Network Communication Between LEO Satellites

Utilizing existing mega constellation infrastructure for LEO satellite missions.

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Outline

Problem

Definition of the problem

- Multiple LEO missions have high latency sensitivity or high throughput requirements.
  - Weather missions
  - Emergency responder missions
  - Military mission
  - Hyperspectral imaging
  - 6G-gNB
- Traditional downlink methods have:
  - Low average throughput
  - High average latency

Average metrics are important for missions spanning the globe

Definition of the problem

Current solutions to the problem:

- Private groundstations
  - Price
  - Time to market
- Shared groundstations
  - KSAT, AWS, Azure
  - Limited resources
  - Still no full coverage

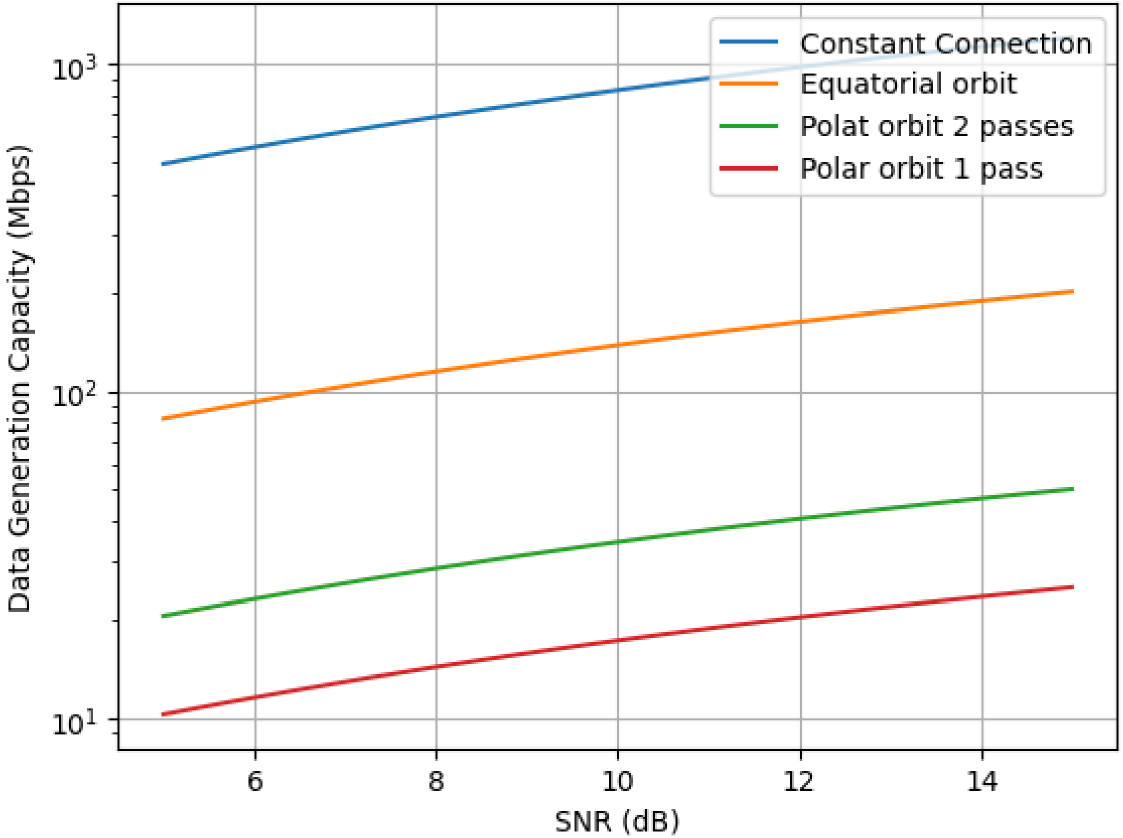


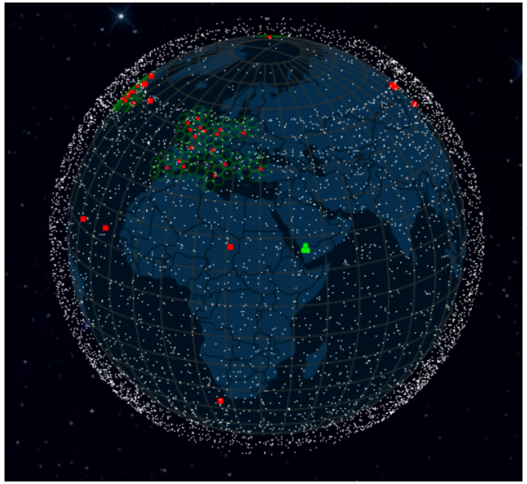
Figure 1: Downlink for smallsat, bandwidth 250 MHz

Proposed solution

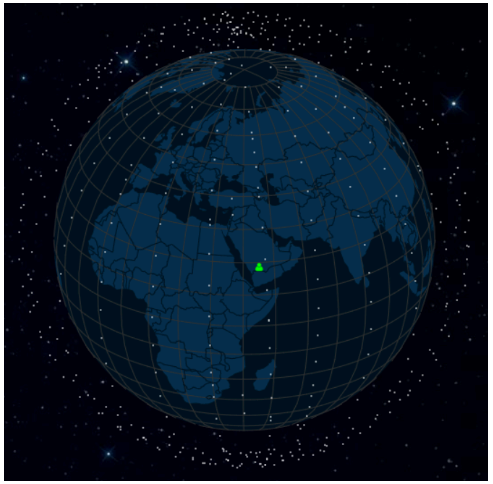
Utilizing existing infrastructure from mega constellations

- Starlink
- OneWeb
- Kuiper

Minimizing or eliminating the deadzones for the SUT satellite.



(a) Starlink Constellation [1]



(b) OneWeb constellation [1]

Focus of this thesis

An ISL selection algorithm for LEO satellite user terminals (SUT).

- For mega constellations assumed connected to the internet.
- Focus on selection of constellation satellites over link establishment.

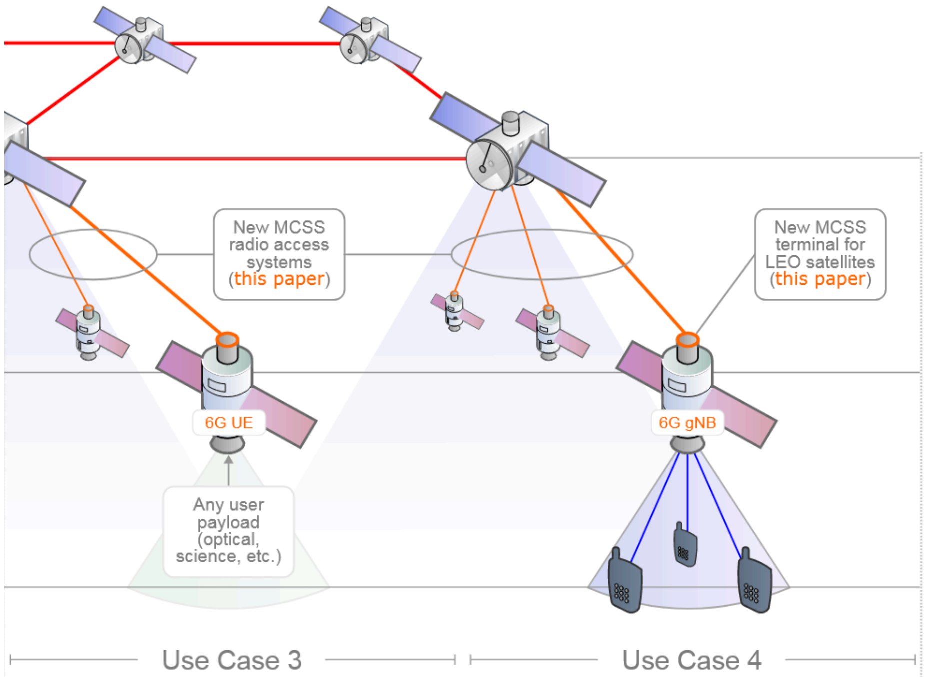


Figure 3: Use Case Examples from [2]

System model

Satellite models

- Radiation pattern
  - User Satellite
  - Network Satellite
- Channel parameters

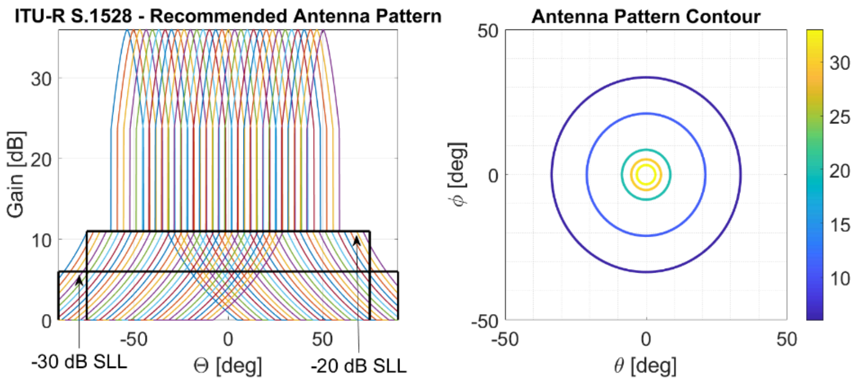


Figure 4: Radiation pattern example [2]

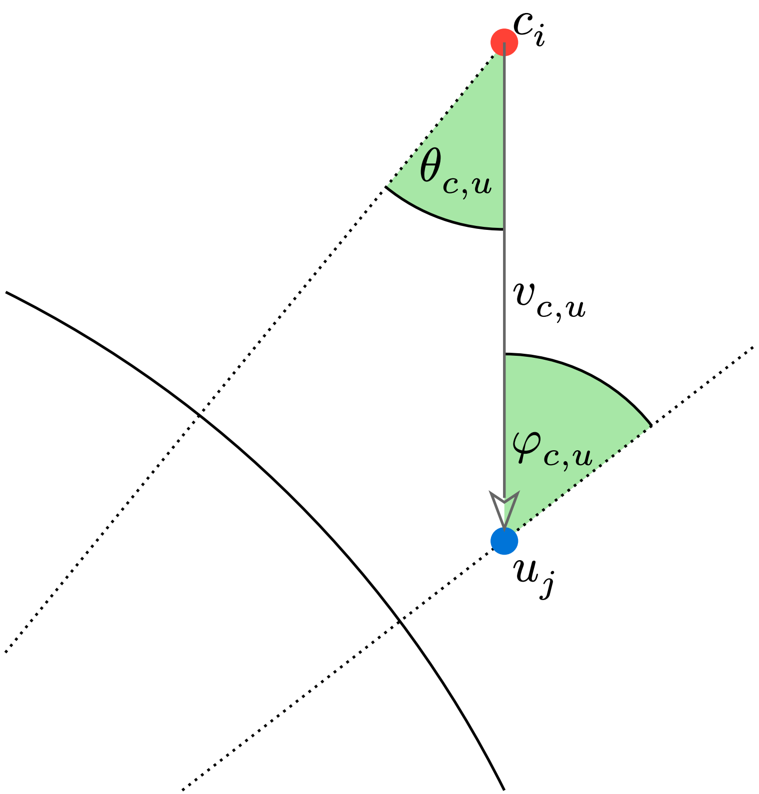


Figure 5: Angles between user u_j and network satellite c_i

Satellite models

- Starlink
  - Shorter connections
  - Higher throughput
- OneWeb
  - Longer connections
  - Lower throughput
- Tradeoff

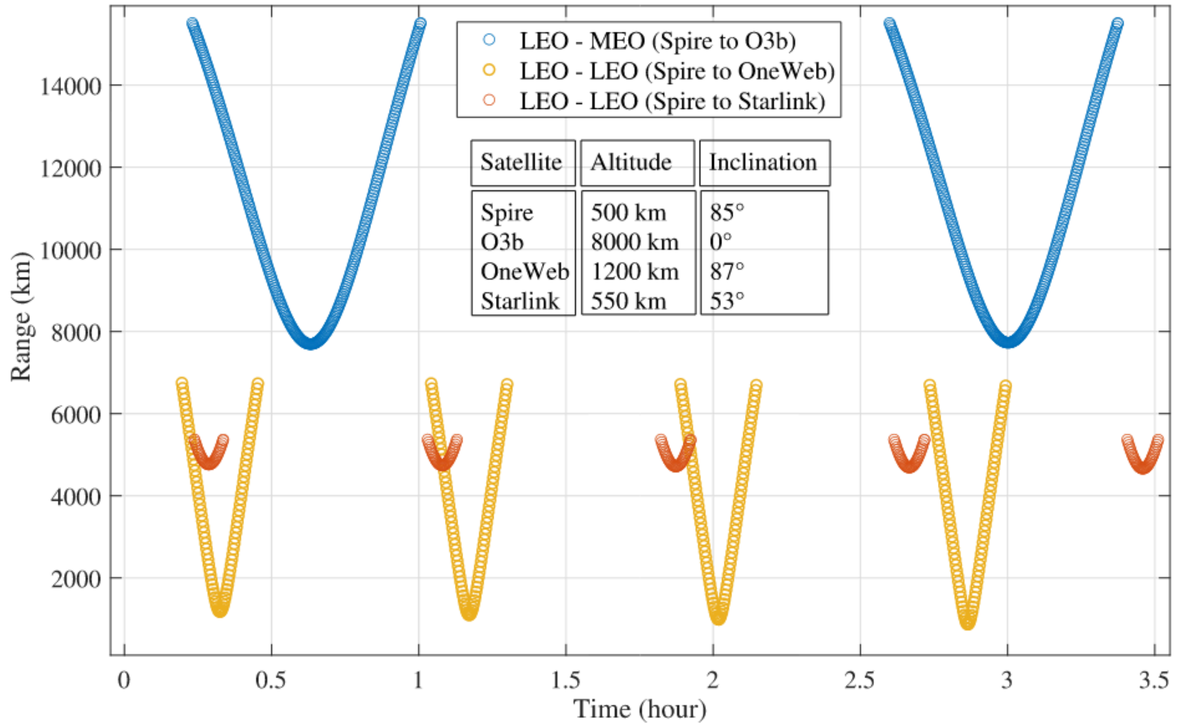


Figure 6: Visibility analysis of NS from SUT perspective [3]

Preliminary results

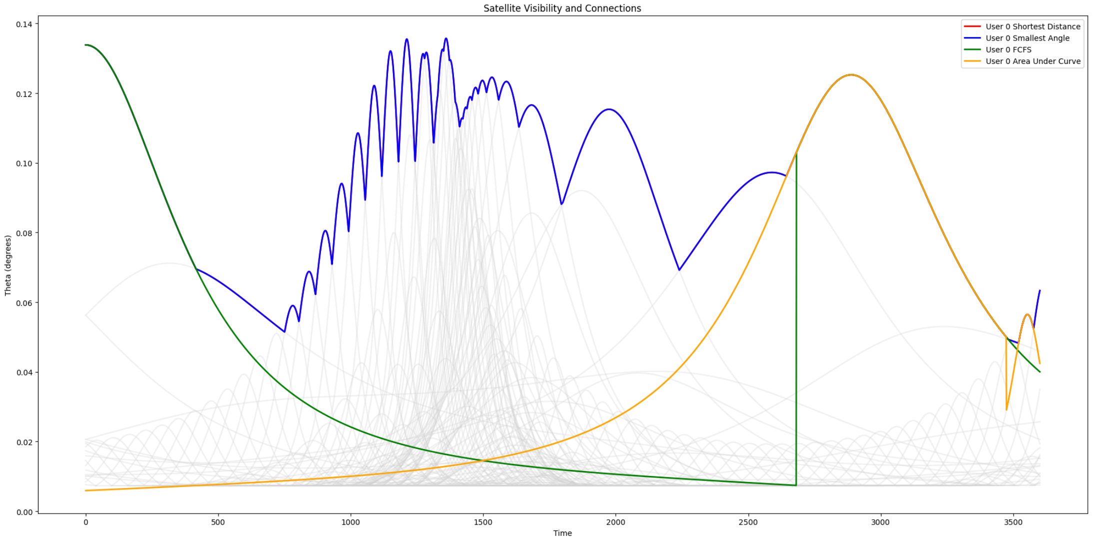
Initial Optimization

- Choosing the best link for each time slot
  - Greedy / Iterative algorithm
- Optimizing for throughput

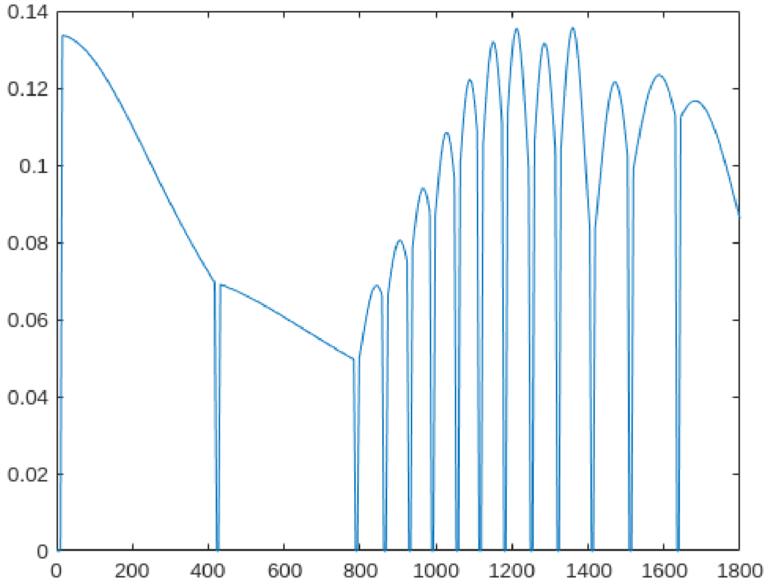
$$\begin{aligned} \underset{x}{\text{maximise}} \quad & f(x) = \frac{1}{T} \sum_{C} \sum_{U} \sum_{T} x_{c,u,t} R_{c,u,t} + \dots \\ \text{subject to} \quad & \sum_{C} x_{c,u,t} \leq 1 \qquad \forall u, t \\ & x_{c,u,t} \in \{0, 1\} \quad \forall c, u, t \end{aligned}$$

Results

OneWeb



(a) Solution using algorithms



(b) Solution using LP

Current / Future work

Discrete MODCODs

- Since the intersatellite links use MODCODs the achievable throughput is discrete

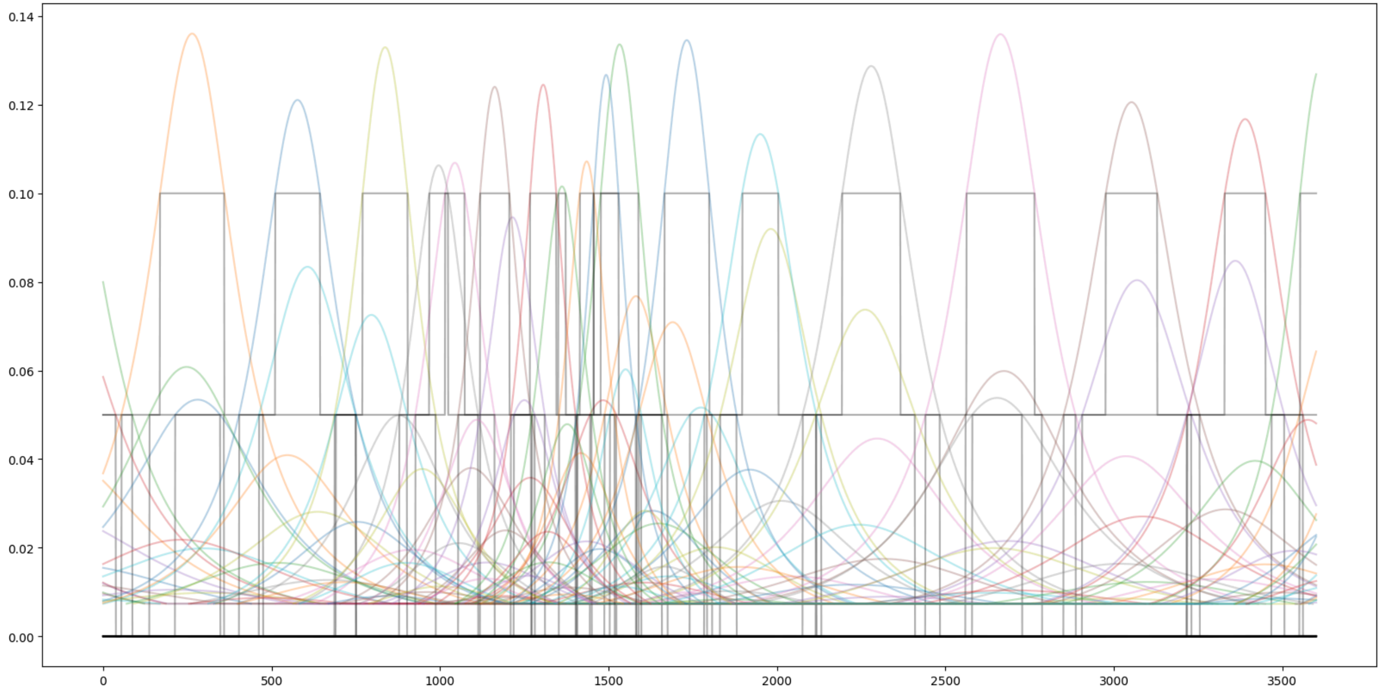


Figure 8: Example of applying modcods to the shannon capacity

Satellite utilization

- Utilization modeling
- Models based on earth cell not satellite
- Simple model (high / low utilization)
- queuing model (M/M/1)

- Satellite coordinates in ECI
- Cell coordinates in ECEF

Figure 9: Europe divided into cells [1]

Optimization reframing

- Utilization as a RV with known distribution.
- Introducing requirements
- Minimize chance of failure to meet requirements

QoS	Use Case
Low End	UE
Common Case	UE or gNB
High End	UE or gNB
High End+	gNB

Table 1: Use Case Examples from [2]

$$\underset{x}{\text{minimize}} \quad g_u(x) = \mathbb{P}\left(\frac{1}{T}\sum_{T} R_t(\alpha, c, u) \leq Q_u\right)$$

$R_t(\cdot)$	Rate function
α	Utilization of satellite
Q_u	Requested rate for SUT u

Implementation (hurdles)

- The optimization problem becomes a large very sparse problem to solve
  - Reduce the compute complexity by representing the problem in a sparse way
- Seperate the problem into a deterministic part (done on central server), and a stochastic part(done on the SUT)?

Bibliography

[1] "Starlink Satellite Tracker." Accessed: Jan. 24, 2025. [Online]. Available: https://satellitemap.space/

[2] G. M. Capez *et al.*, "On the Use of Mega Constellation Services in Space: Integrating LEO Platforms into 6G Non-Terrestrial Networks," *IEEE Journal on Selected Areas in Communications*, p. 1, 2024, doi: 10.1109/JSAC.2024.3459078.

[3] H. Al-Hraishawi, M. Minardi, H. Chougrani, O. Kodheli, J. F. M. Montoya, and S. Chatzinotas, "Multi-Layer Space Information Networks: Access Design and Softwarization," *IEEE Access*, vol. 9, pp. 158587–158598, 2021, doi: 10.1109/ACCESS.2021.3131030.