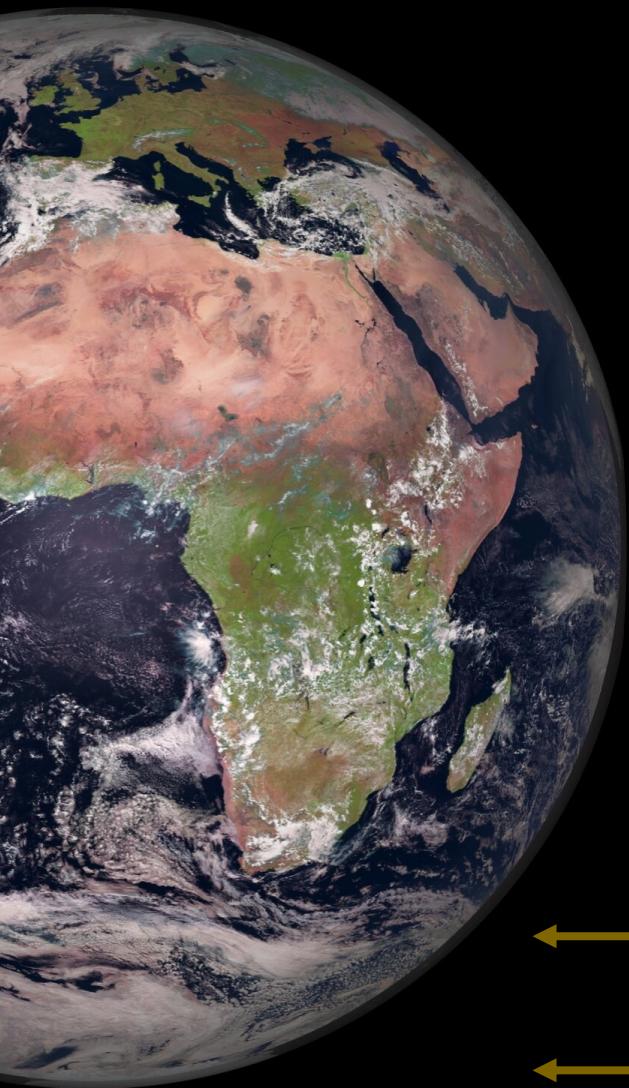


# Large-Scale Realistic LEO Networks Emulation

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# Internet from Space

2018



LEO Satellites



MEO Satellites



GEO Satellites

From 1963

500 – 2000 KM

2000 – 10000 KM

36000 KM

# Mega Constellation Era



Lower  
Launching Cost



Race to send  
10,000s LEO  
satellites



Low-latency,  
high bandwidth  
+ Earth  
Observation

# How LEO Mega-constellations are different



01

**Latency:** High latencies are not the issue, however the abrupt change of the latency

02

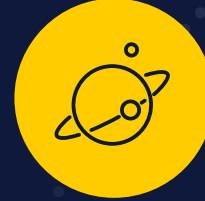
- **Terminal - Satellites Handover:** which satellite to connect to

03

- **Routing:** Fast moving satellites and routing tables

# Why we need Emulator

Design and Implement  
new protocols



Plan  
new constellations



Large scale  
performance  
measurements



Future  
Scenarios  
(e.g., ISL)



# Why we need Emulator

01

Scalability

02

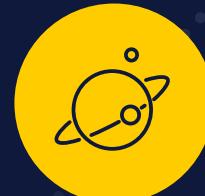
Realistic

Design and Implement  
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Plan  
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Large scale  
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UNIVERSE

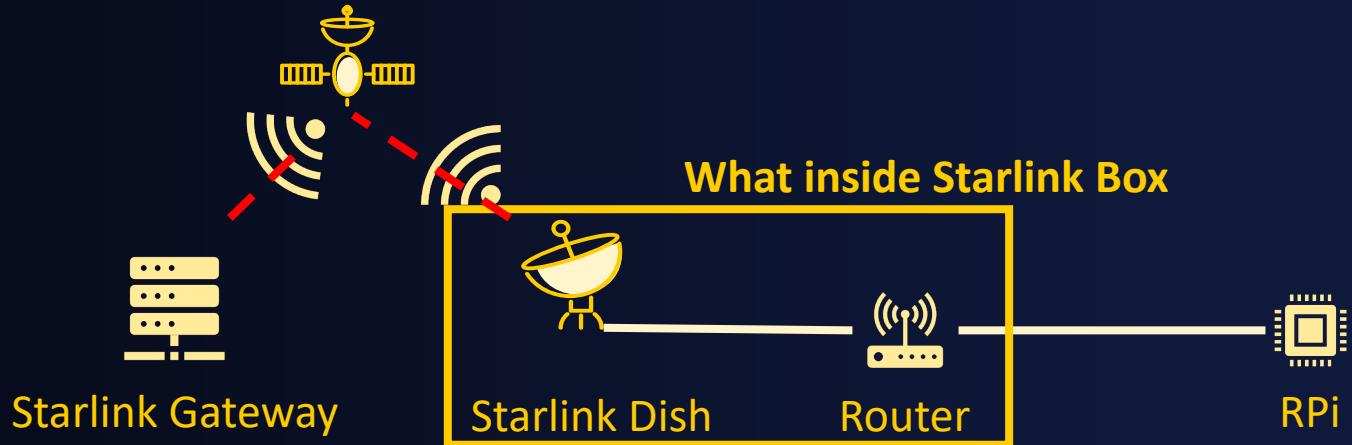
	Simulators	Measurement Platform	Hardware in the Loop	Emulation
Transport Layer development on LEO	✓	✓	✗	✓
Arbitrary or Planned Constellation	✓	✗	✗	✓
Scalability	✗	✗	✗	✓
Real network deployment	✗	✓	✓	✗
High fidelity (on L1, L2)	✗	✗	✓	✗
Realism	✗	✓	✗	✓

# Measurement Platform

## Volunteer measurement nodes

01

- Bent Pipe Architecture
- Active measurements on RPi



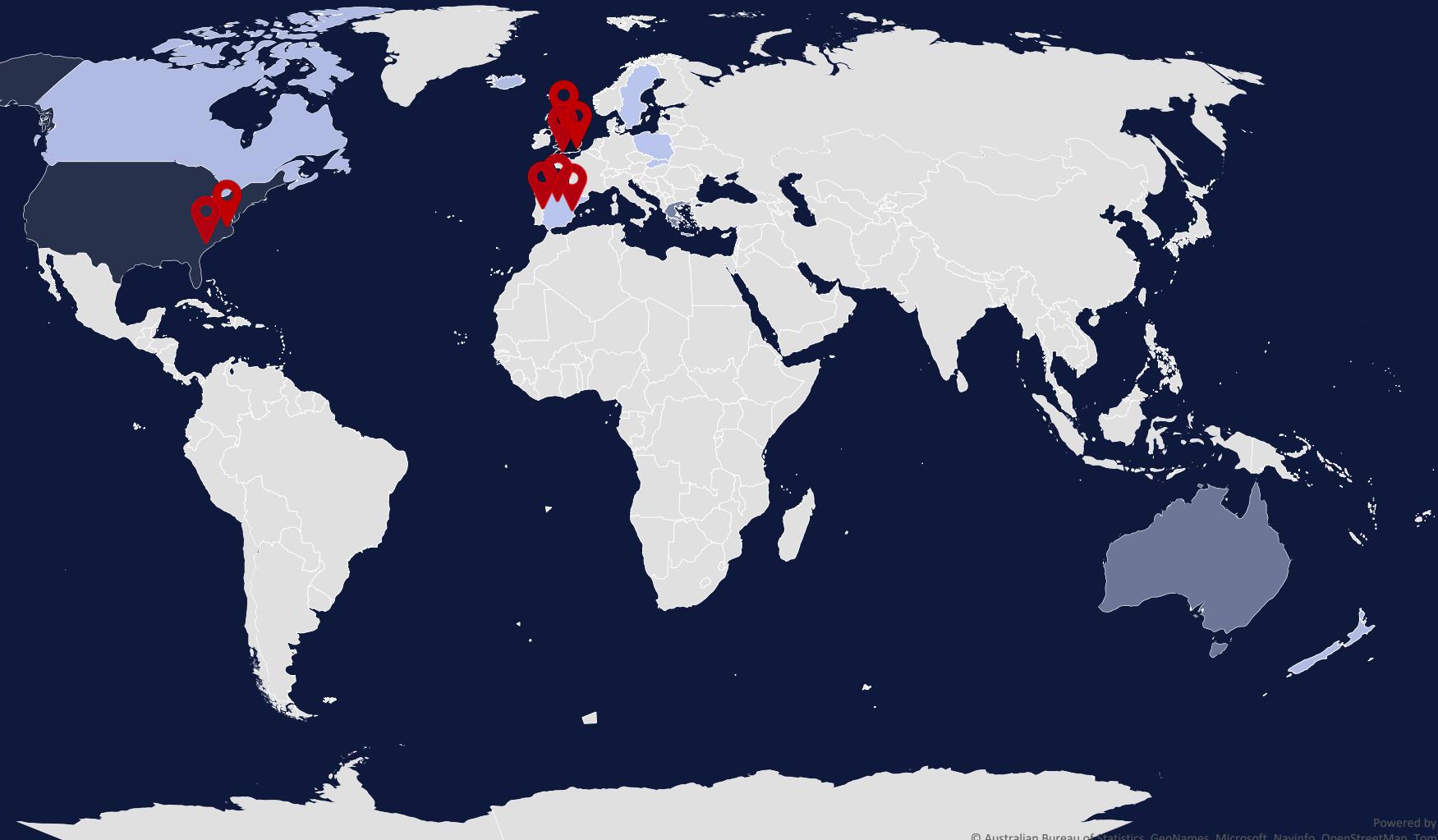
## Weather conditions

02

- OpenWeatherMap API
- Fixed weather stations

# The Dataset – Users' Distribution

- **8 Volunteers**
- 5 cities, 2 Continents
- Throughput
- Latency
- Losses
- Dish contextual data



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# Hardware-in-the-loop

Software Defined Radio  
(SDR), e.g., USRP

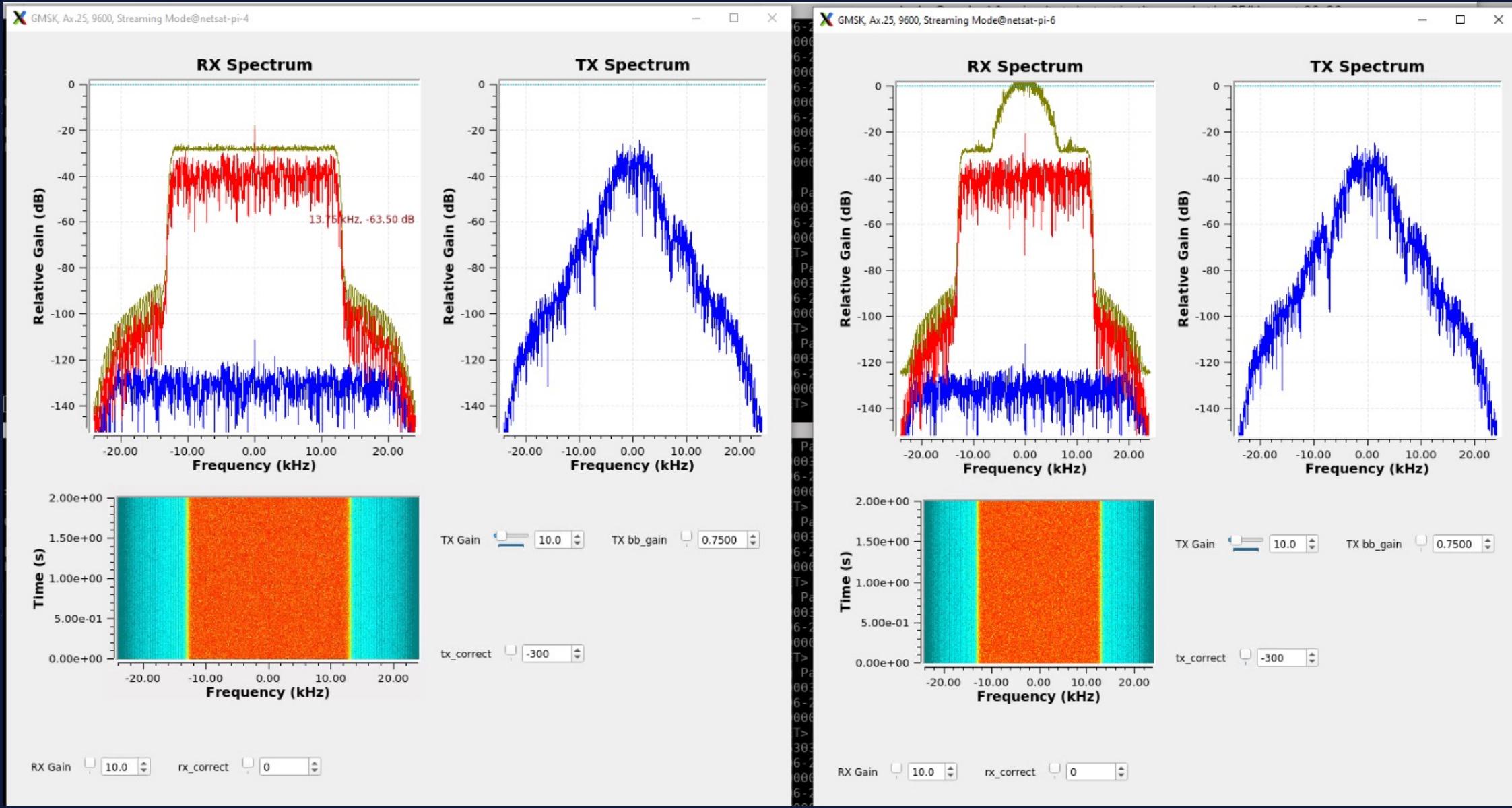
Single-Board  
Computers, e.g., RPi  
Ground Station 1



Channel Attenuator

Software Defined Radio  
(SDR), e.g., USRP

Single-Board  
Computers, e.g., RPi  
Satellite A



## SpaceNet Testbed

### Simulators      Measurement Platform      Hardware in the Loop

	Simulators	Measurement Platform	Hardware in the Loop
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### Emulation



# Emulation

Traffic generation

Constellation and Emulation Configuration

Link  
Characteristics

Routing

Mobility  
Management

Mininet

```

1 constellation:
2   operator: starlink
3   number_of_shells: 1
4   shell1:
5     name: shell1
6     orbits: 72
7     sat_per_orbit: 22
8     altitude: 550
9     elevation_angle: 25
10    inclination: 53
11
12 topology:
13   association_criteria_GSL: BASED_ON_DISTANCE_ONLY_MININET
14   ISL: grid
15
16 routing:
17   algorithm: static_latency
18   ip_range: 12.0.0.0
19   interDomain_routing: 1
20   border_gateway: gs0
21   other_constellation_ip_range: 11.0.0.0
22
23 ground_stations:
24   gs_file: ../mobility/ground_stations_small.txt
25
26 simulation:
27   start_time: 2022,10,13,1,1,13
28   length: 10
29   step: 1
30   debug: 1
31
32 application:
33   type: iperf
34   source: gs0
35   destination: gs22
36   duration: 30
37   congestion_control: cubic
38   background_traffic: no
39   tcpdump: no
40
41 data_n_results:
42   connectivity_matrix: ../utils/connectivity_matrix/starlink/
43   routing: ../utils/routing/starlink/
44   simulation_results: ../results

```

## Constellation and Emulation Configuration

- Constellation operator (use that to get the TLE files)
- Number of shells
- Shell parameters
- Topology:
  - GSL Handover strategy
  - ISL or bent pipe
- Routing
- Cross-constellation routing
- IP addresses
- Ground station data (coordinates, elevation)
- Simulation start time
- Duration
- Resolution
- Application type (e.g., iperf, ping, etc)
- Source and destination
- Duration
- Congestion control
- Output
- Output files and routing data



# Emulation

Traffic generation

Constellation and Emulation Configuration

Link  
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## Link Characteristics

- Latency
- Capacity
- Link Budget (based on RF parameters from FCC filings)
- Signal-to-Noise Ratio (SNR)
- Cell density
- Weather effect (ITU models)
- Real-world weather data



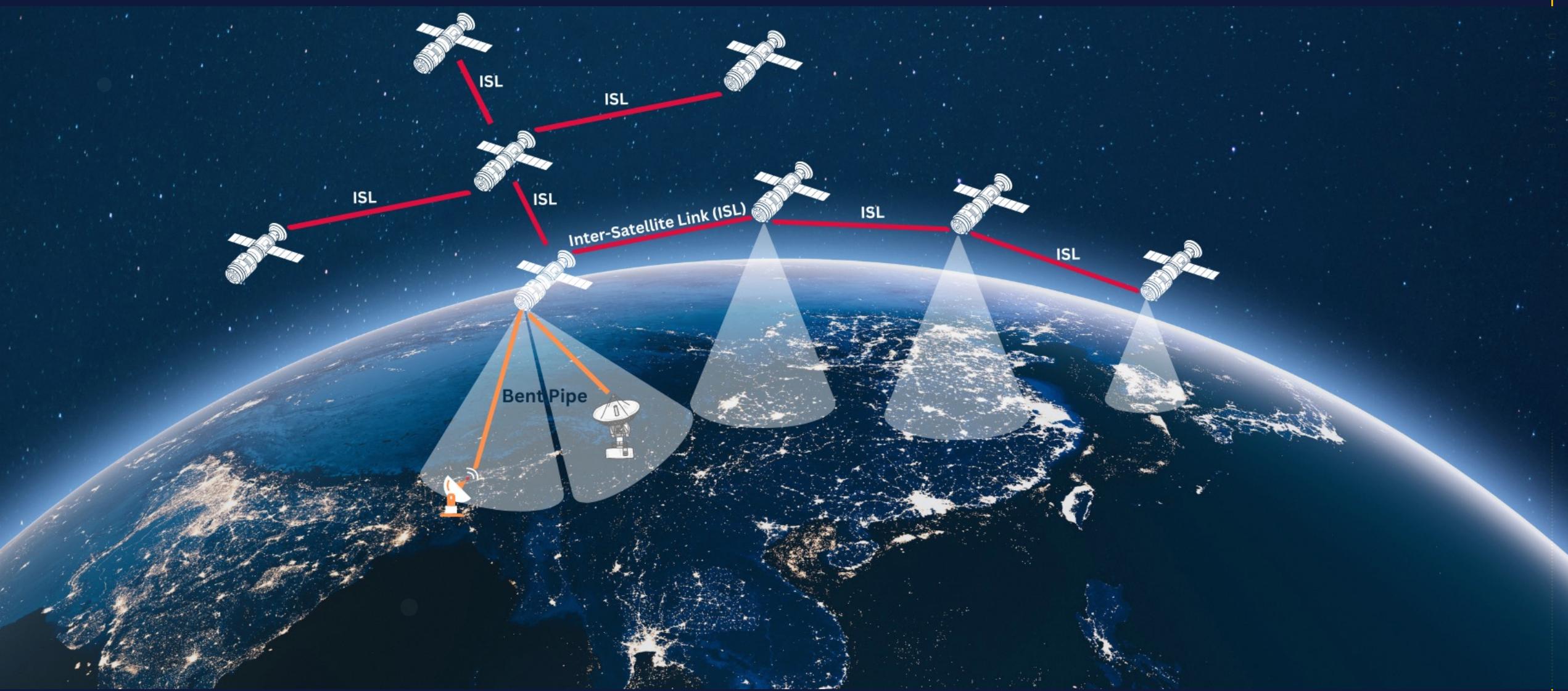
## Routing

- Pre-compute routes
- Static routing based on:
  - Latency
  - Capacity
  - Hop count
- Inter-domain routing (cross-constellations)
  - Through gateways
  - Some gateways of different constellations are connected
  - Through satellites?
- Dynamic routing can be integrated
  - BGP
  - OSPF



## Mobility Management

- Use TLE files to compute the future satellites' locations
- Resolution can be as minimum as 1 ms
- Rebuild the topology ("connectivity matrix")
- Topology
  - Bent pipe
  - Inter – Satellite Links (ISLs) – Grid





## Mobility Management

- Use TLE files to compute the future satellites' locations
- Resolution can be as minimum as 1 ms
- Rebuild the topology ("connectivity matrix")
- Topology
  - Bent pipe
  - Inter – Satellite Links (ISLs) – Grid
- Handover strategy for Ground-Stations Satellite Links (GSLs):
  - Shortest distance
  - SNR-based
  - Longest attachment



# Mininet

- Setup the nodes in Mininet (i.e., satellites and ground stations)
- Build the topology and the ISLs, GSLs between Mininet nodes
- Configure the interfaces through tc (netem) in Mininet with capacity and latency
- Run the application (e.g., iperf, ping)
- Update loop that reconfigure the changes according to the mobility of the satellites



# THANK YOU