Rethinking networking for an “Internet from space”

Ankit Singla, ETH Zürich

Debopam Bhattacherjee

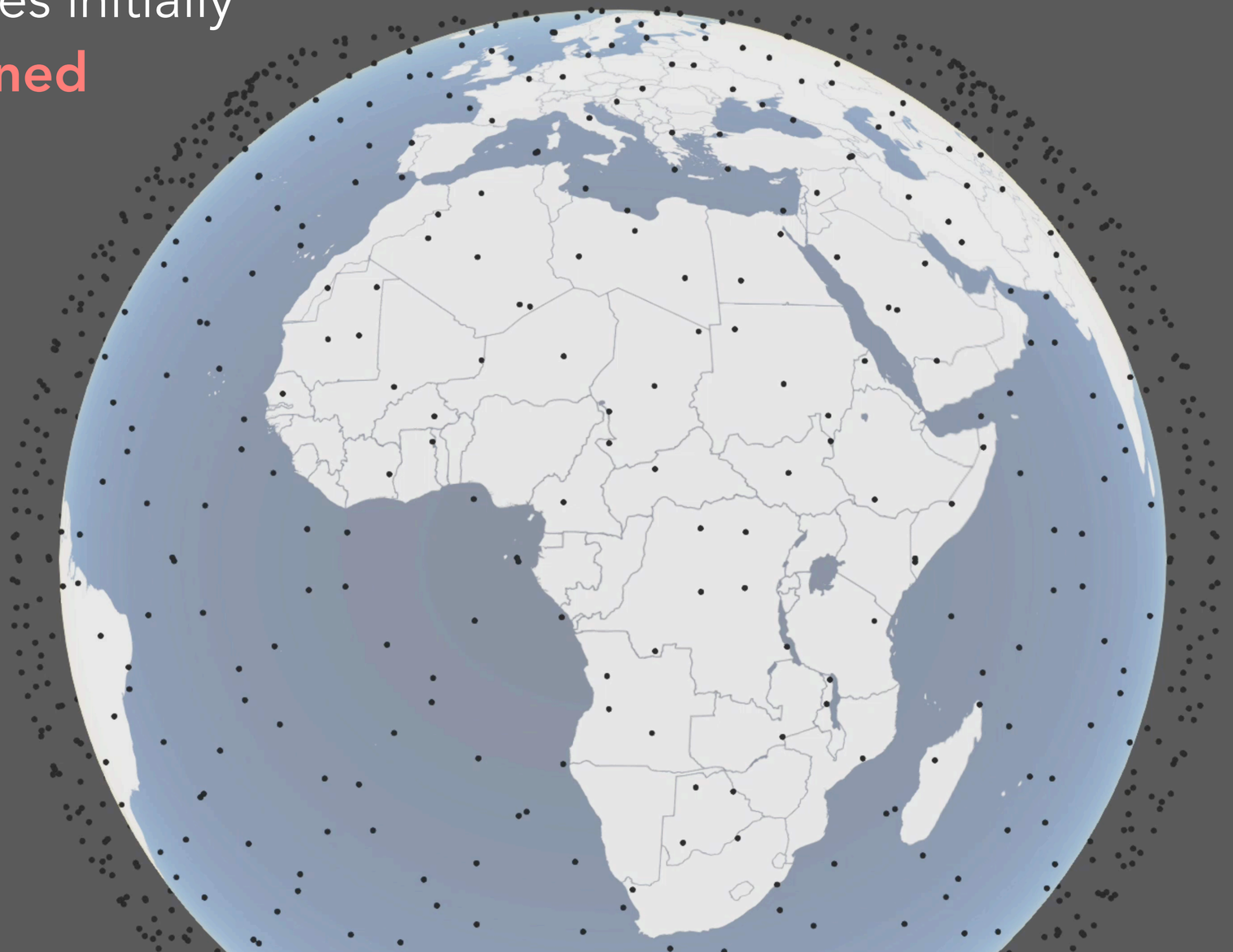
Simon Kassing

… with contributions from André Baptista Águas, Jens Eirik Saethre

SpaceX Starlink

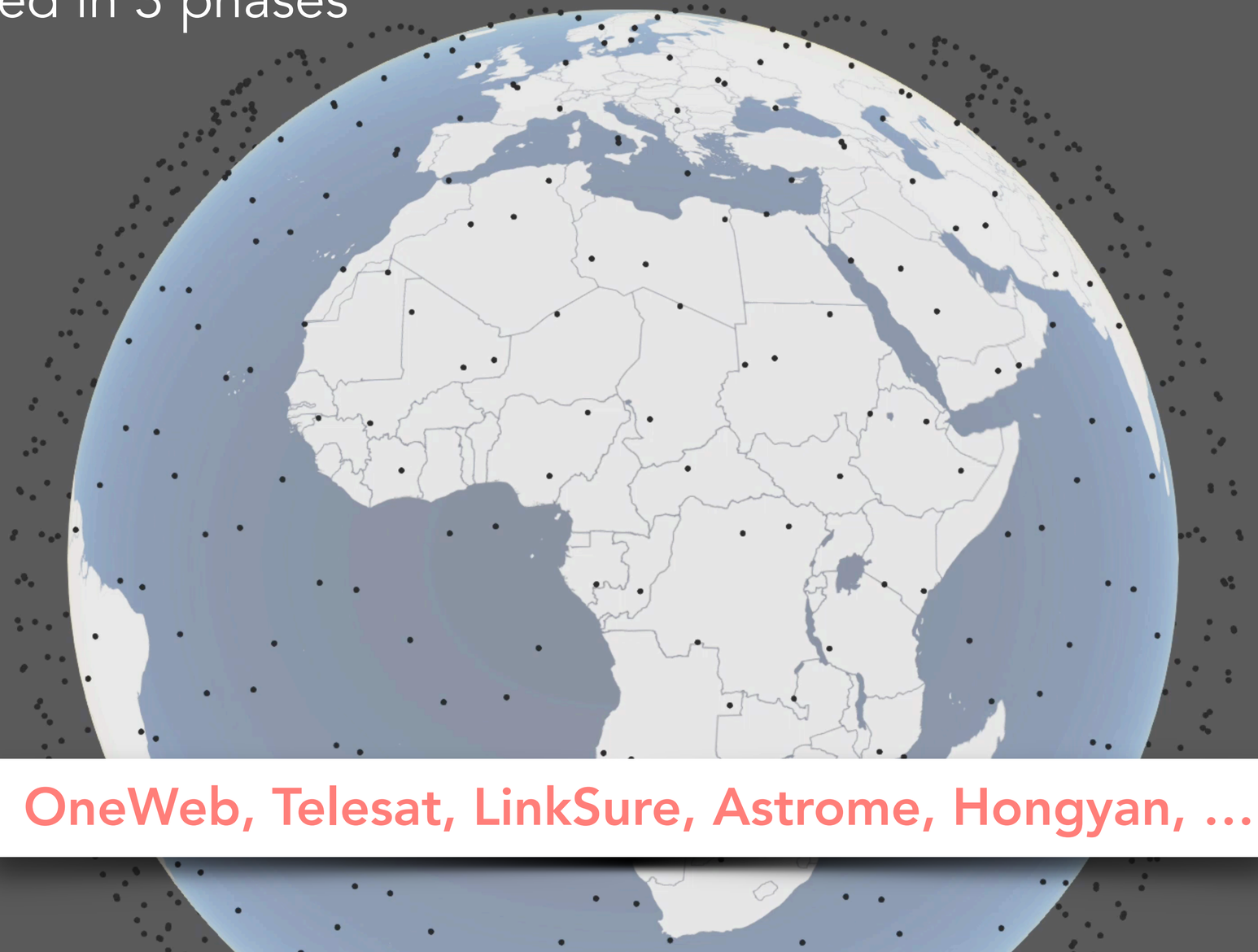
1,600 satellites initially

42,000 planned



Amazon Kuiper

3,200 planned in 3 phases

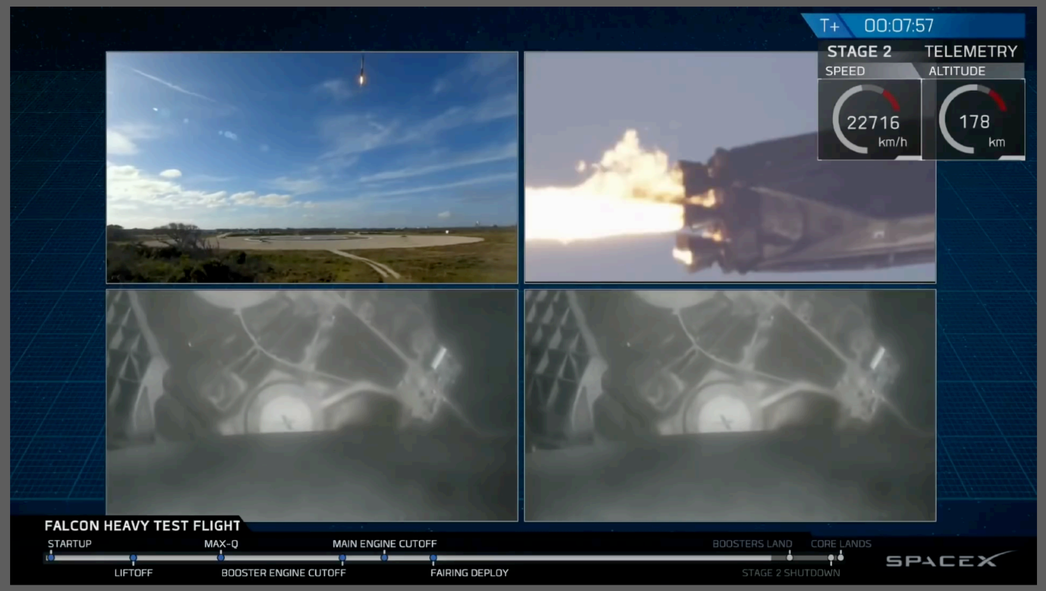


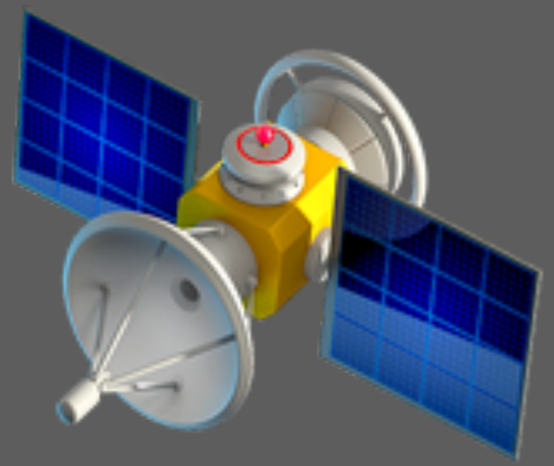
OneWeb, Telesat, LinkSure, Astrome, Hongyan, …

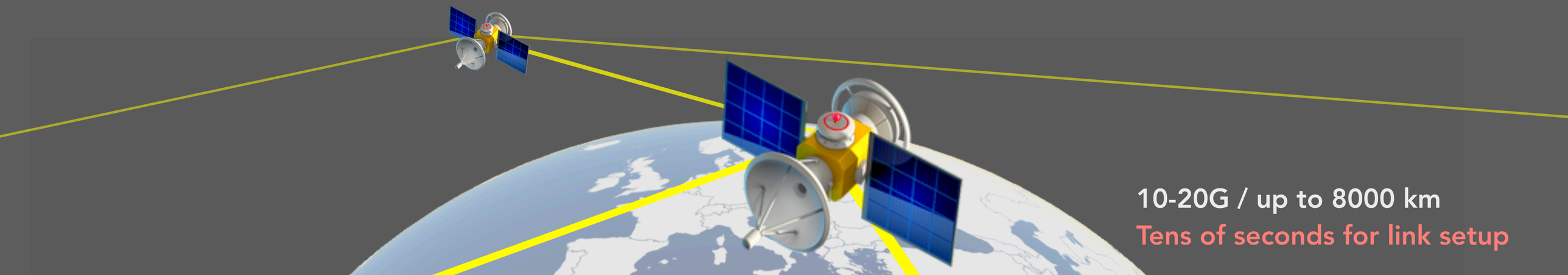
Isn’t satellite networking old?

- Scale: 10s → 10,000s
- Goals: niches → global broadband
- Dynamics: GEO → LEO

Enabling technologies







10-20G / up to 8000 km

Tens of seconds for link setup

Global low-latency Internet coverage

How do we …

… pick satellite trajectories to serve target areas?

… interconnect satellites?

… route efficiently within a constellation?

… integrate such networks into Internet routing?

… do efficient congestion control on such networks?

… design applications that run on top?

Topology

Routing

Transport

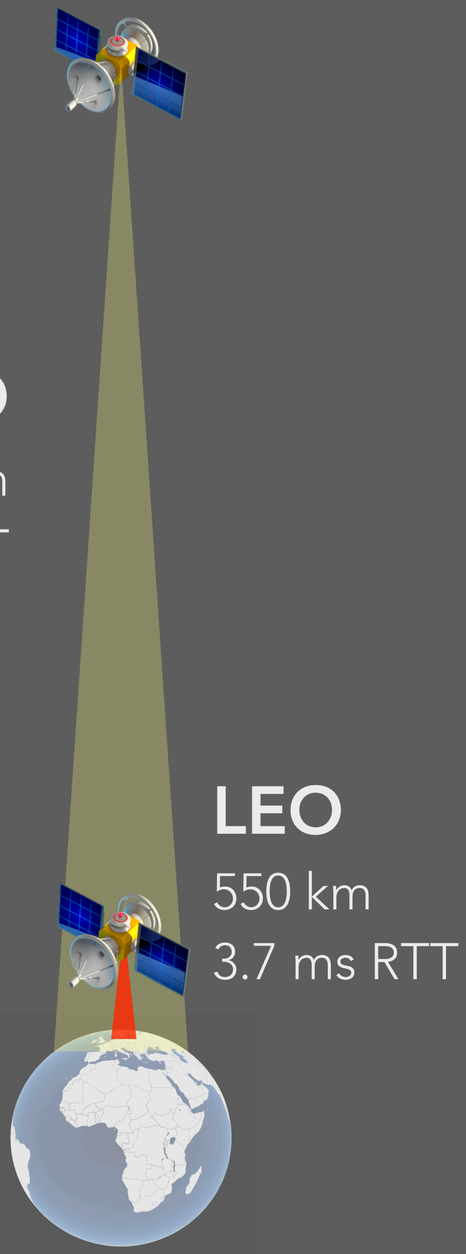
Apps

Bread and butter networking questions …

… except your routers are zooming about in space at ~27,000 km/hour

Brief primer on satellite constellations

1. Altitude



GEO

35,768 km

238.4 ms RTT

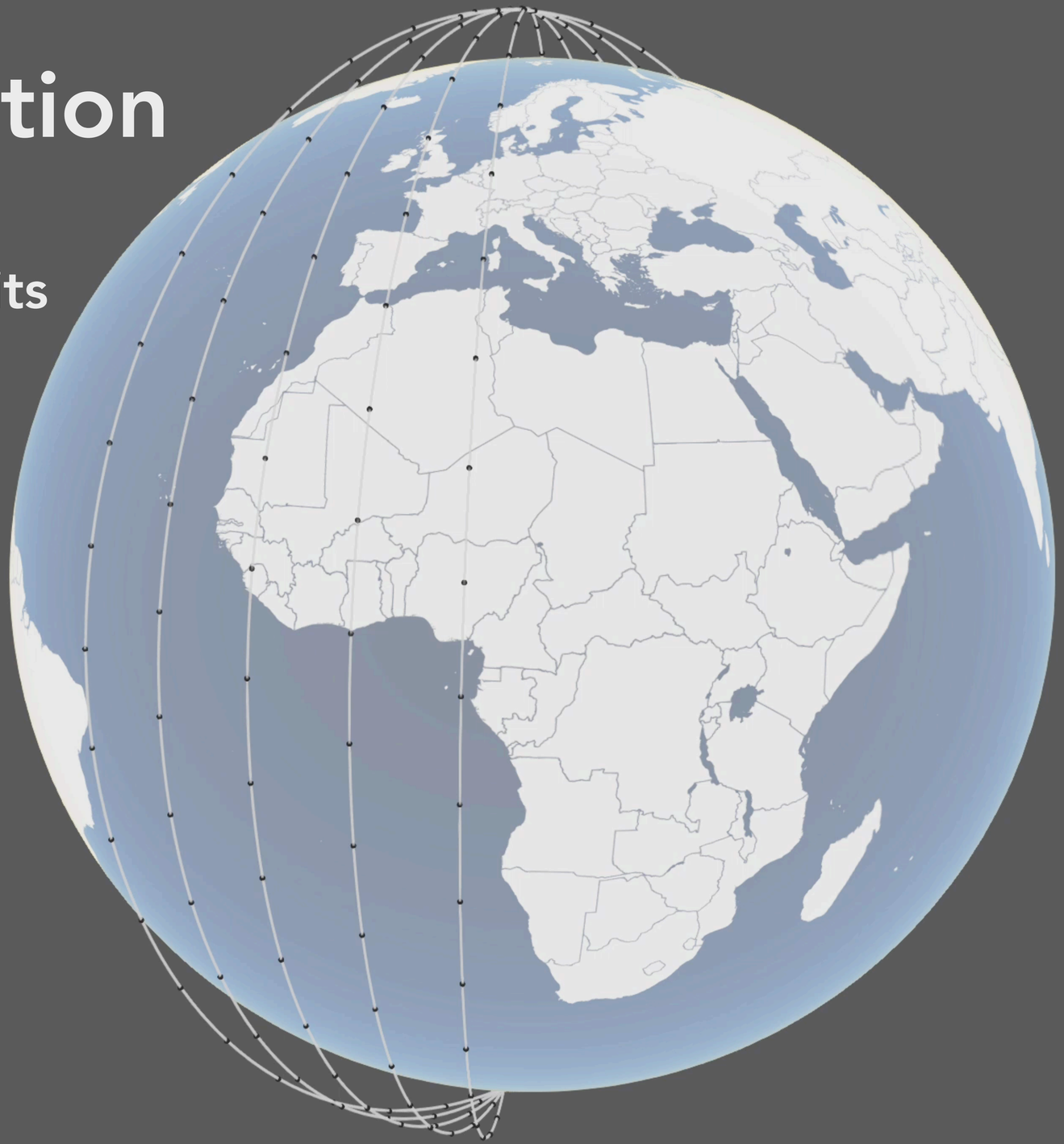
LEO

550 km

3.7 ms RTT

2. Inclination

Polar orbits



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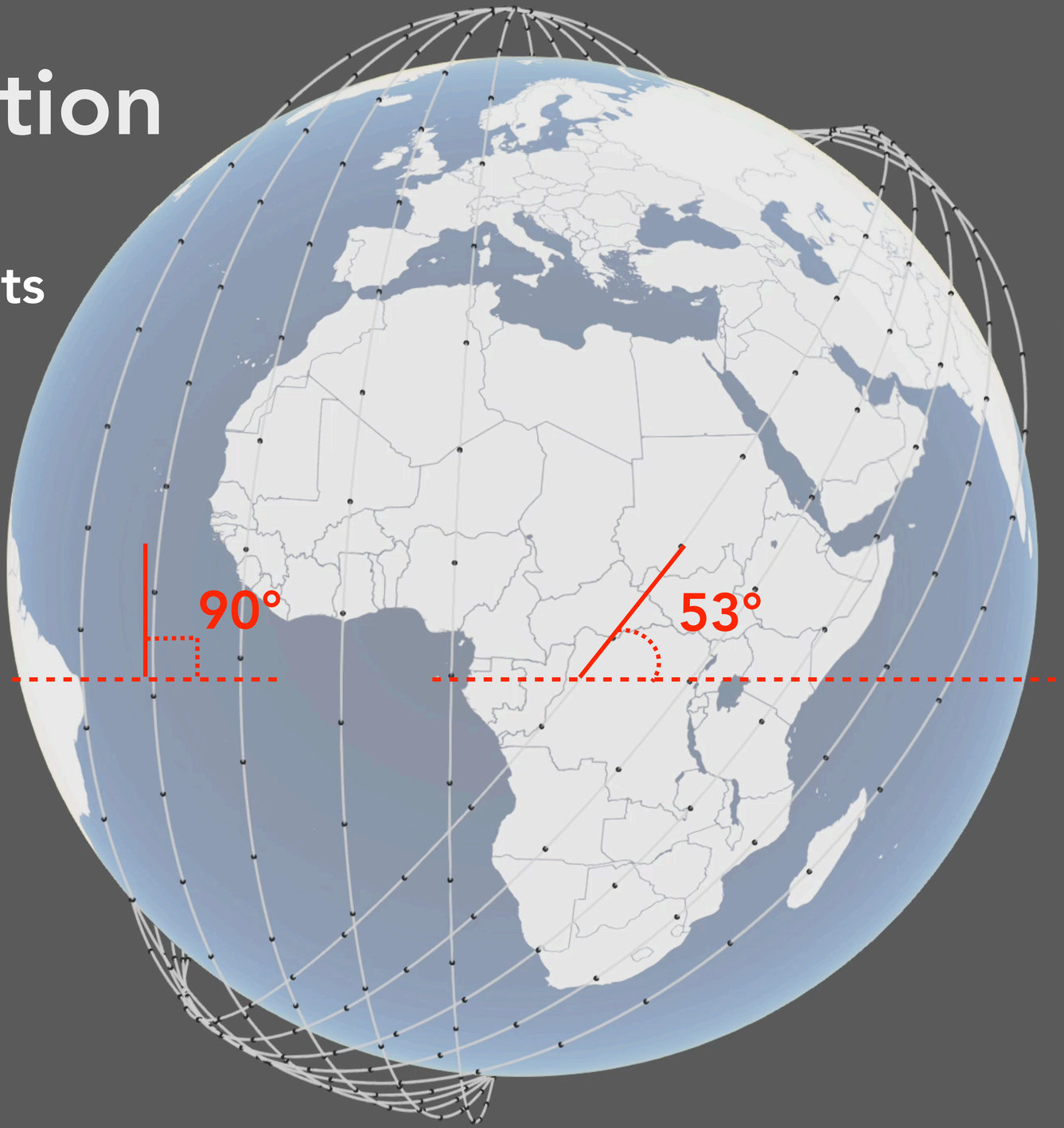


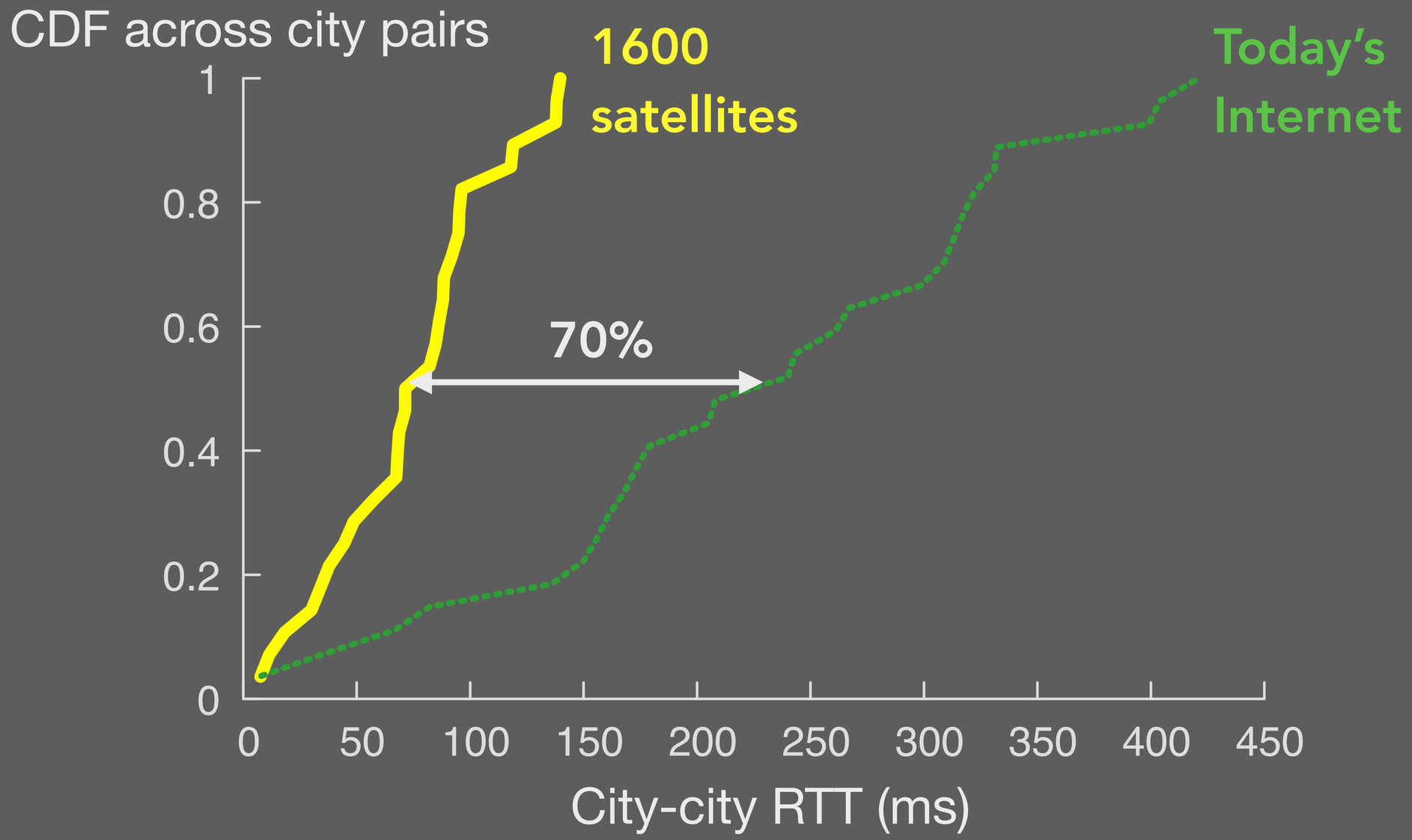
Inclined orbits

3. Connectivity

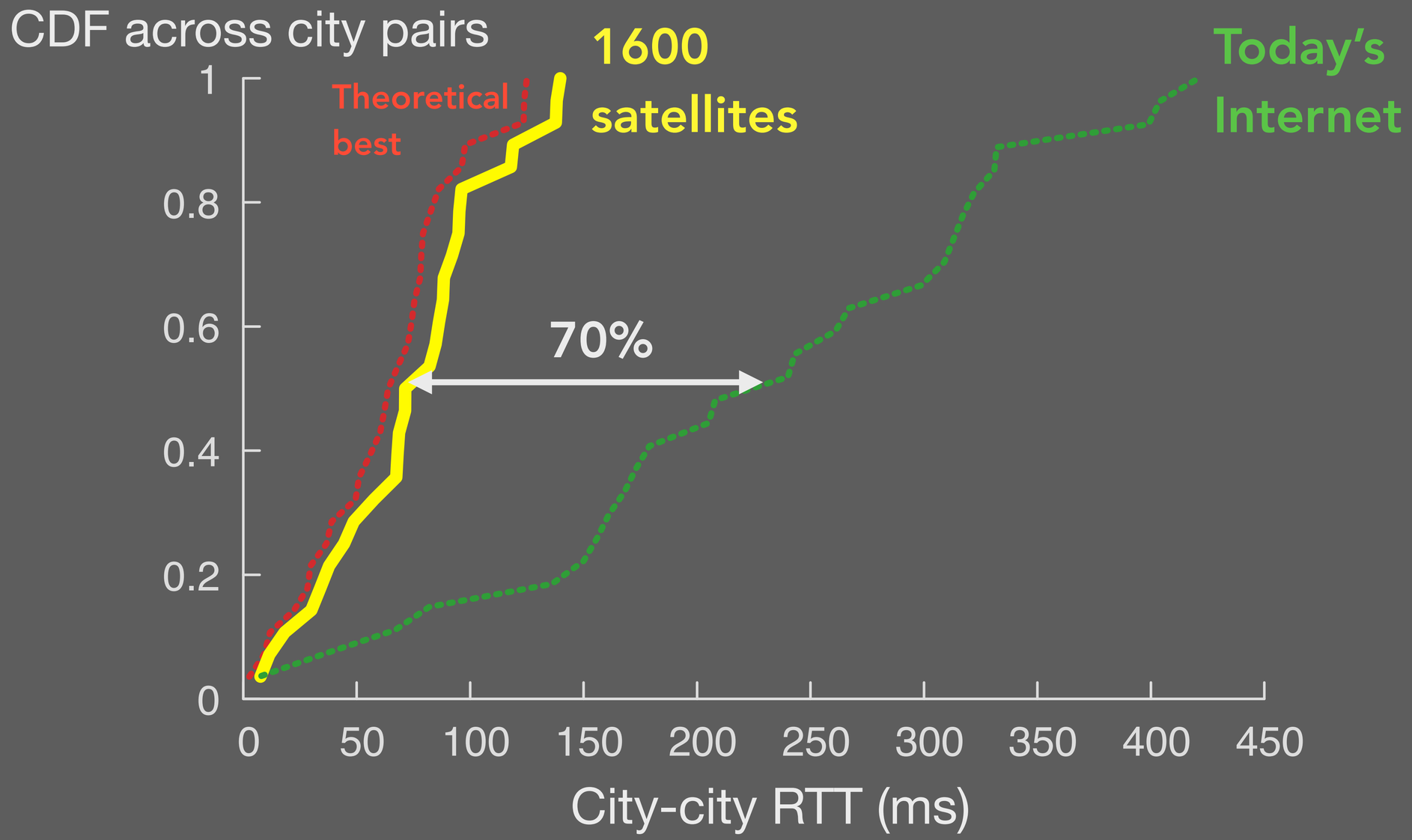
+Grid

4. Latency

4. Latency


CDF across city pairs
1600 satellites
Today's Internet
70%
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
350
400
450
City-city RTT (ms)

4. Latency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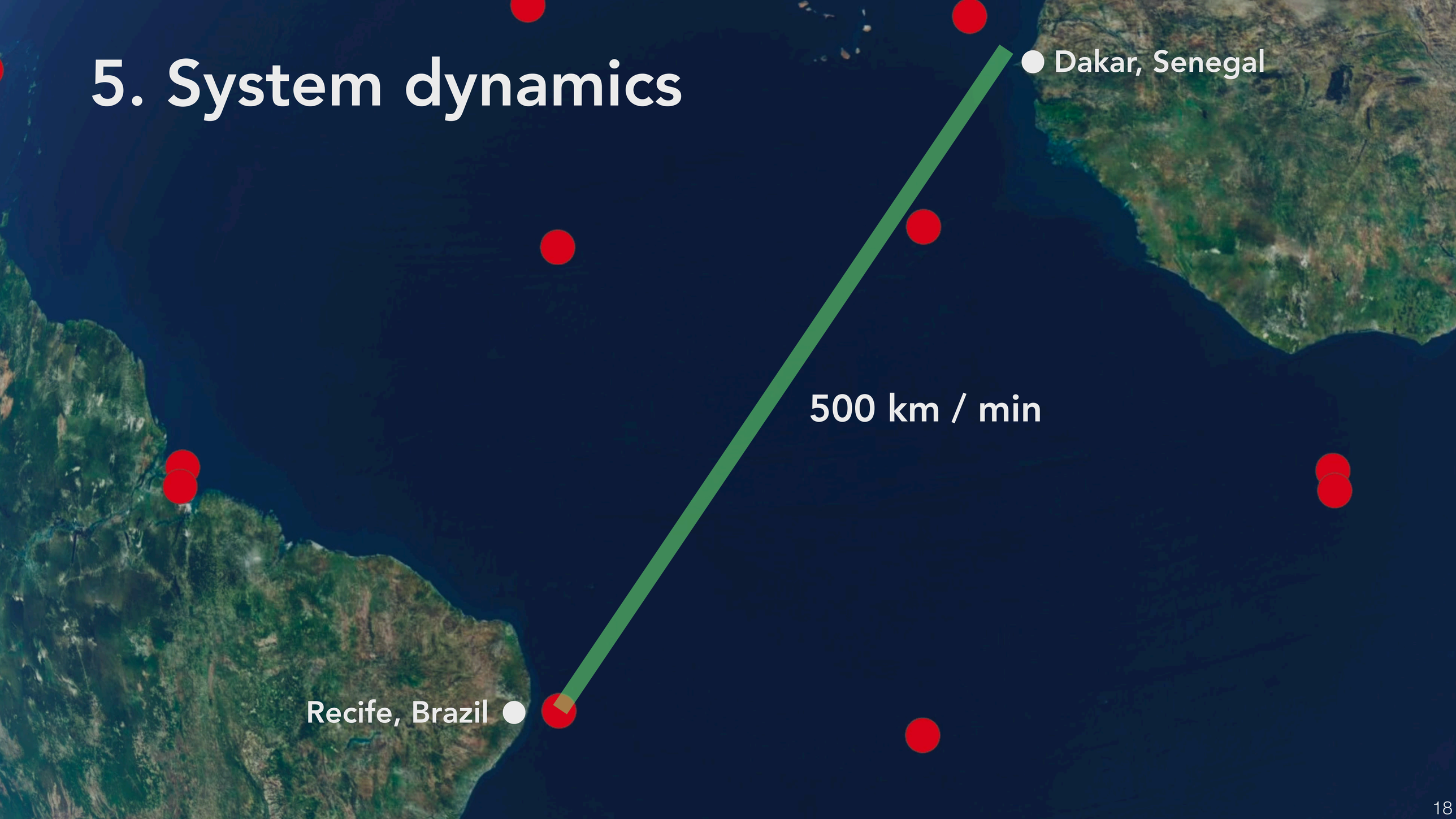
City-city RTT (ms)

5. System dynamics



How do we …

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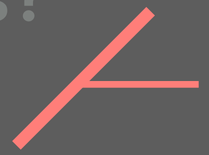


Topology

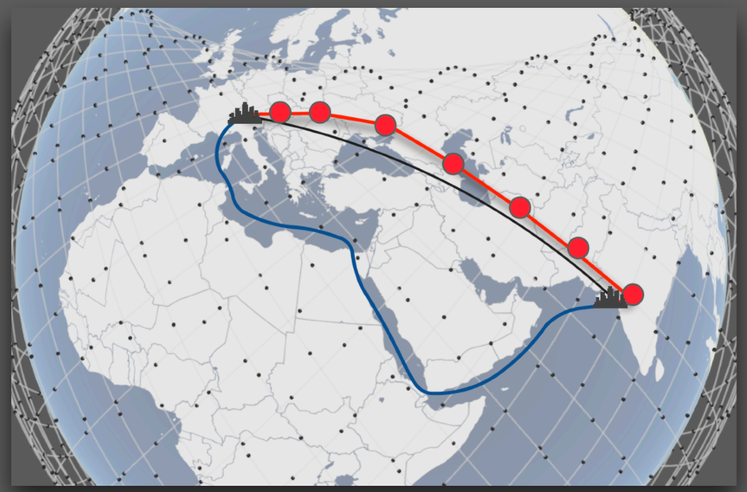
… route efficiently within a constellation?

… integrate such networks into Internet routing?

… do efficient congestion control on such networks?

… design applications that run on top?

How do we interconnect satellites?



CoNEXT 2019, IRTF Applied Networking Research Prize 2020

Network topology design at 27,000 km/hour

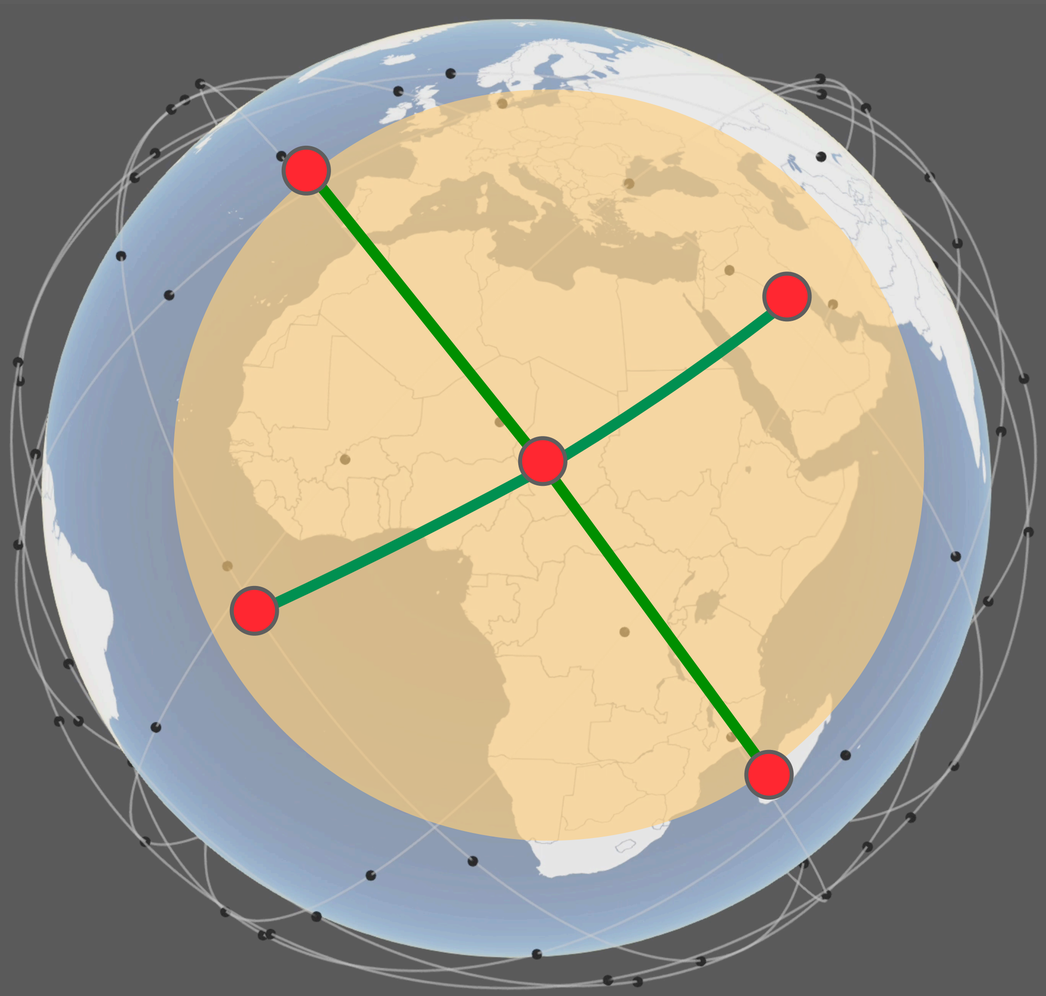
Debopam Bhattacherjee, Ankit Singla
Department of Computer Science, ETH Zürich

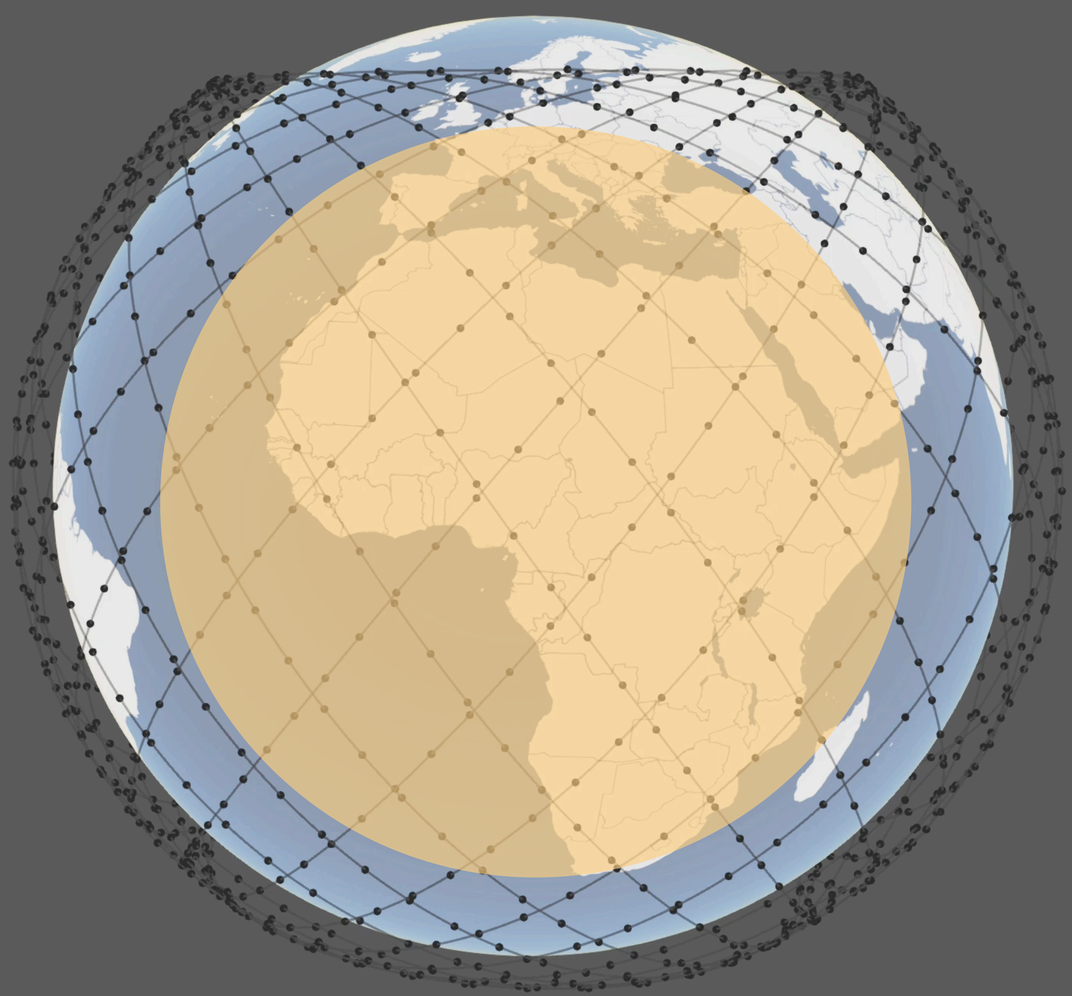
Assumptions

- Given satellite trajectories
- Ground-satellite connectivity is range-bounded
- +Grid is the baseline

+Grid

Design space beyond +Grid

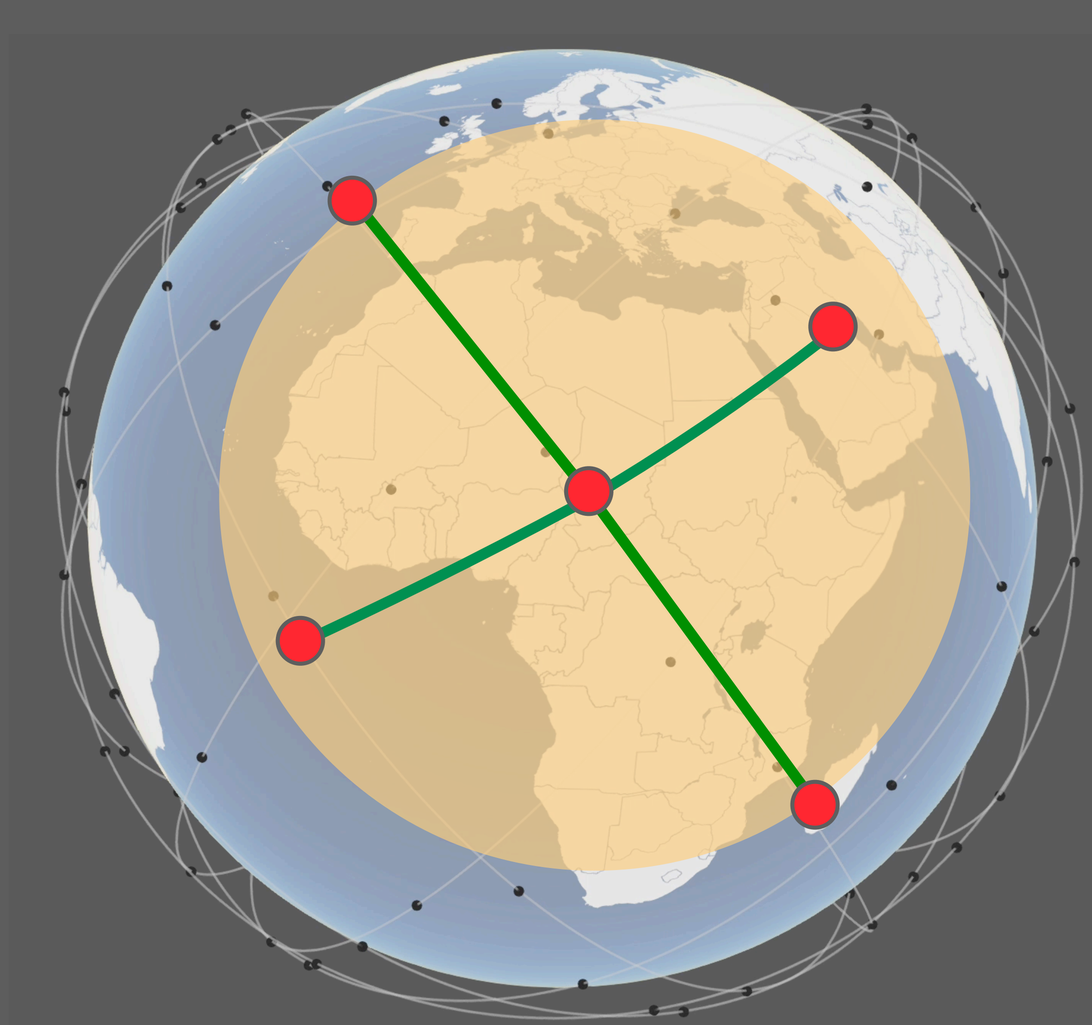


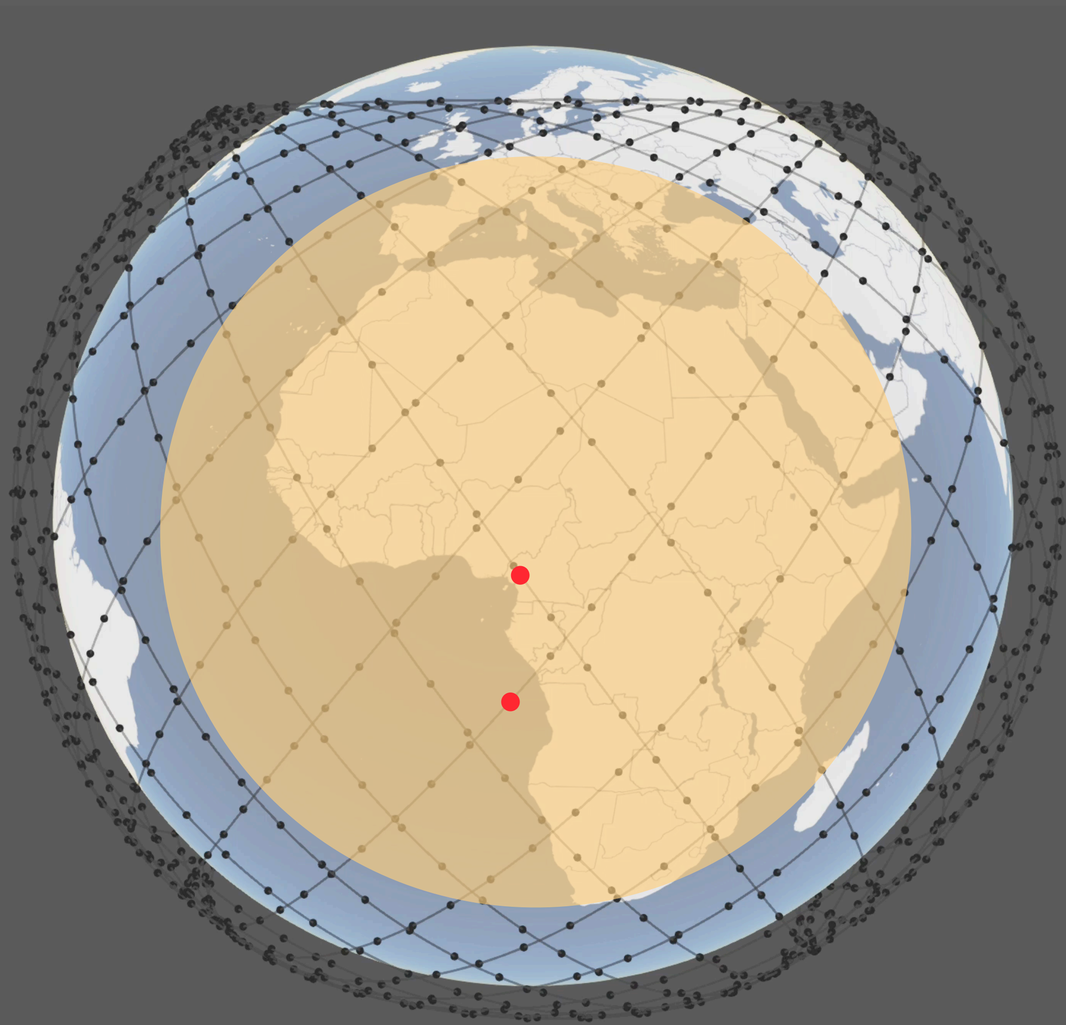


Why not use Integer programming?

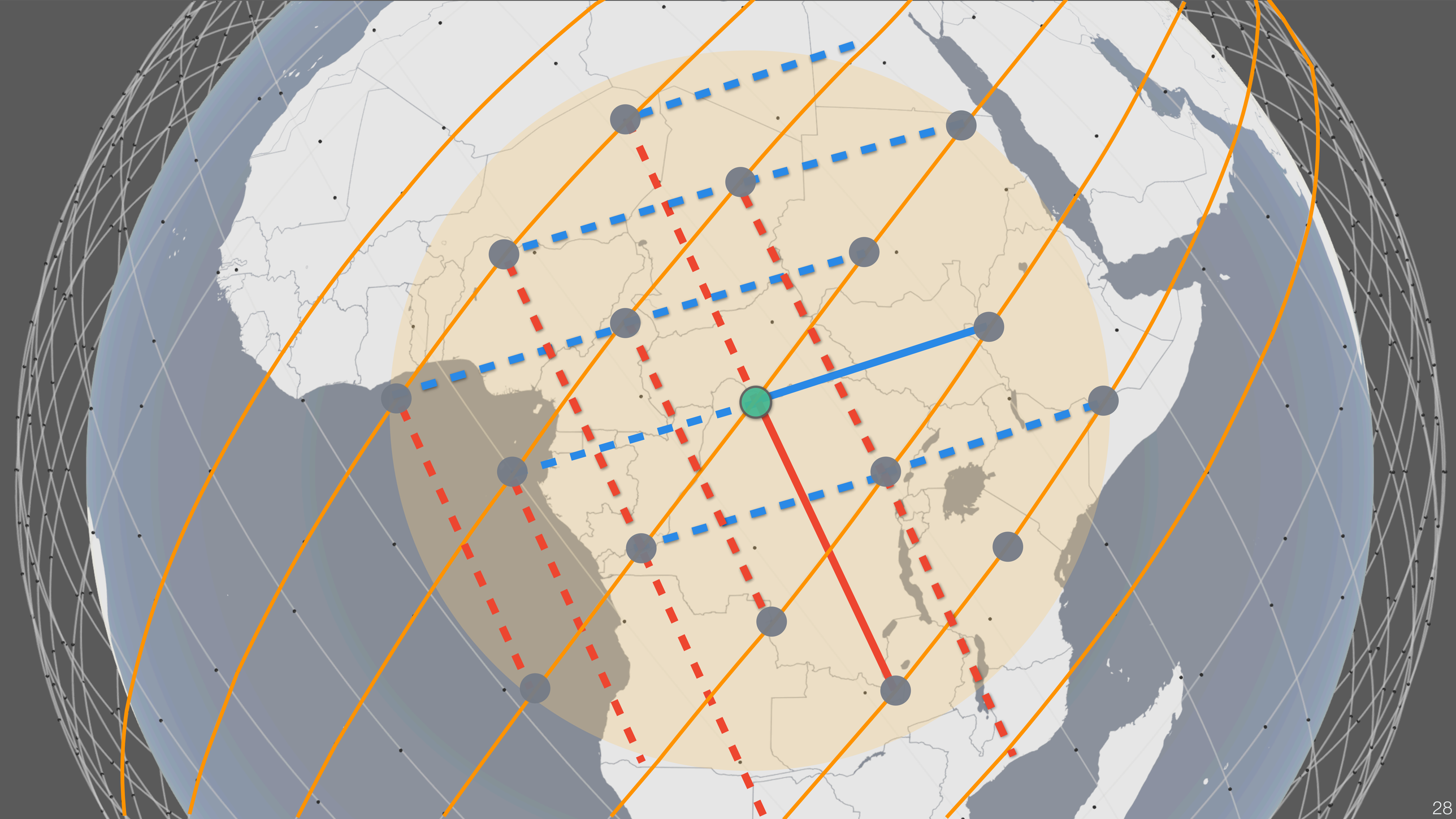
For 1000 cities, would take ~10^{29} days

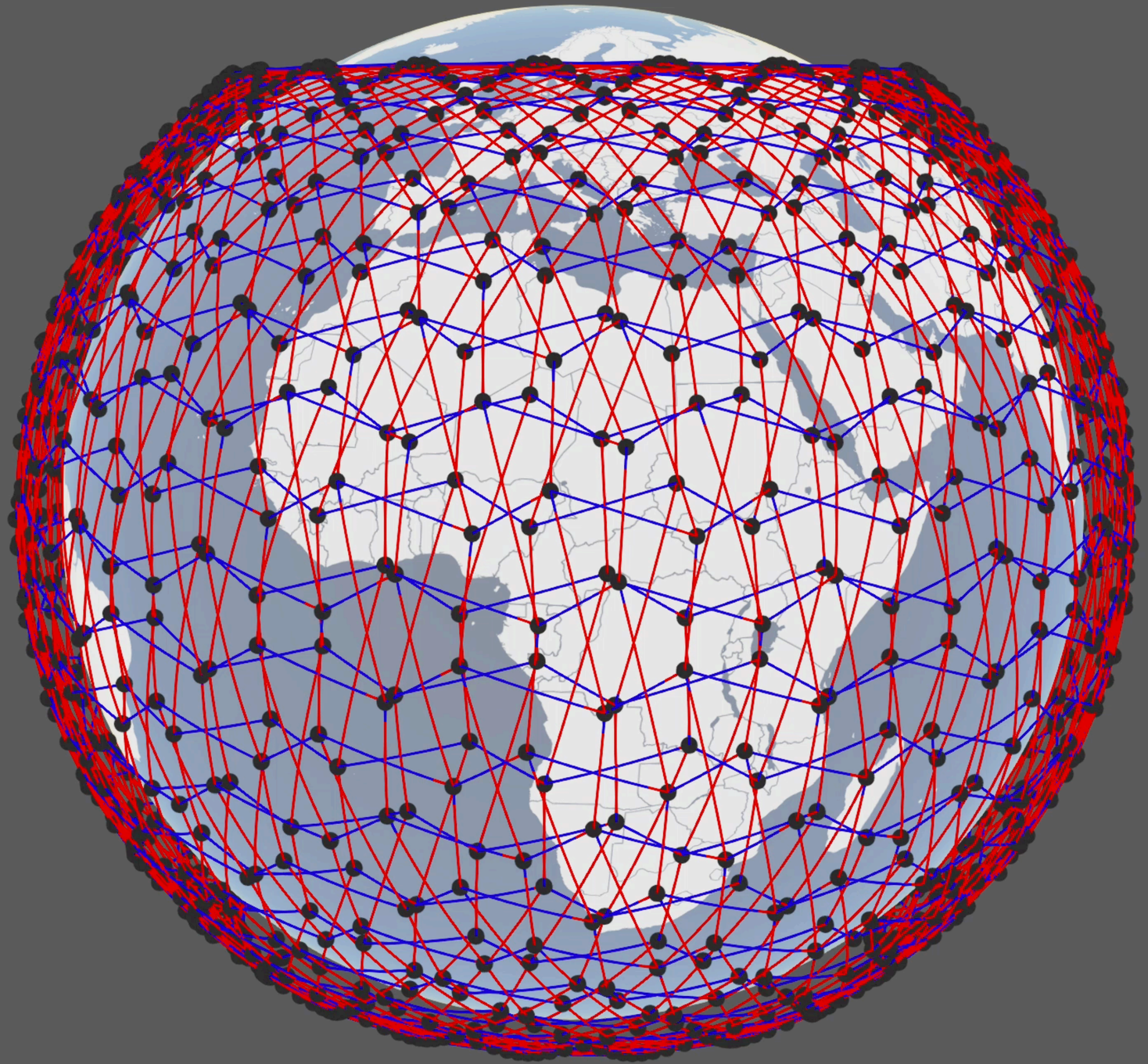
No prior work tackles dynamics





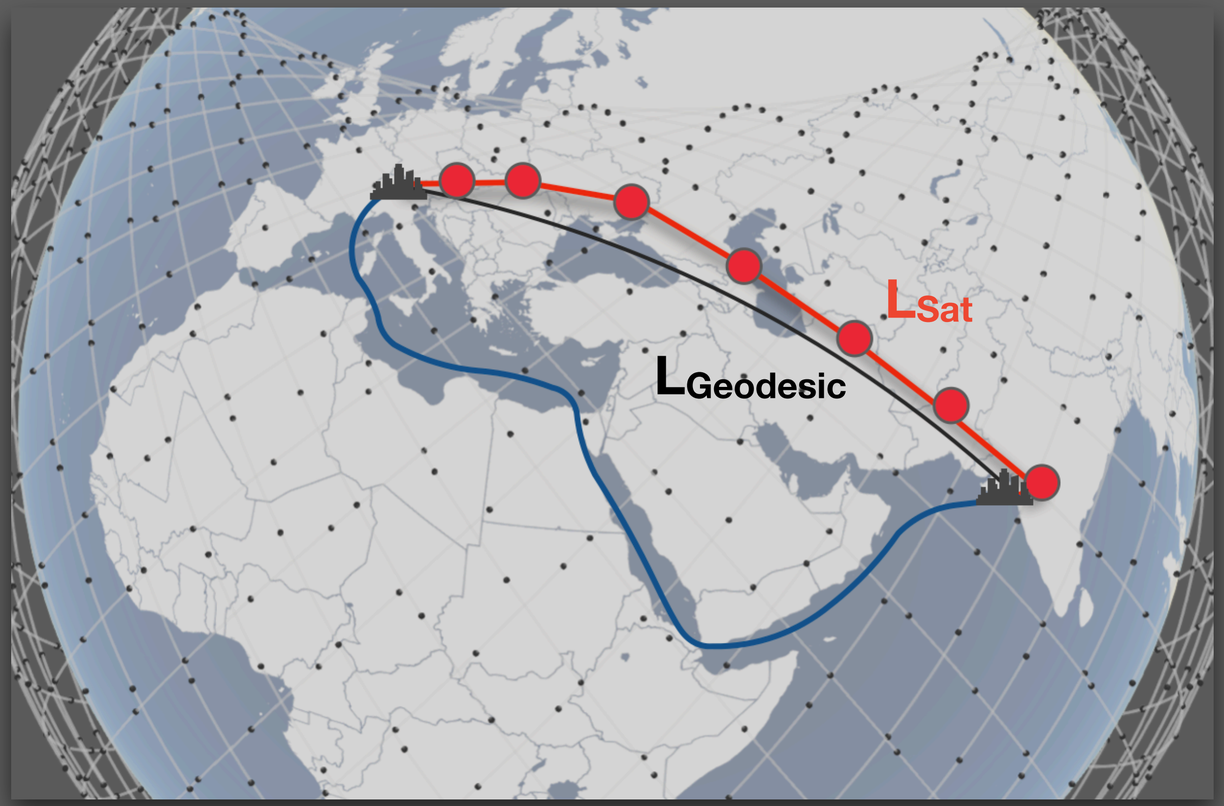
Our approach





What do we optimize for?

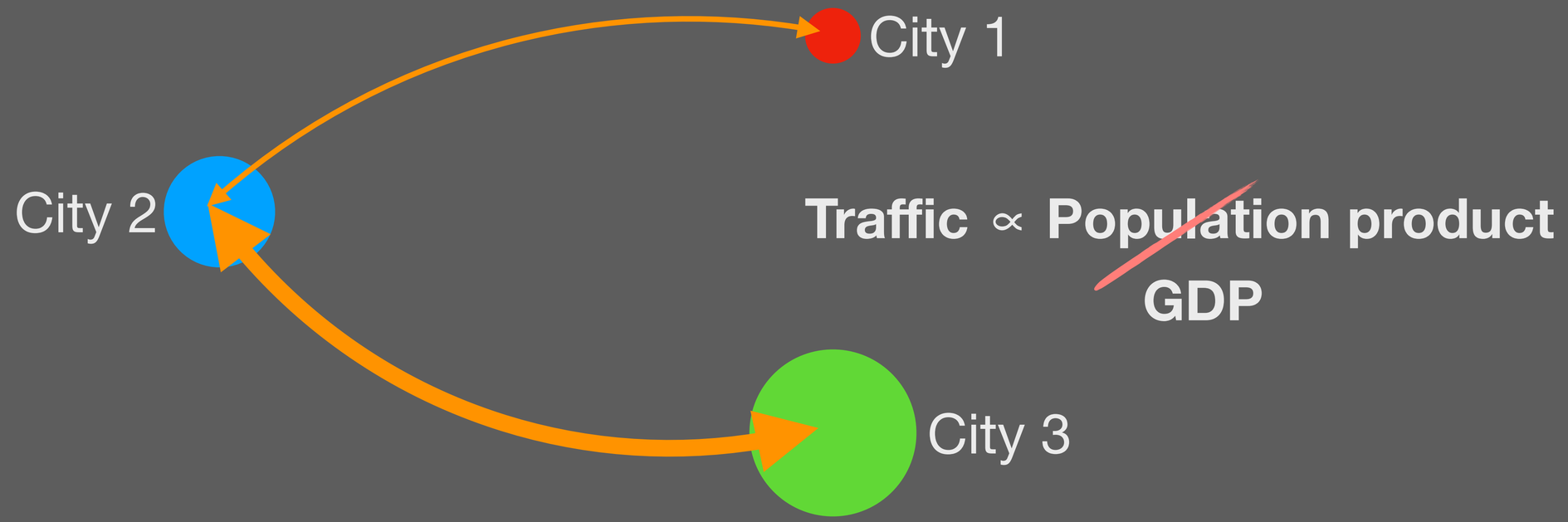
Metrics



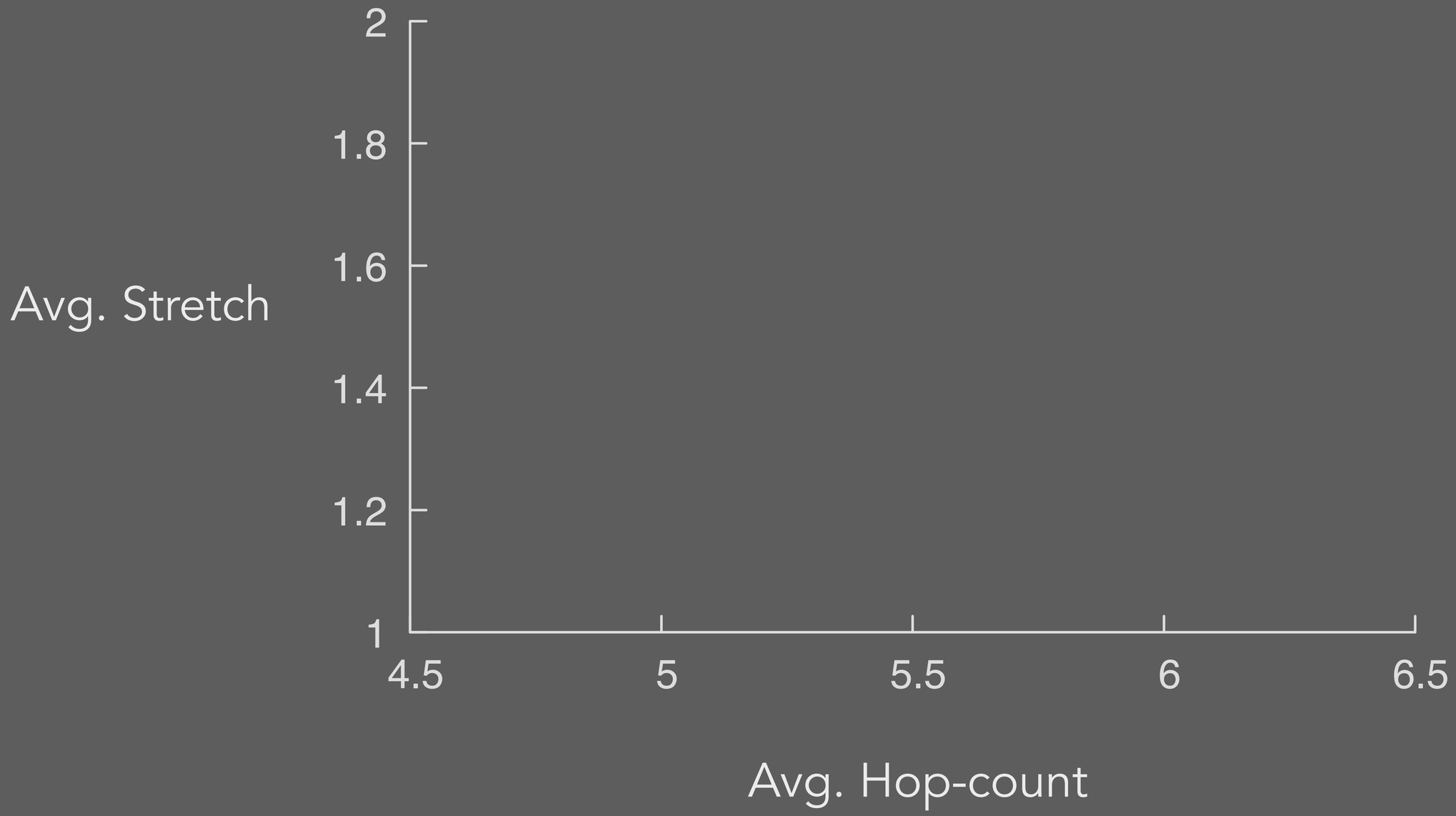
$$\text{Stretch} = \frac{L_{Sat}}{L_{Geodesic}}$$

Hop count

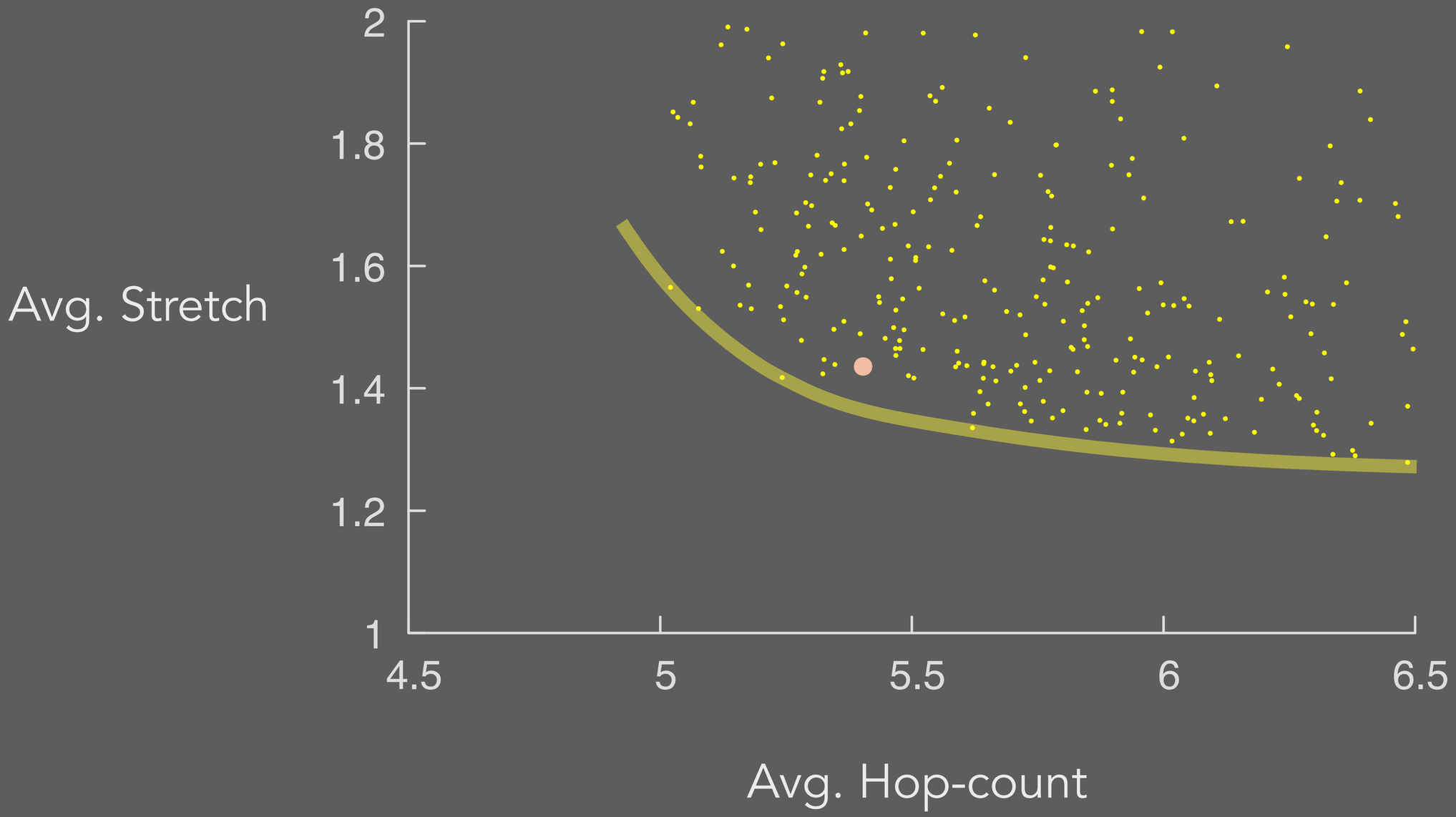
Traffic matrix



A large number of design points



+Grid is a low-efficiency motif



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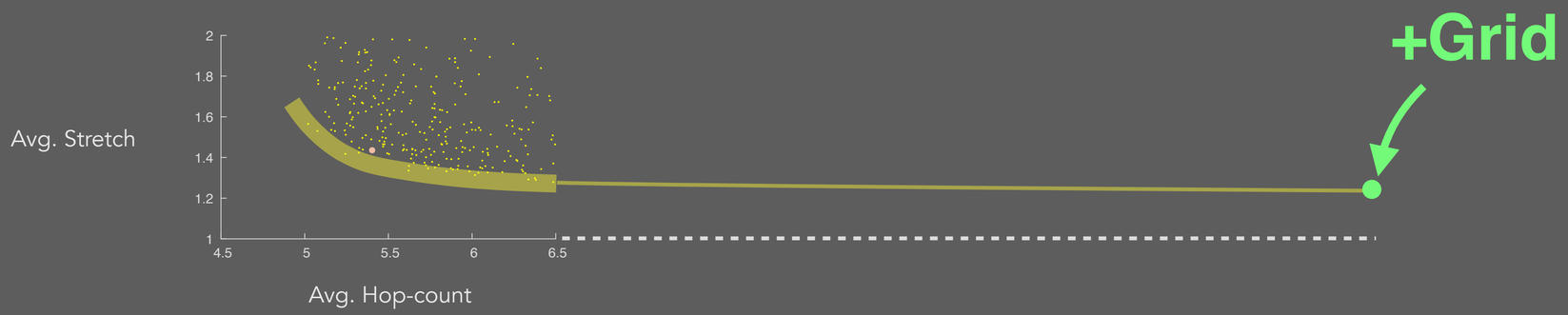

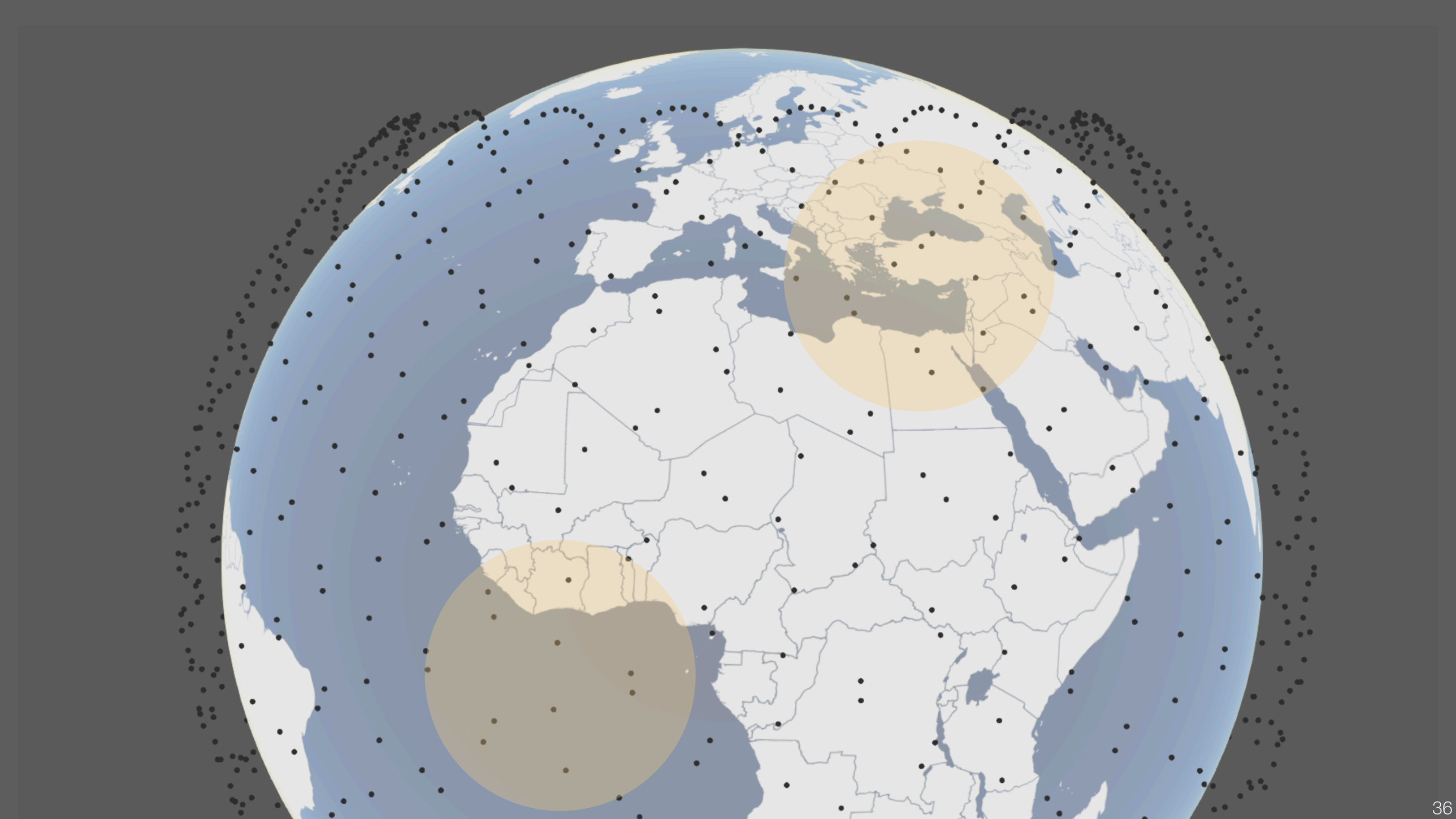

Performance improvements

Starlink	54%
Kuiper	45%
40^2	48%

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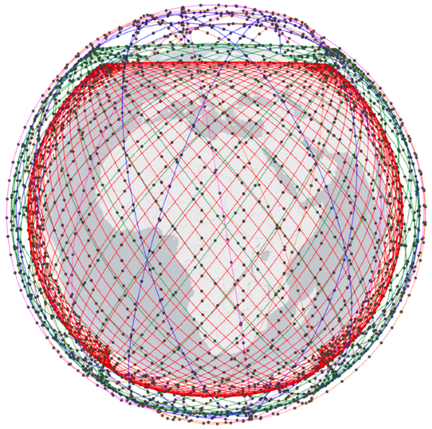
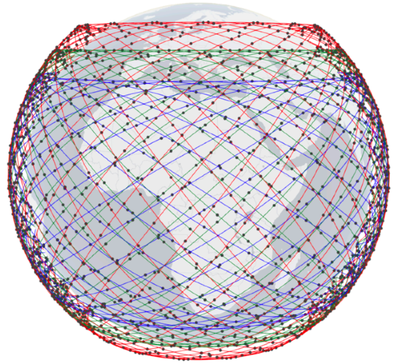
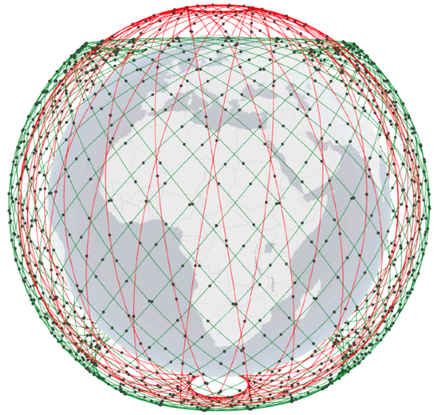
Hypatia

A simulation and visualization tool for satellite networks

IMC 2020, Best Paper Award

Exploring the "Internet from space" with HYPATIA

Simon Kassing*, Debopam Bhattacherjee*, André Baptista Águas, Jens Eirik Saethre, Ankit Singla
ETH Zürich

Satellite trajectories

Network topology

Ground stations

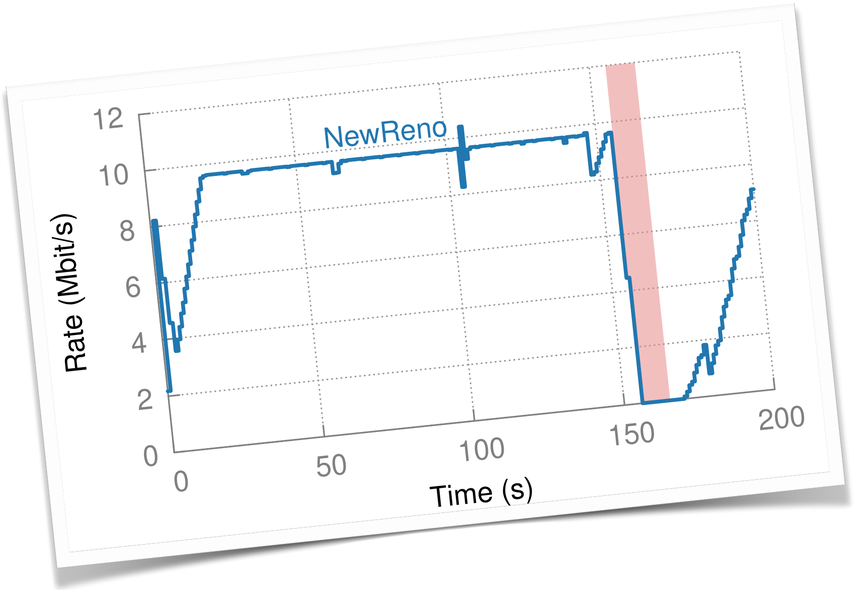
Traffic flows

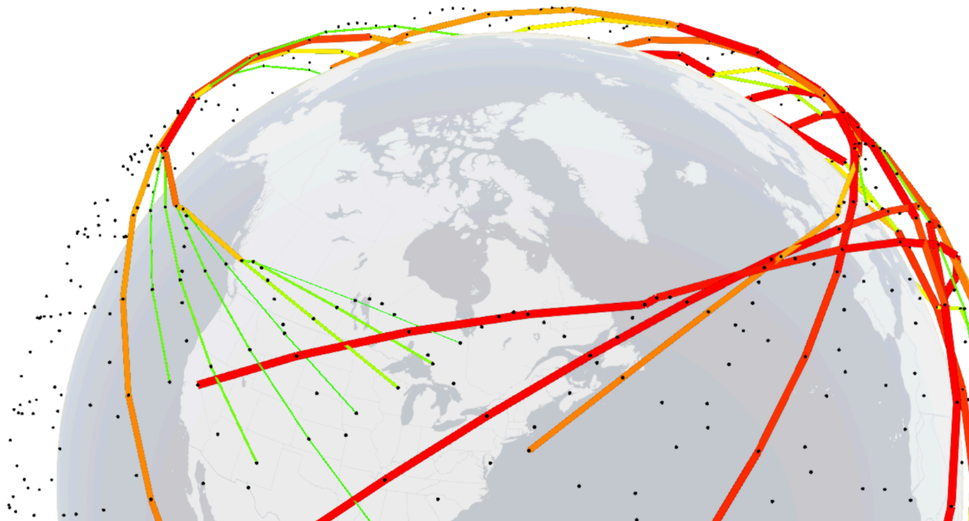
Extends ns-3

LEO dynamics

Precomputed states

Cesium 3D library





Experiment setup

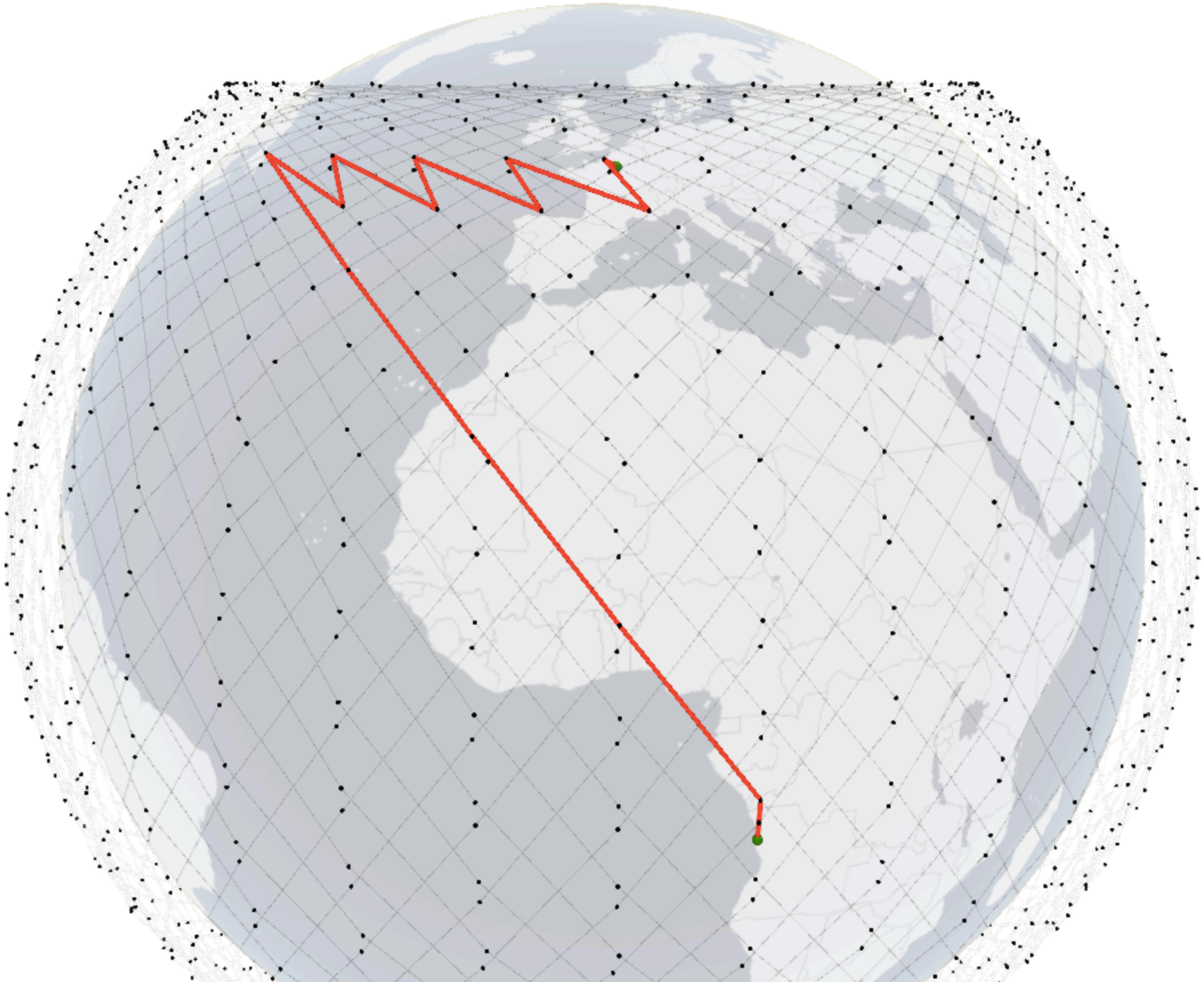
First shell of Kuiper

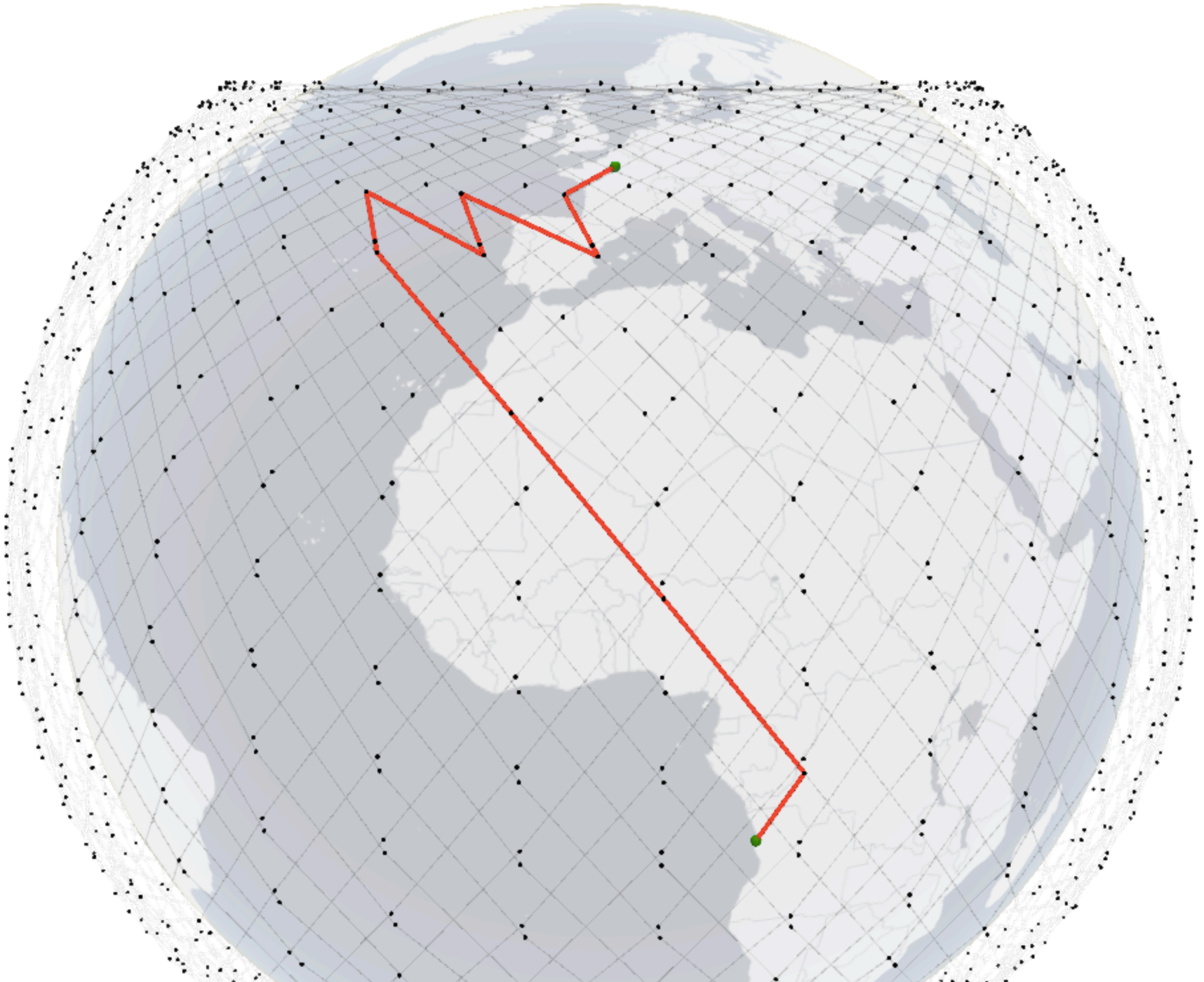
- 630 km height
- 34 orbits, each with 34 satellites
- 51.9° inclination

Connectivity is +Grid, routing is shortest path

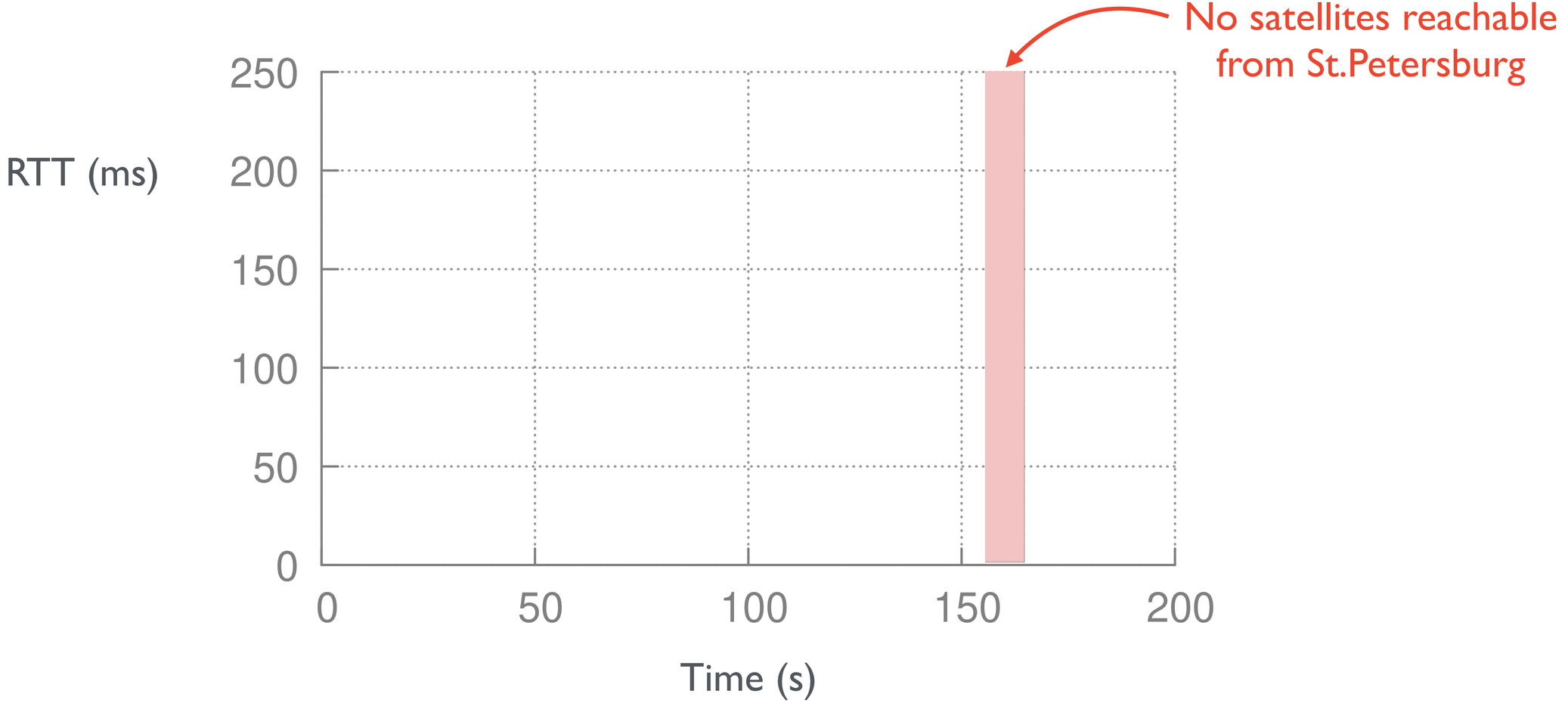
Ground stations in top-100 most populous cities

All links are 10 Mbps



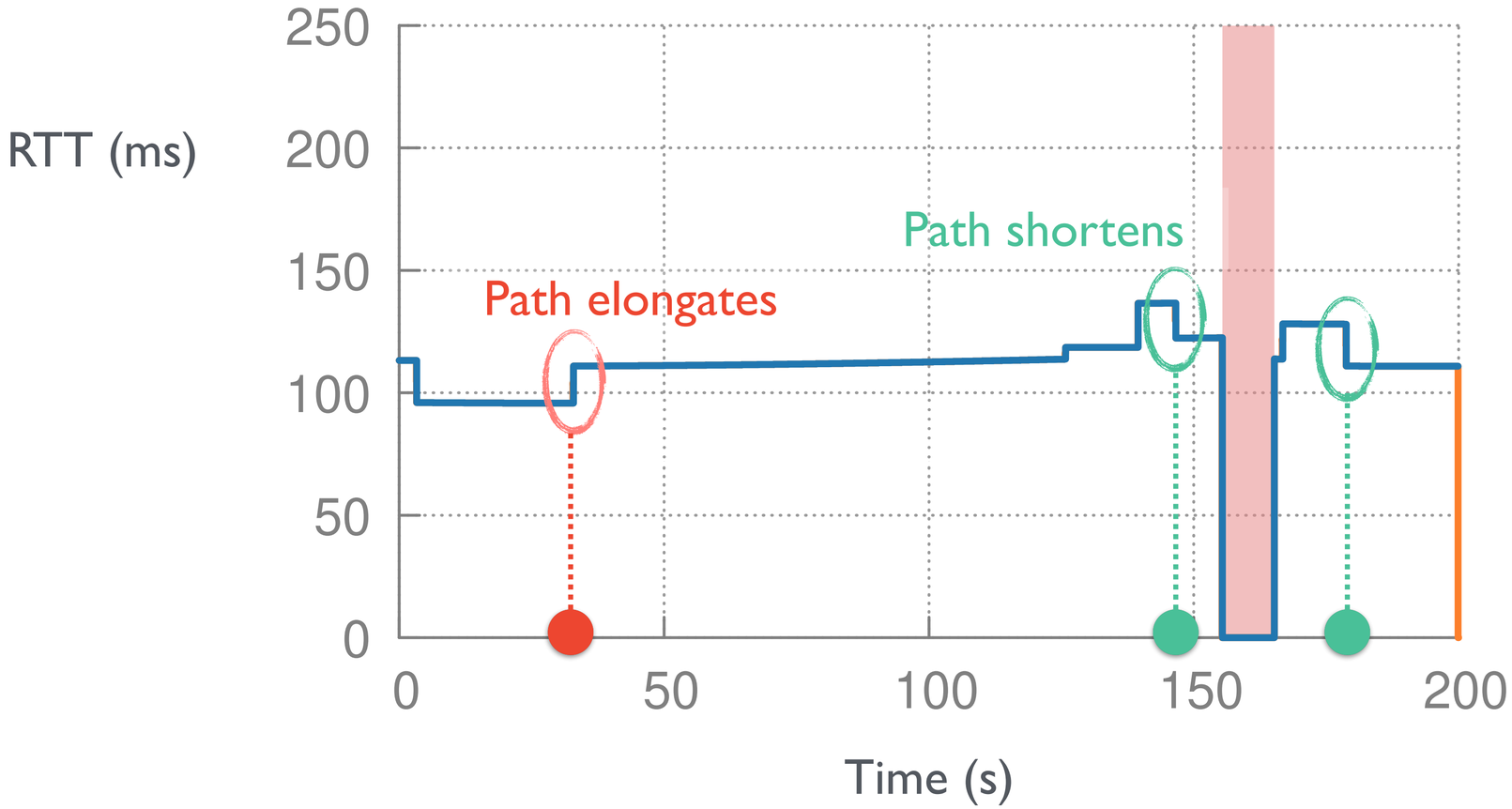


RTT fluctuation: Rio de Janeiro to St. Petersburg



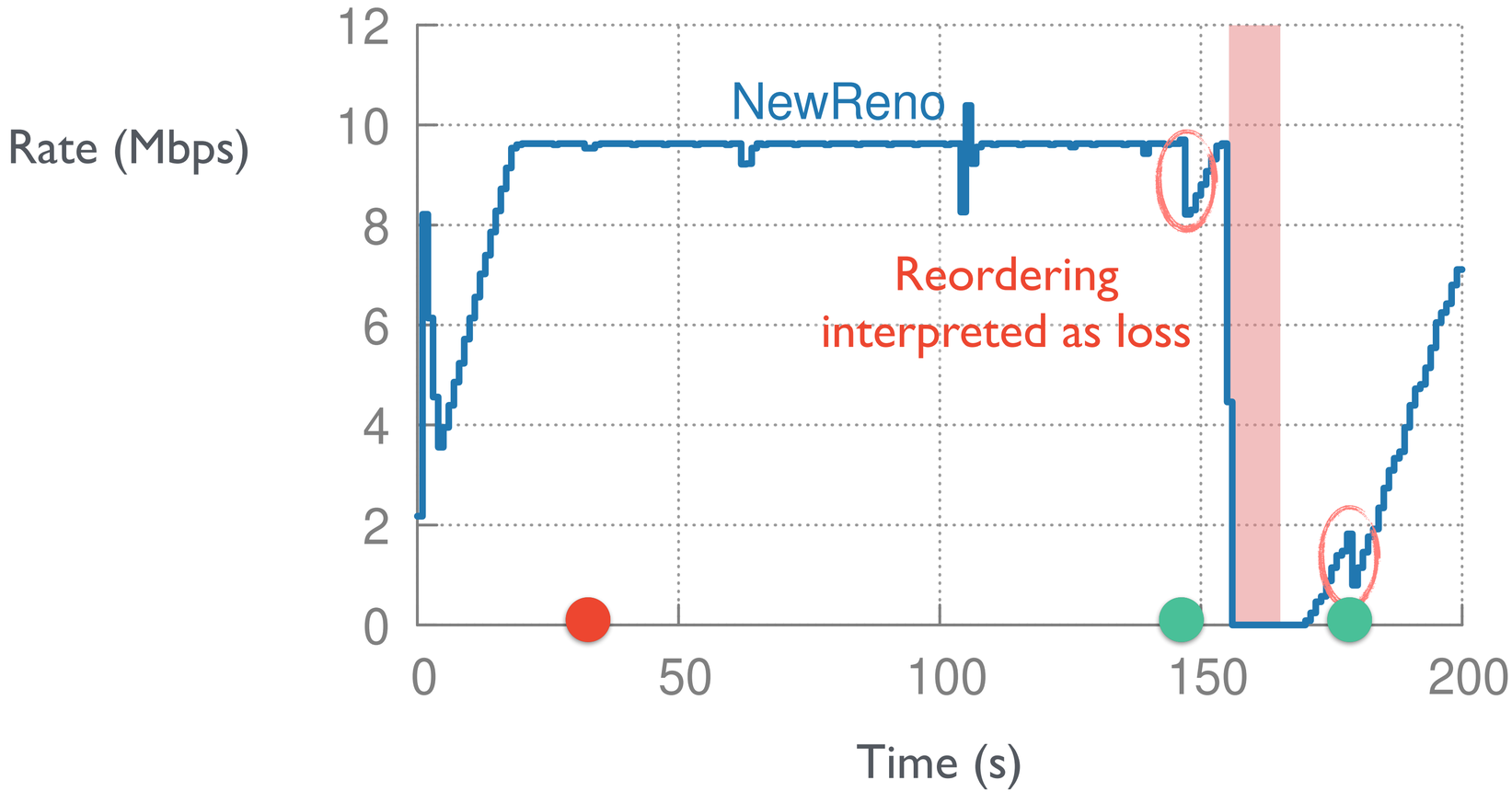
RTT fluctuation: Rio de Janeiro to St. Petersburg

This is without any other traffic in the network



Impact on loss-based CC is small

This is without any other traffic in the network



Delay-based CC suffers

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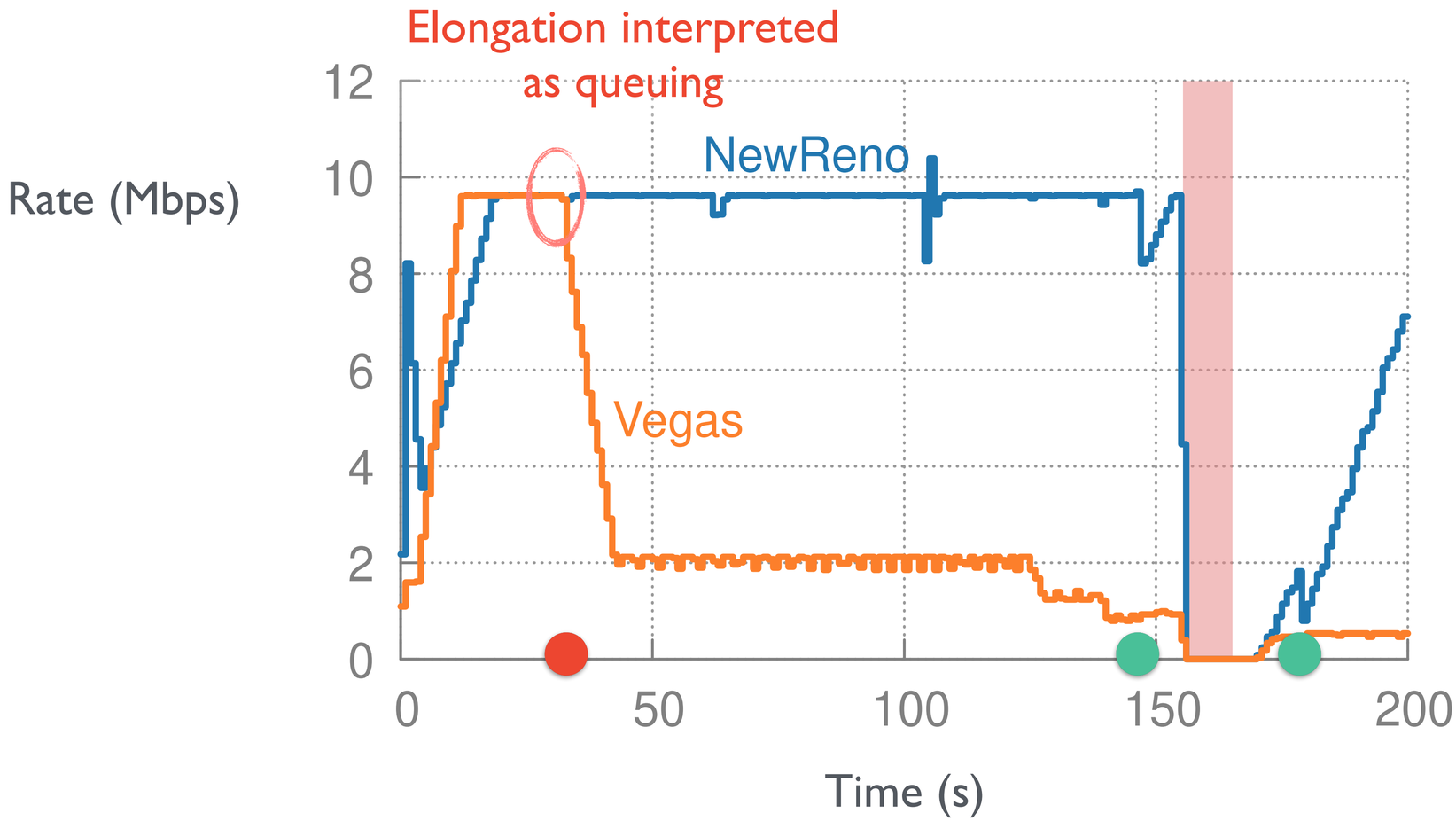


RTT variation and congestion control

RTT changes can hamper delay-based CC

Loss-based CC is also problematic

- Typically, able to maintain high rate
- But unlucky short flows can suffer
- Also suffers the known issue of increased latency

Further work needed on CC,

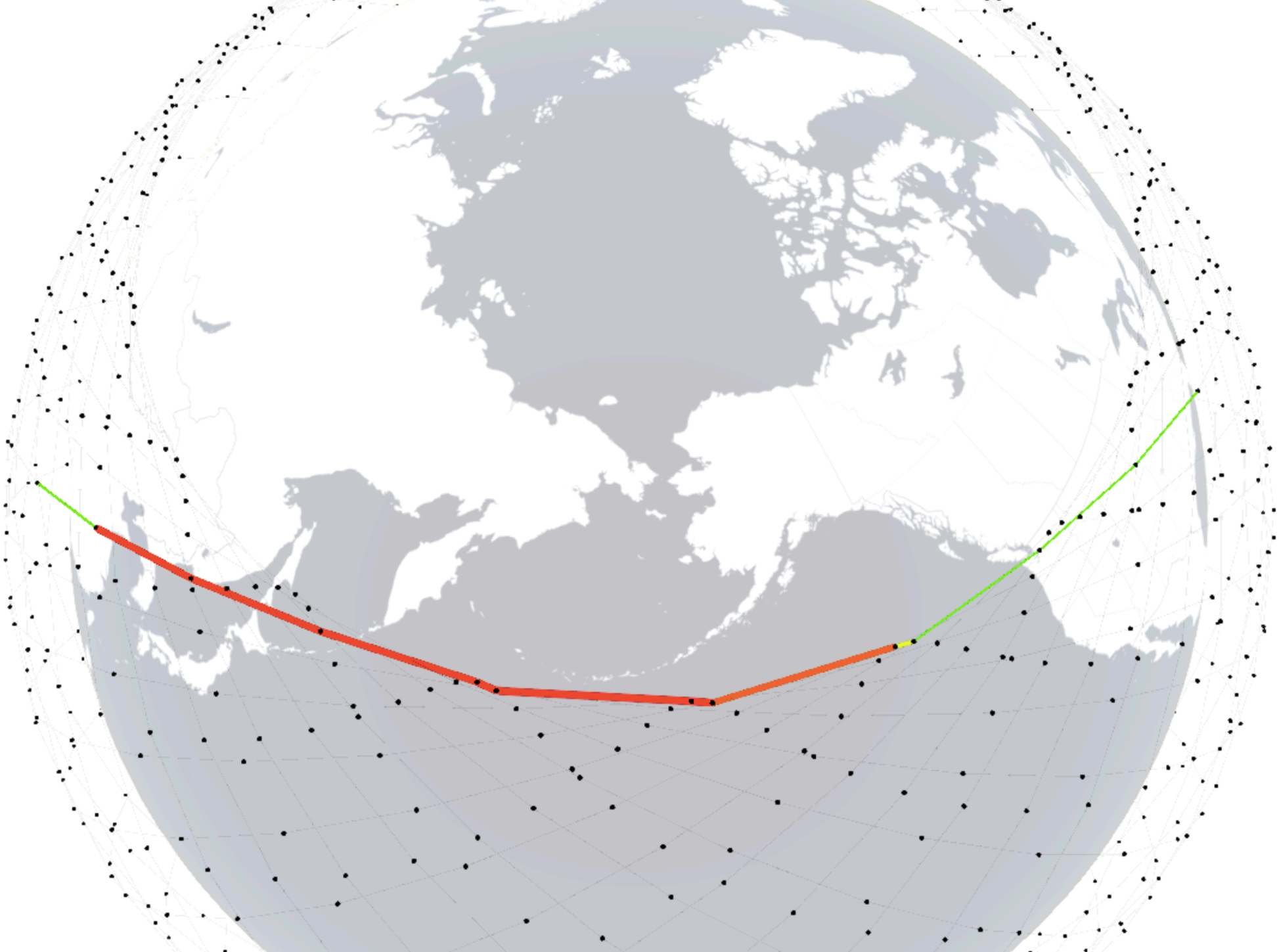
especially, analysis of more recent delay-based protocols

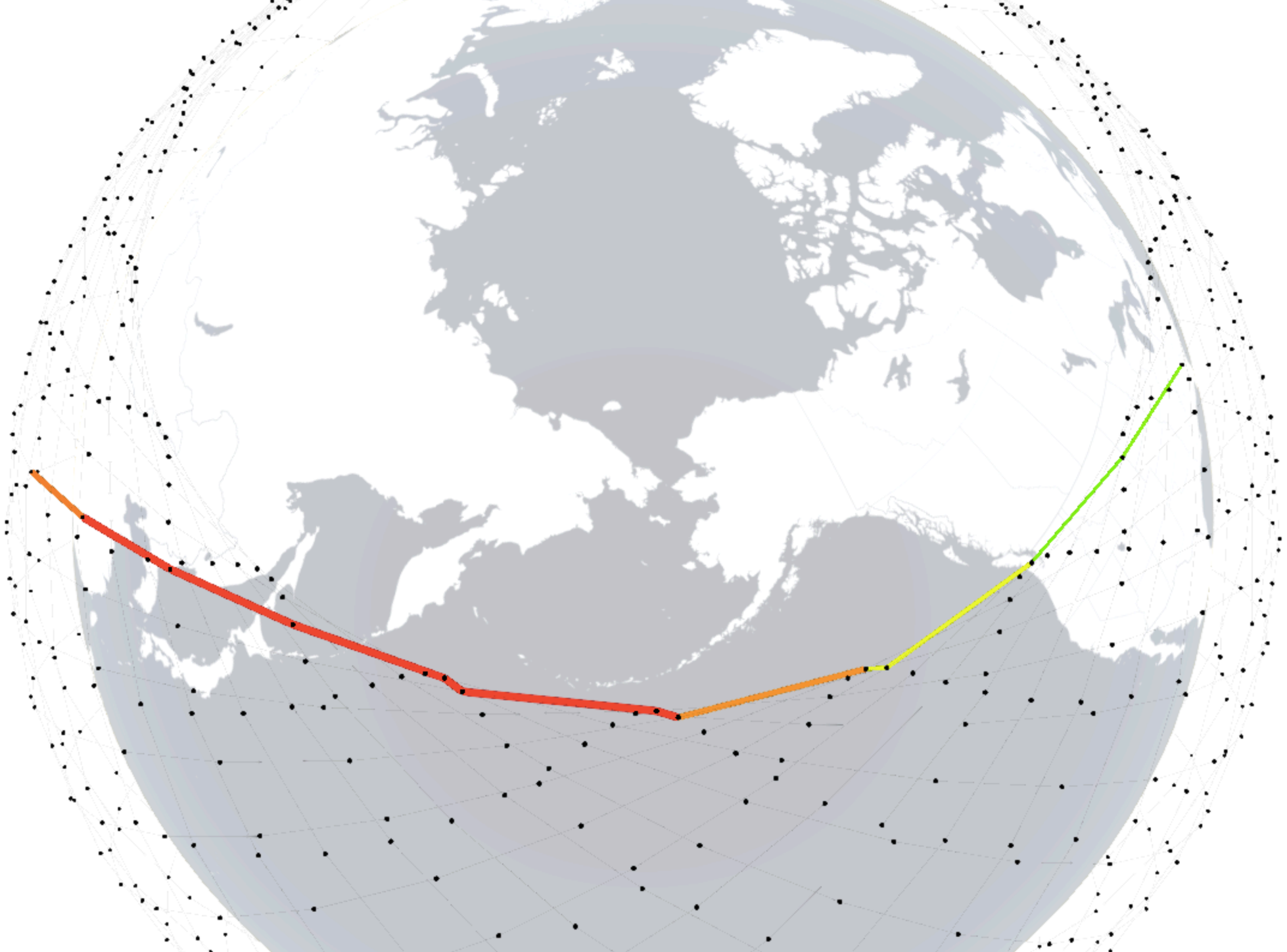
Path structure change has network-wide impact

Few link changes per city-pair per minute

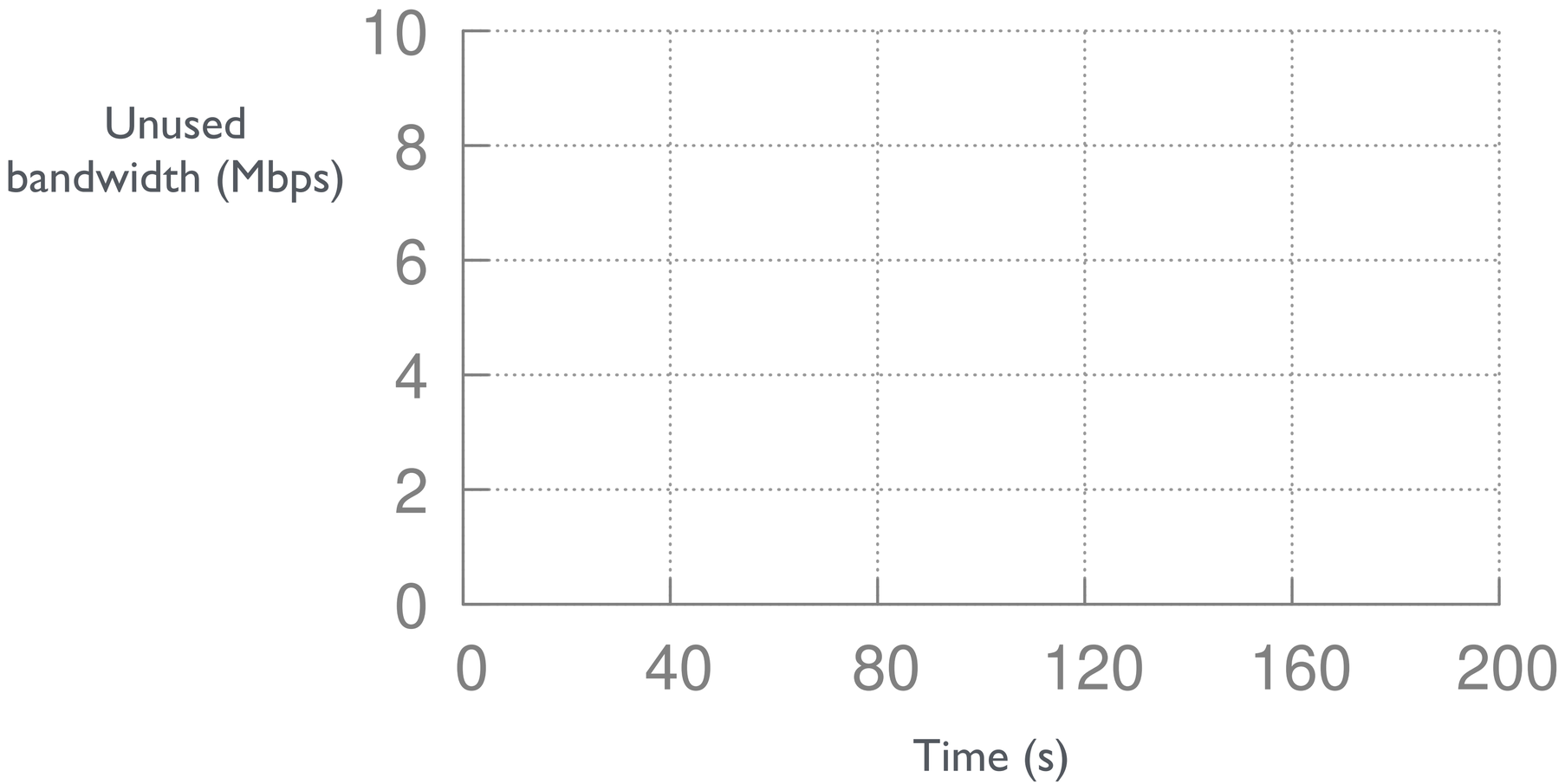
But large number of changes network-wide

An uncongested link can suddenly see added traffic





How well does TCP adapt?



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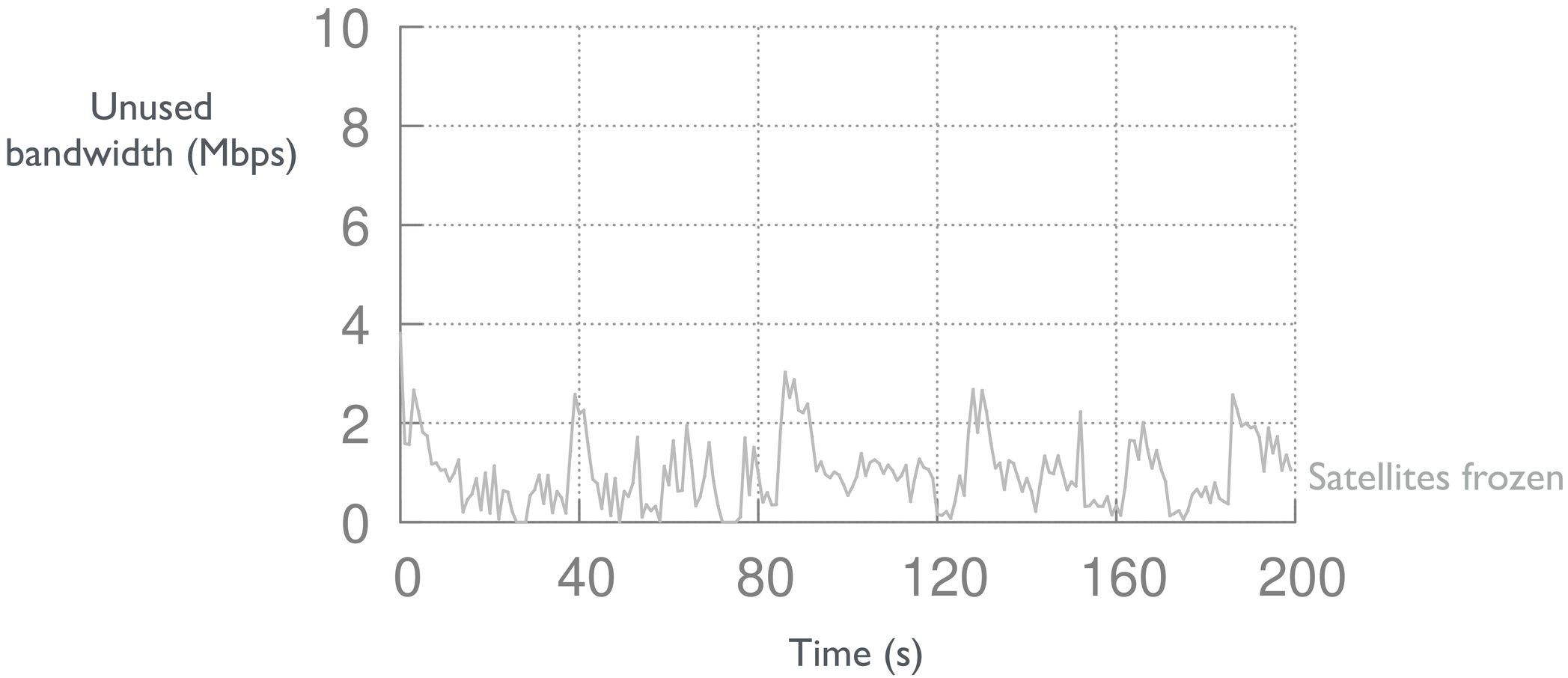
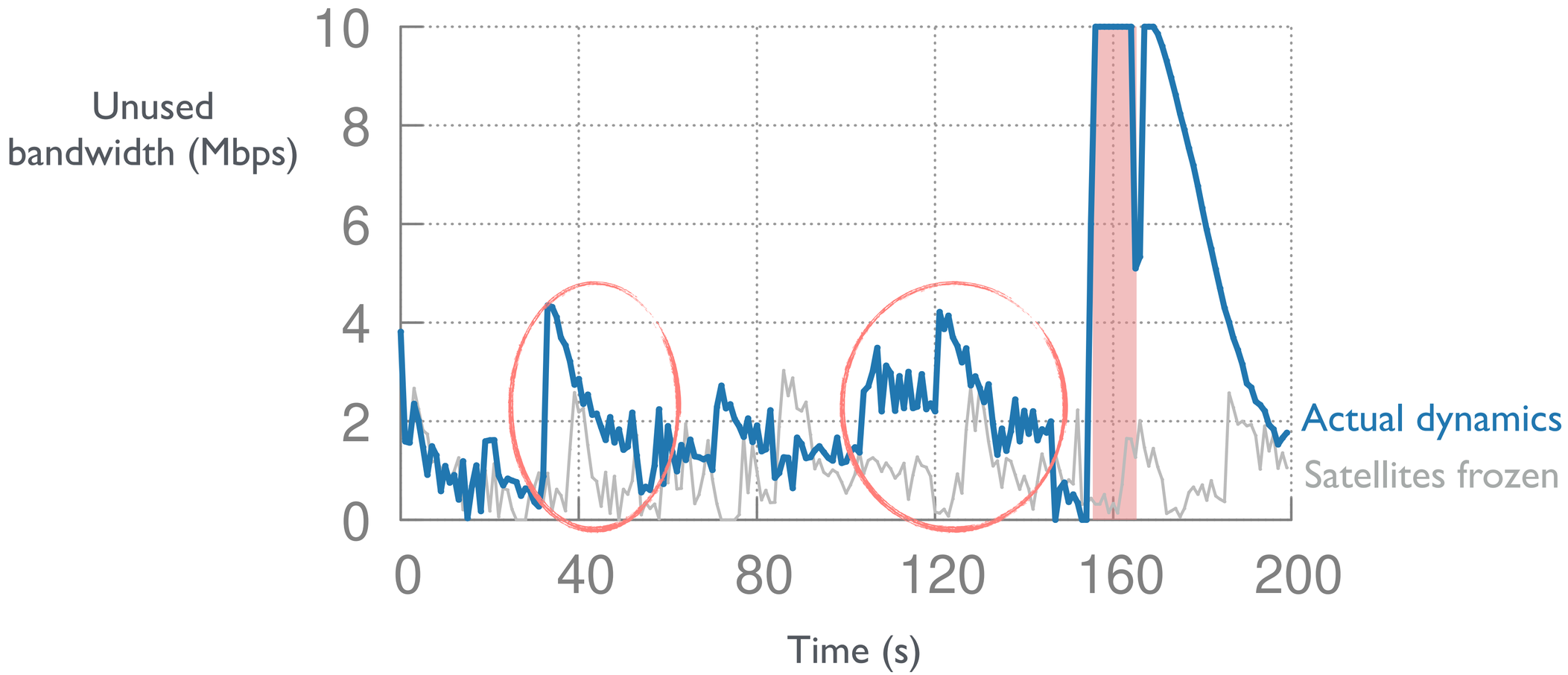


TCP doesn't adapt fast



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Challenge for transport: fast convergence

Challenge for TE: planning across time

Wide open space for research

In-orbit Computing: an Outlandish Thought Experiment? **HotNets '20**
Debopam Bhattacherjee*, Simon Kassing*, Melissa Licciardello, Ankit Singla

"Internet from Space" without Inter-Satellite Links? **HotNets '20**
Yannick Hauri, Debopam Bhattacherjee, Manuel Grossmann, Ankit Singla

Internet Backbones in Space, **SIGCOMM CCR '20**
Giacomo Giuliari, Tobias Klenze, Markus Legner, David Basin, Adrian Perrig, Ankit Singla

Gearing up for the 21st Century Space Race, **HotNets '18**
Debopam Bhattacherjee, Waqar Aqeel, Ilker Nadi Bozkurt, Anthony Aguirre,
Balakrishnan Chandrasekaran, P. Brighten Godfrey, Gregory Laughlin, Bruce Maggs, Ankit Singla

SatNetLab: a platform for experimentation

Inspired by PlanetLab

Start with university sites with SpaceX equipment

- one-time cost — CHF 500 dish + installation
- operational yearly cost — CHF 1500

With a nucleus, likely to get Starlink users involved

Facilitate measurements, test congestion control

App performance under loss and delay variation

If we build it, would you come? :)

Questions?

asingla@ethz.ch