



清華大學  
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

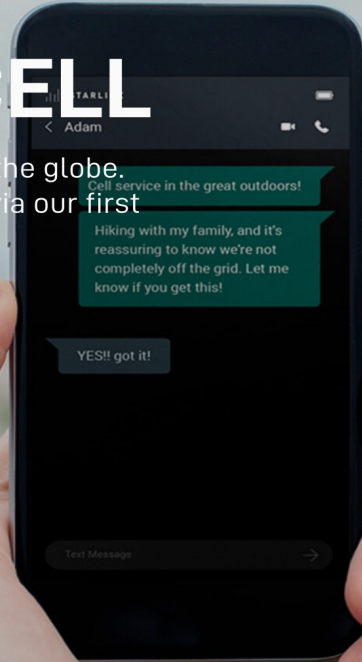
# ➤ Direct-to-Cell Satellites

## 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.

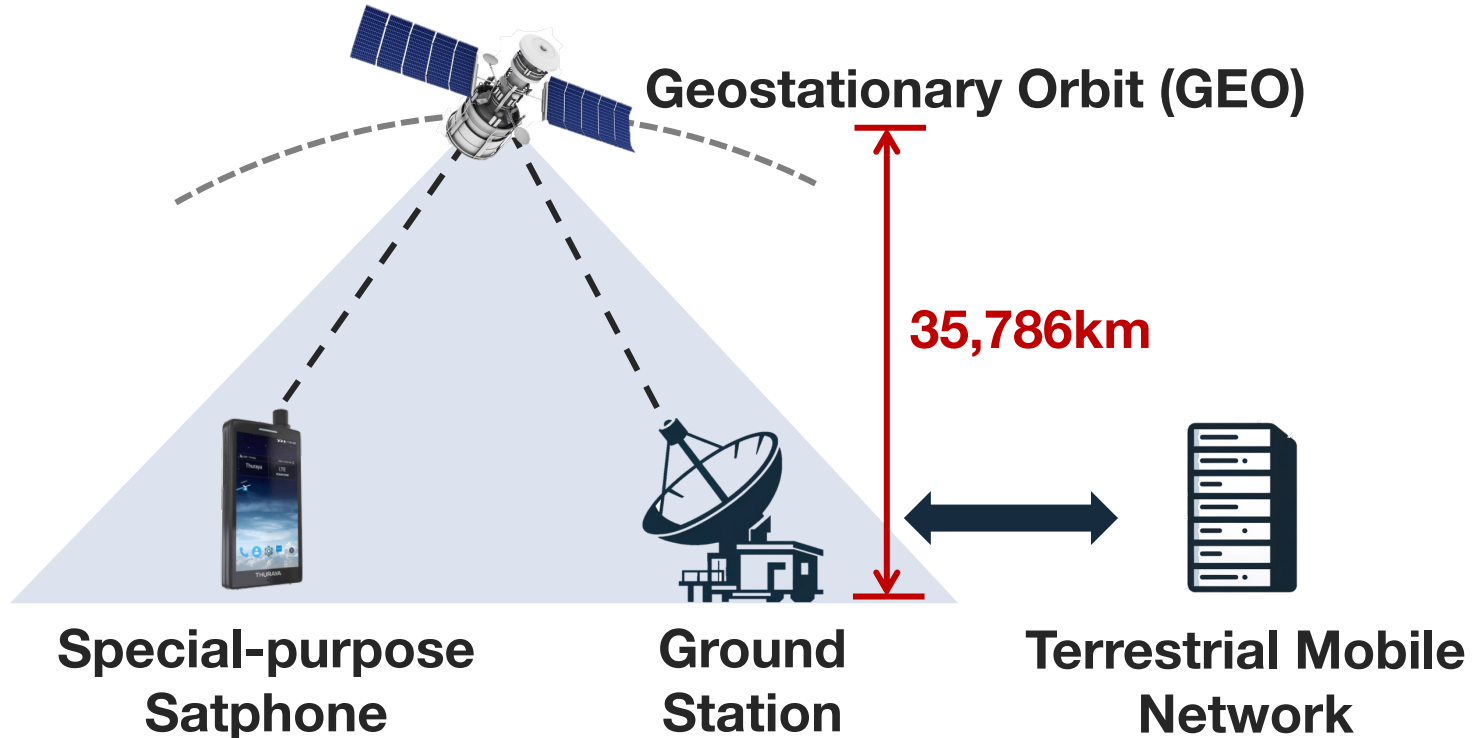
LEARN MORE

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



# ➤ Why Direct-to-Cell Satellites?

Affordable ubiquitous connectivity for our regular phones

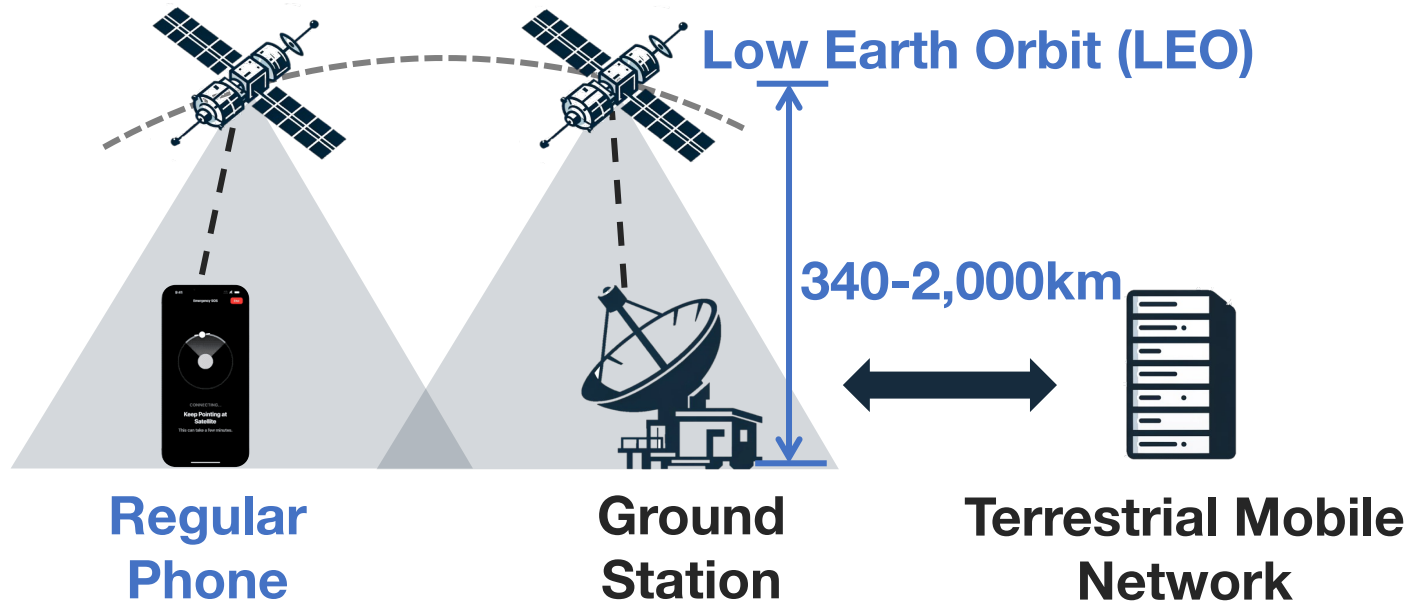


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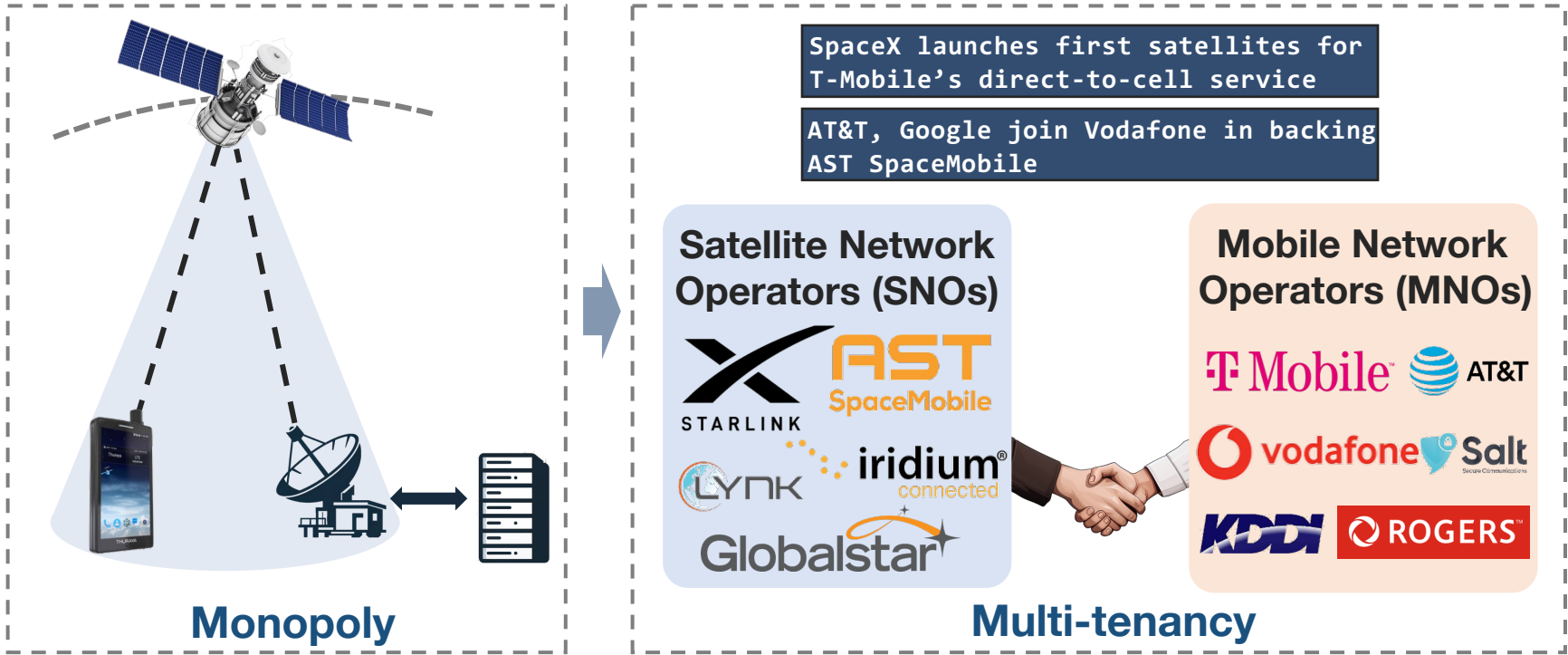
Affordable ubiquitous connectivity for our regular phones

Lower energy cost

More affordable hardware



# ➔ From Monopoly to Multi-Tenancy



# ➤ Why LEO Satellite Multi-Tenancy?



Mobile Network **T-Mobile**  
Operators (MNOs)  **AT&T**

Scarce satellite resources



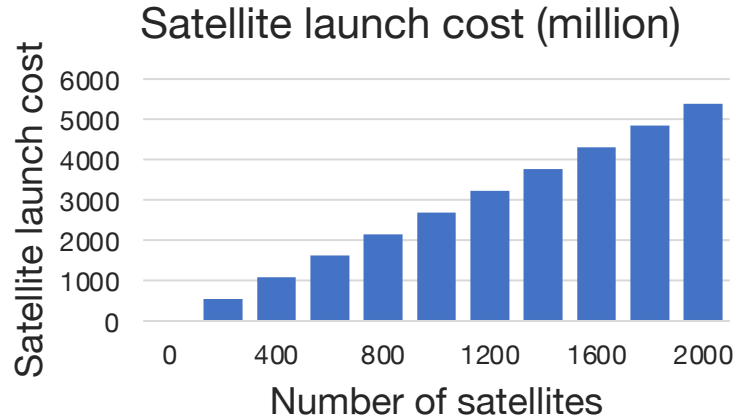
# ➤ Why LEO Satellite Multi-Tenancy?



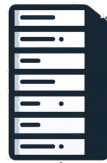
Mobile Network **T-Mobile**  
Operators (MNOs) **AT&T**

Scarce satellite resources

Prohibitive capital expenses



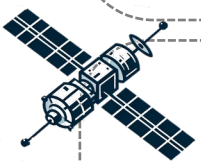
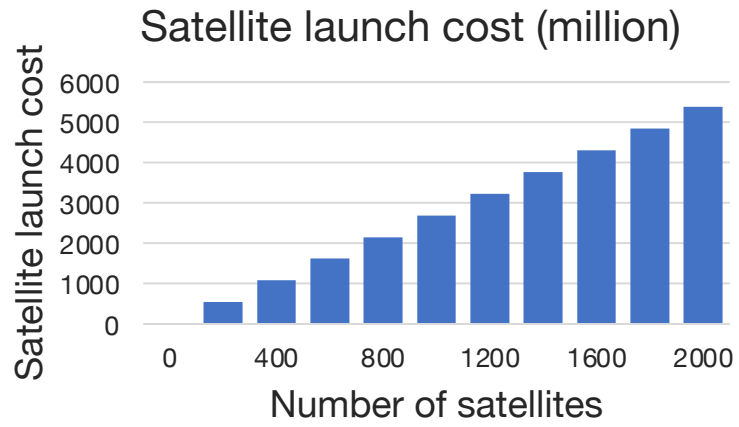
# ➔ Why LEO Satellite Multi-Tenancy?



Mobile Network Operators (MNOs)  

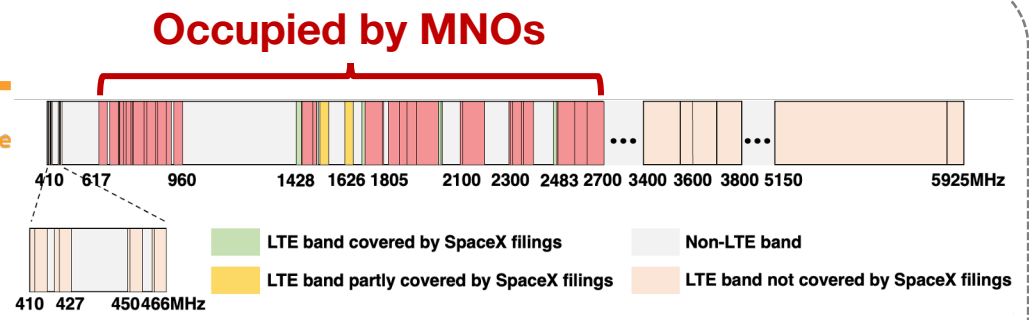
Scarce satellite resources

Prohibitive capital expenses



Satellite Network Operators (SNOs)  

Lack of licensed spectrums





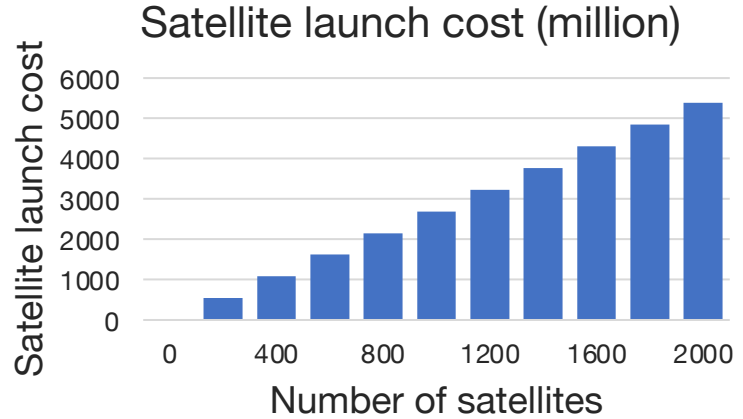
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Mobile Network **T-Mobile**  
Operators (MNOs) **AT&T**

Scarce satellite resources

Prohibitive capital expenses



Satellite Network **STARLINK**  
Operators (SNOs) **AST SpaceMobile**

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

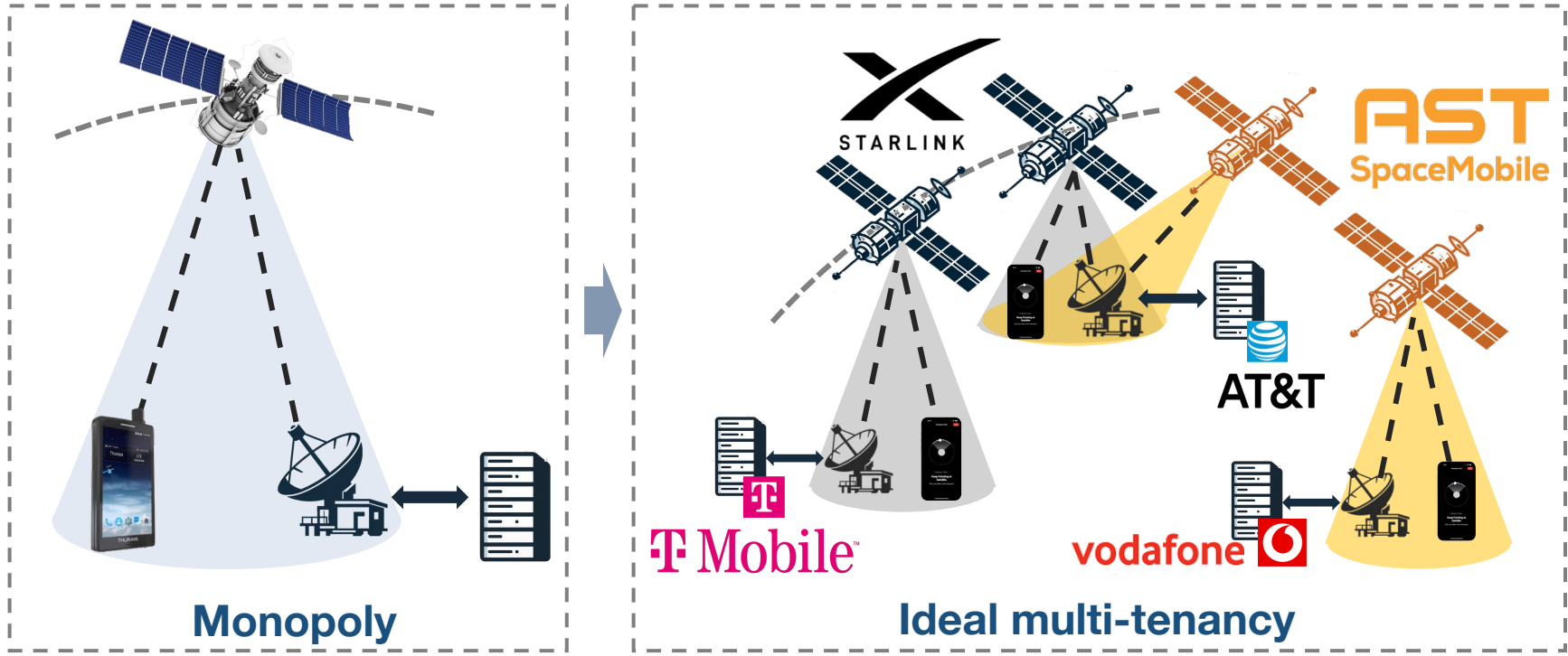
**FCC FACT SHEET\***  
**Single Network Future: Supplemental Coverage from Space**  
Report and Order and Further Notice of Proposed Rulemaking  
GN Docket No. 23-65 and IB Docket No. 22-271

**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

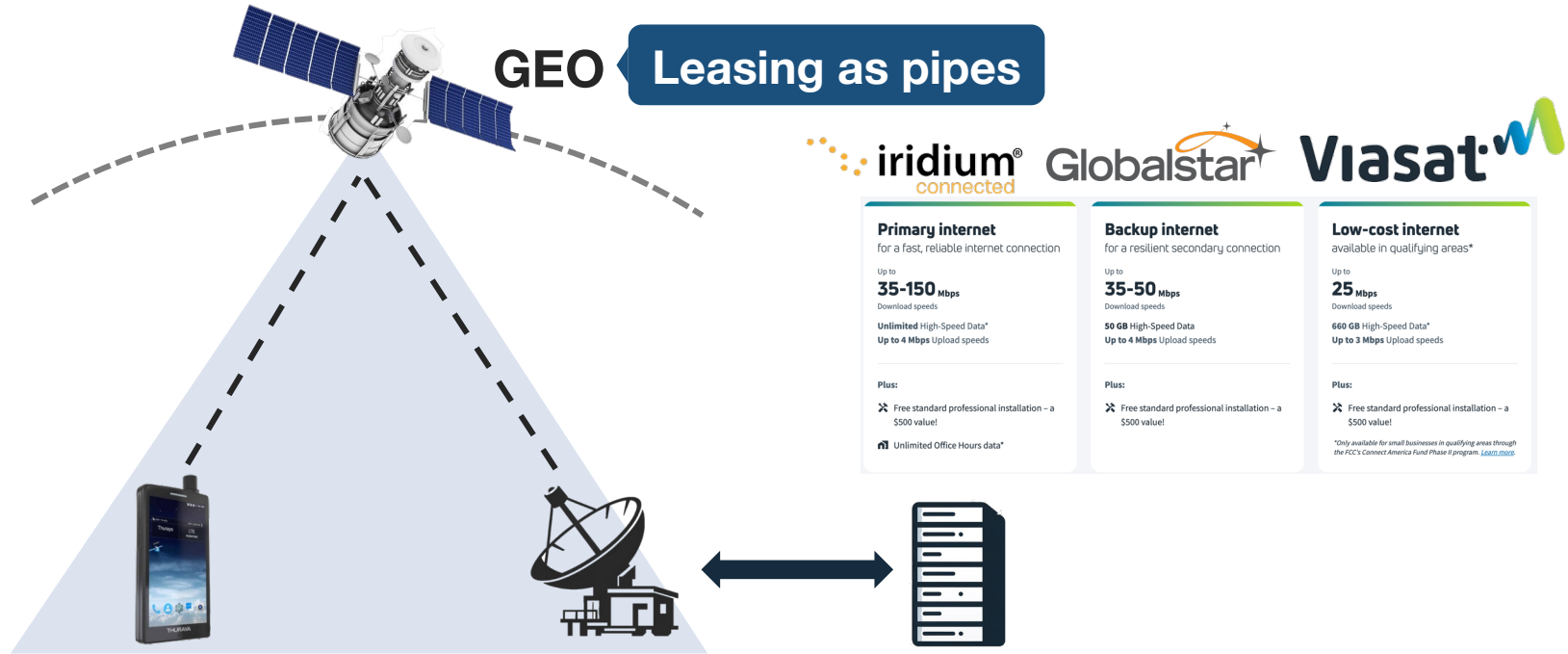
# ➤ How Should Multi-Tenancy Work?



 UEs    Satellite Network Operators (SNOs)    Mobile Network Operators (MNOs)

# ➤ How to Enable LEO Satellite Multi-Tenancy?

## Option 1: Infrastructure-as-a-Service Model



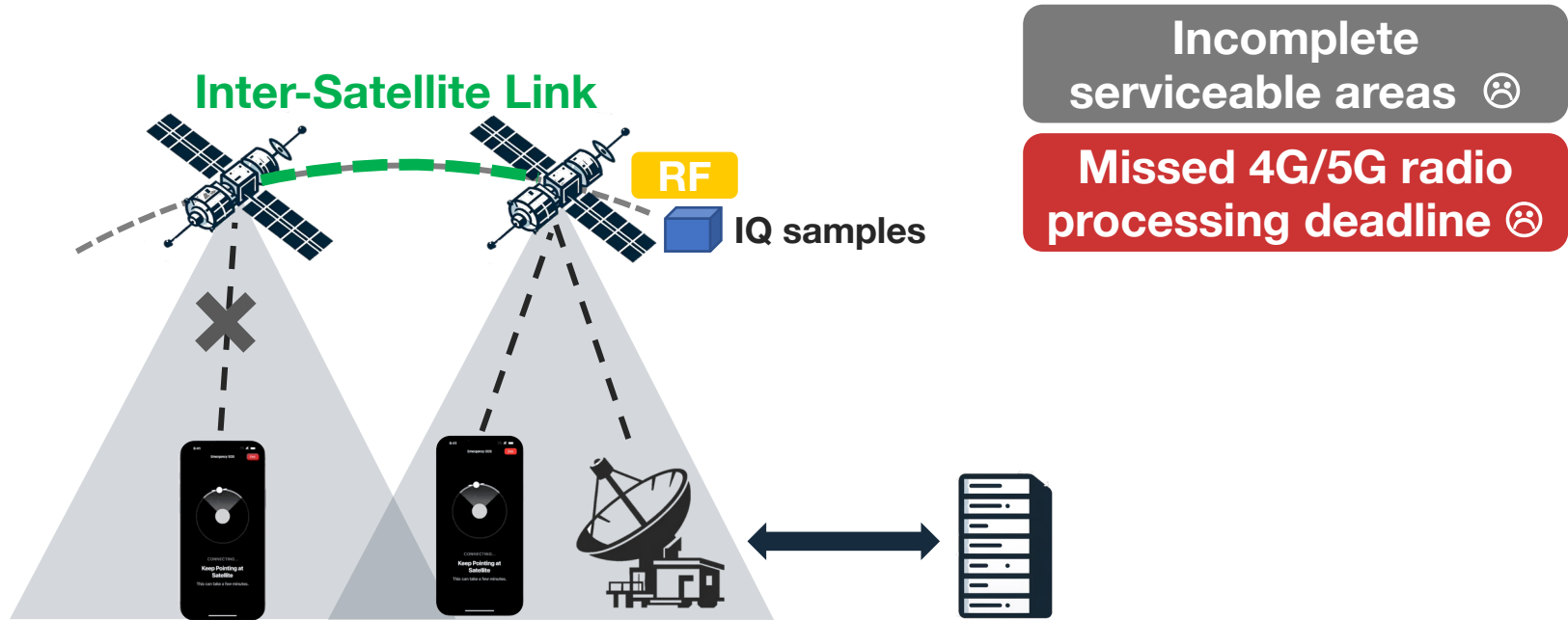
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## Option 1: Infrastructure-as-a-Service Model



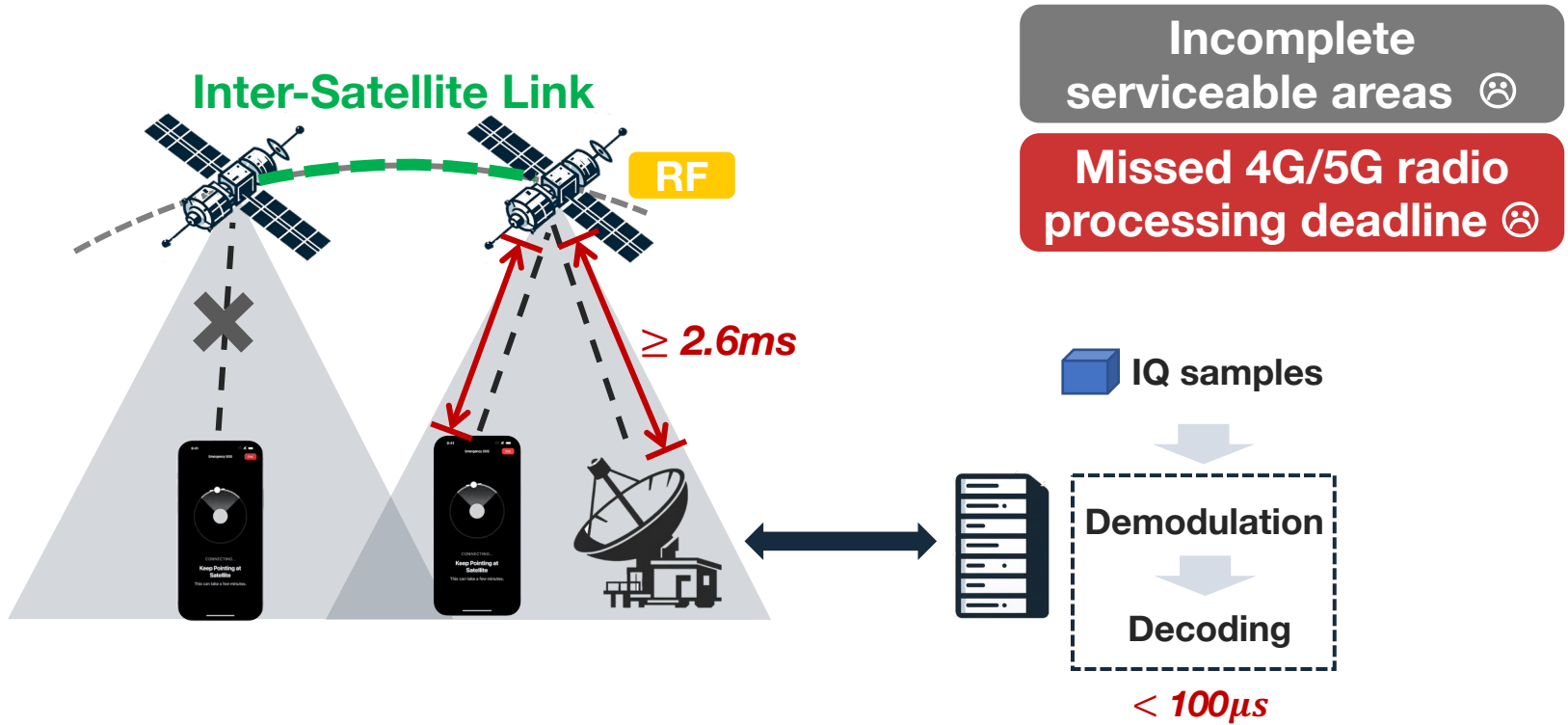
# ➤ How to Enable LEO Satellite Multi-Tenancy?

## 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?

## Option 2: Function-as-a-Service Model

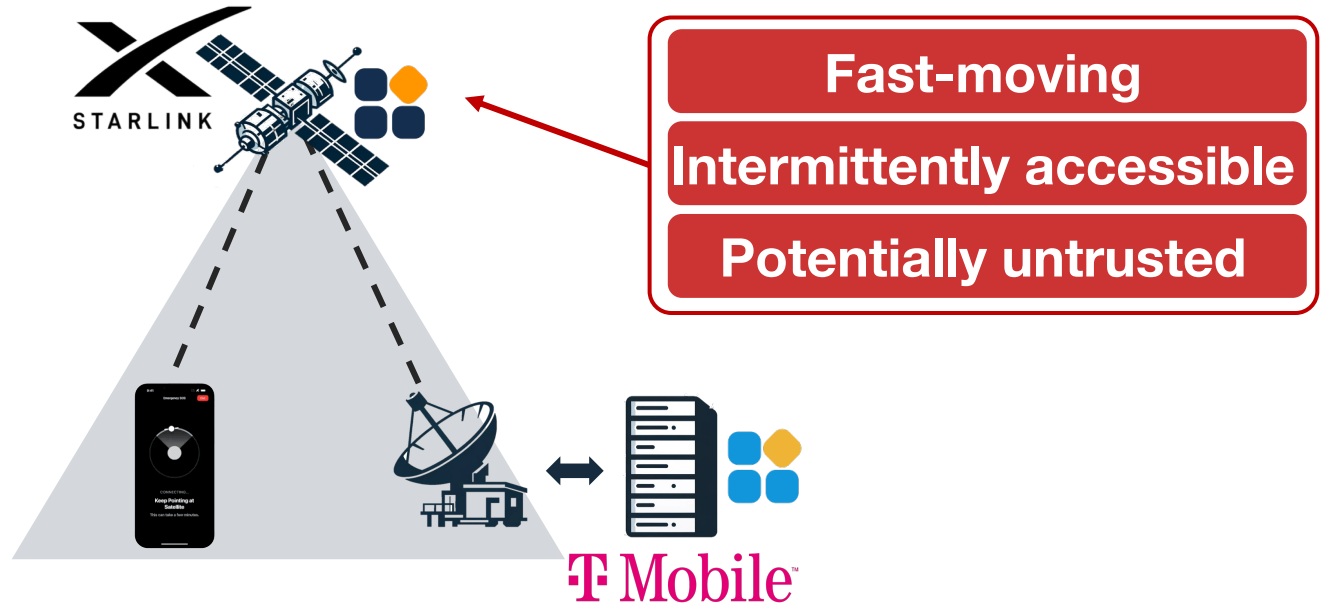


**Can this model enable multi-tenancy?**

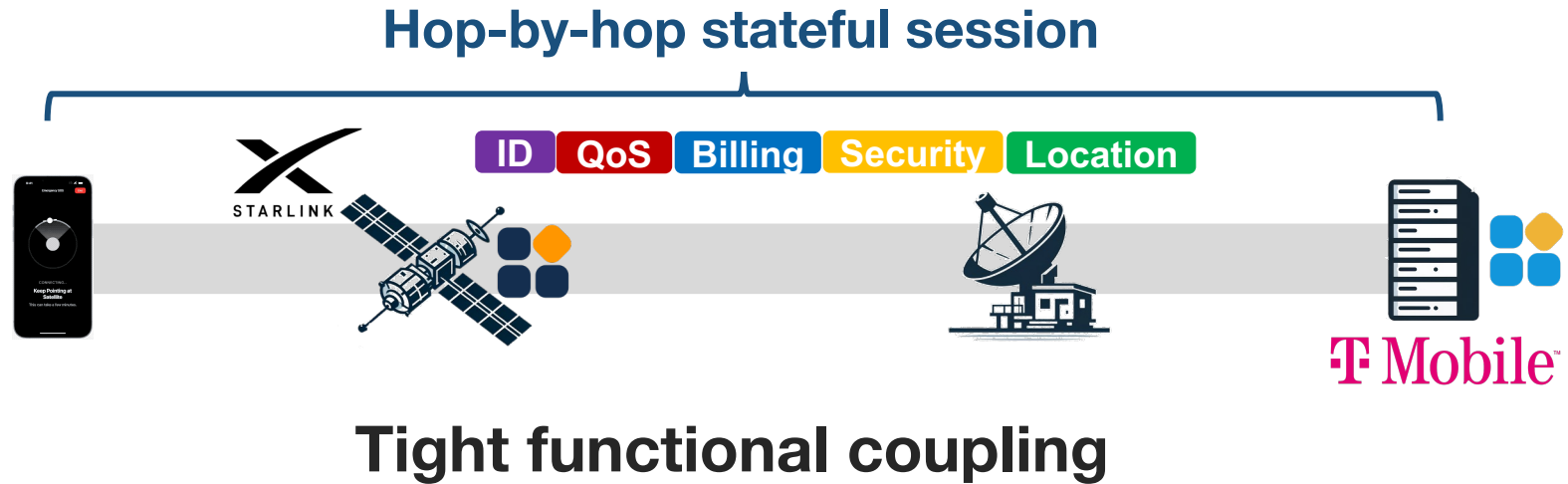


# ➤ Function-as-a-Service Model in Space?

MNO's cellular functions are offloaded to SNOs' satellites

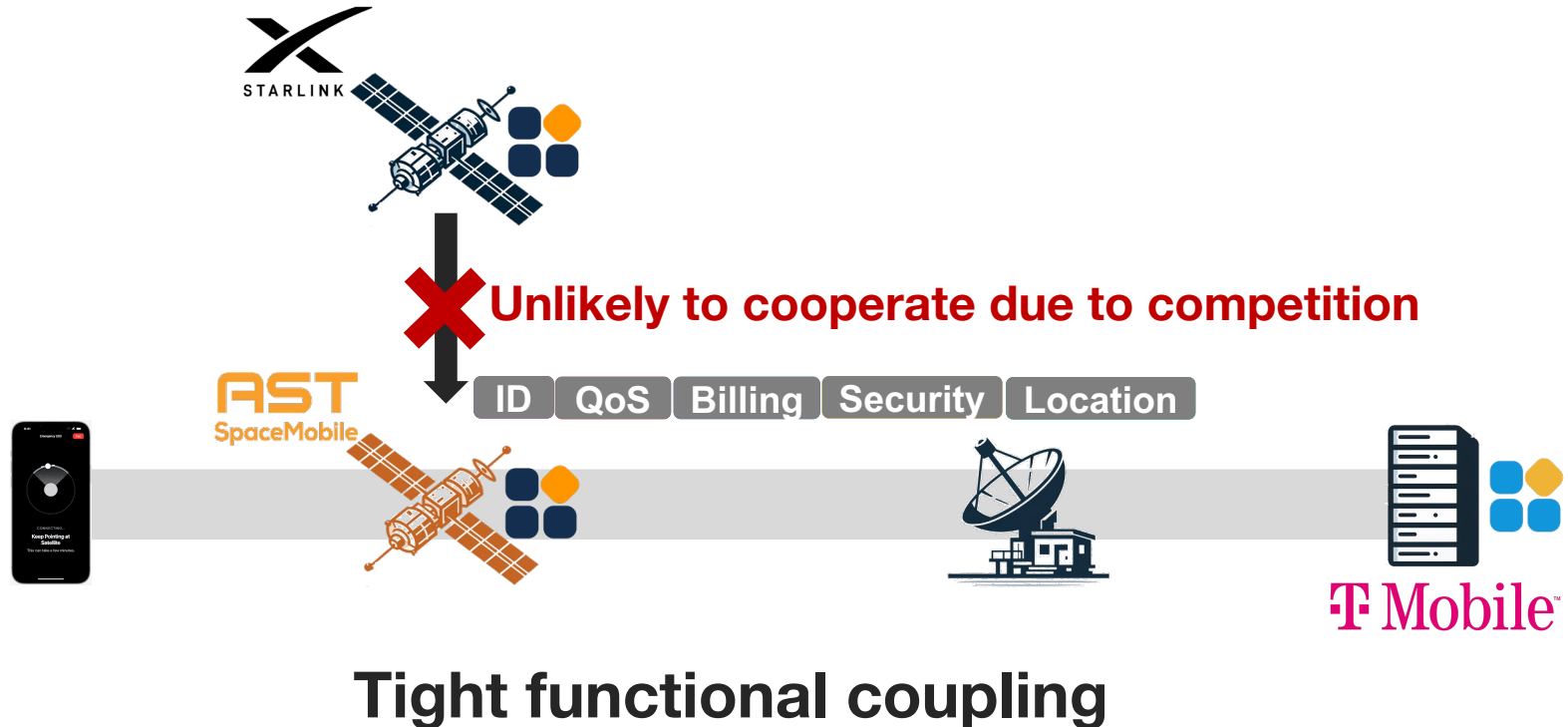


# ➤ Function-as-a-Service Model in Space?



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

Inflexible use of SNOs ☹️

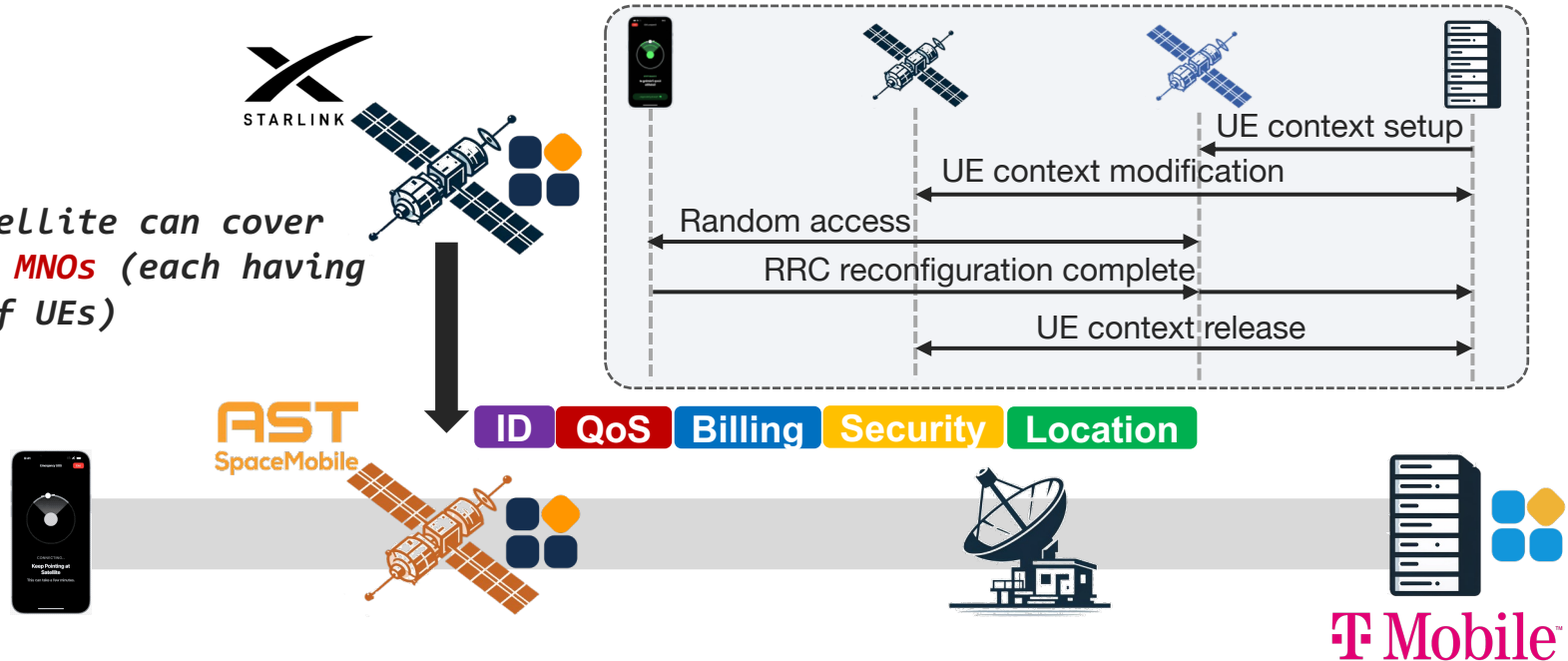


# ➤ Function-as-a-Service Model in Space?

Inflexible use of SNOs ☹️

Signaling storms due to huge coverage ☹️

Each satellite can cover multiple MNOs (each having 1,000s of UEs)



Tight functional coupling

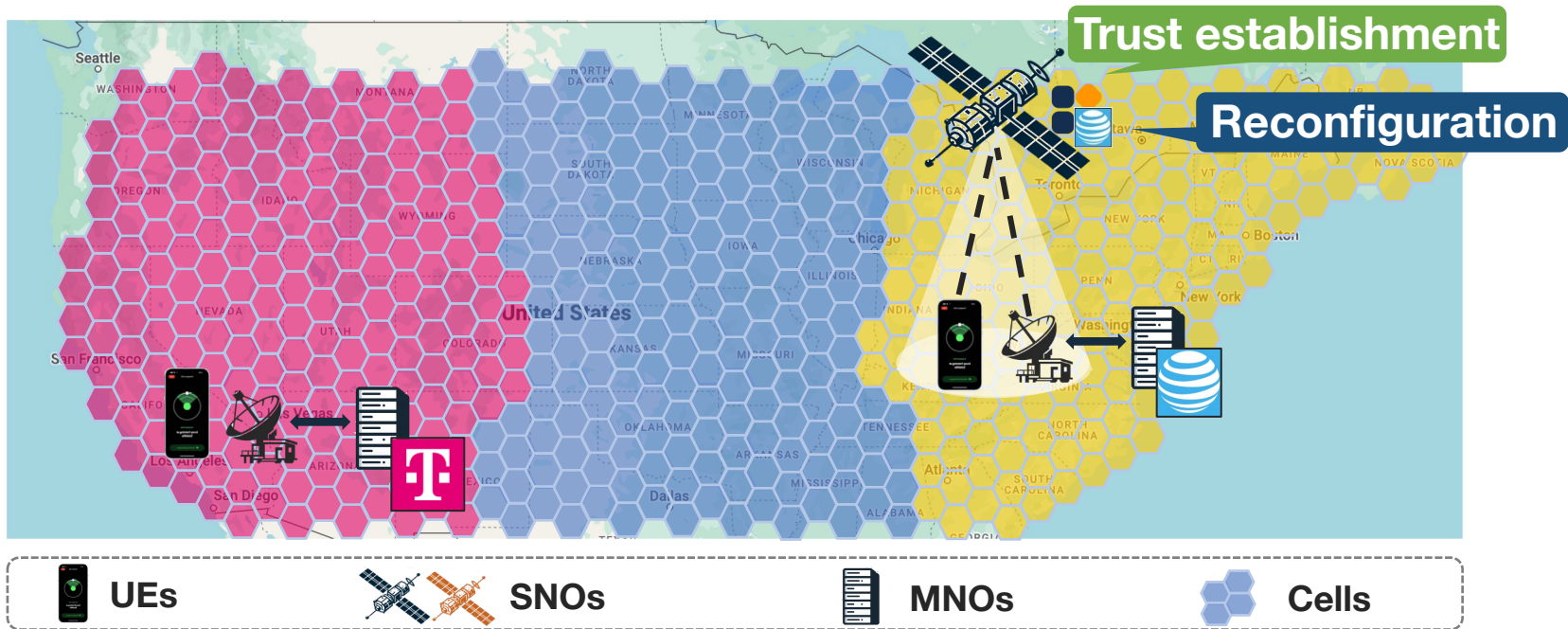
# ➤ Function-as-a-Service Model in Space?

## Dynamic SNO-MNO-UE service relationship



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## Dynamic SNO-MNO-UE service relationship

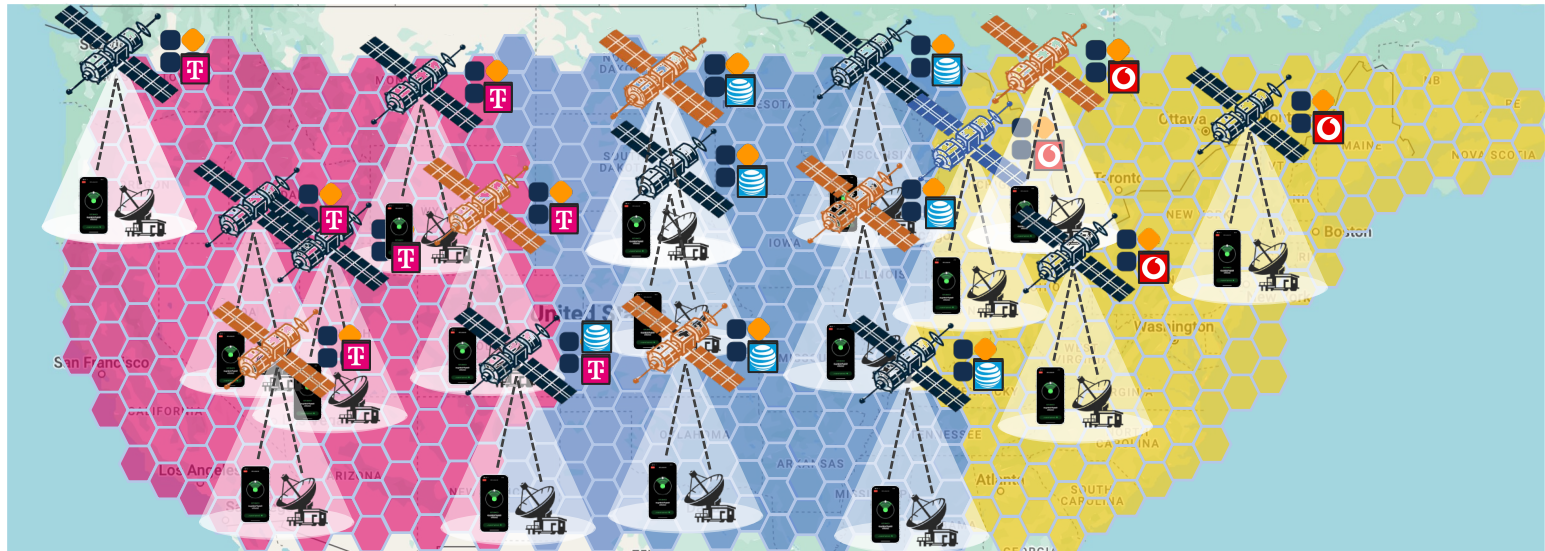


# ➤ Function-as-a-Service Model in Space?

## Dynamic SNO-MNO-UE service relationship

Exhaustive MNO reconfigurations ☹️

Dynamic trust establishment ☹️



UEs



SNOs



MNOs



Cells

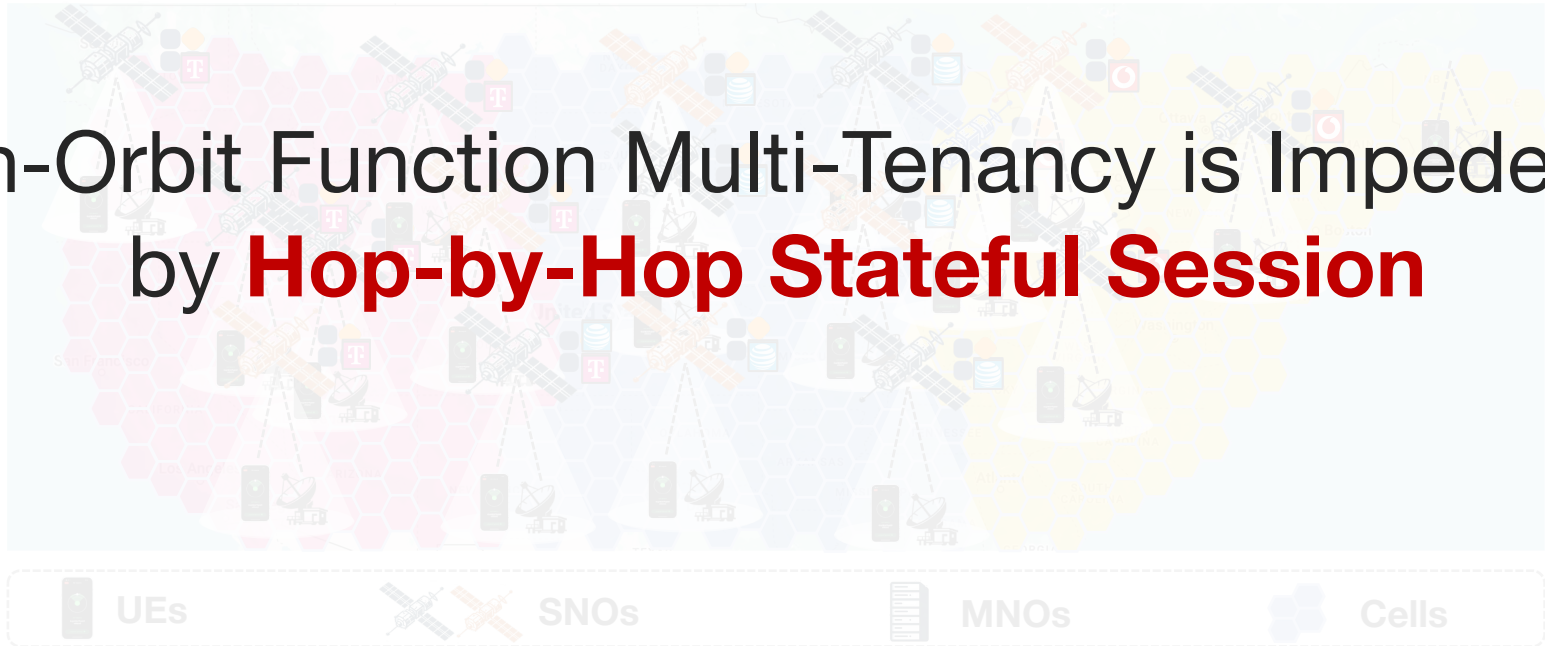
# ► Function-as-a-Service Model in Space?

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**



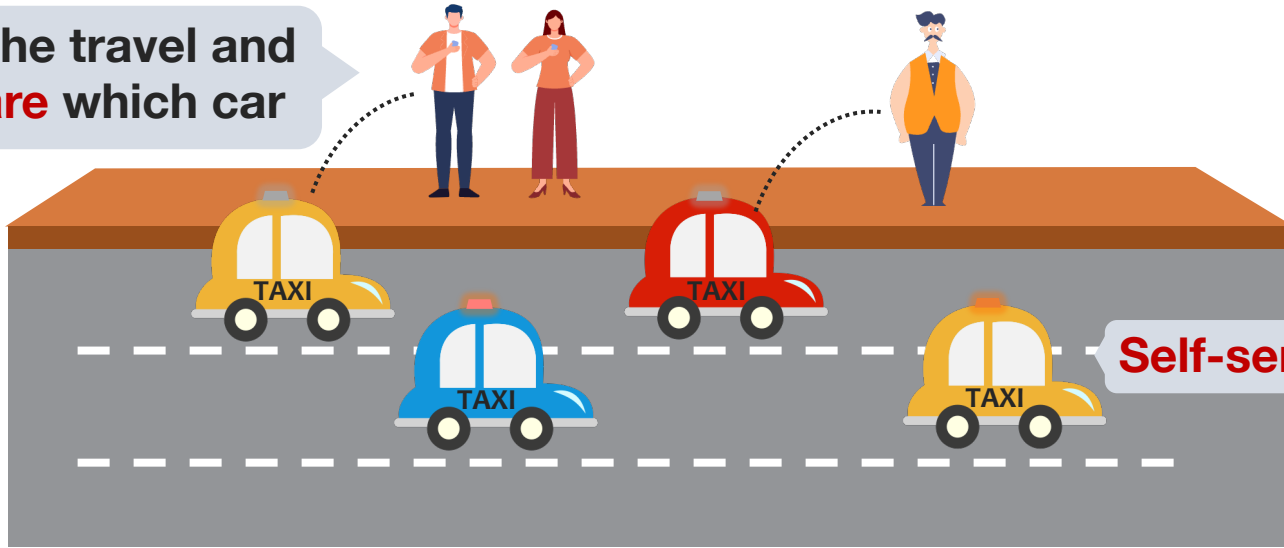


# ➤ How to Enable LEO Satellite Multi-Tenancy?

How do we share mobile infrastructure in life?



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



**Self-service** car

**Pay-as-you-go self-service**

# ► How to Enable LEO Satellite Multi-Tenancy?

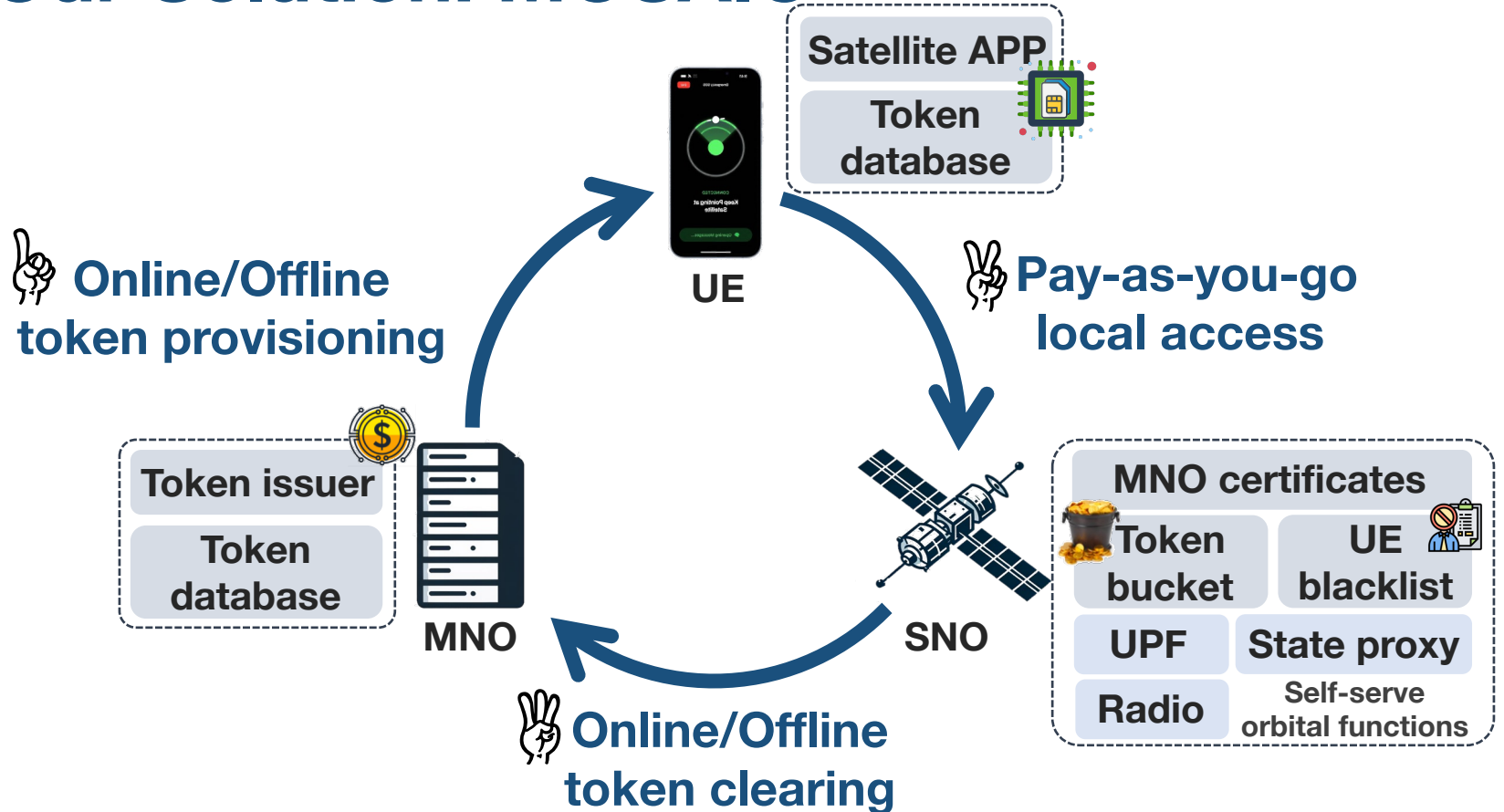
## Pay-as-you-go satellite self-service

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



**Self-service** SNO

# ➔ Our Solution: MOSAIC



# ➤ How to Realize MOSAIC?

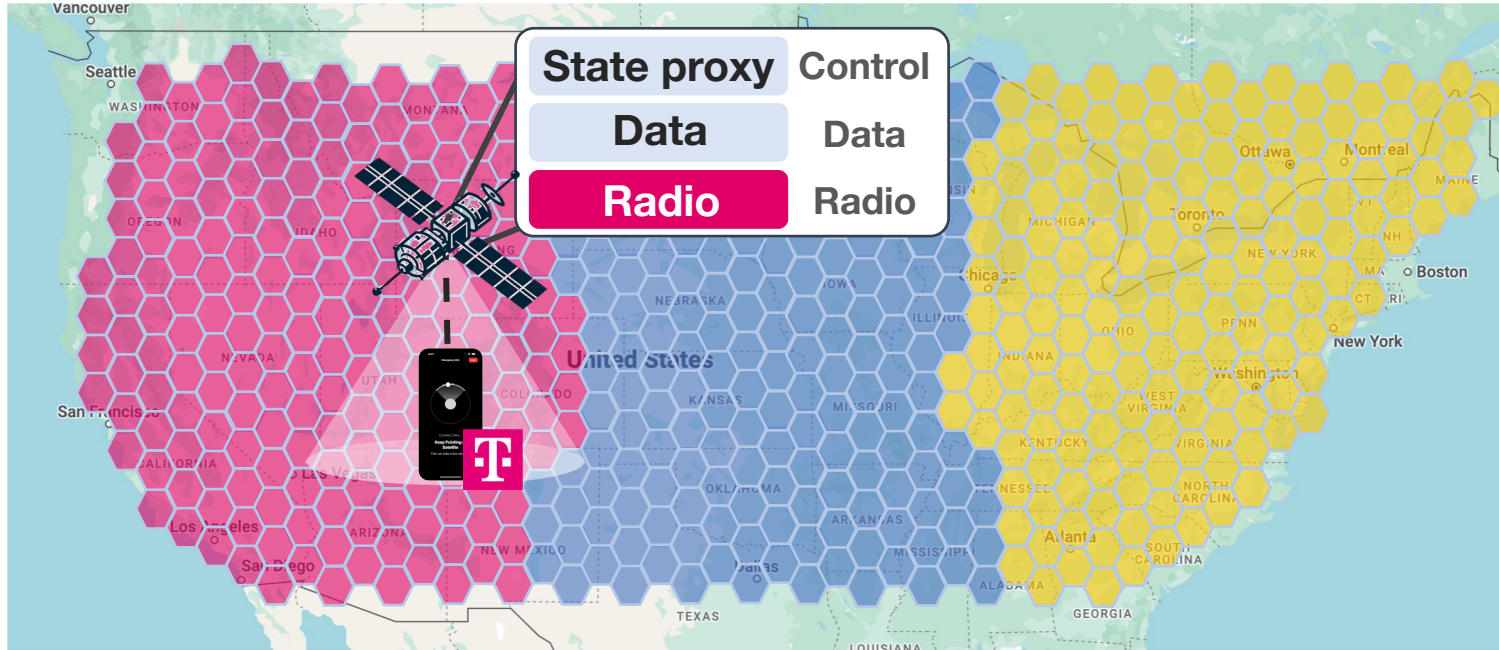
- ? How can SNOs enable self-service?
- ? How can MNOs enable pay-as-you-go tokens?
- ? How can UEs access satellite with tokens?

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

Self-service



Full-fledged cellular functions

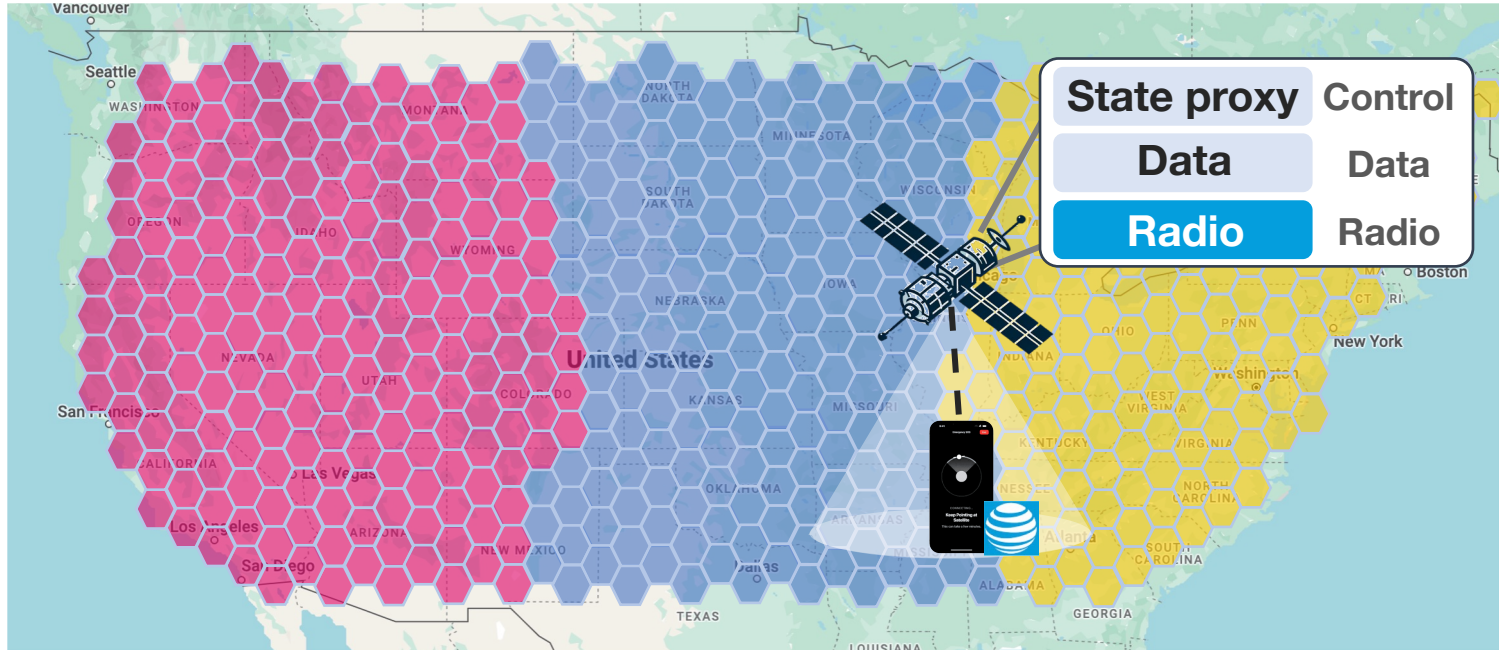


# ➤ How can SNOs Enable Multi-Tenant Self-Service?

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Full-fledged cellular functions



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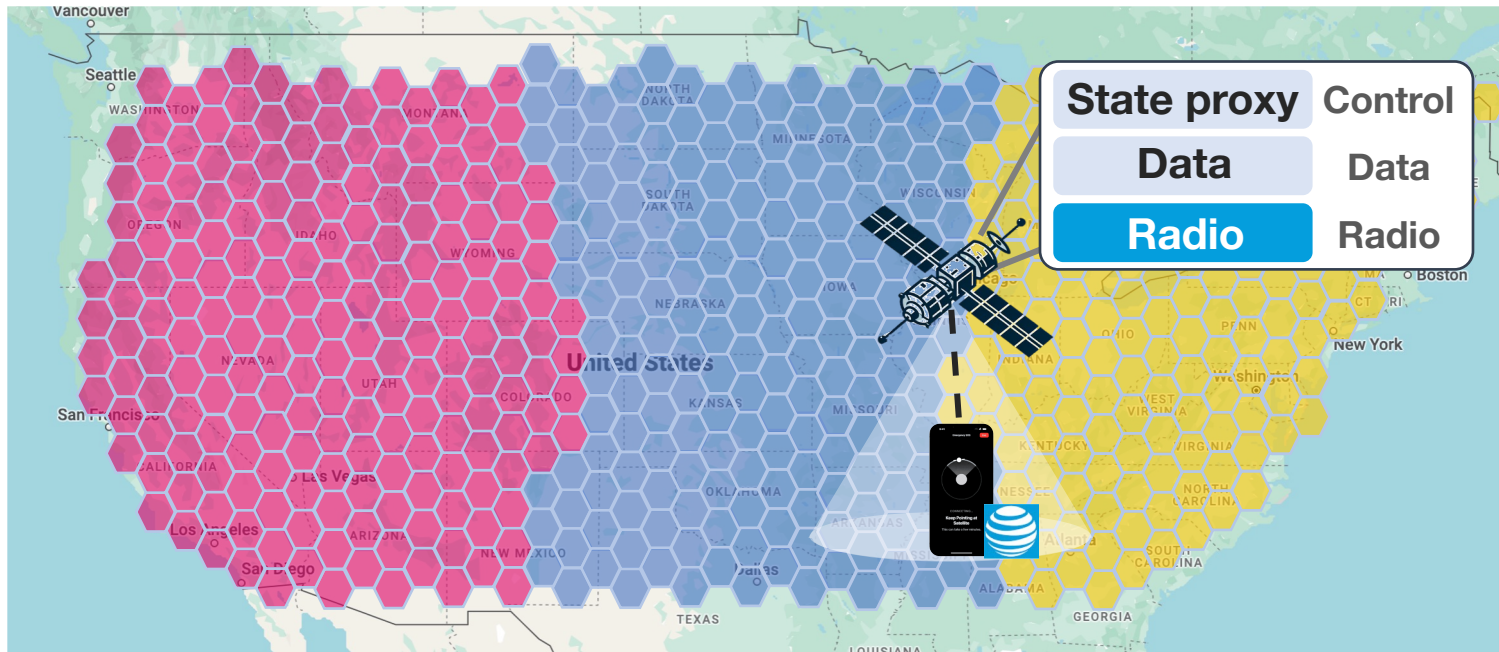


Full-fledged cellular functions

Multi-tenancy

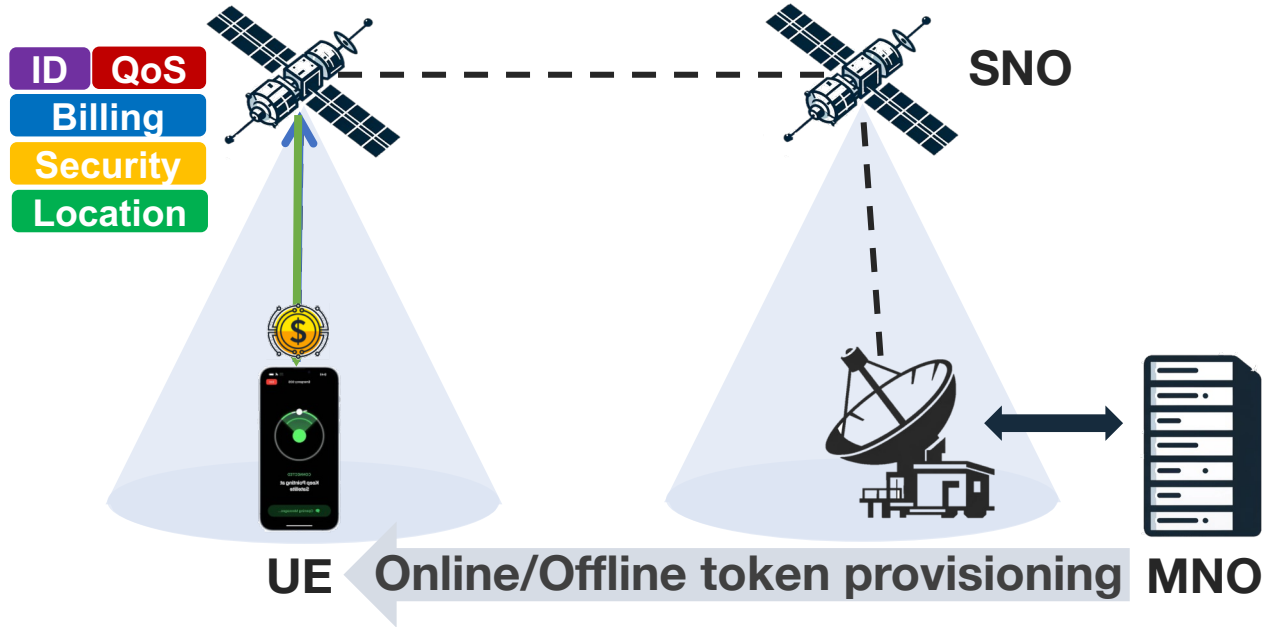


Decouple function in a stateless design



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

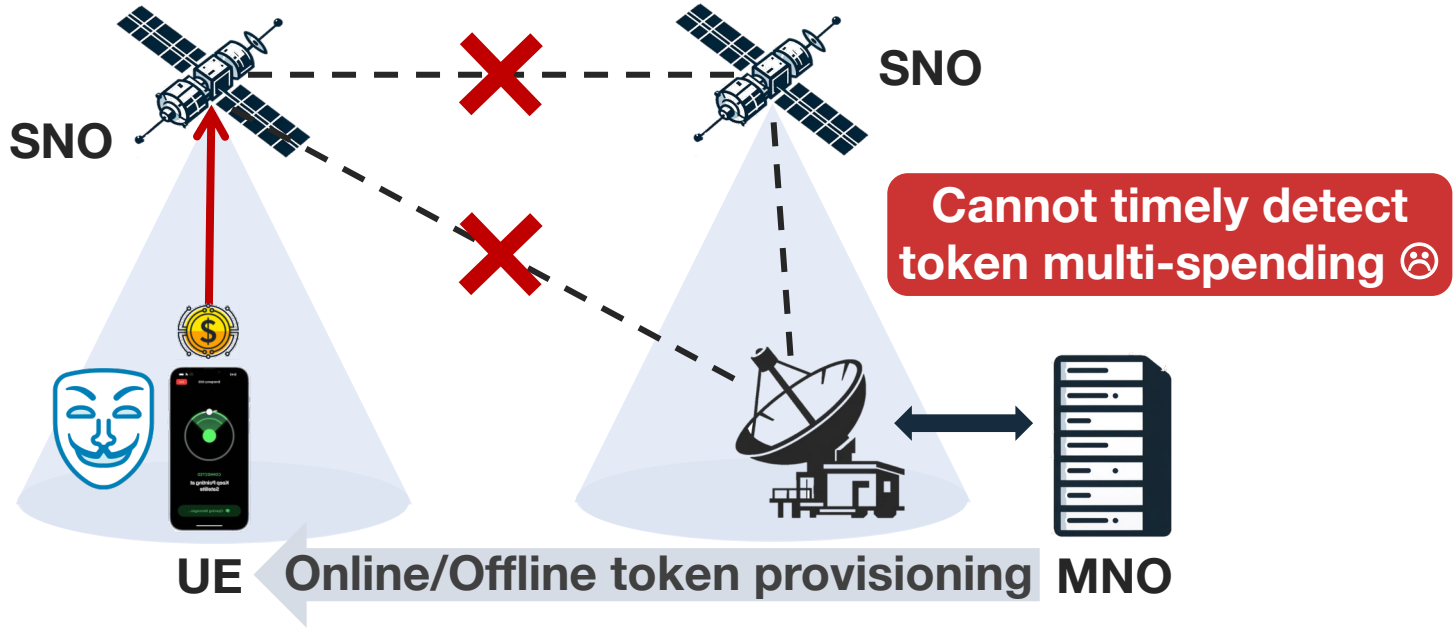
## Policy-embedded tokens





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

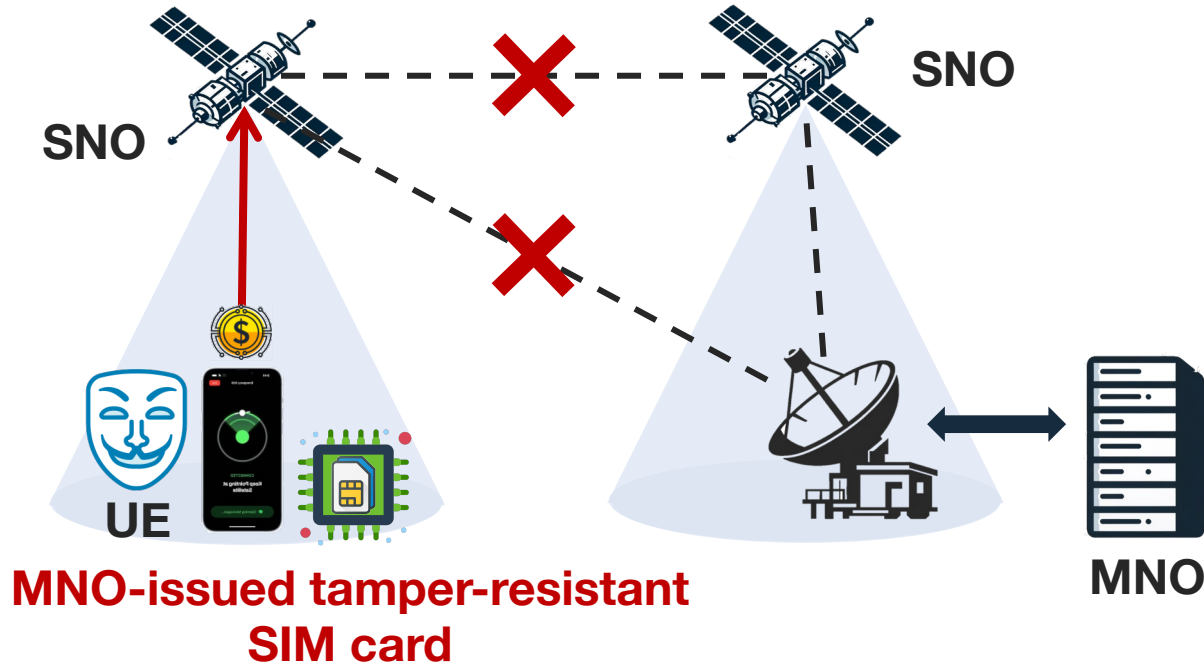
Concern: Token misuse



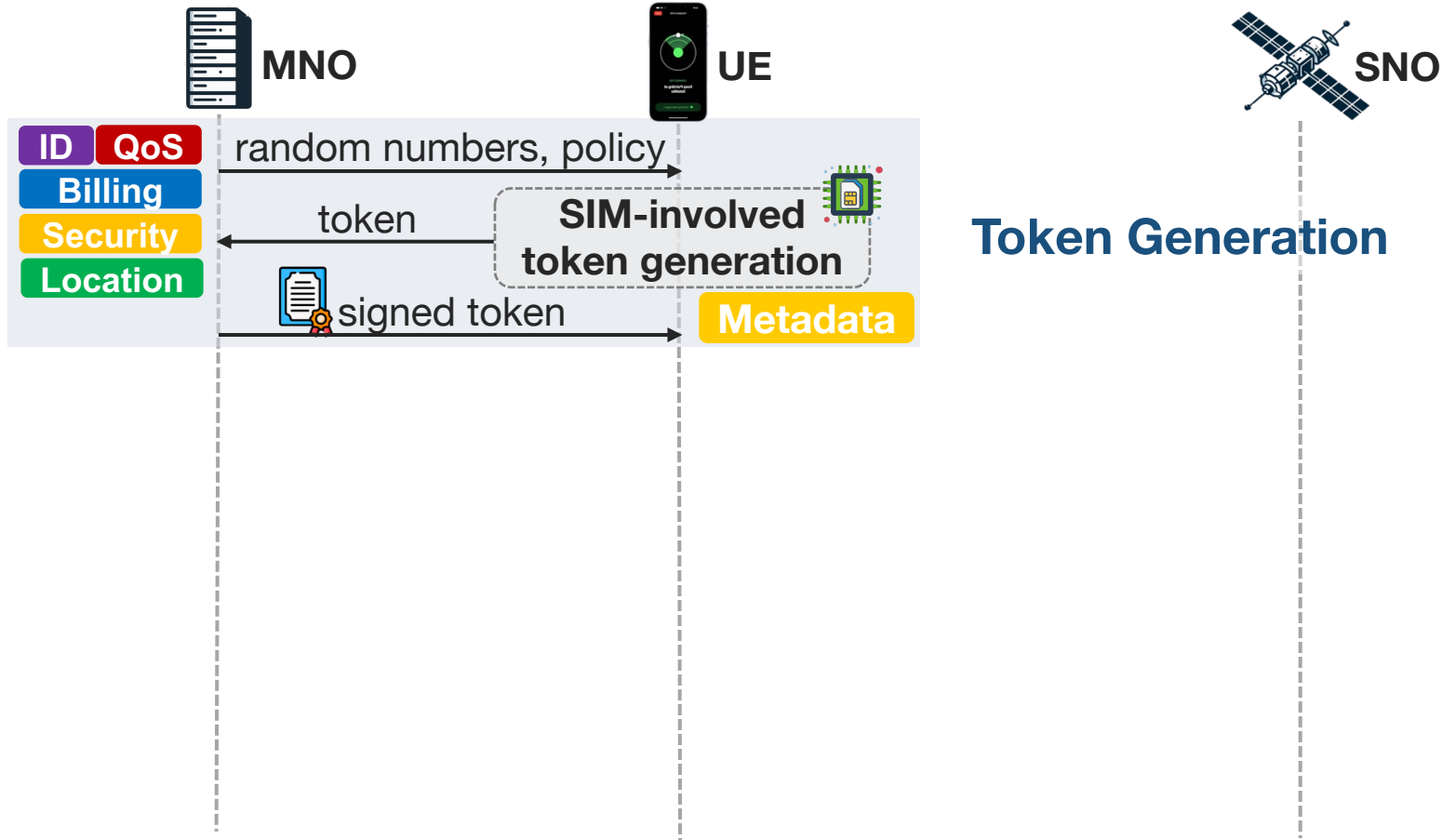
**Multi-spending one token to gain free satellite access**

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

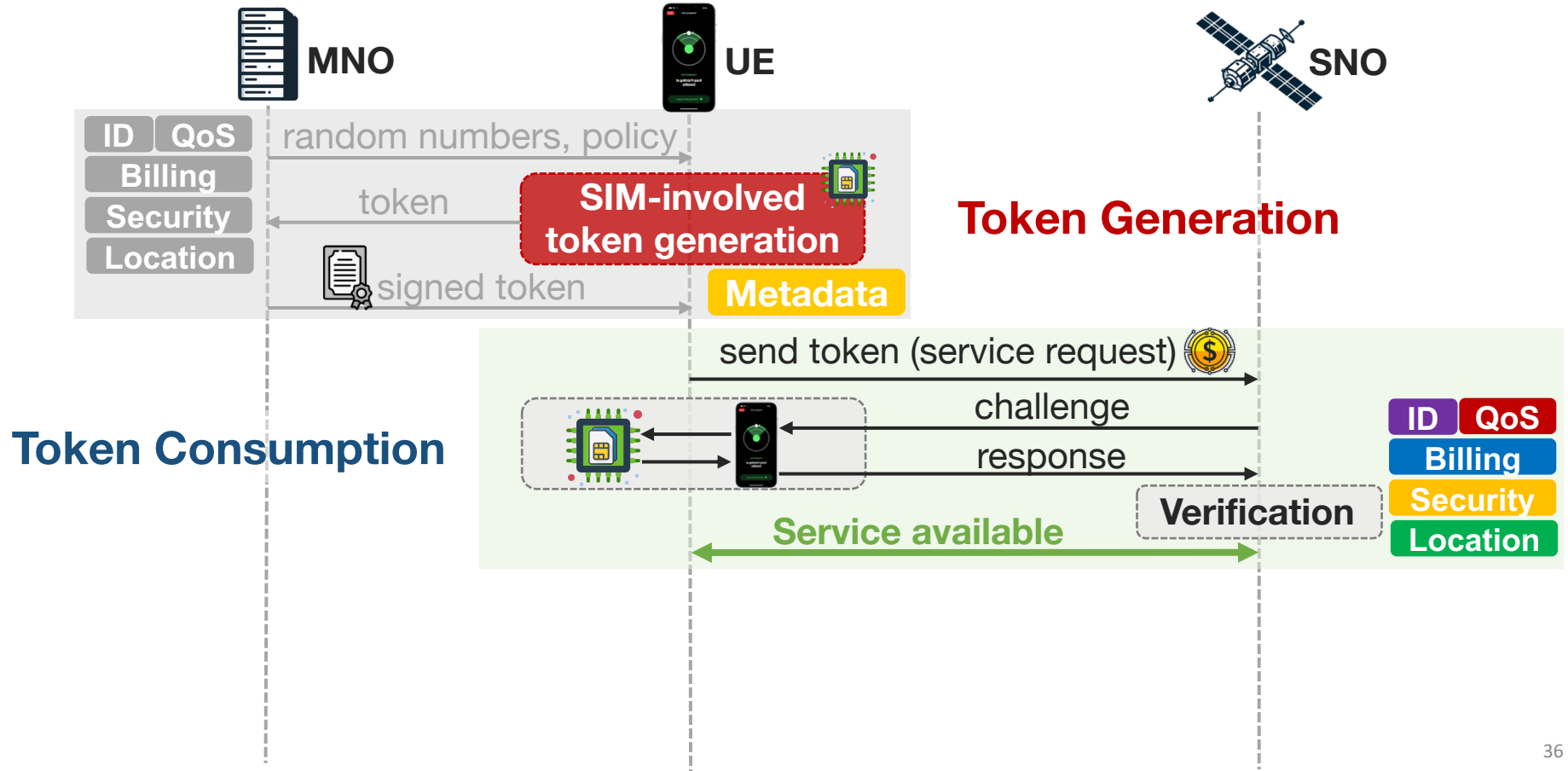
Key idea: SIM-enforced one-time token consumption



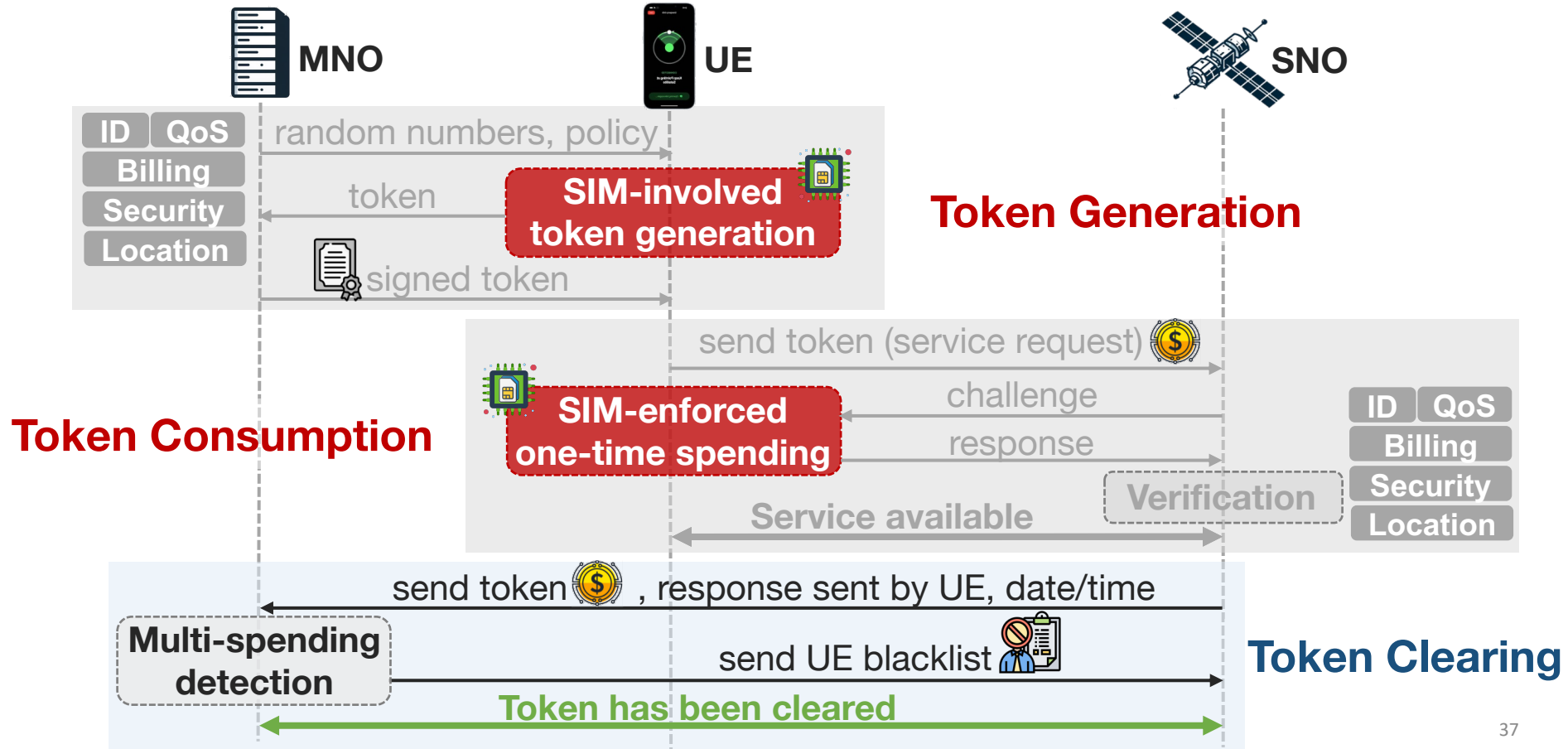
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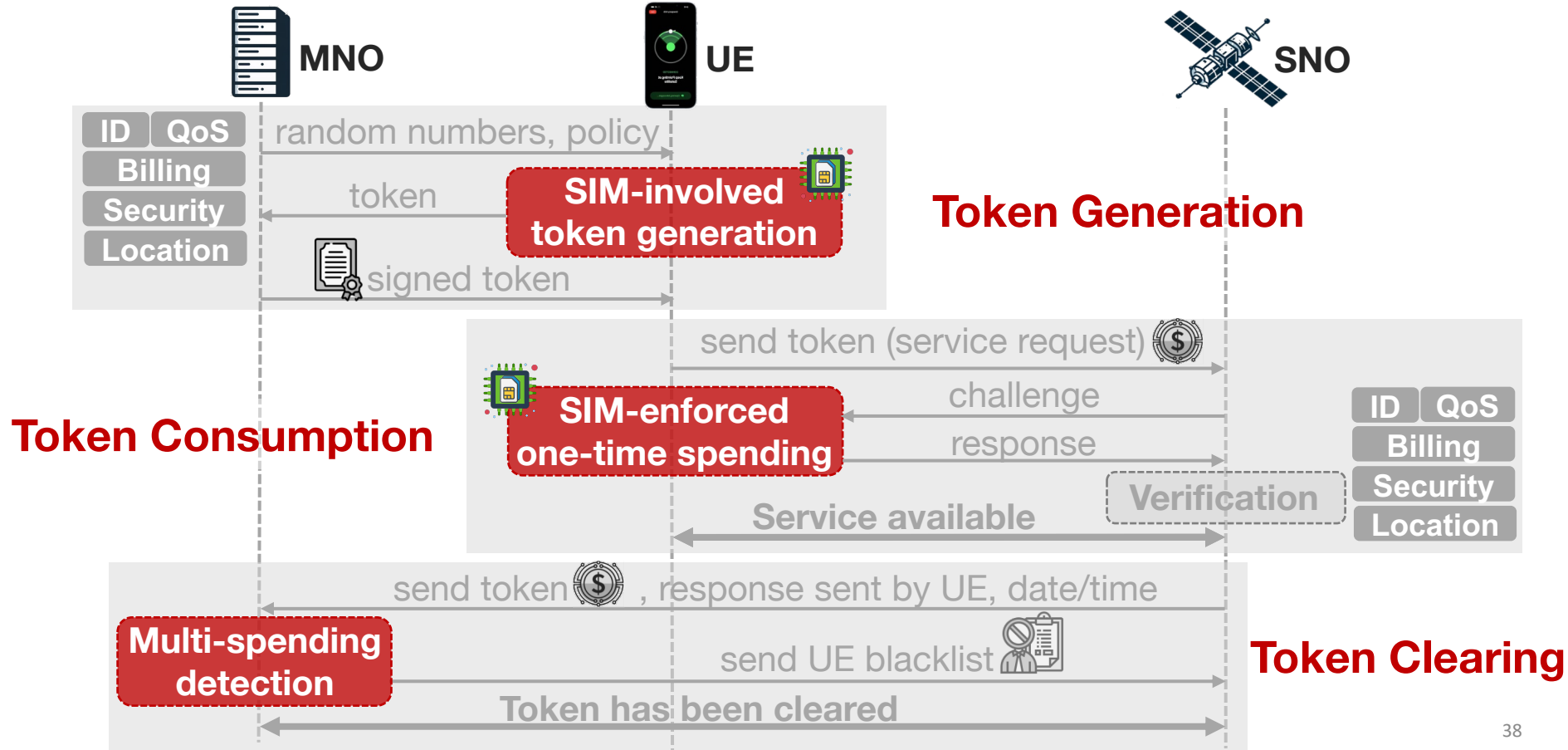
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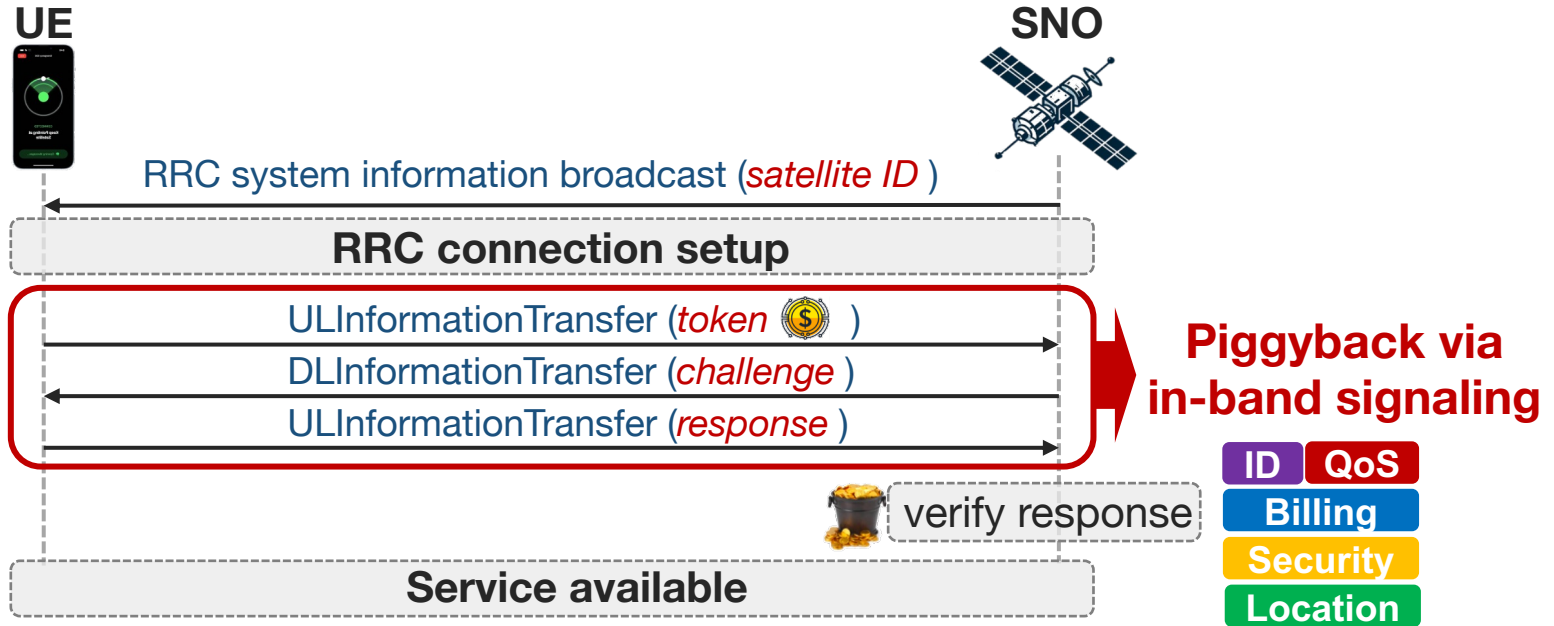
# ➤ How can MNOs Enable Pay-As-You-Go Token?



# ➤ How can UEs Access Satellite with Tokens?

Alleviate the dependency on MNOs

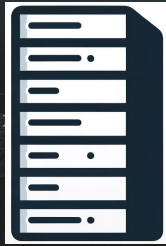
Minimize the amount of signaling



# ➤ Experimental Setup

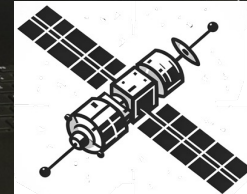
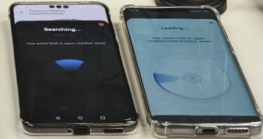
Commodity off-the-shelf 3GPP Non-Terrestrial Network (NTN) protocol stack (Amarisoft Callbox NR-4-U Ultimate)

Driven by **operational satellite datasets**



**MNO**

**UE**



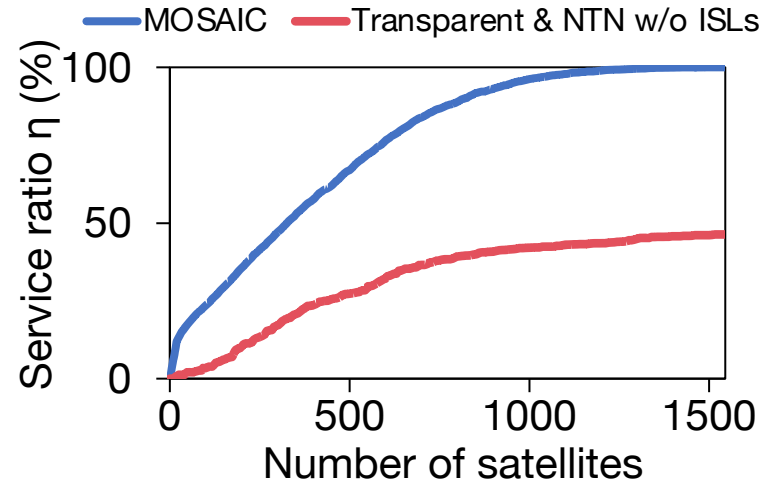
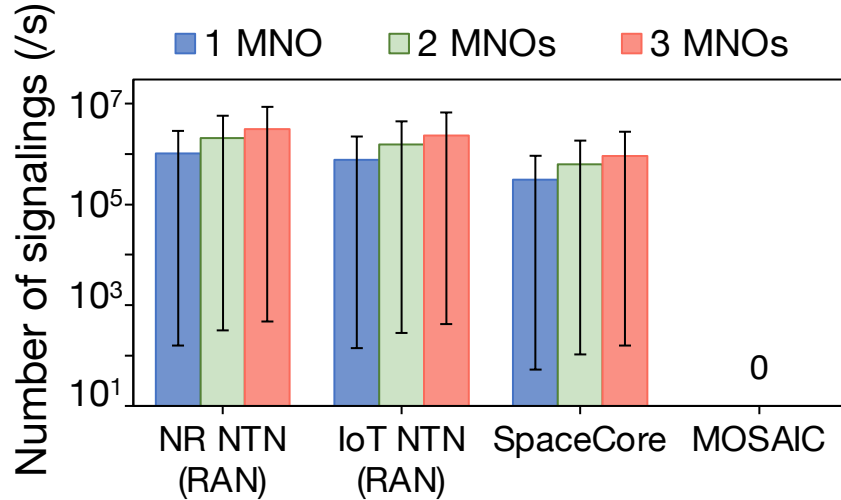
**SNO**



# ➤ Evaluation: Overall Benefits

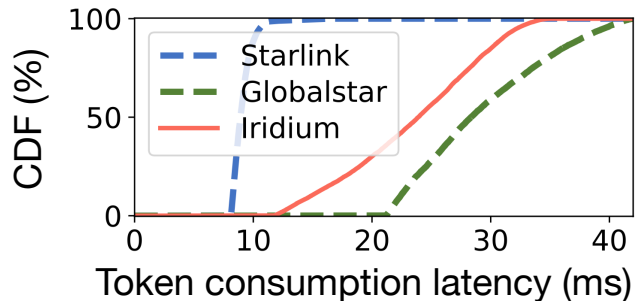
**SNOs:  
Signaling storm freedom**

**MNOs & UEs:  
100% serviceable area**

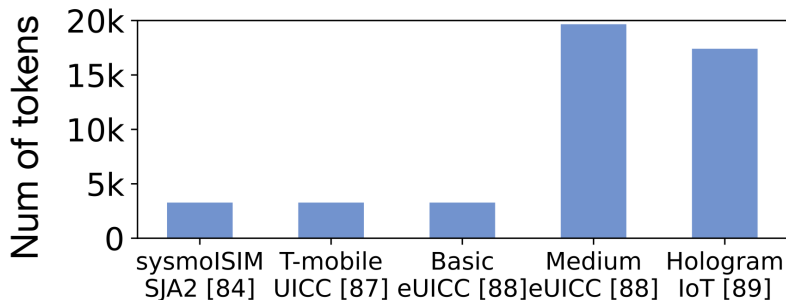


# ➤ Evaluation: Overhead

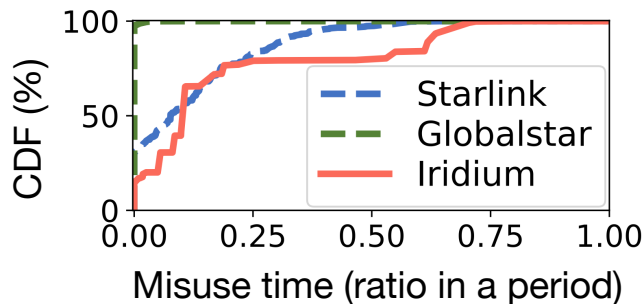
## Low token consumption latency



## 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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