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Simulating Large Constellations of Satellite Networks

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Introduction

- Currently 1613 Low-Earth Orbit (LEO) satellites orbiting the earth which are all part of SpaceX's vast plan for global high-speed internet access.

- Features Include:
  - Interconnected dynamic mesh of thousands of satellites
  - Substantial Latency reductions in comparison to the best fibre available today
  - Aggregate capacity expected to reach multiple Tbps
  - Average Round-Trip-Time (RTT) in a sub-10ms range between a the first satellite and Earth.

SpaceX Current Authorization					
Orbital Planes	72	72	36	6	4
Satellites per plane	22	22	20	58	43
Altitude	550 km	540 km	570 km	560 km	560 km
Inclination	53°	53.2°	70°	97.6°	97.6°

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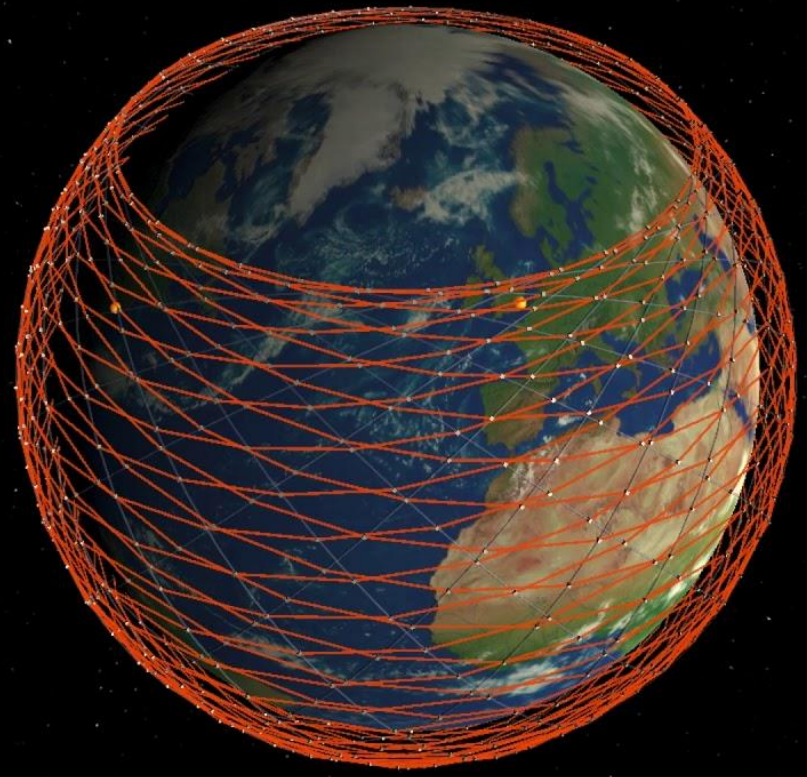
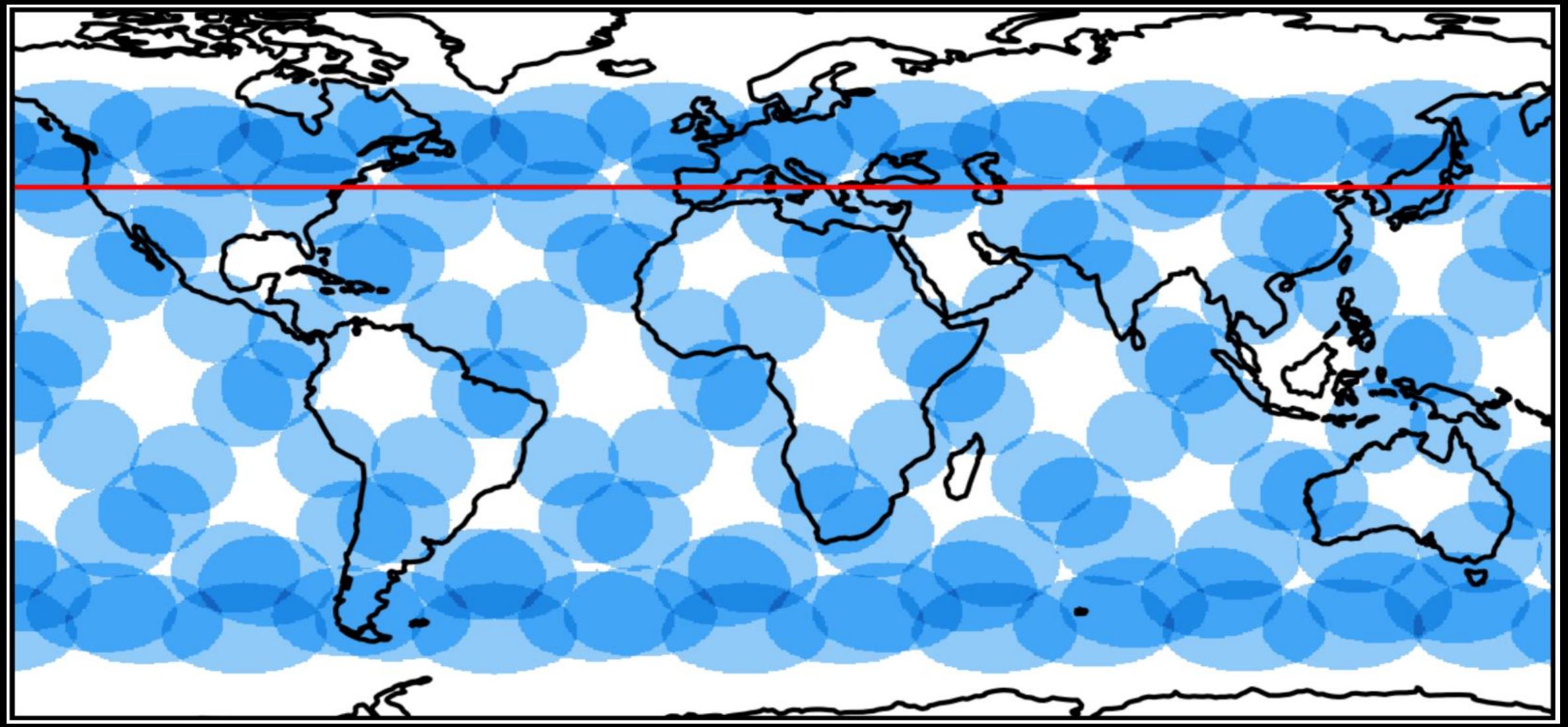
- Inter-Satellite Links
  - Four Links per Satellite
  - Free Space Lasers limited by the speed of light in a vacuum (47% higher speeds than in fibre!)

- Phased-Array Beams
  - Ground-Satellite Connections
  - Slight path loss due to the Earth's atmosphere but this is negligible (0.03% slower)





Existing Research

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- Mark Handley - Low Latency Routing in Space
  - 2018 and 2019 Evaluation of Starlink. A custom simulation model was tested, where Dijkstra's Shortest Path Algorithm, with link latencies as metrics, to find the lowest latency paths.
- Klenze et al. - Networking in Heaven as on Earth
  - Similarly built a simulation framework for satellite networks and evaluated 10 percent of Starlink's 2018 first phase.
- Bhattacherjee et al. - Gearing up for the 21st century space race
  - Built a simple simulation framework to evaluate polar orbit LEO satellite constellations.

Objectives of this Project

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- Develop a Low Earth Orbit satellite constellation simulation model in OMNeT++/INET.

- Evaluate the round-trip times (RTT) between ground-stations using the simulation model and reproduce results reported in the existing research.

The Open-Source Satellite Simulator (OS³)

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- OMNeT++ framework that provides satellite mobility models (no communication modelling).
- Uses the 2015 versions of OMNeT++ (4.6) and INET (2.5)
- Takes in existing satellite data (TLE data sets) and propagates the orbit using an orbital model.

Implementation

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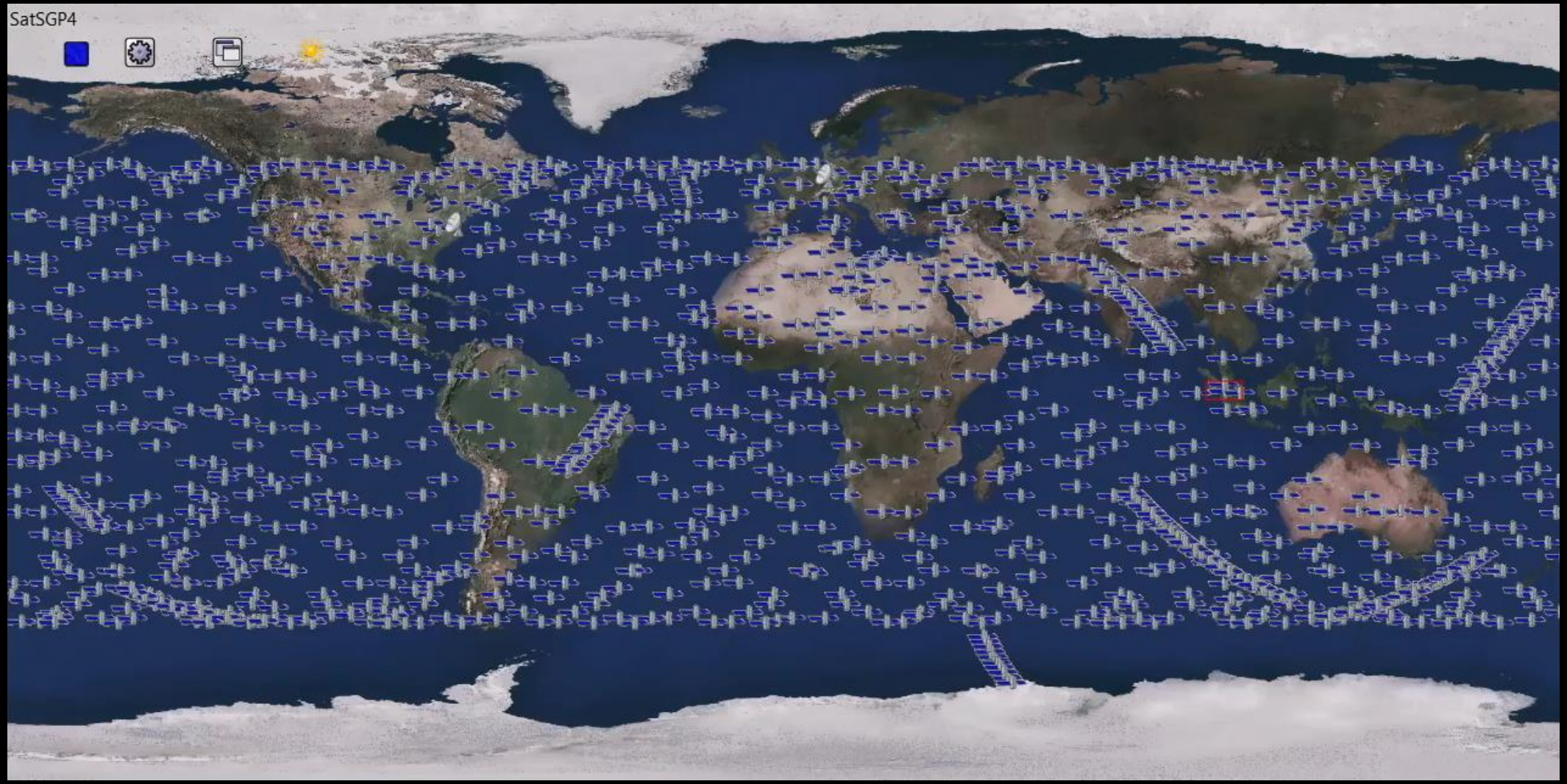
- Porting OS³ to the latest OMNeT++ and INET versions.
- Developing INET models
  - Physical and Transport Layer Models
    - Unit Disk Transmitter and Transmission Models
    - Propagation Model
  - Routing Model
- Removing the requirement of existing data for the OS³ mobility models.


SatSGP4

Unit Disk Radio Models

- Unit Disk Radio Models – Simple but fast and predictable physical layer behaviour
  - SatelliteUnitDiskTransmitter
  - SatelliteUnitDiskTransmission

Routing

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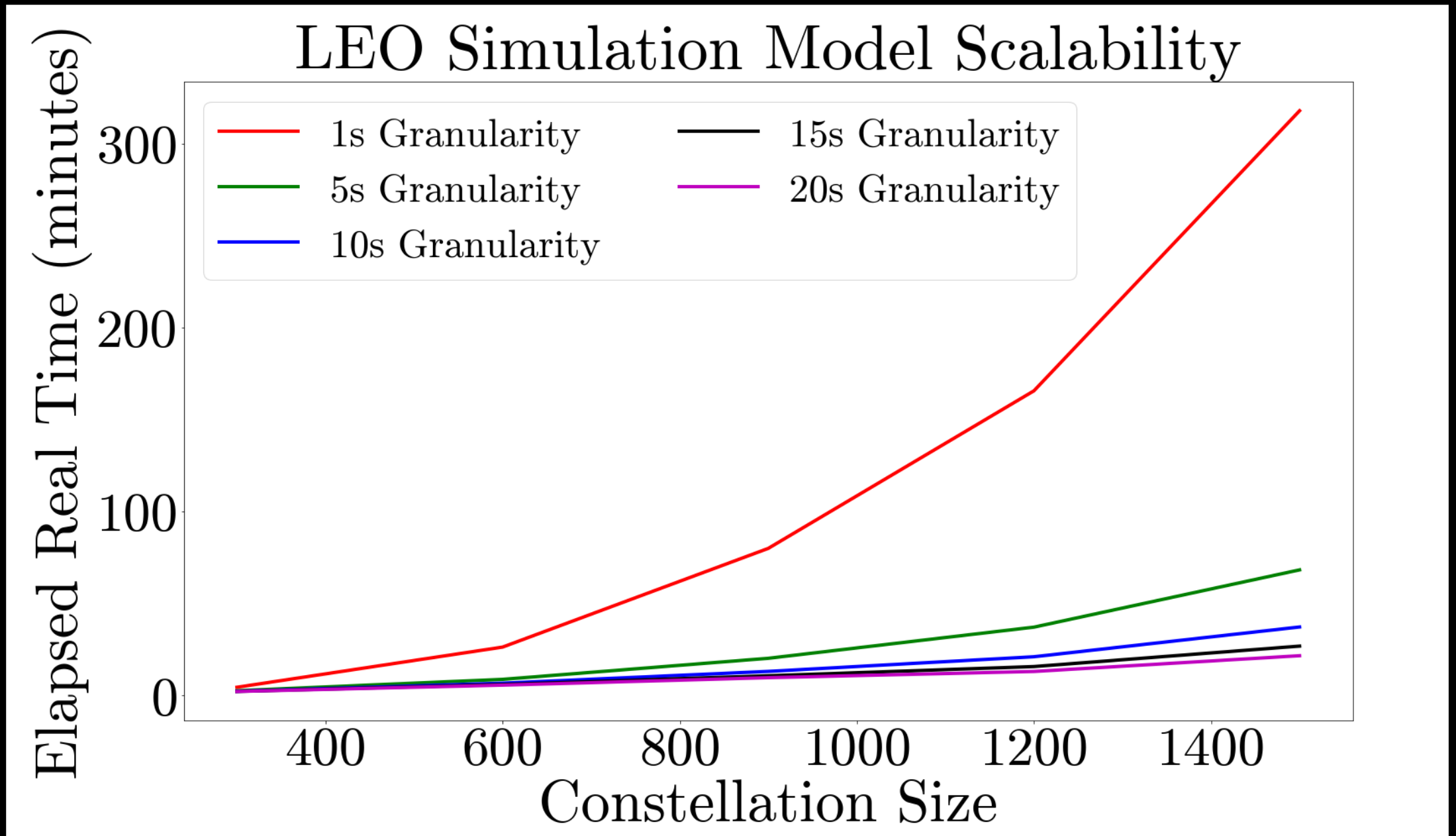
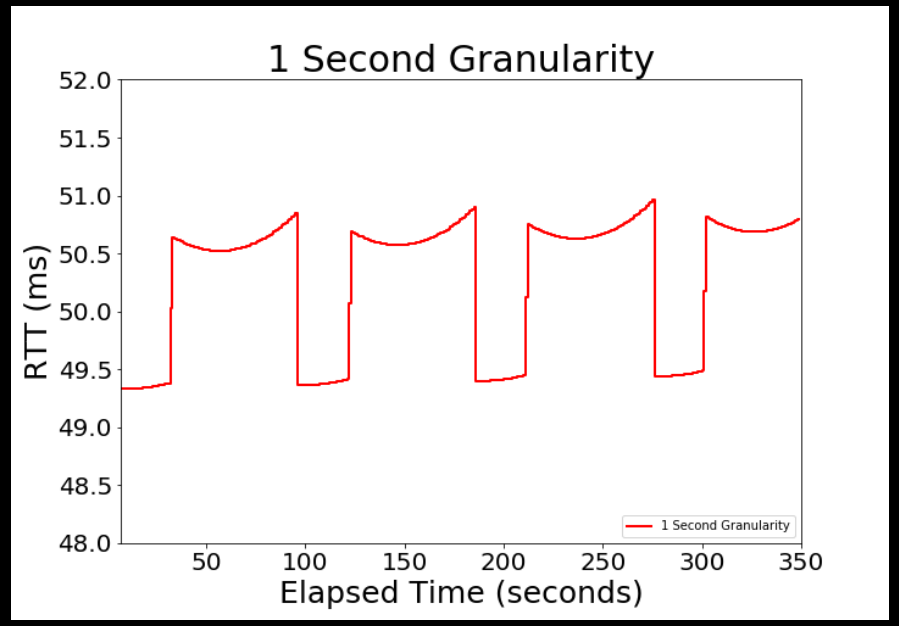
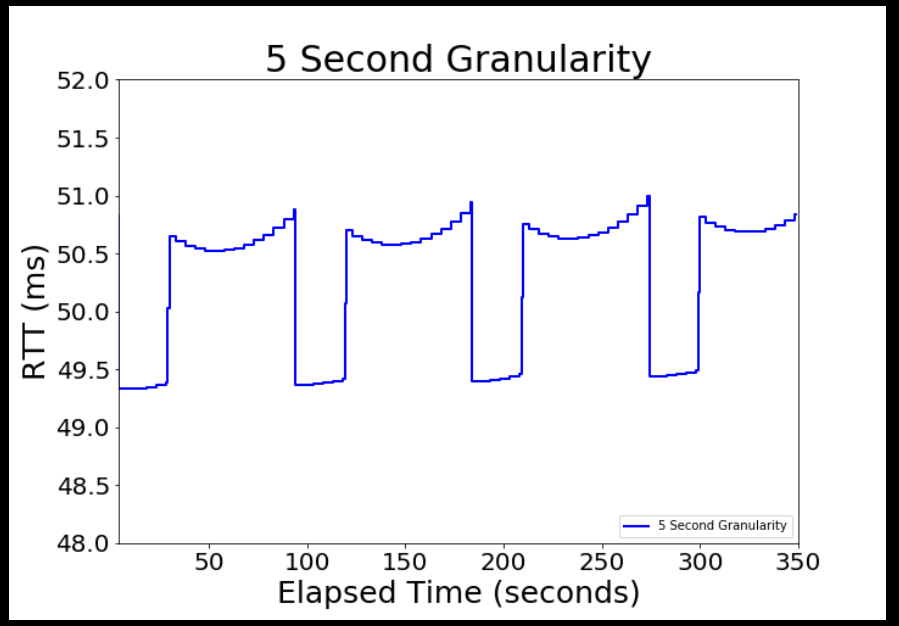
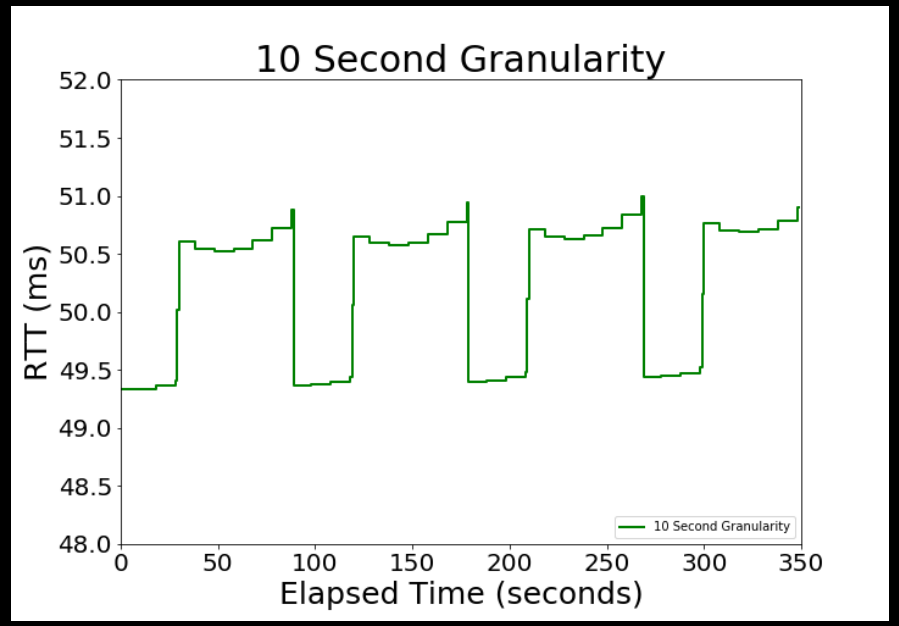
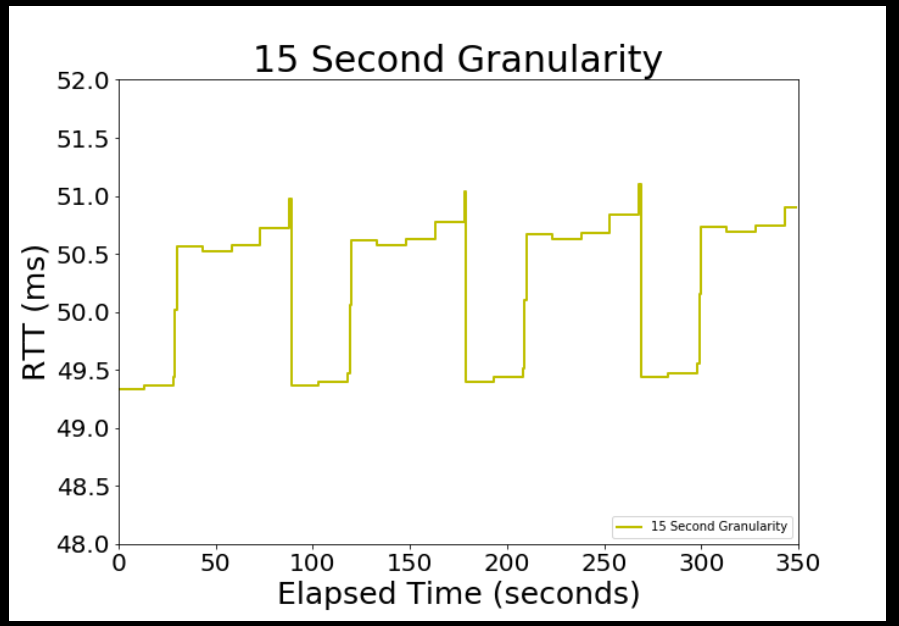
- Every x milliseconds simulation time a graph is built representing the current satellite network topology.
- IP addresses are automatically assigned.
- Links are filtered
  - Each link is checked to make sure it is valid, including whether it or not satellite-satellite links are compatible as inter-satellite links.
- Dijkstra's Shortest Path Algorithm is run with link latencies as metrics to determine the shortest route from every node.


LEO Simulation Model Scalability
1s Granularity
5s Granularity
10s Granularity
15s Granularity
20s Granularity
Elapsed Real Time (minutes)
0
100
200
300
400
600
800
1000
1200
1400
Constellation Size


1 Second Granularity
RTT (ms)
Elapsed Time (seconds)
1 Second Granularity


5 Second Granularity
RTT (ms)
Elapsed Time (seconds)
5 Second Granularity


10 Second Granularity
RTT (ms)
Elapsed Time (seconds)
10 Second Granularity


15 Second Granularity
RTT (ms)
Elapsed Time (seconds)
15 Second Granularity

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```
network SatelliteConstellation
{
    parameters:
        int numOfSats; // Number of satellites
        int numOfMCCs; // Number of Mission Control Centers
        @display("bgi=background_earth,s;bgb=2160,1080");
    submodules:
        visualizer: <default("IntegratedCanvasVisualizer")> like IIntegratedVisualizer if hasVisualizer() {
            @display("p=305.665,67.625`");
        }
        configurator: SatelliteNetworkConfigurator {
            @display("p=183.94,67.625");
        }
        satellite[numOfSats]: LaserSatellite {
            parameters:
                @display("p=238.04,327.305;i=satellit_blue");
        }
        MCC[numOfMCCs]: GroundStation {
            parameters:
                @display("p=238.04,343.535;r=10;i=device/receiverdish");
        }
        radioMedium: <default("UnitDiskRadioMedium")> like IRadioMedium {
            parameters:
                @display("p=421.98,64.92;i=misc/sun");
        }
    connections allowunconnected:
}
```

```
**.numOfSats = 700
*.satellite[*].NoradModule.planes = 32
*.satellite[*].NoradModule.satPerPlane = 50
*.satellite[*].NoradModule.eccentricity = 0.0001698
*.satellite[*].NoradModule.inclination = 53*0.0174533
*.satellite[*].NoradModule.phaseOffset = 1
```

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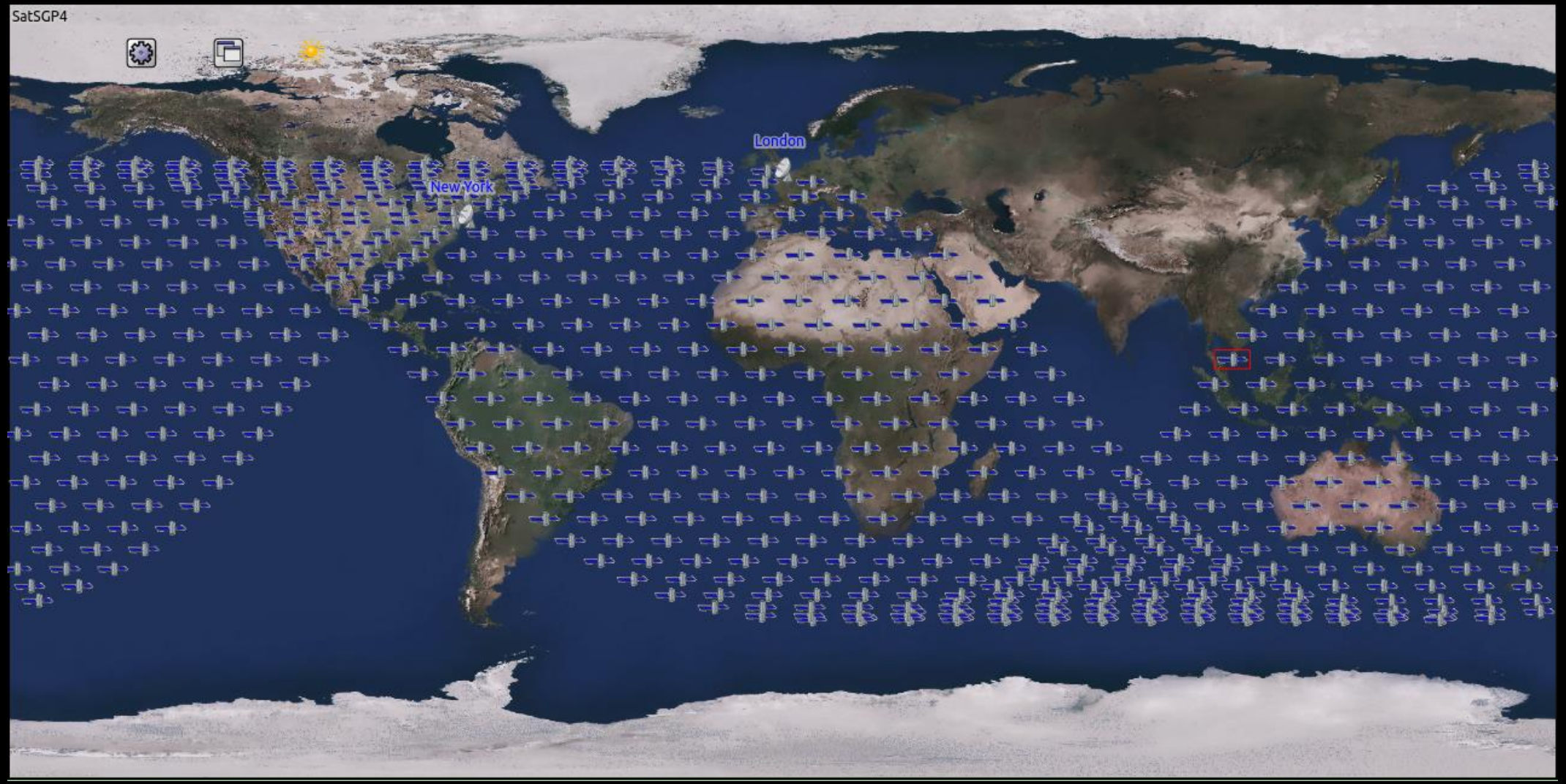

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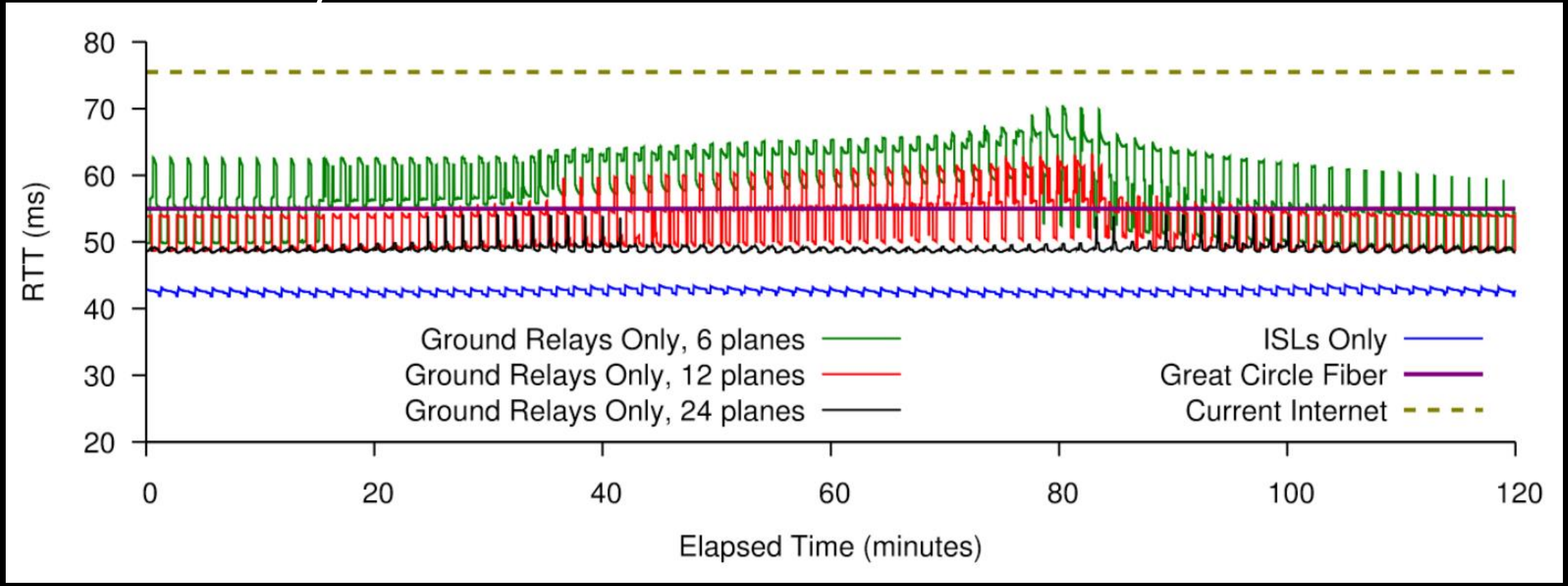
Results

Handley – London to New York




Main Brook
MCC
Gaspe
Newfoundland
Jander
Sydney
Yarmouth
New York
ping7
Ship 1
ping7-reply
Ship 2
Killarney
rtt: 0.04907 s

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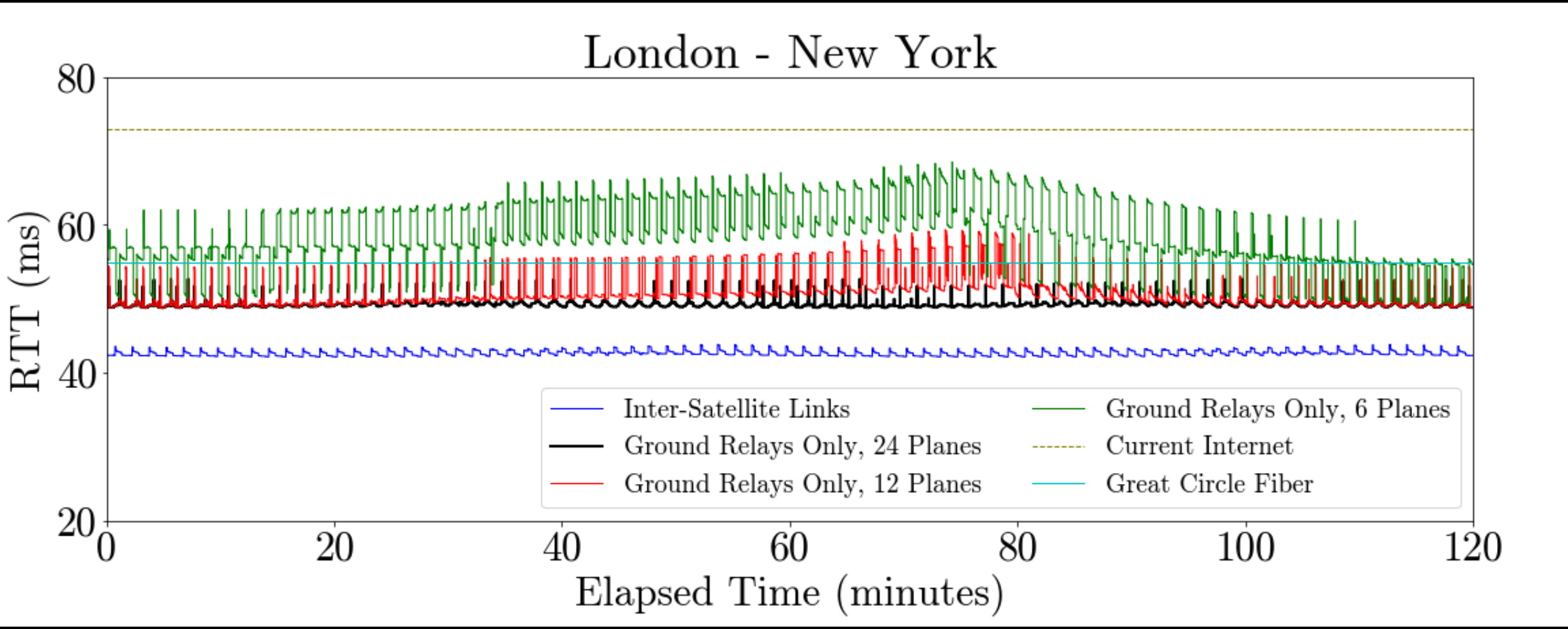
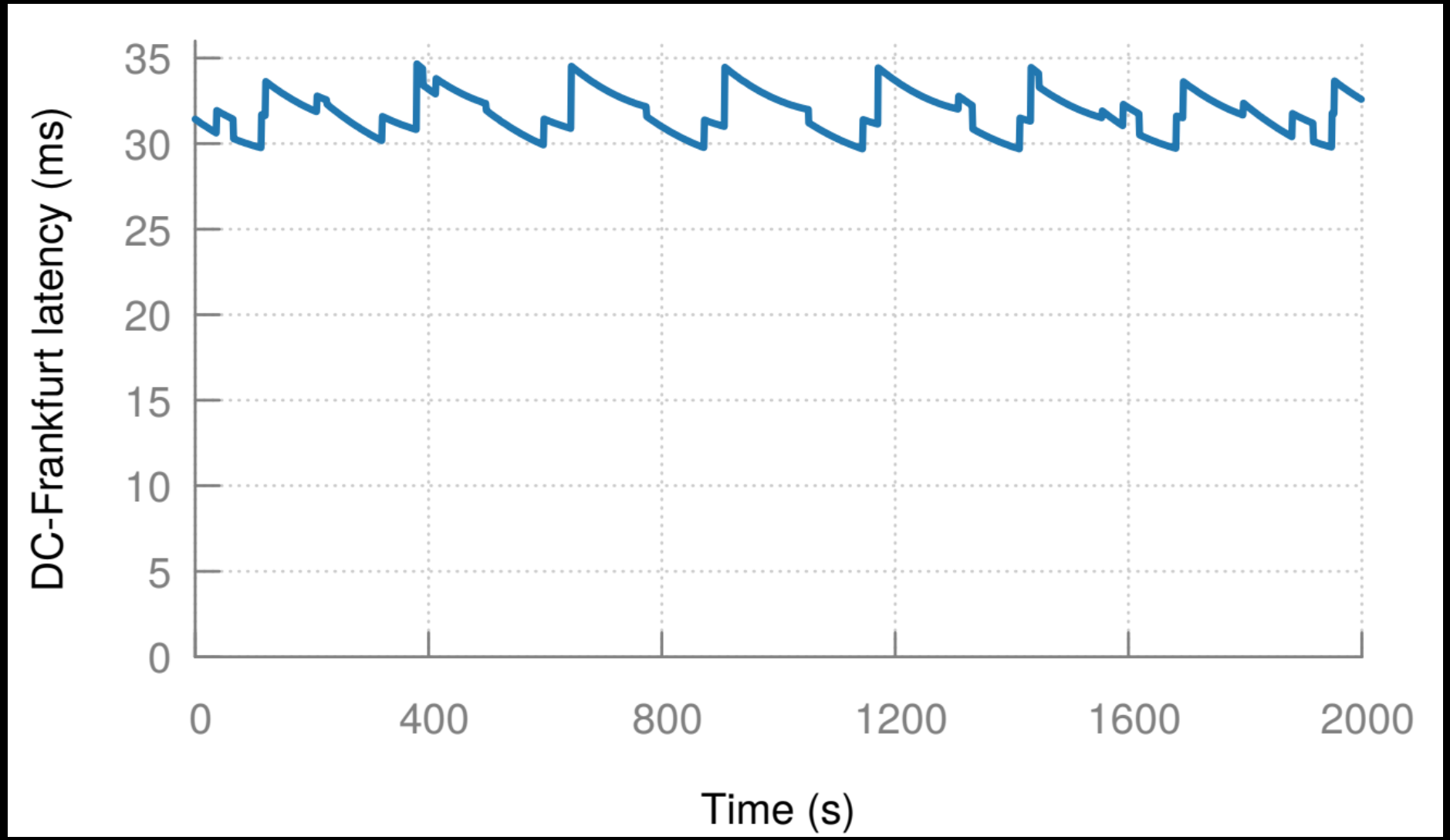
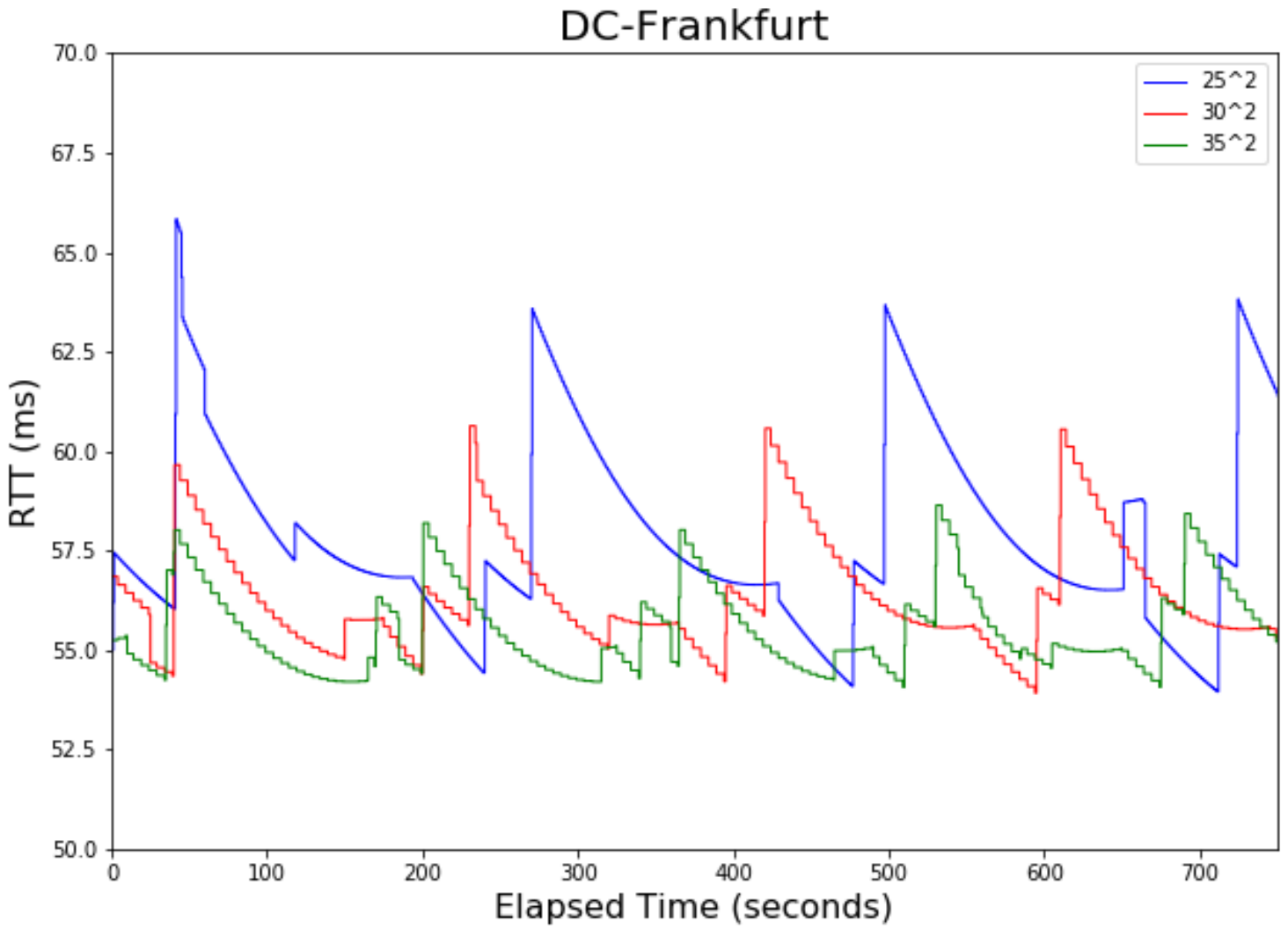


Bhattacherjee et al. DC - Frankfurt




ping14-reply
ping14
Frankfurt
rtt: 0.05056 s



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GitHub Repository

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- Ported OS3 Framework:
- https://github.com/Avian688/os3

- Low Earth Orbit Satellite Framework:
- https://github.com/Avian688/leosatellites

Next Steps

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- Improve routing computation.

- Evaluate existing INET data transport protocols on the simulation model such as TCP and data centre protocols such as NDP and SCDP.

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Questions?