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A survey of LEO simulators and routing topologies

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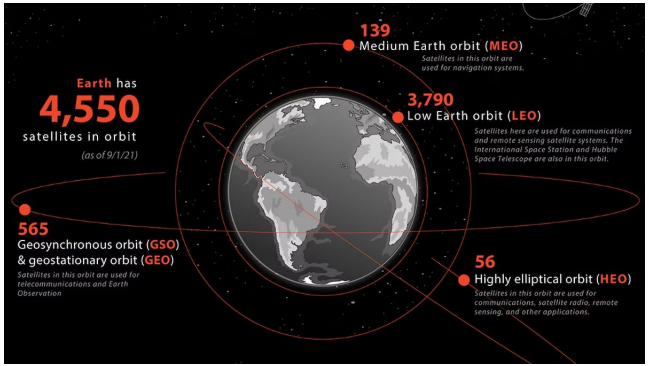
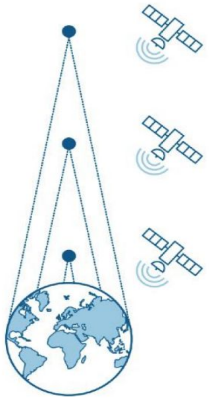
Objective

- How Simulator/Emulator development interact with the study of LEO

Overview

- Low Earth Orbit(LEO) satellites orbit between 2,000 and 160 kilometers above the earth. LEO satellites are commonly used for communications, military reconnaissance, spying and other imaging applications.
- LEO satellites move at approximately 7,500 m/s and are within the operational range of terrestrial ground stations for only minutes at a time





GEO satellites at altitudes of 35,786 km
Full orbital period of 24 hours
Latency (round trip) of approximately 477 ms

MEO satellites at altitudes of 2,000–35,786 km
Full orbital period of 127 minutes to 24 hours
Latency (round trip) of approximately 27–477 ms

LEO satellites at altitudes of 160–2,000 km
Full orbital period of 88–127 min
Latency (round trip) of approximately 2–27 ms

Motivation

- The consistent connection of satellites presents challenges due to their high mobility.
  - Satellite to Satellite, and Satellite to ground station
- And LEO satellites are not reachable for us, How can we emulate the communication traffic?
  - Simulator and Emulator can Helps

Technical Approach

1. Past Research on Routing Topology and Their requirements for simulators
2. Current Simulators and Their Pro/Cons
3. StarryNet Simulation

Routing: Use Case Study

Case 1 : Giuliari, Giacomo, et al. "Internet backbones in space." ACM SIGCOMM Computer Communication Review 50.1 (2020): 25-37.

- Custom simulator that simulates satellite orbits, and the resulting connectivity and latency
- The constellation considered in our simulation is SpaceX Starlink

Pros:

- Take dynamic connectivity and rain fade into account
- Flexibility as deploy 4 different routing methods (Customization)

Cons:

- Limited Scale, as only 10% of deployment of Starlink simulated
- High Level abstraction
- Limited Network Aspects

Routing: Use Case Study

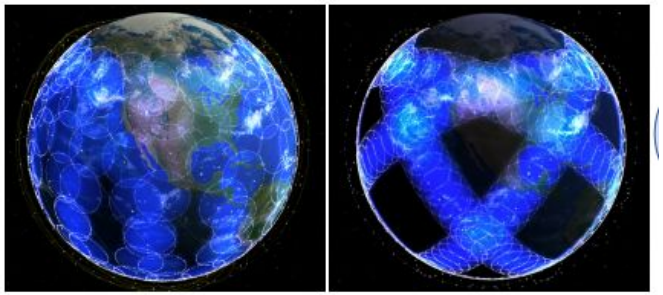
Case 2 : Handley, Mark. "Using ground relays for low-latency wide-area routing in megaconstellations." Proceedings of the 18th ACM Workshop on Hot Topics in Networks. 2019.

Pros:

- Customization (can adjust to different # of planes and # of satellites in each plane)
- Realistic (Simulated SpaceX Starlink phase 1 - 1600 Satellites) in a range of possible configurations
- Dynamic connectivity (Up to 4hrs)

Cons:

- Hardware complexity due to large # of satellites, ISl and ground station
- Missing precision due to the computational Intensity



11s*24p 66 s*6p

Topology

1. With more inter-satellite links (ISLs)

D. Bhattacherjee and A. Singla. *Network topology design at 27,000 km/hour*.

Pros:

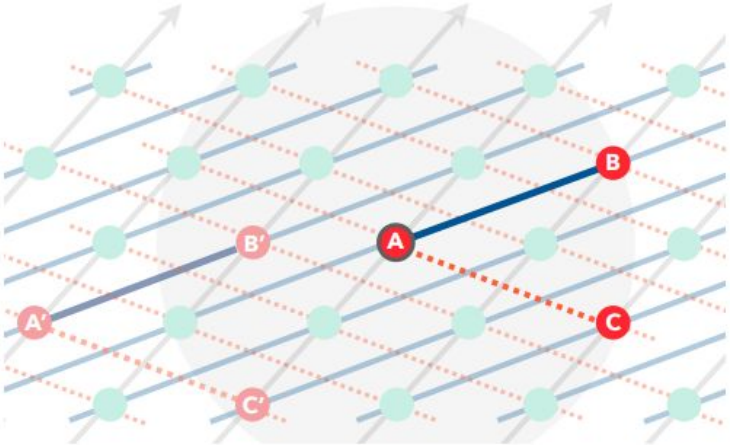
Connect to further satellites to reduce handoff overhead

Higher overall throughput and less overall latency

Cons:

Higher cost

Much more routing overhead



Simulator

Uses close source emulator

Can implement self-defined node connection

Limitation:

1. Limited scalability: “Even for just 25 cities, the ILP does not finish within 2 days on a machine with 64 cores and ~500 GB of memory”
2. Temporal variability

2. With less ISLs

Y. Hauri, D. Bhattacherjee, M. Grossmann, and A. Singla. *"Internet from Space" without Inter-Satellite Links*.

Pros:

Lower cost

Less calculation overhead

Cons:

More fluctuation

More vulnerable to weather

Simulator

Uses IPU-Rpy

Can simulate atmospheric conditions

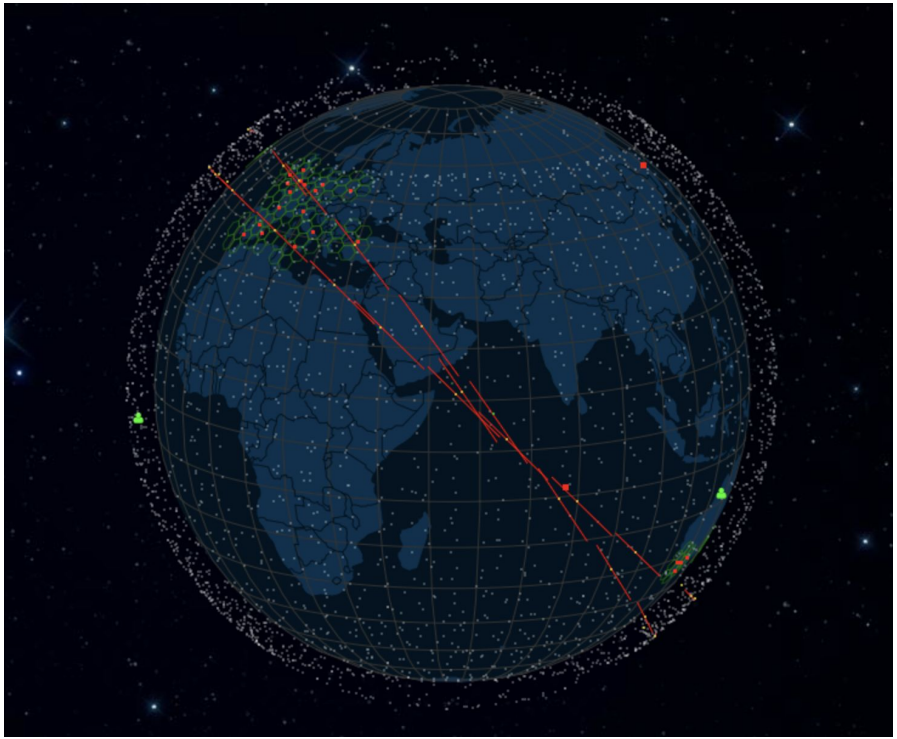
Customizable topology

Limitation:

Limited factors other than atmospheric attenuation

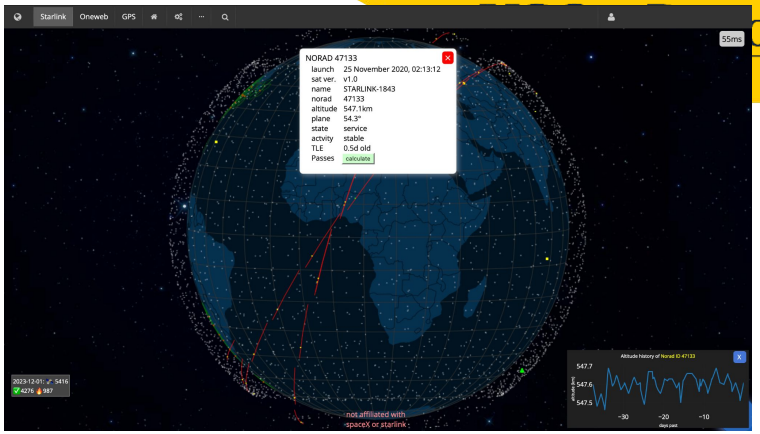
Modern Satellite tools

- Live LSN: Live starlink, Planet Lab, Emulab
- Analysis tools & Simulators: STK, GMAT, Hypatia, Starperf
- Emulators: Mininet Hi-Fi, Diecast, Etalon



Live LSN (Live Starlink)

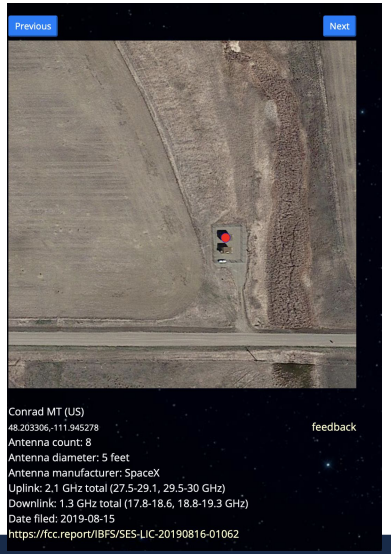
- Pros:
  - live and real informations from live broadcasting.
  - Quick check with satellite info.
  - Trackable star link time, tech specs.
  - Can specify locations, orbits, versions, etc
- Cons:
  - Hard to apply new topologies onto it.
  - Limited info to download.



STARLINK-1843

Local Time	Light	Bearing	Dur.
12/1/2023, 9:45:59 PM	night	9→101	3 mins
12/2/2023, 11:27:29 AM	night	215→36	5 mins
12/2/2023, 9:39:09 PM	night	345→123	4 mins
12/3/2023, 11:21:19 AM	night	236→18	4 mins
12/3/2023, 9:32:29 PM	day	324→143	5 mins
12/4/2023, 11:15:19 AM	night	257→357	3 mins

projected passes



Simulator (Starperf)

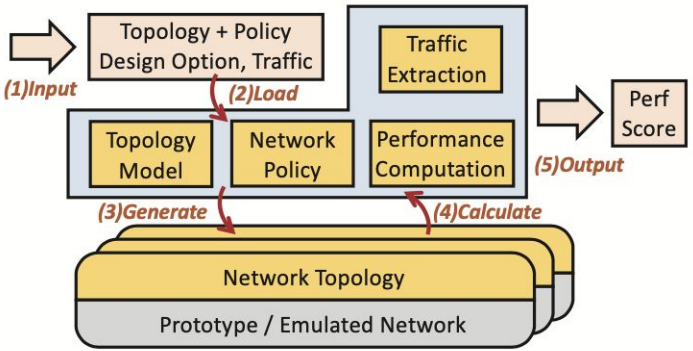
Decision	Options and range of values
Inclination	inclination of orbit i (Inc_i)
Altitude	altitude of orbit i (Alt_i)
Phase shift	phase shift of orbit i (Pha_i)
# of orbit	total number of orbits (Num_{orb})
# of satellite	number of satellites in ith orbit ($SatN_i$)
# of GS	total number of ground stations
Location of GS	location distribution of GS
Link band	band range: S/X/Ku/Ka/optical
Link type	type range: bent-pipe, circuit- or packet-switched

Pros:

- Allow customize topology
- Two different routing options:
  - distributed routing strategies (OSPF,GPSR)
  - centralized routing strategies (DSR)
- Modeled result: coverage rate, latency, throughput

Cons:

- Simulator based on public data released by satellite operators
- Only abstraction level simulator, can't apply to interactive network systems.



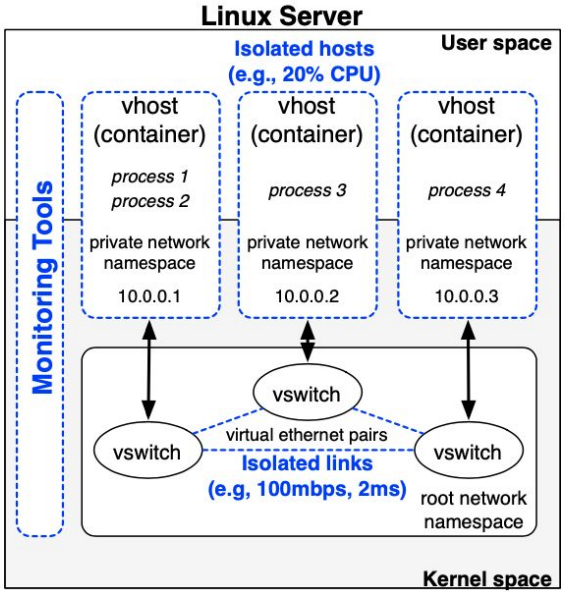
Emulator (Mininet Hi-Fi)

Pros:

- Combination of the live LSN and simulator
- Performance isolation
  - **Control Groups:** allow a group of processes to be treated as a single entity for scheduling and resource management
  - **CPU Bandwidth Limits** enforce a maximum time quota for a cgroup within a given period of time. CPU time is fairly shared among all cgroups.
  - **Traffic Control**: using tc configures link properties such as bandwidth, delay, and packet loss.

Cons:

- Require kernel-level coding, hard to use.
- Large scenario still requires very long time to emulate. (e.g Emulab, 250 nodes, 10 physical machine, 48 hours)



Future Development Overview - StarryNet

- Pros:
  - Scalability
  - Various interfaces
  - Realism
  - Low-cost
  - Easy to use
- Cons:
  - Resource management (performance)

+grid topology

starlink_2-10-10-550-53-grid-LeastDelay > 1.txt

```
0.00,22.42,0.00,0.00,0.00,0.00,0.00,0.00,0.00,22.37,
22.42,0.00,22.44,0.00,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,22.44,0.00,22.36,0.00,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,22.36,0.00,22.25,0.00,0.00,0.00,0.00,0.00,
0.00,0.00,0.00,22.25,0.00,22.25,0.00,0.00,0.00,0.00,
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22.37,0.00,0.00,0.00,0.00,0.00,0.00,0.00,22.40,0.00,
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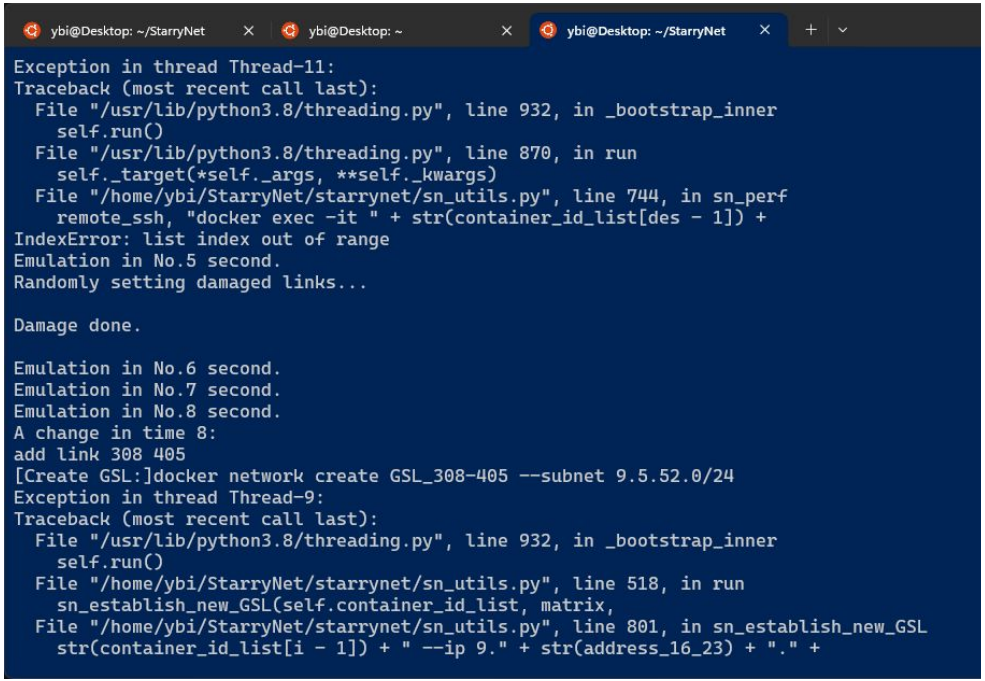
Limitation

1. Functions to be implemented
2. Performance optimization
3. Data collection
4. Datasource



Run-time

5*5 Satellite, 2 ground station: 10s second

10*10 Satellite, 10 ground Station: 1-2 minutes

20*20 Satellite, 10 ground station: 10s minutes

50*50 Satellite, 10 ground station: ~1 hour

70*70 Satellite, 100 ground Station: Not enough memory

70*70 Satellite, 2 ground station: Not enough memory

Conclusion

- Run on interactive network system
- Topology and routing customization
- Simulation Performance
- Environment parameters

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Thank you!