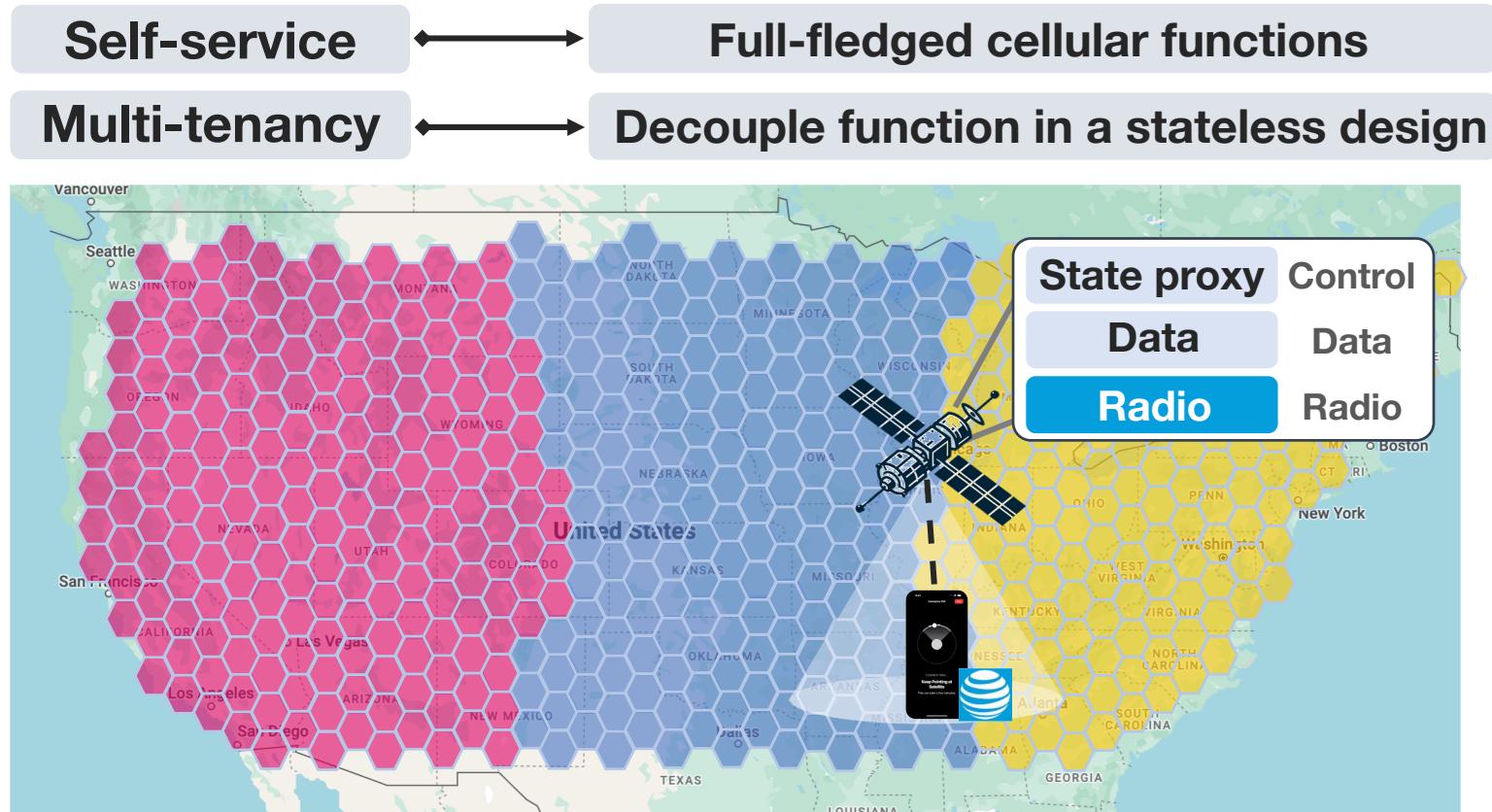
➤ How can SNOs Enable Multi-Tenant Self-Service?

Self-service

Full-fledged cellular functions

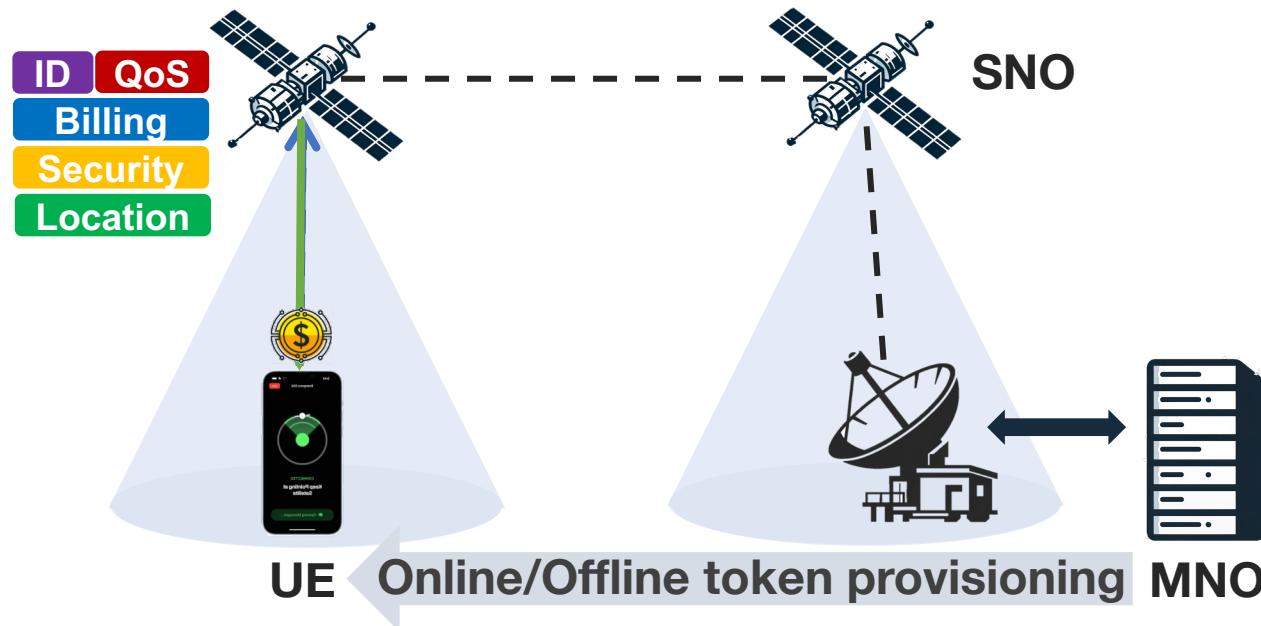


➤ How can SNOs Enable Multi-Tenant Self-Service?



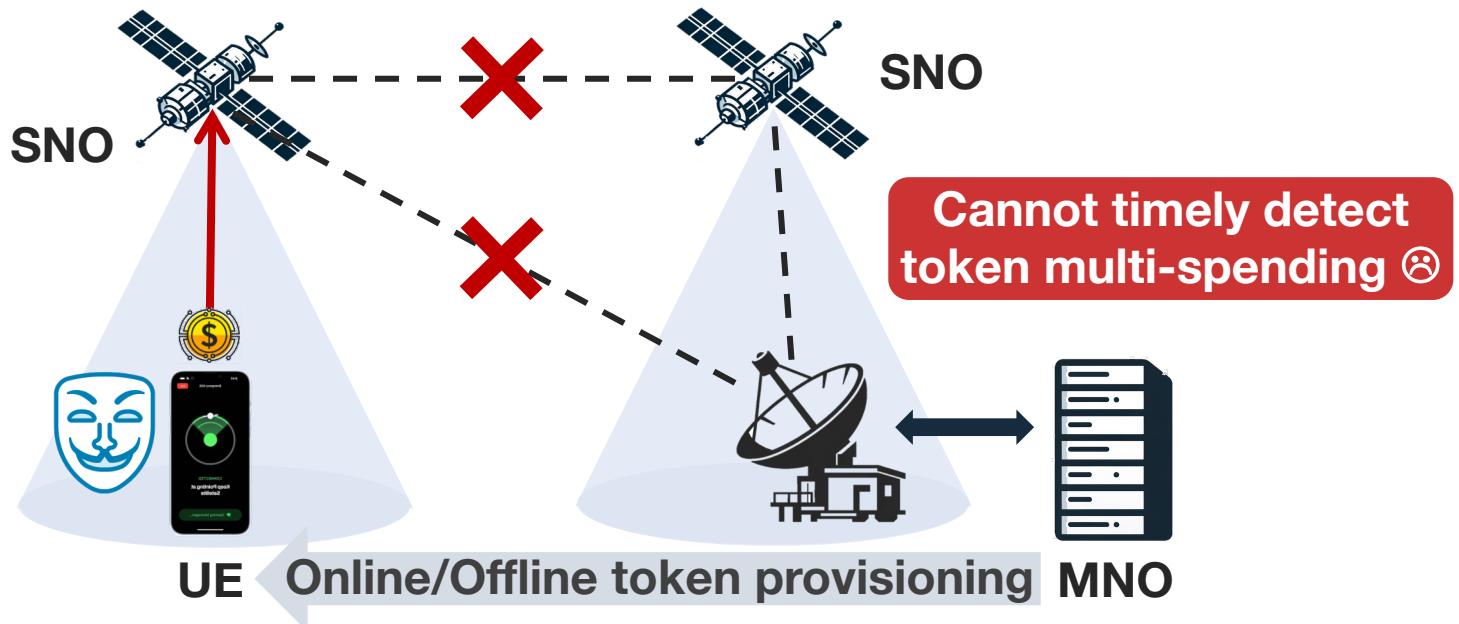
➤ How can MNOs Enable Pay-As-You-Go Token?

Policy-embedded tokens



➤ How can MNOs Enable Pay-As-You-Go Token?

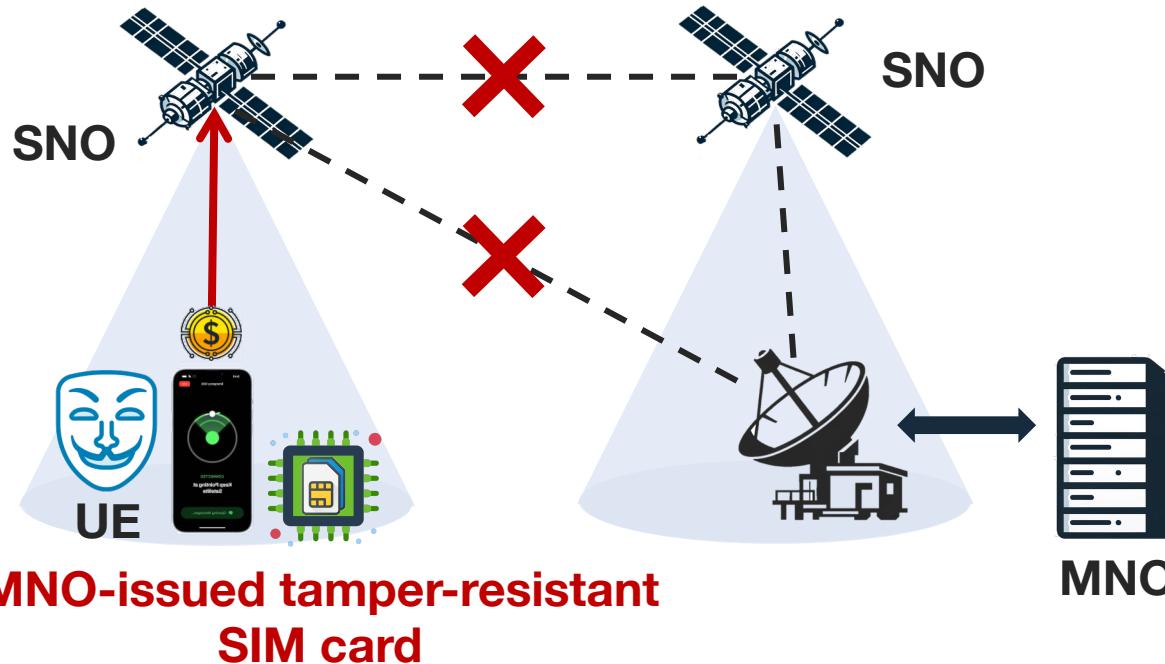
Concern: Token misuse



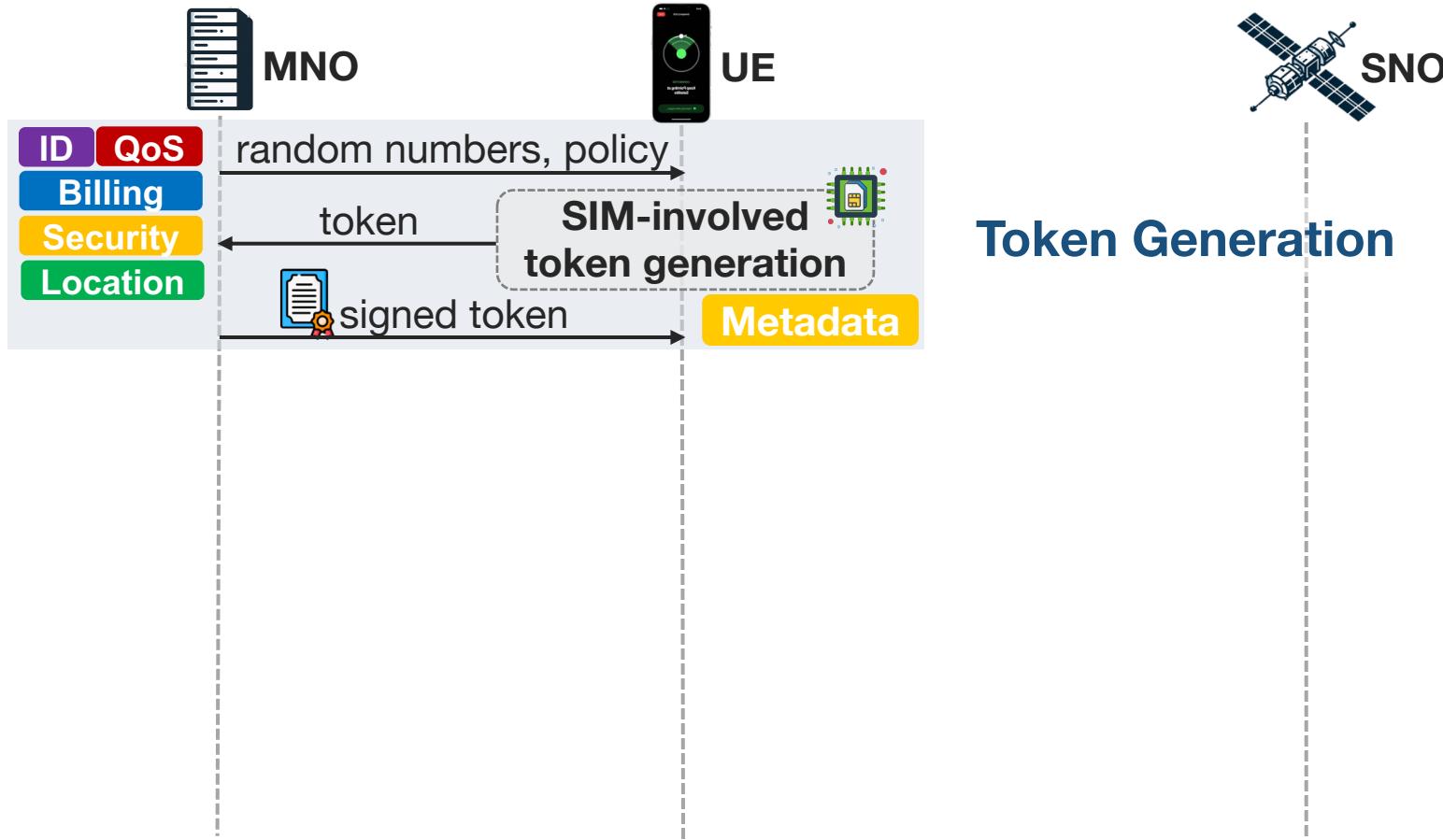
Multi-spending one token to
gain free satellite access

► How can MNOs Enable Pay-As-You-Go Token?

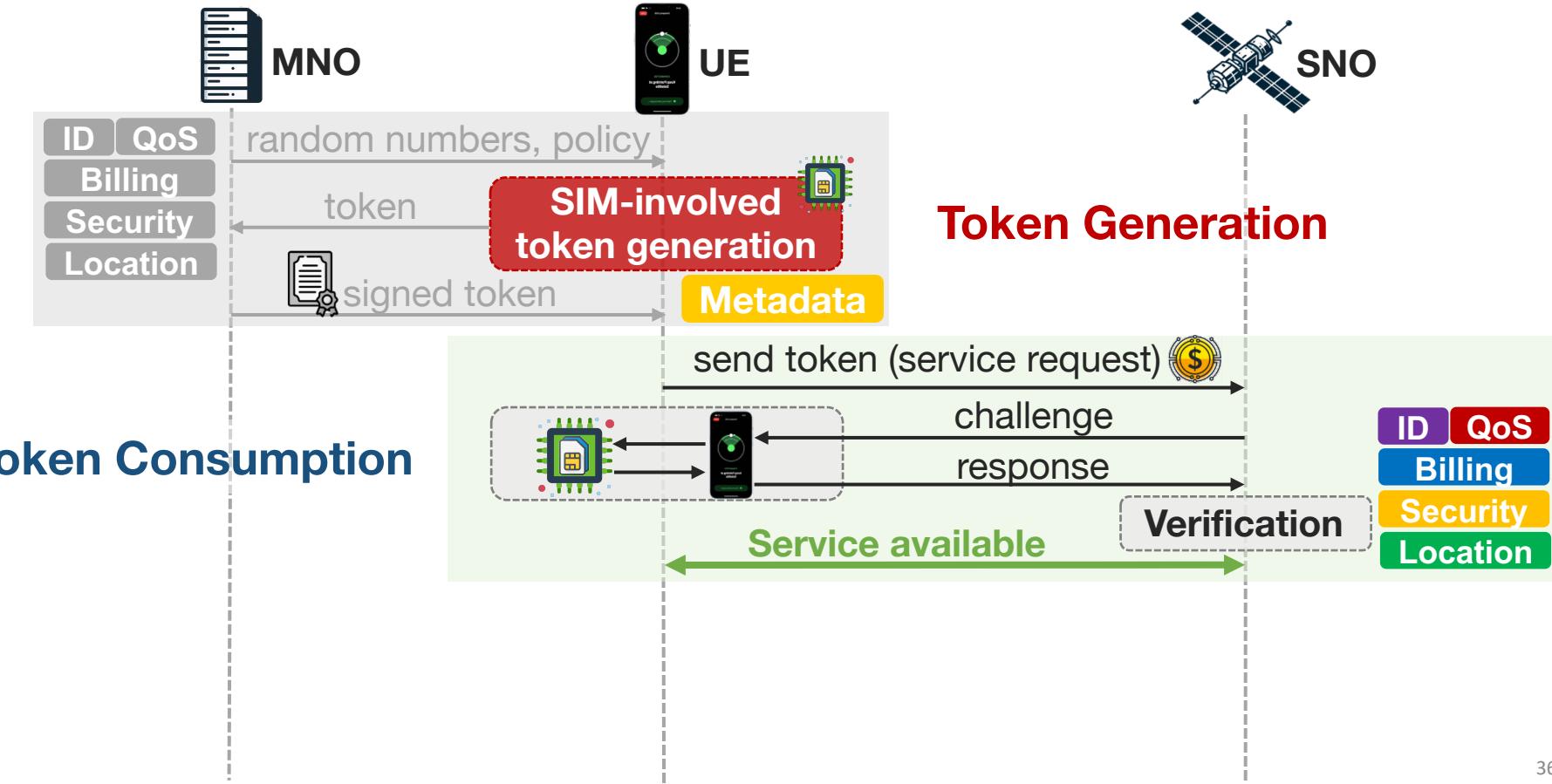
Key idea: SIM-enforced one-time token consumption



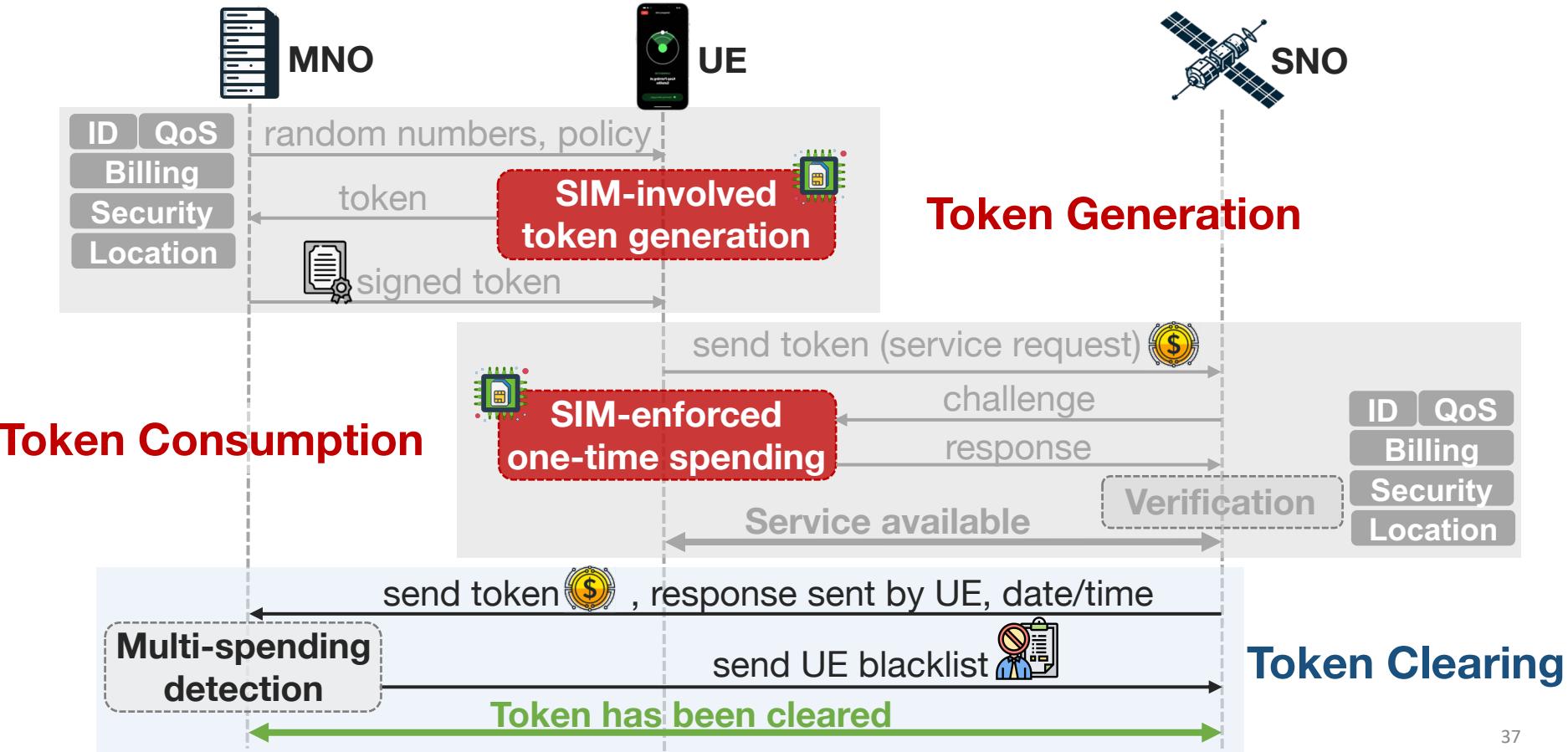
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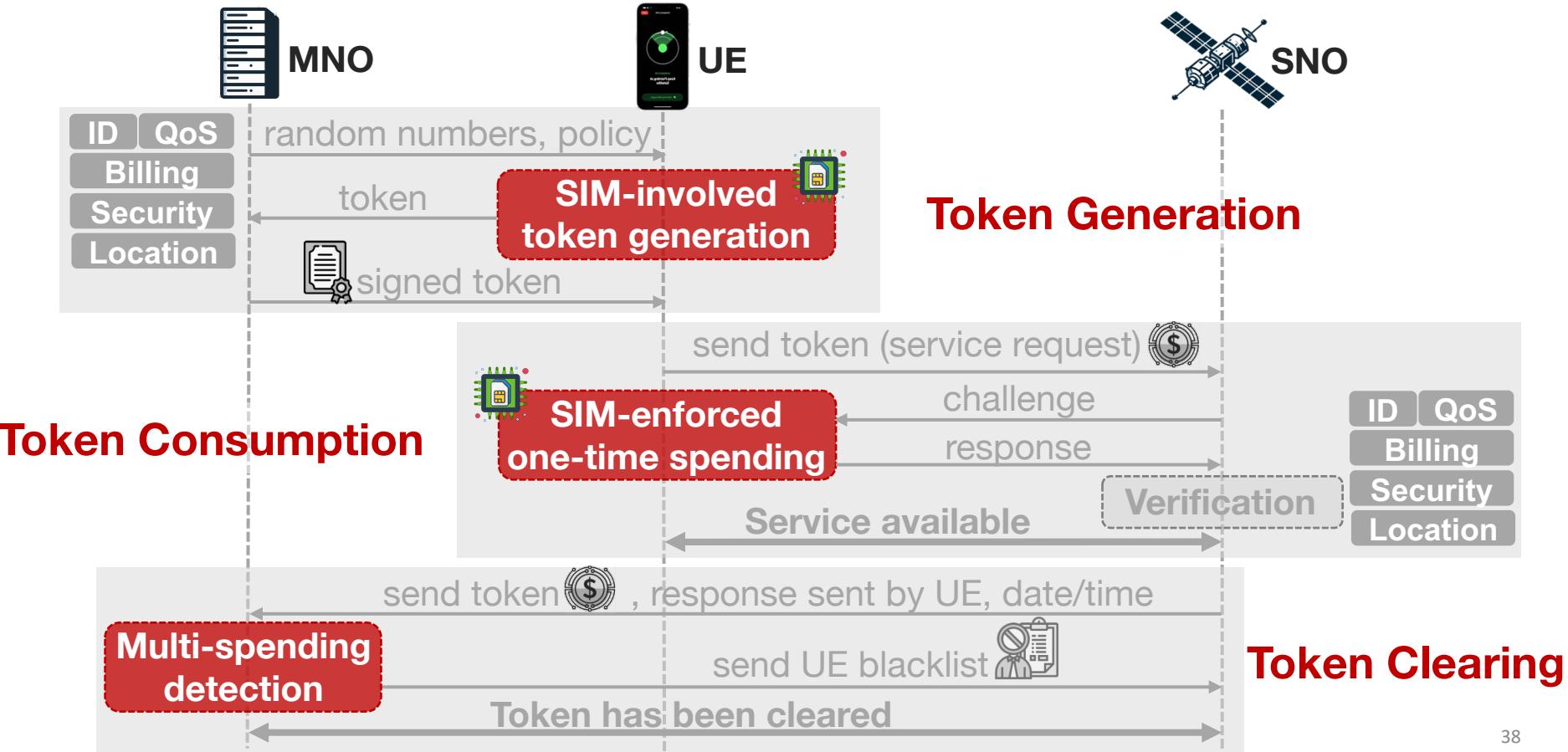
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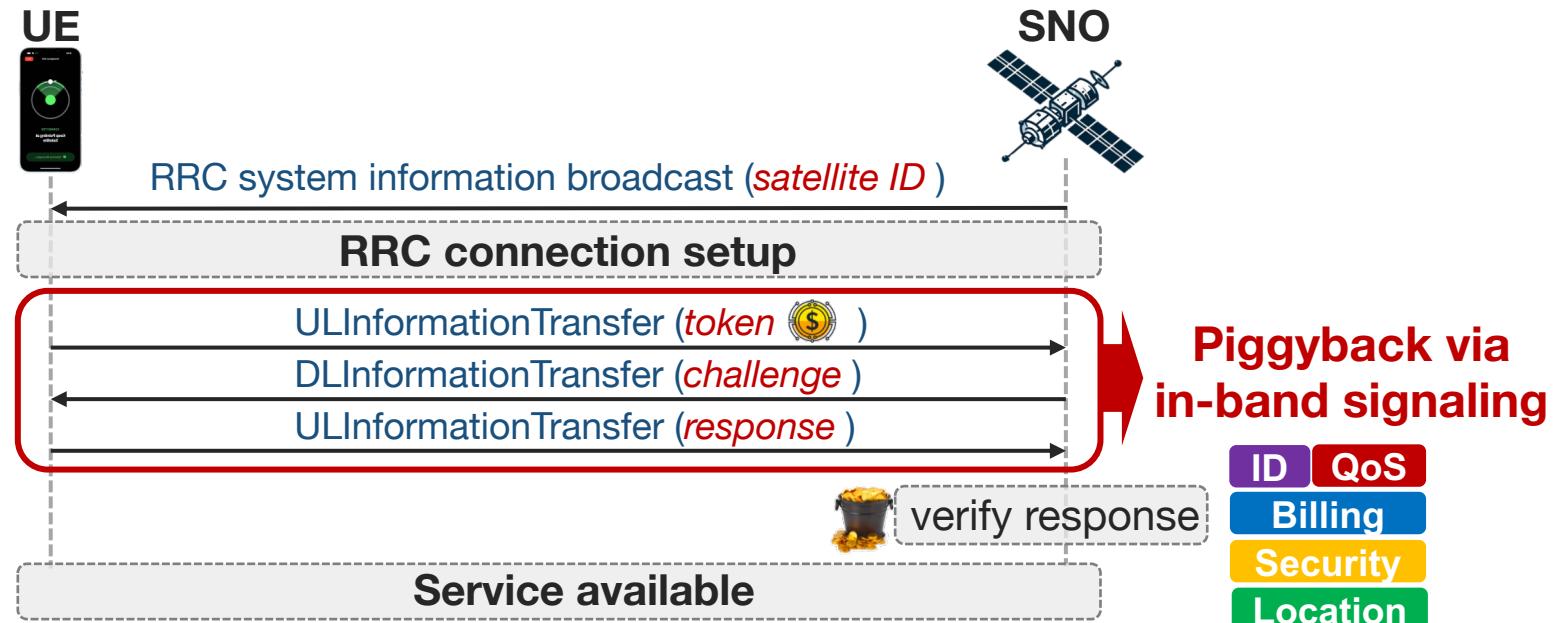
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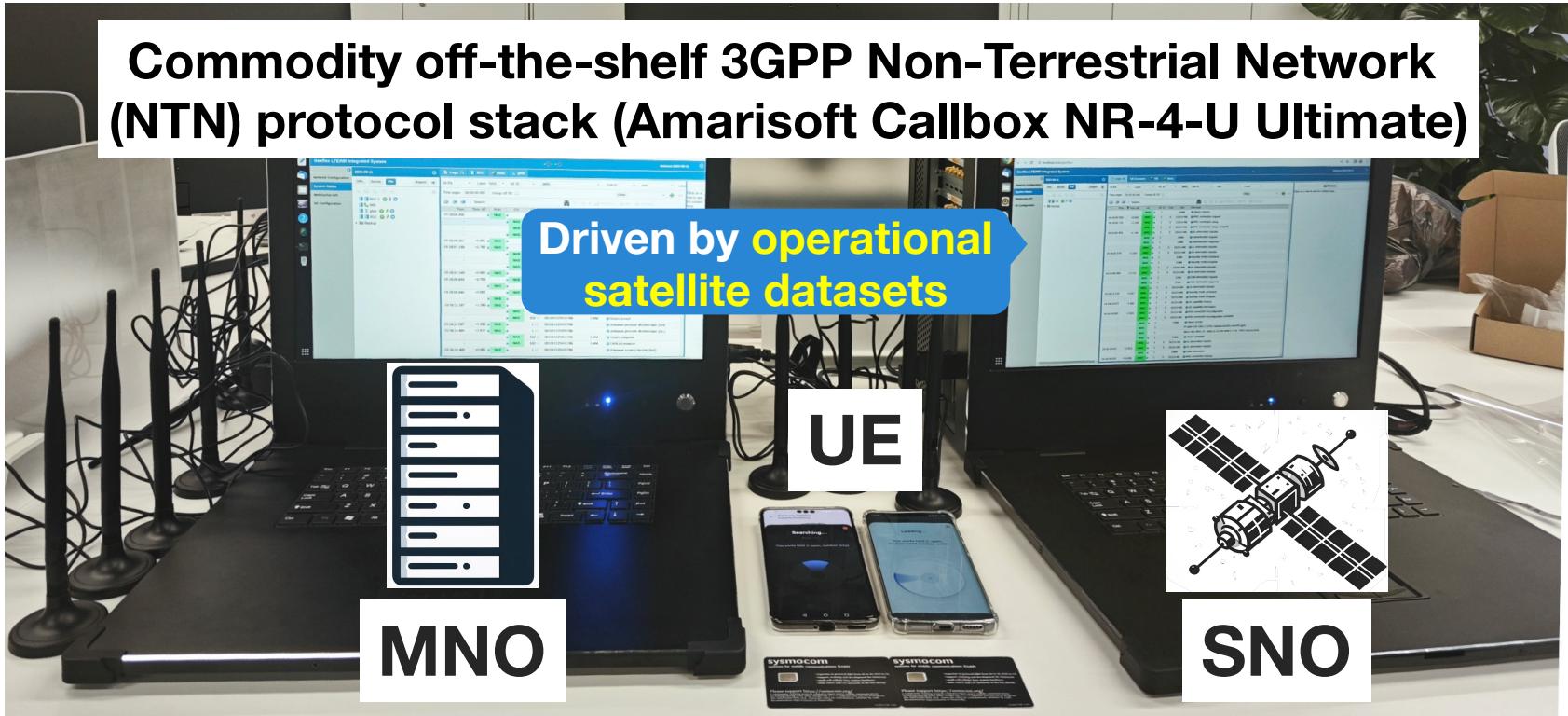
➤ How can UEs Access Satellite with Tokens?

Alleviate the dependency on MNOs

Minimize the amount of signaling

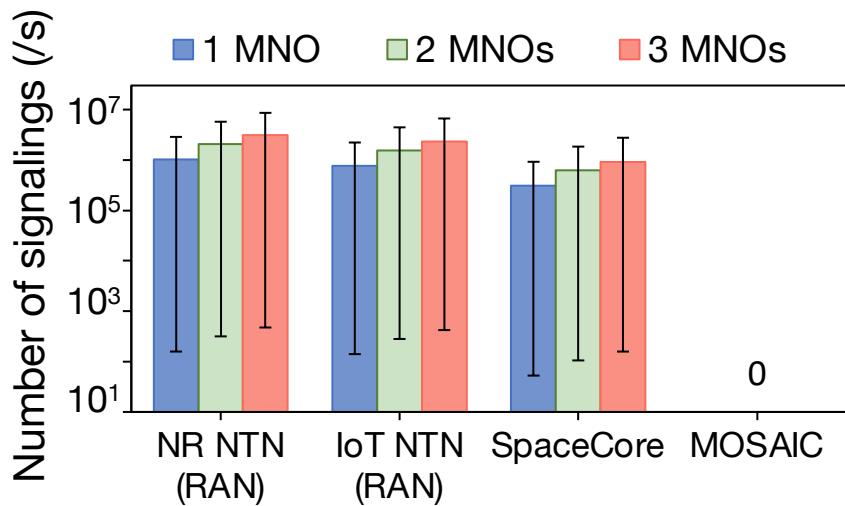


► Experimental Setup

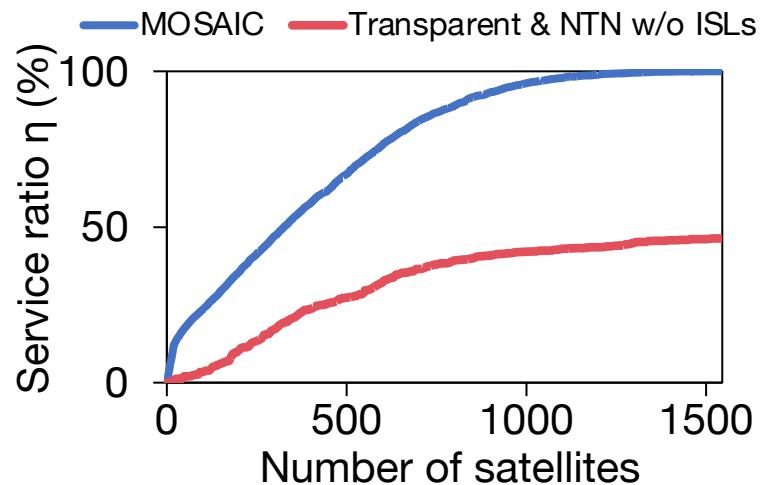


➤ Evaluation: Overall Benefits

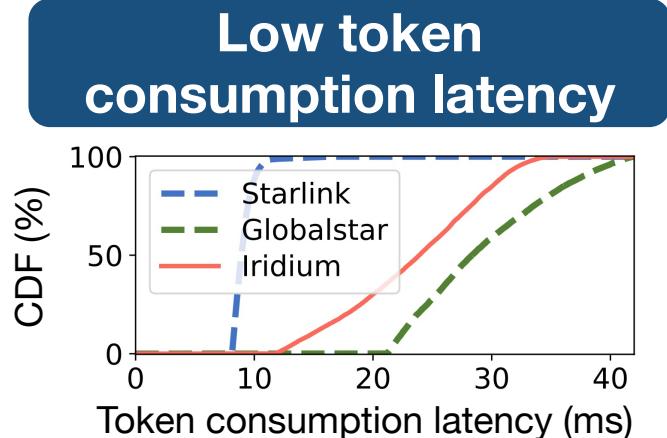
SNOs:
Signaling storm freedom



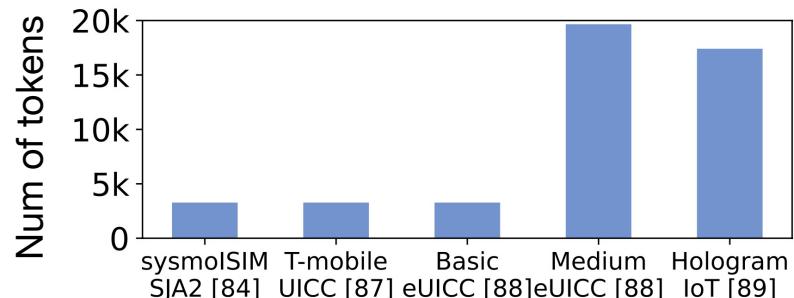
MNOs & UEs:
100% serviceable area



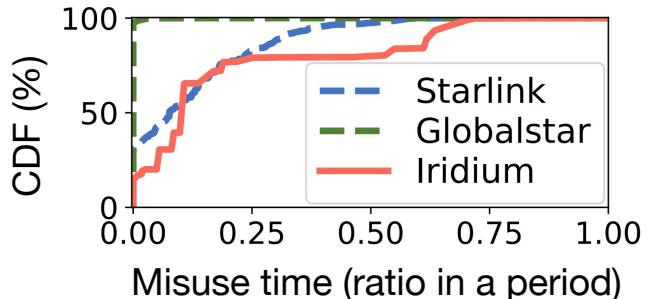
➤ Evaluation: Overhead



Existing SIM cards can host sufficient tokens



Token misuse time is still bounded in the worst case



➤ Conclusion

- Direct-to-cell satellite multi-tenancy: A win-win solution.
- **MOSAIC:** Pay-as-you-go satellite self-service
 - As easily shareable as ridesharing.
- A long voyage toward full multi-tenancy for 6G and beyond.



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Thank you!

Q&A

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