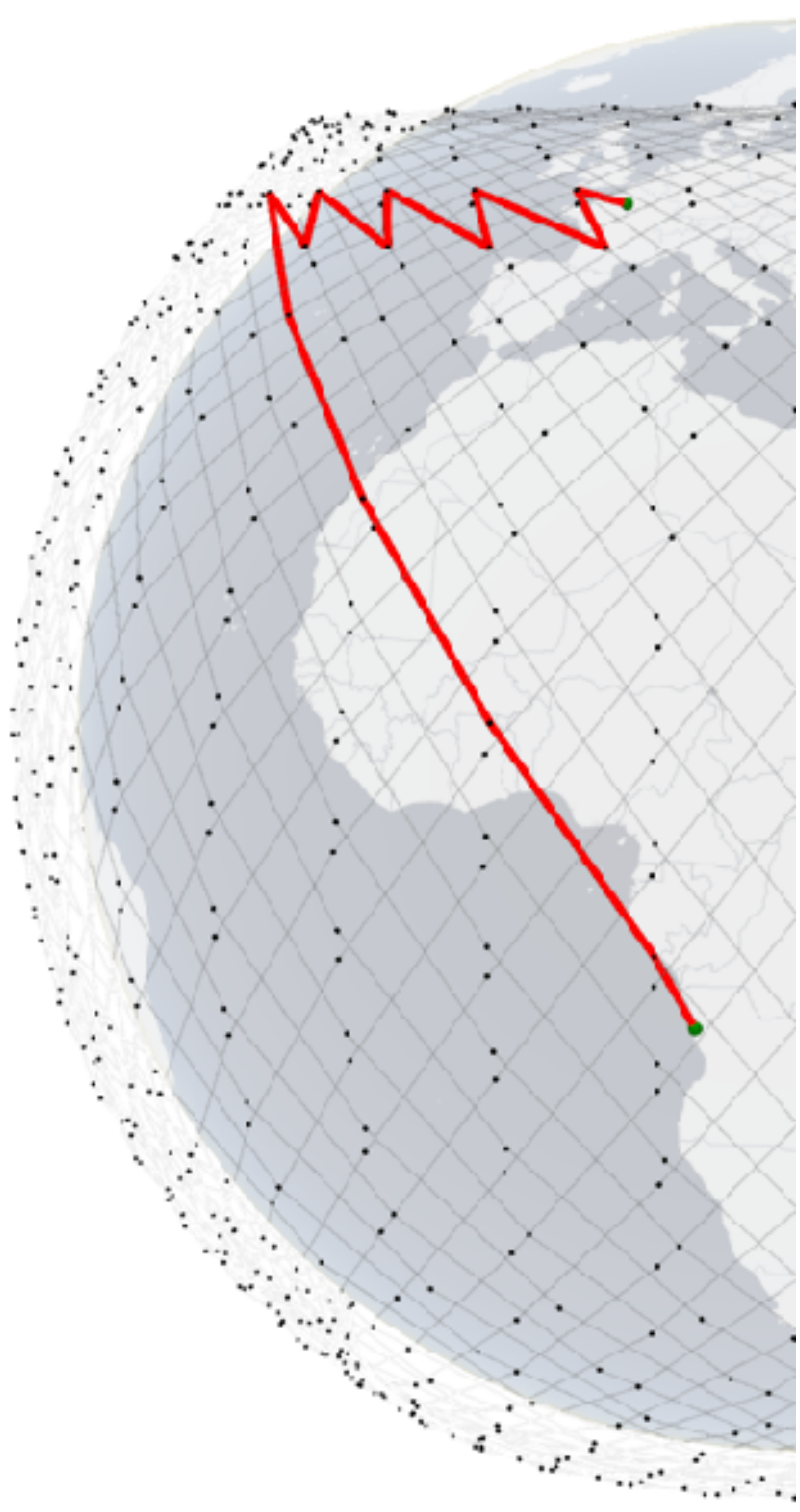
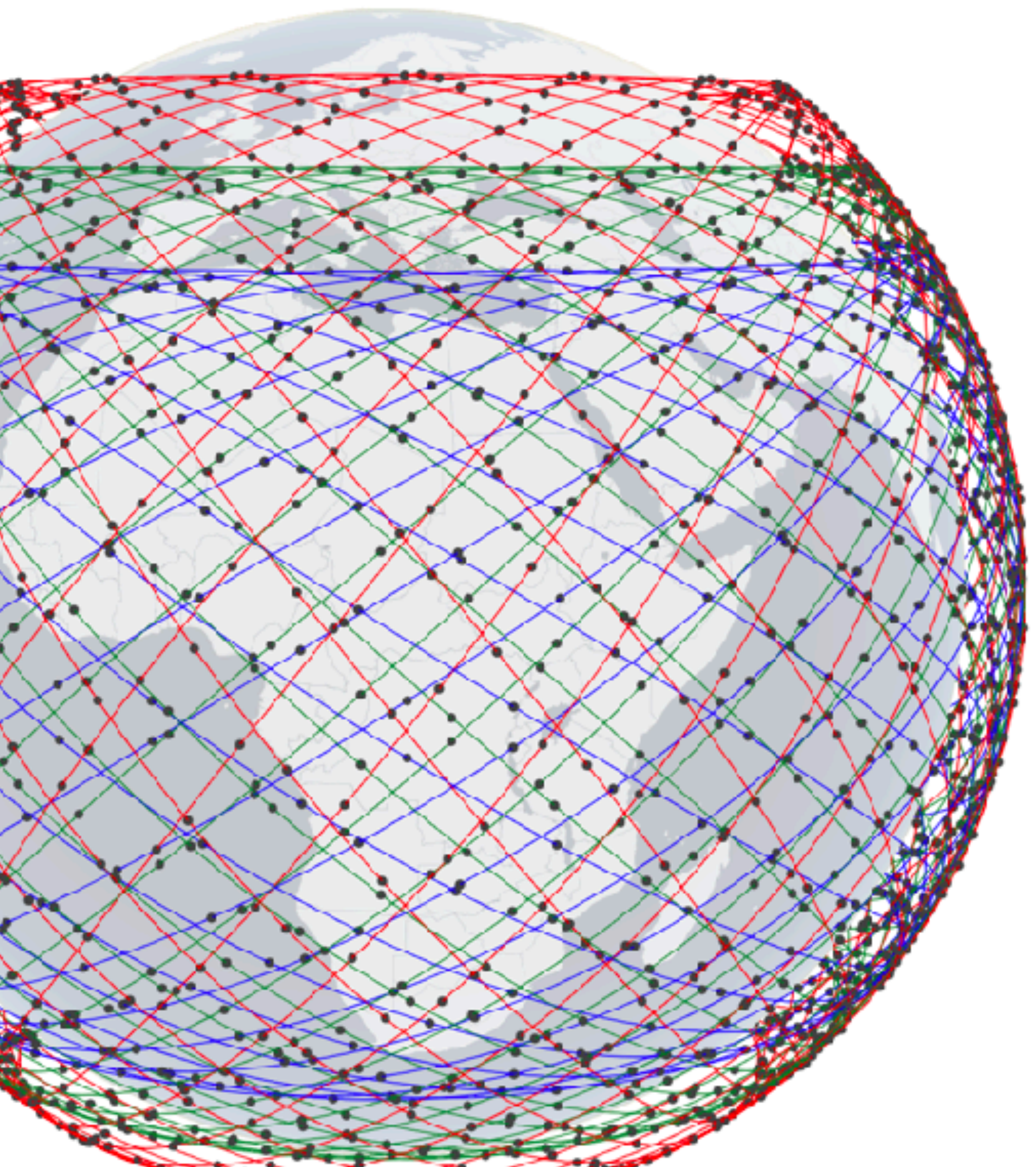


Towards Measuring Low-Earth Orbit Network Performance

Debopam Bhattacherjee
Microsoft Research

bdebopam.github.io



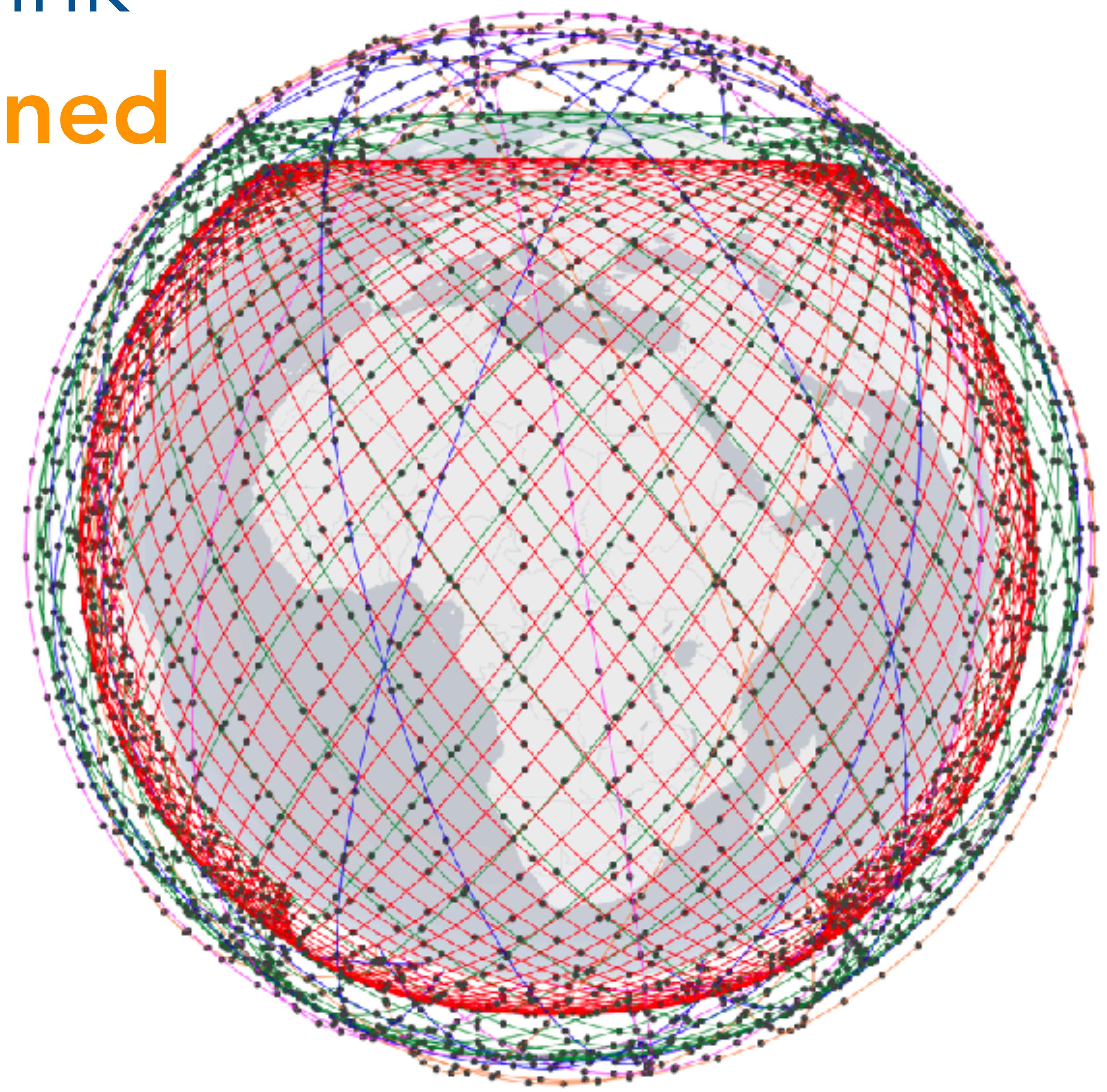
Agenda

- **What is the LEO hype about?**
- Understanding LEO networks
- LEO topology design
- LEO simulations
- A global testbed & beyond

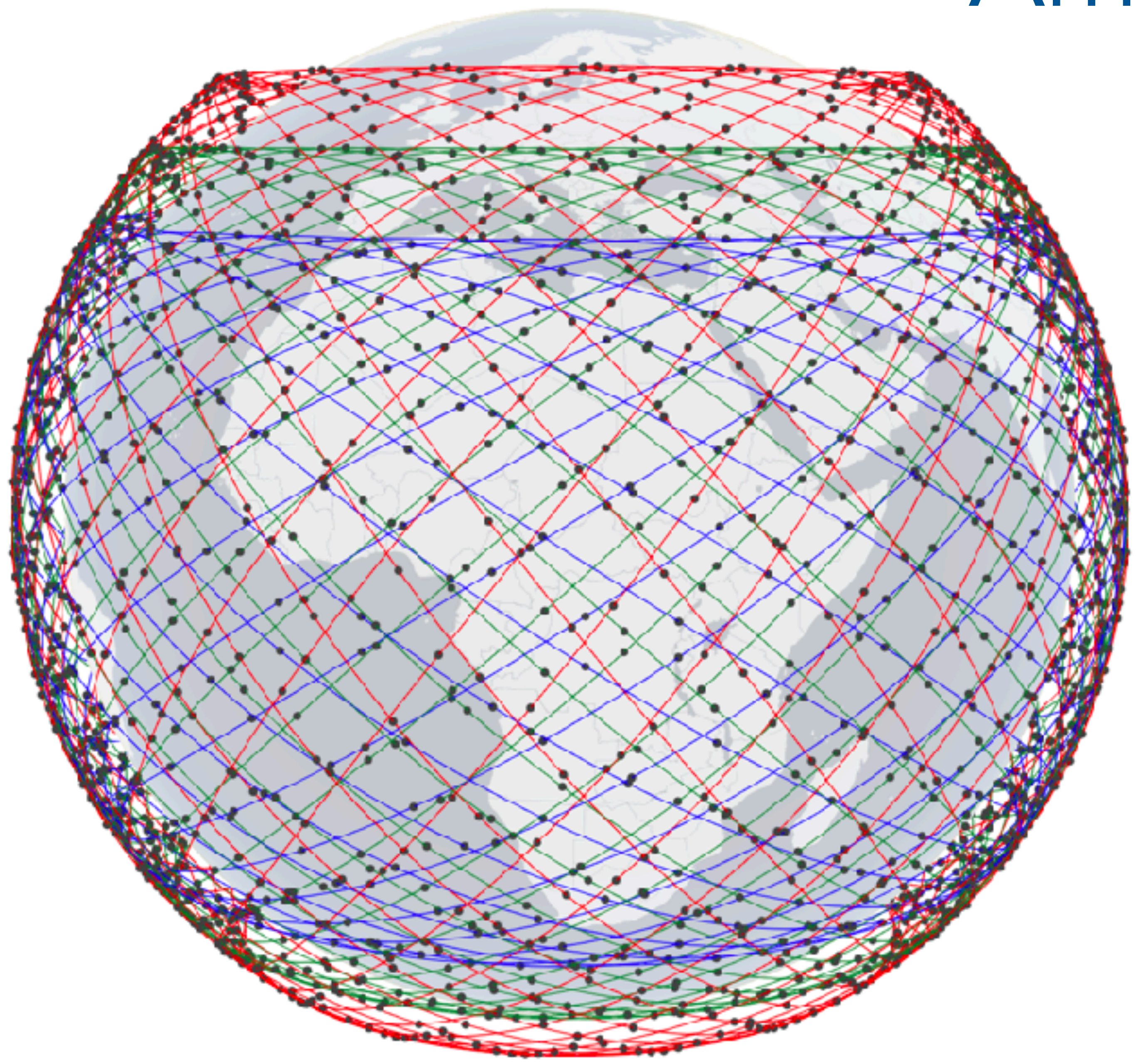
Tens of thousands of satellites

SpaceX Starlink

42,000 planned

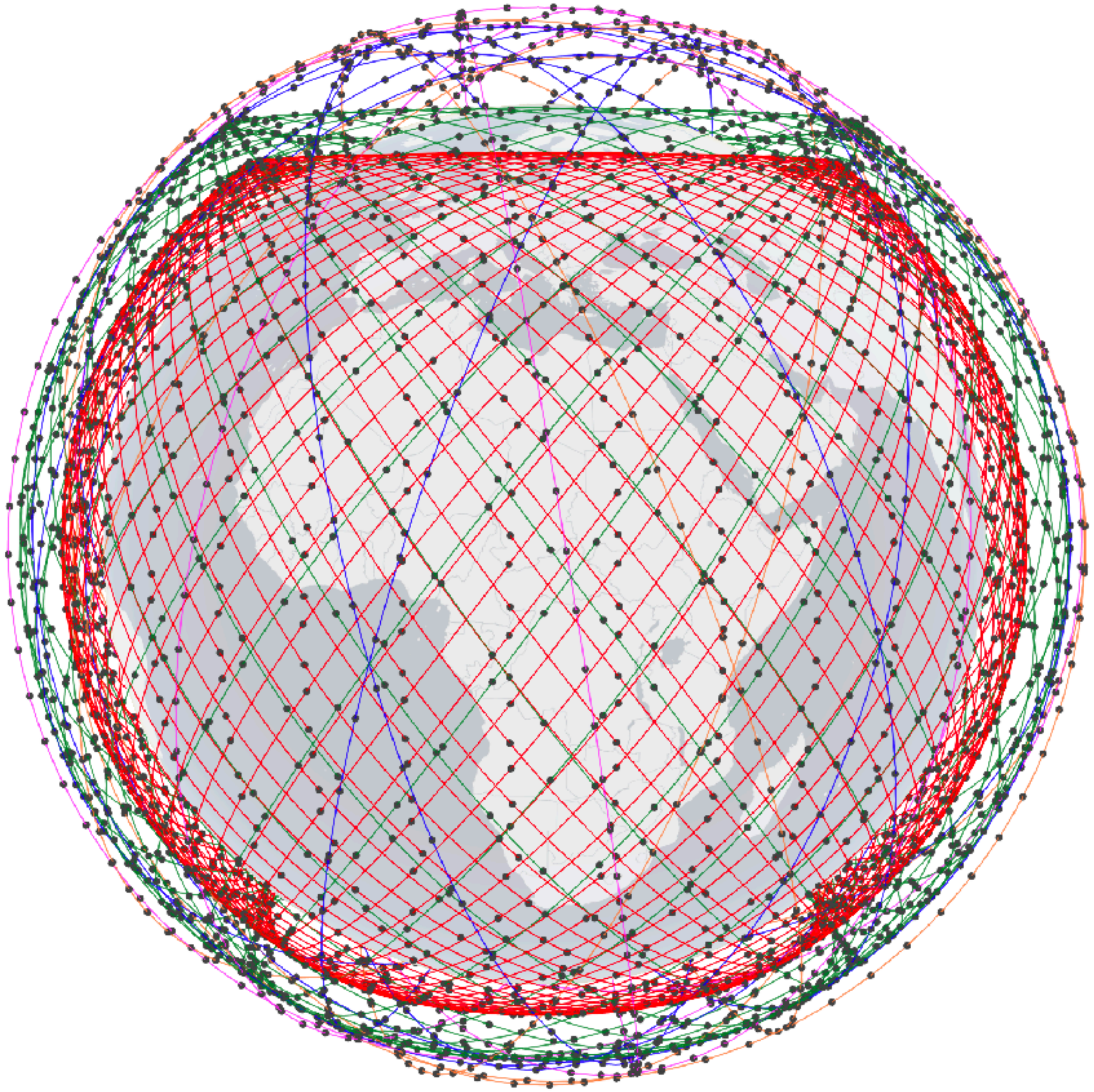


Amazon Kuiper



Telesat, OneWeb, LinkSure, Astrome, GuoWang, ...

SpaceX Starlink

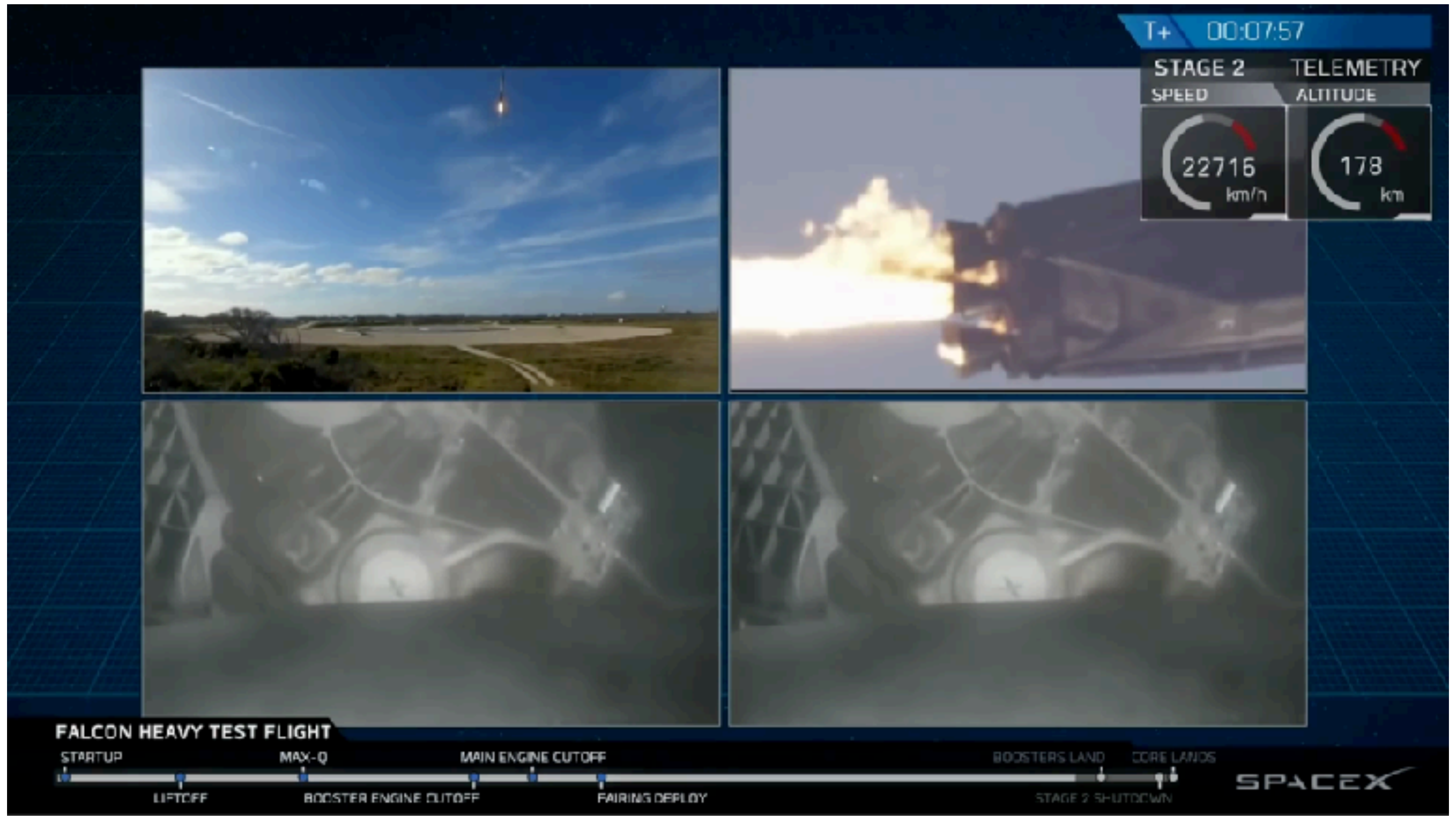


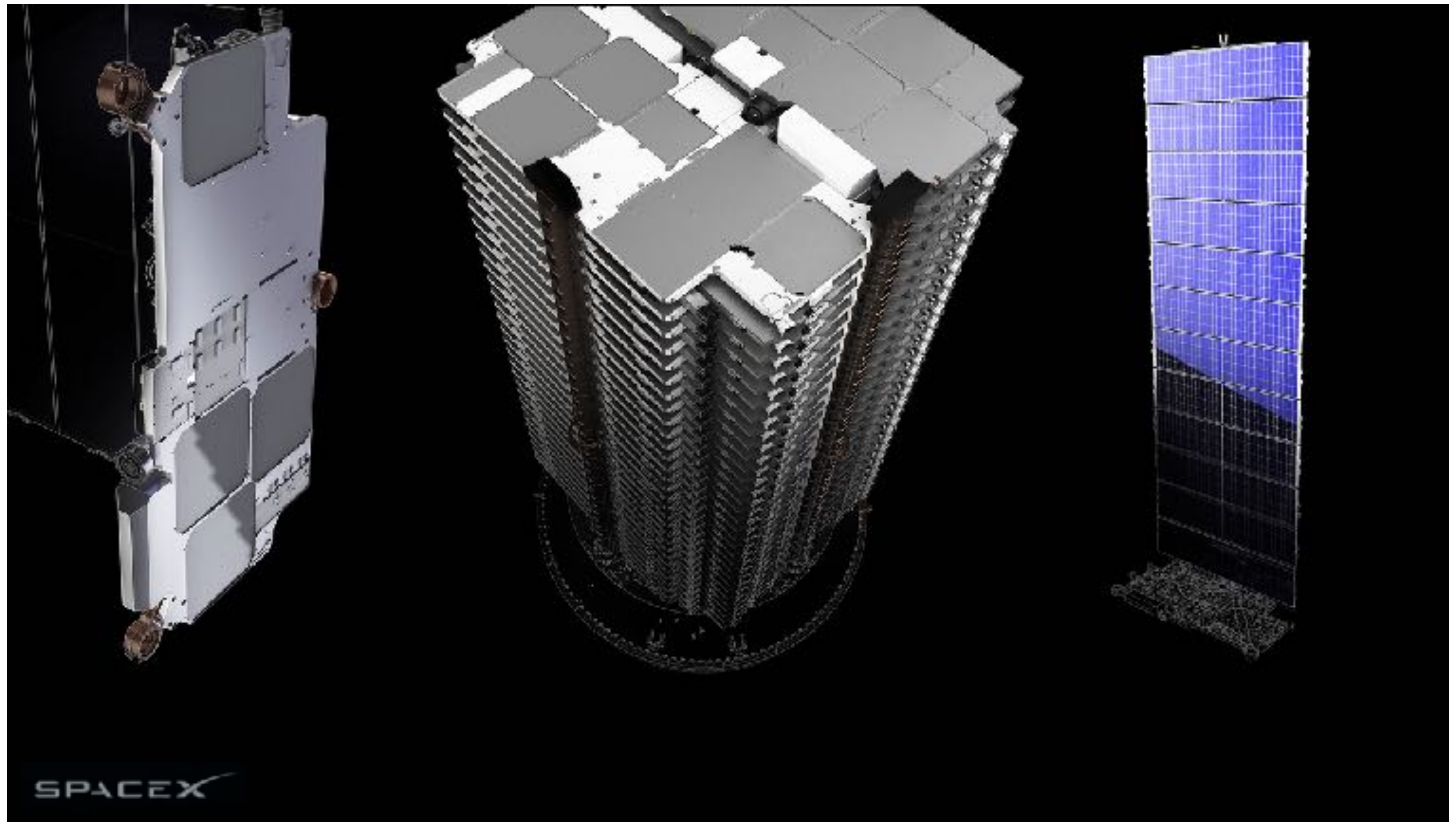
- **3K+** in orbit [Largest]
- Services in **40 countries**
- Soon to use **Starship** (~400 sats/launch) instead of Falcon 9 (60 sats/launch)

Isn’t satellite networking old?

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

Recent advances





10-20G / up to 8000 km

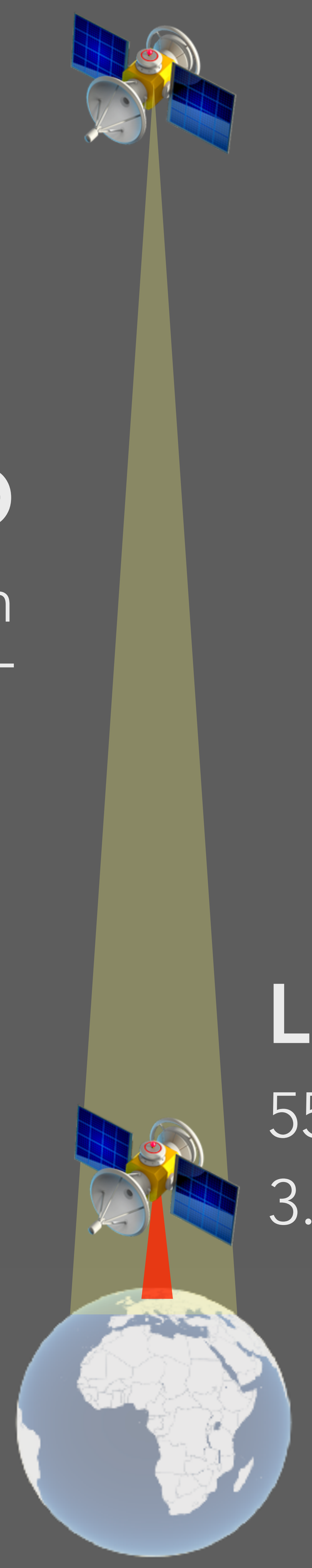
Global low-latency Internet coverage

- **3.7 billion (49%)** people still not online.
- **607 million** people reside in areas with no mobile data coverage.
- **> 5 billion** people more than 10 km away from any fiber optic cable infrastructure.
- **1.6 billion** students (**99%** of students in low and middle-income countries) affected by school closures in 2020.
- **< 1%** of Africa’s retail sales are made online although there exists a huge market.
- **90%** of the Earth’s surface does not have any connectivity although **75 billion** IoT devices are expected to come online by 2025.

Agenda

- What is the LEO hype about?
- **Understanding LEO networks**
- LEO topology design
- LEO simulations
- A global testbed & beyond

1. Altitude



GEO

35,768 km

~238.4 ms RTT

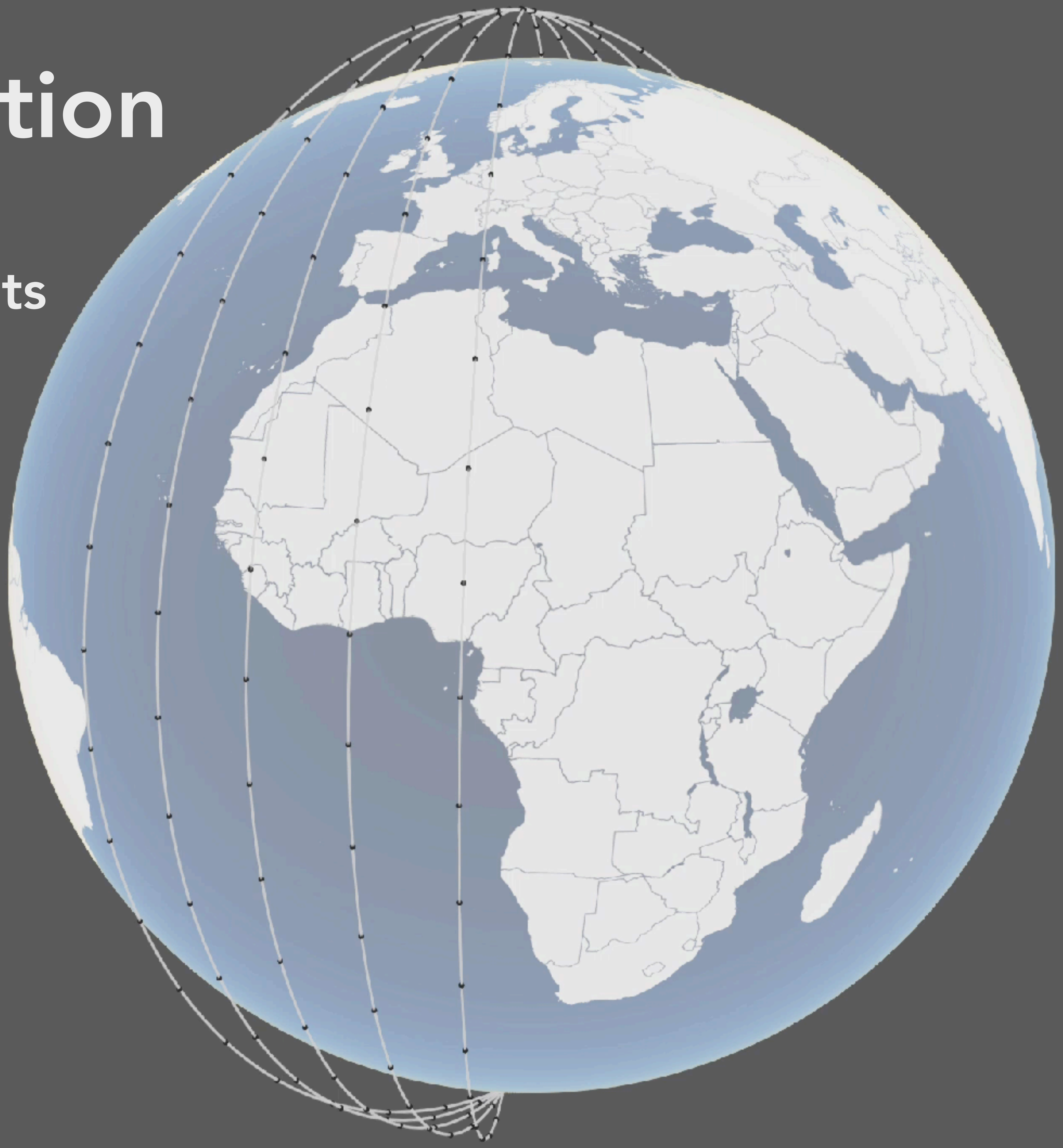
LEO

550 km

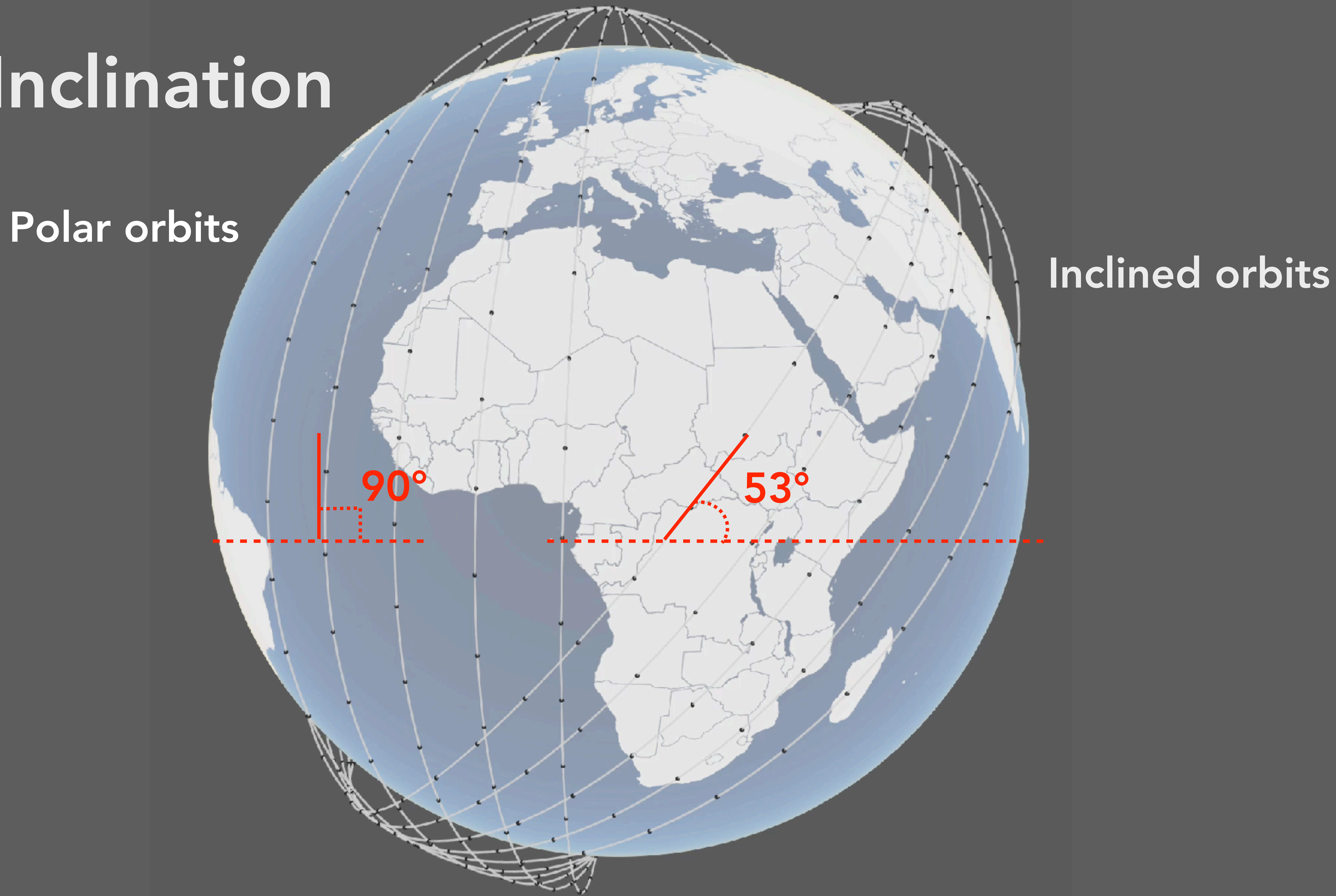
3.7 ms RTT

2. Inclination

Polar orbits



2. Inclination

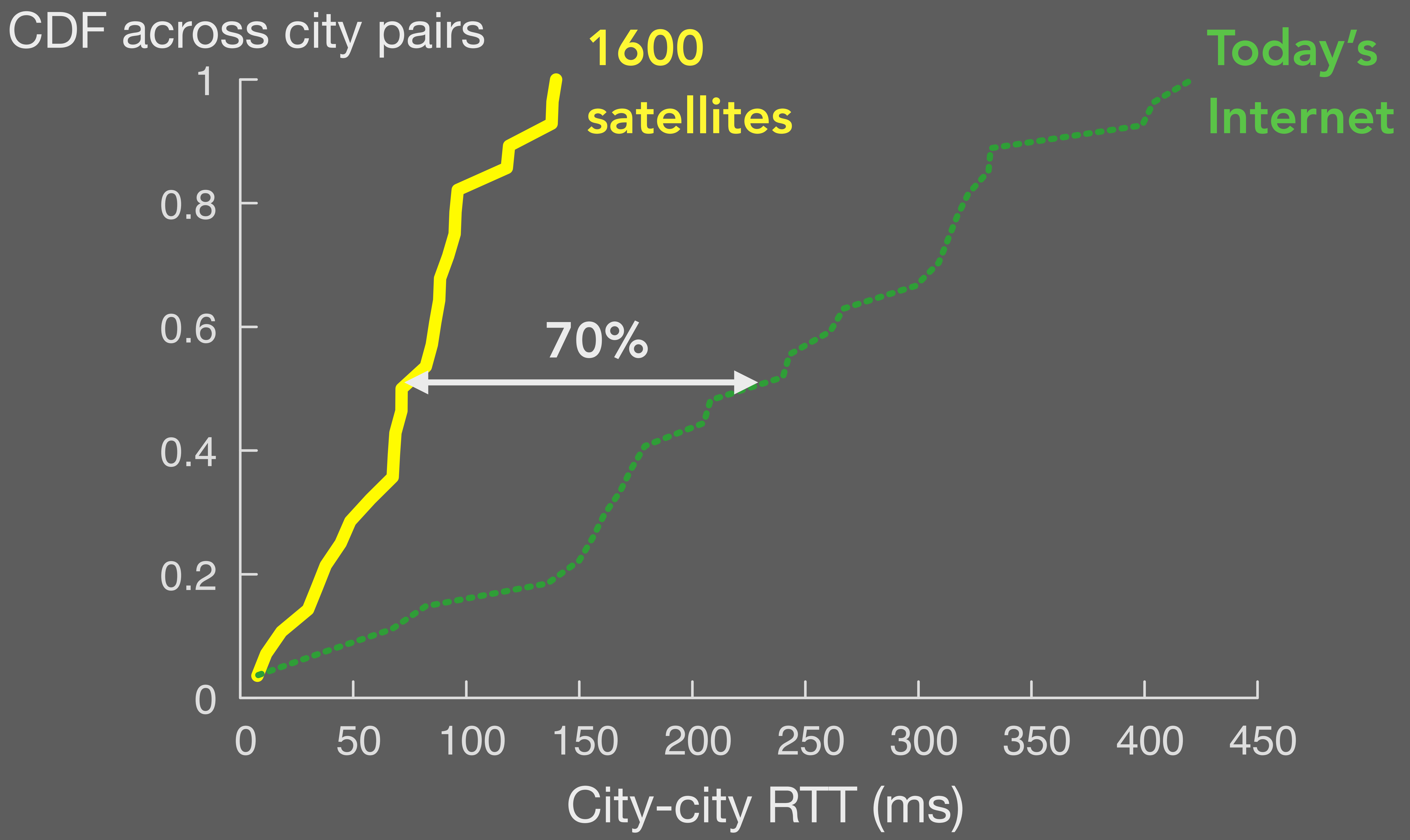


3. Connectivity

+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)

5. System dynamics

Agenda

- What is the LEO hype about?
- Understanding LEO networks
- **LEO topology design**
- LEO simulations
- A global testbed & beyond

“Internet from Space” without Inter-satellite Links?

Yannick Hauri, Debopam Bhattacherjee, Manuel Grossmann, Ankit Singla
ETH Zürich

HotNets’20

FCC specification

presumptively acceptable risk and encourage "design for demise," i.e. designing spacecraft so that they burn up completely upon re-entry into the Earth's atmosphere,[450] but maintain the possibility for approval

- No mention of silicon carbide component

Bent-pipe connectivity (BP)

Bent-pipe connectivity (BP)

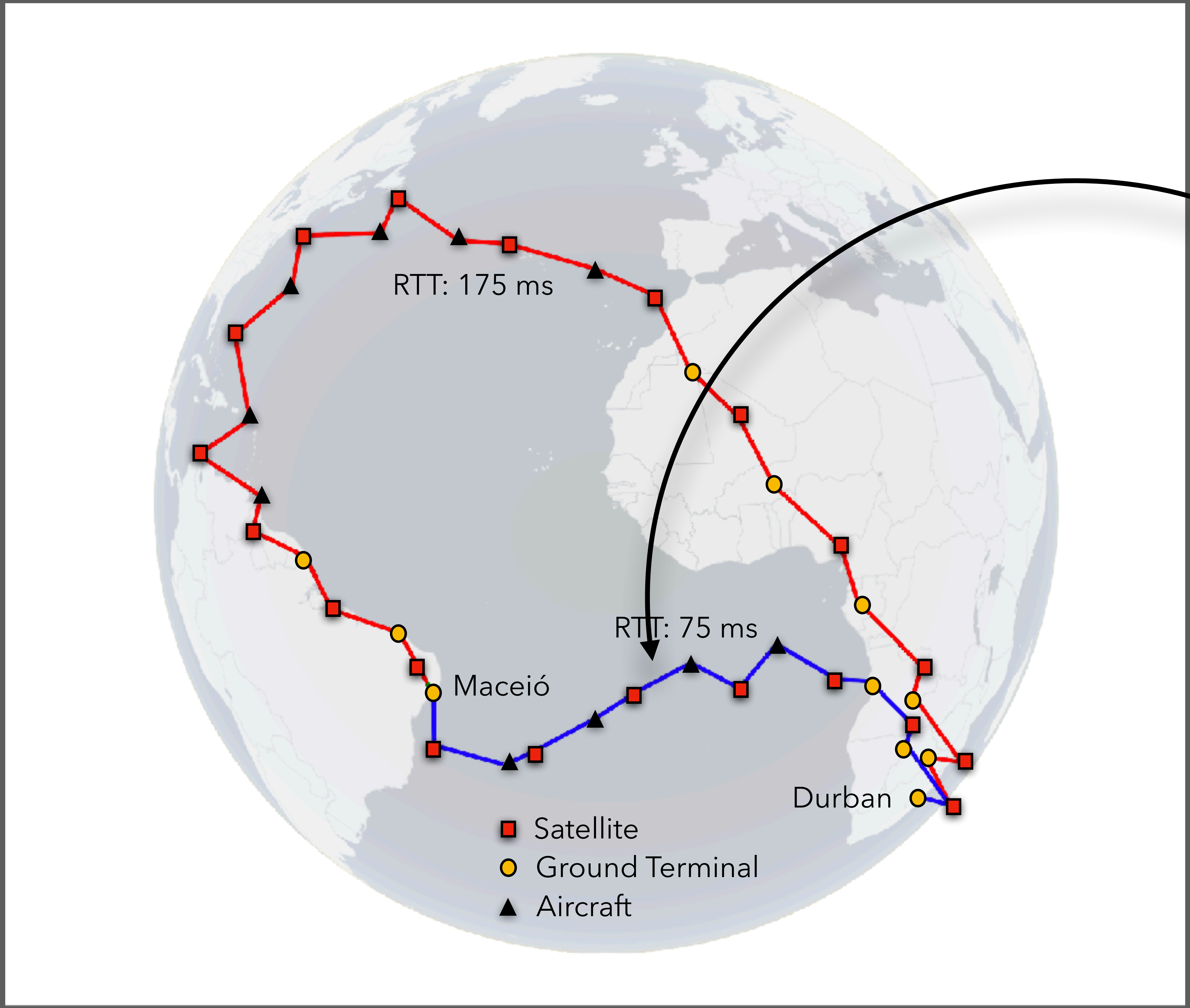
Bent-pipe connectivity (BP)

Bent-pipe connectivity (BP)

ISL versus BP

- Latencies and **variations** thereof
- Impact on network-wide **throughput**
- Resilience to **weather**

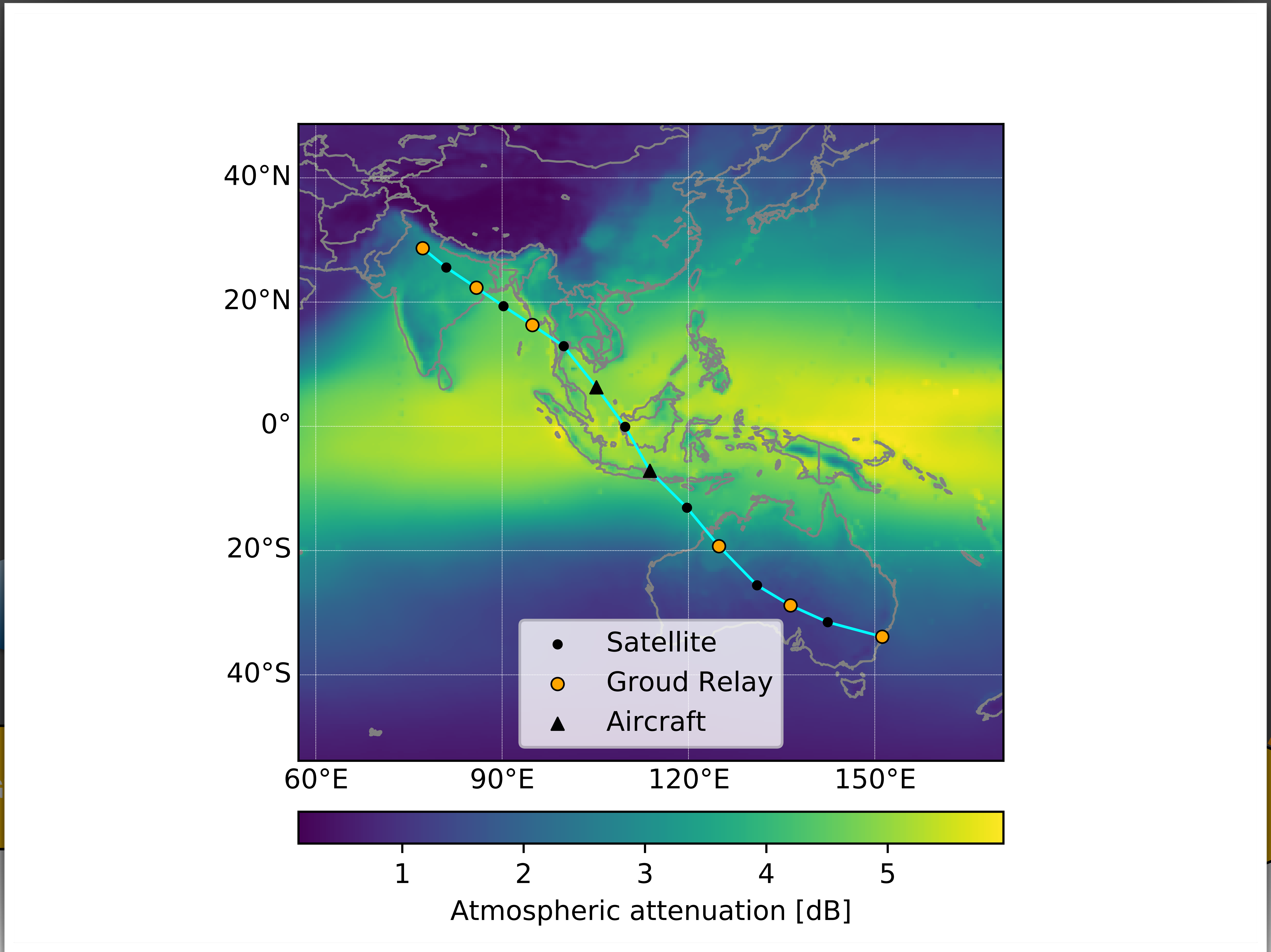
High latency variations in BP



Sparser air traffic over South Atlantic

- Inflation of ~100 ms
- North Atlantic paths get congested

Impact of weather



Starlink deploying ISLs

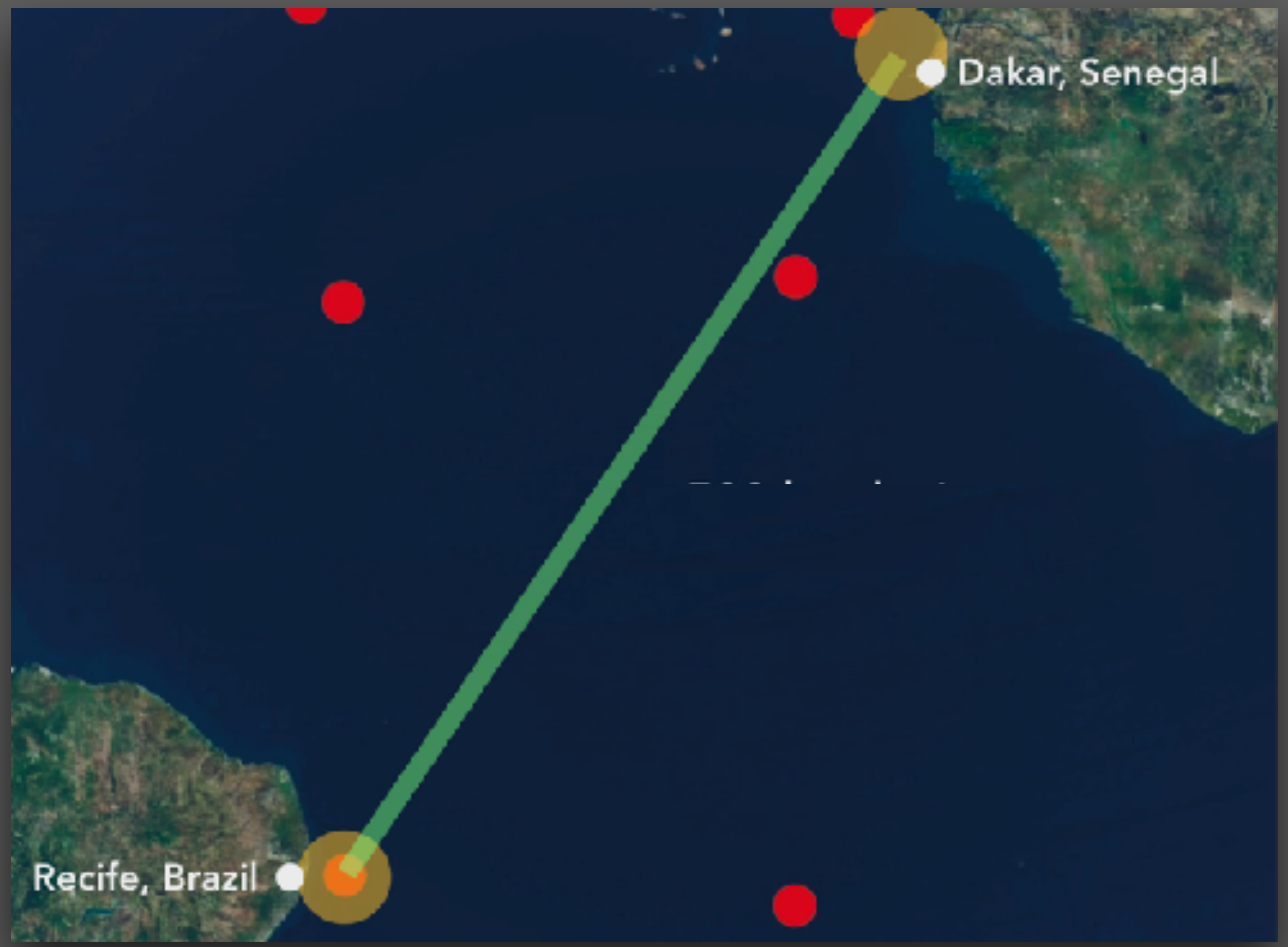
Uncertainties

- ISL capacities?
- Pointing, acquisition, and tracking
- Topology
- OneWeb's no-ISL design

Network topology design at 27,000 km/hour

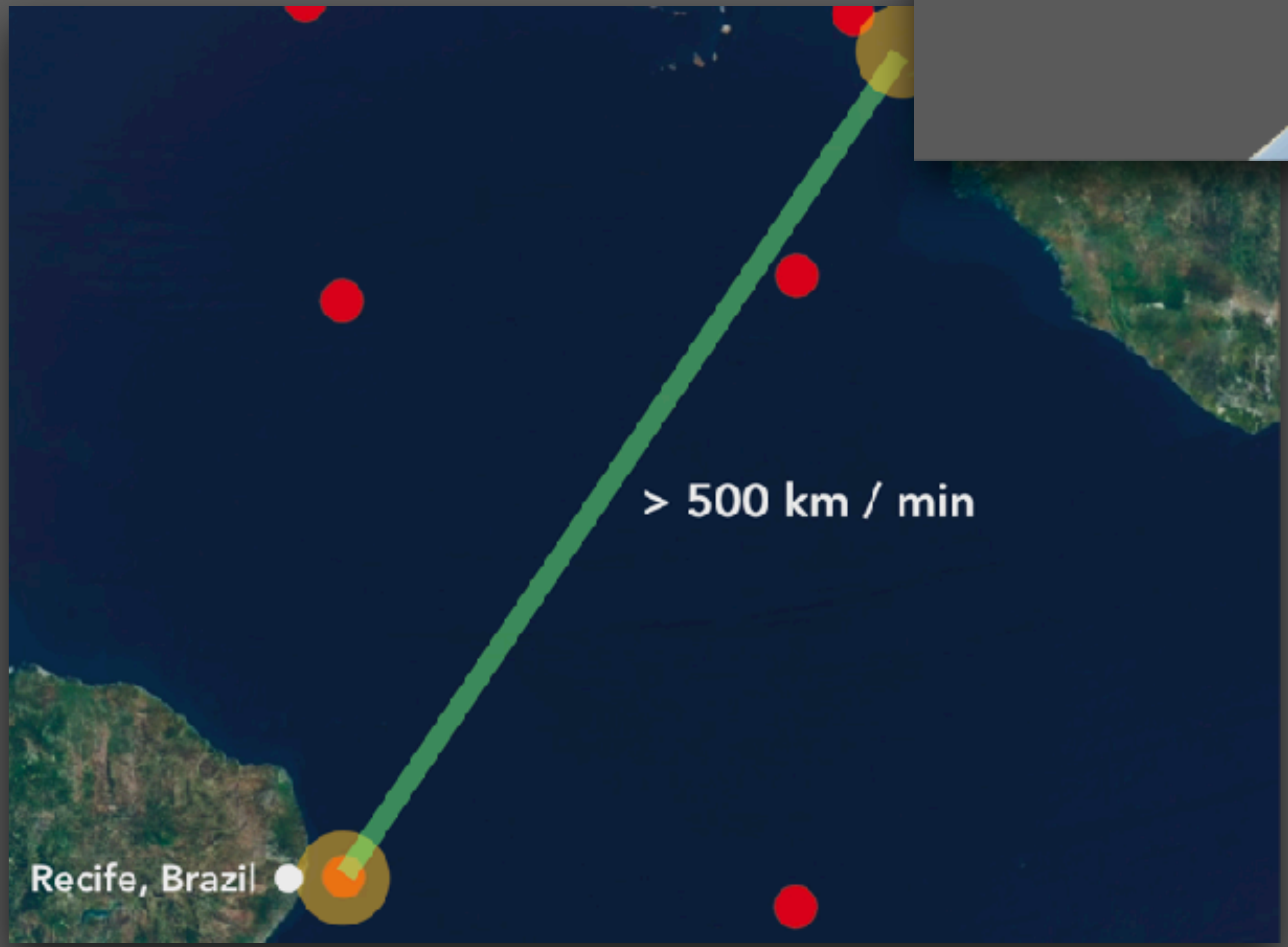
Debopam Bhattacherjee, Ankit Singla
Department of Computer Science, ETH Zürich

CoNEXT'19

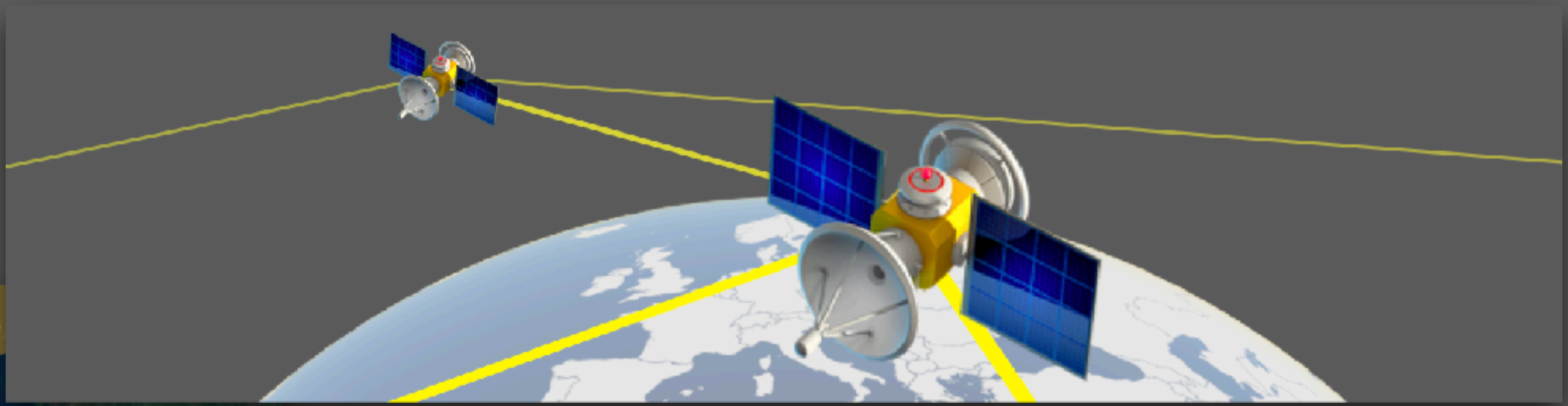


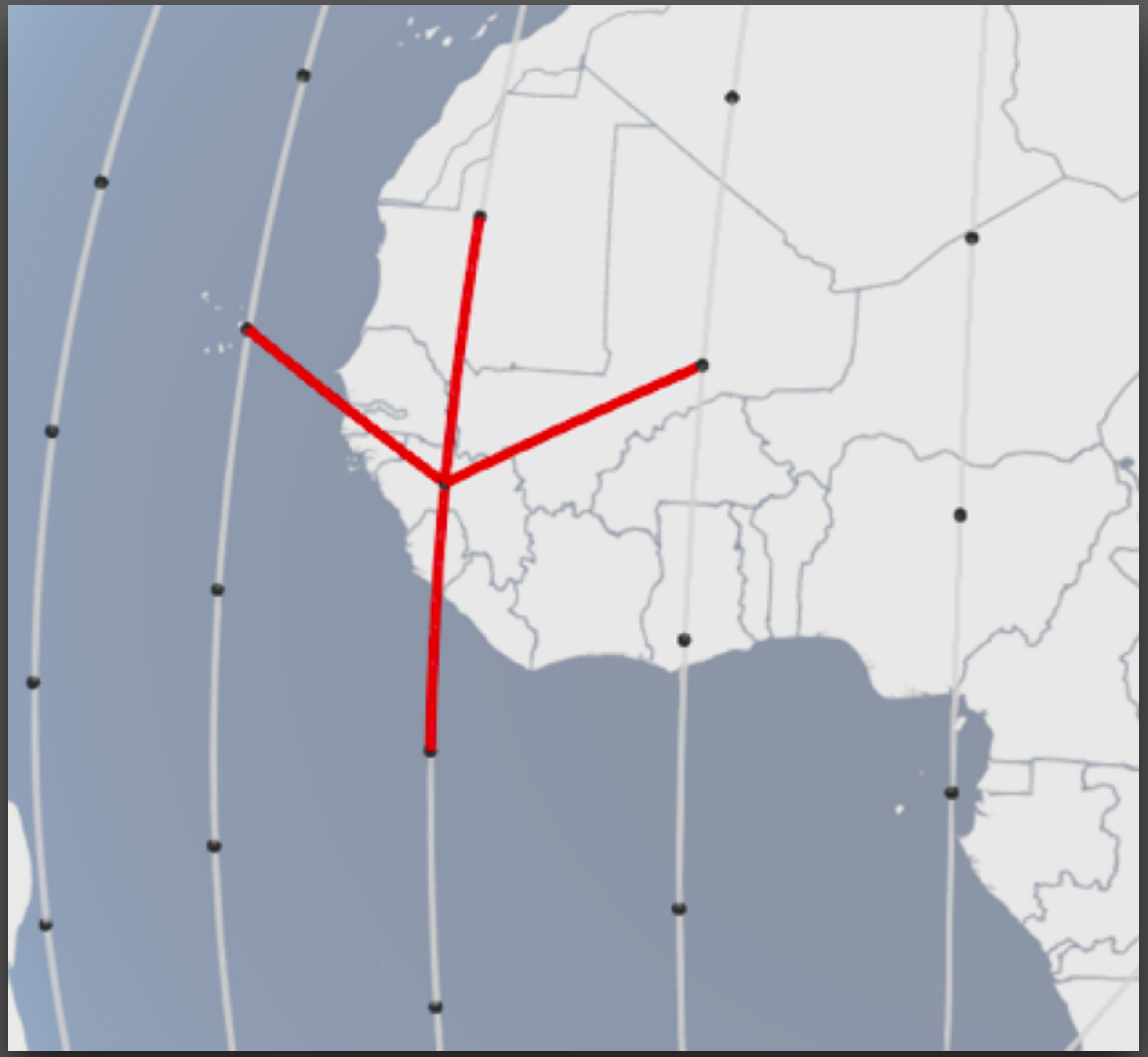
Key constraints

System dynamics



Link setup times





Max. no of links per satellite

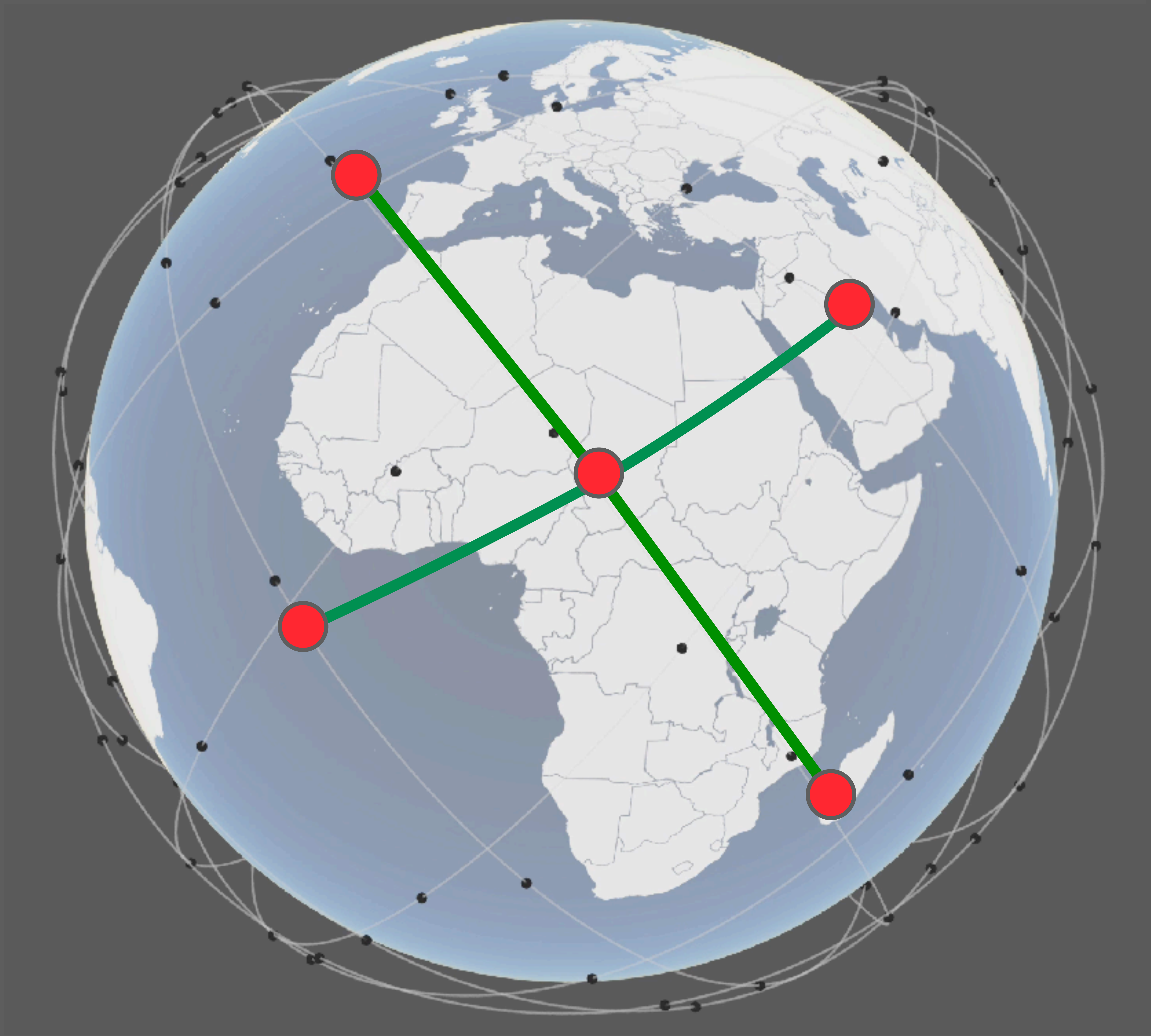
Assumptions

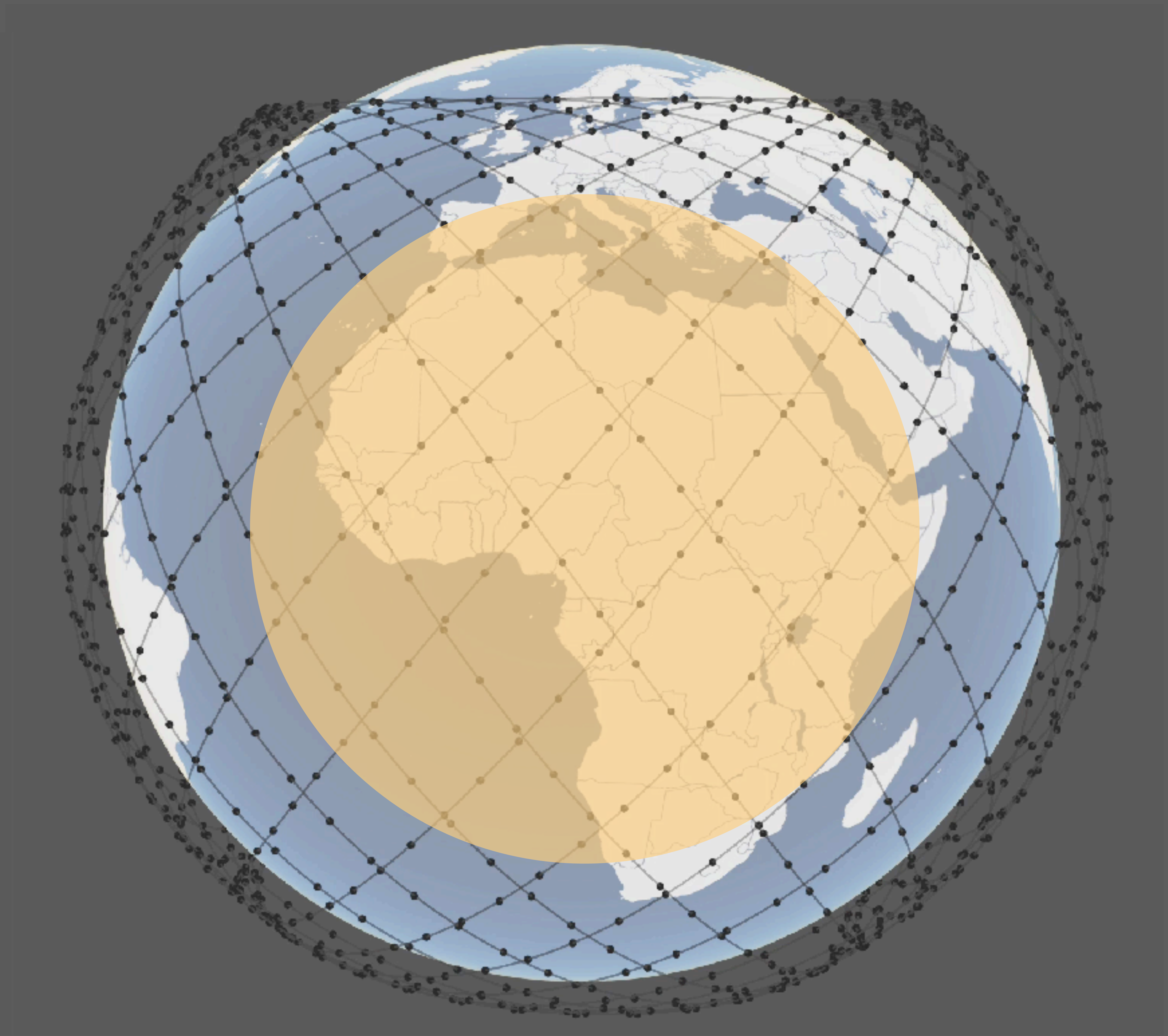
- Given satellite trajectories
- Traffic matrices drawn from intuition
- Ground-satellite connectivity is range-bounded
- +Grid is the baseline

+Grid

Can use much longer links

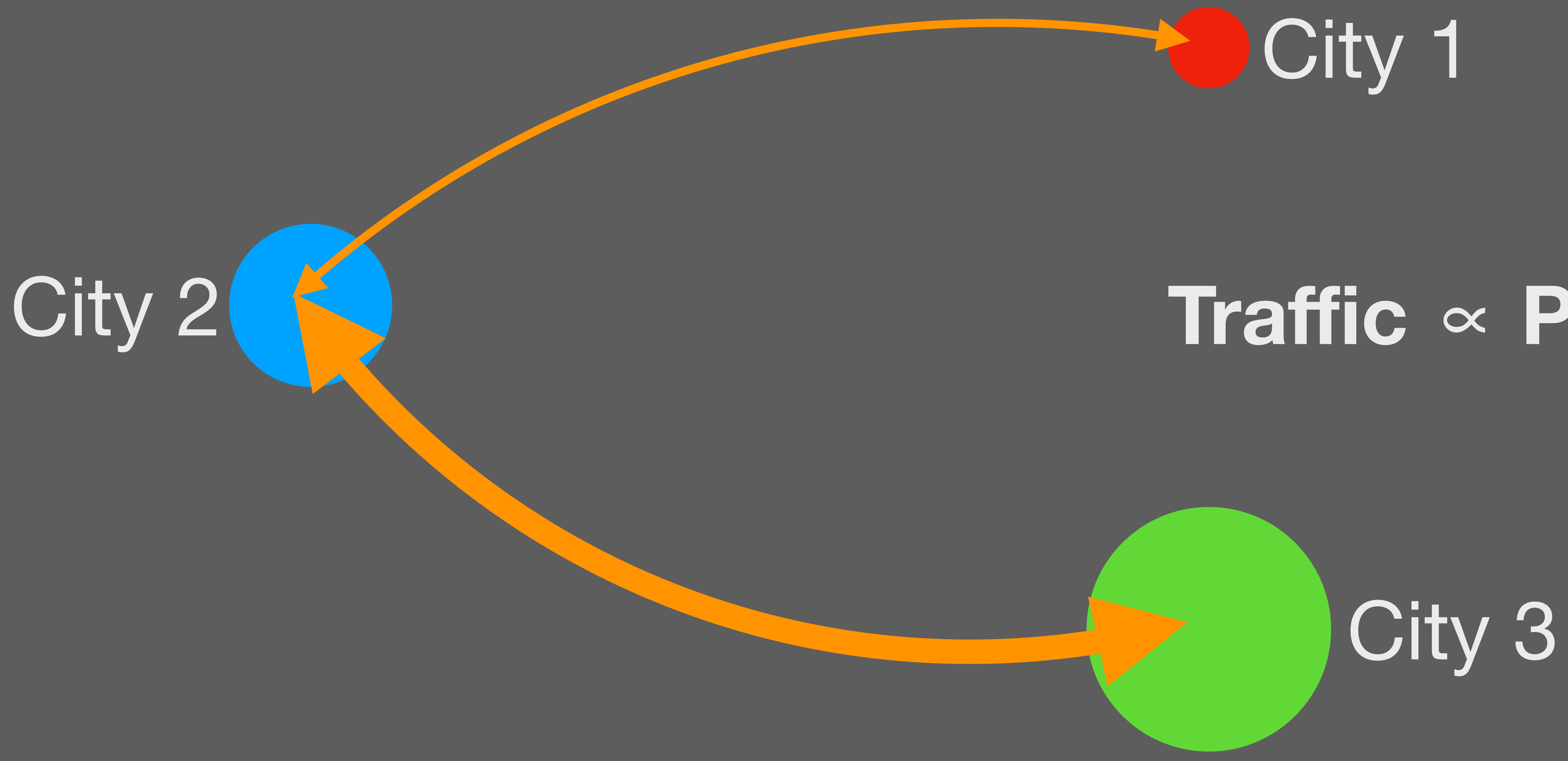
Much larger design space





What do we optimize for?

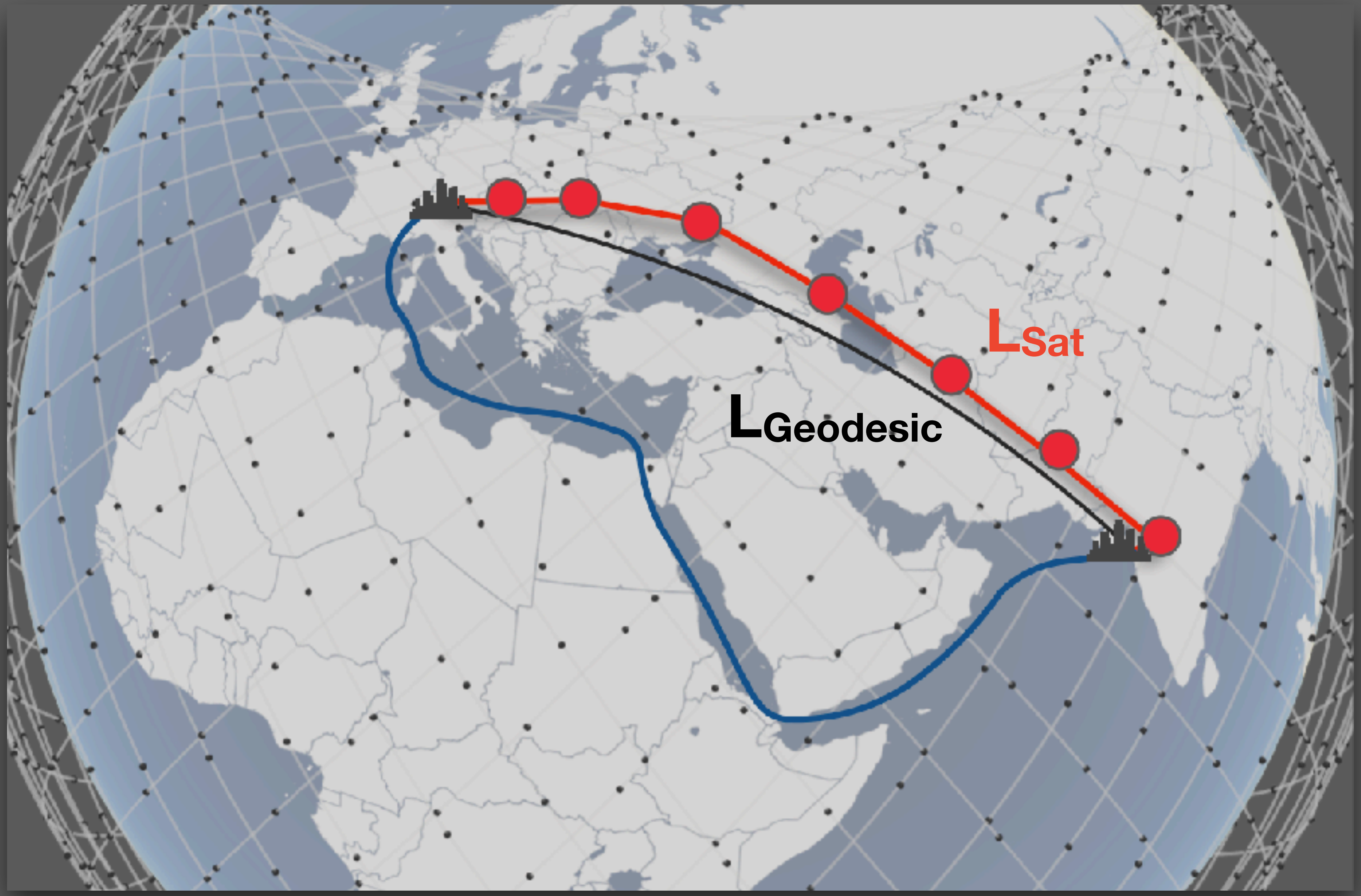
Traffic matrix



Traffic $\propto$ ~~Population~~ product

GDP

Metrics



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

Hop count

M = α Stretch + Hop count

Why aren’t obvious / traditional methods enough?

Why not use Integer programming?

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

One minute apart ~91% links are different

ISL setup times: few seconds to 10s of seconds

Why not use random graphs?

In 5 mins, 19% of links become infeasible

Cannot optimize for arbitrary objectives

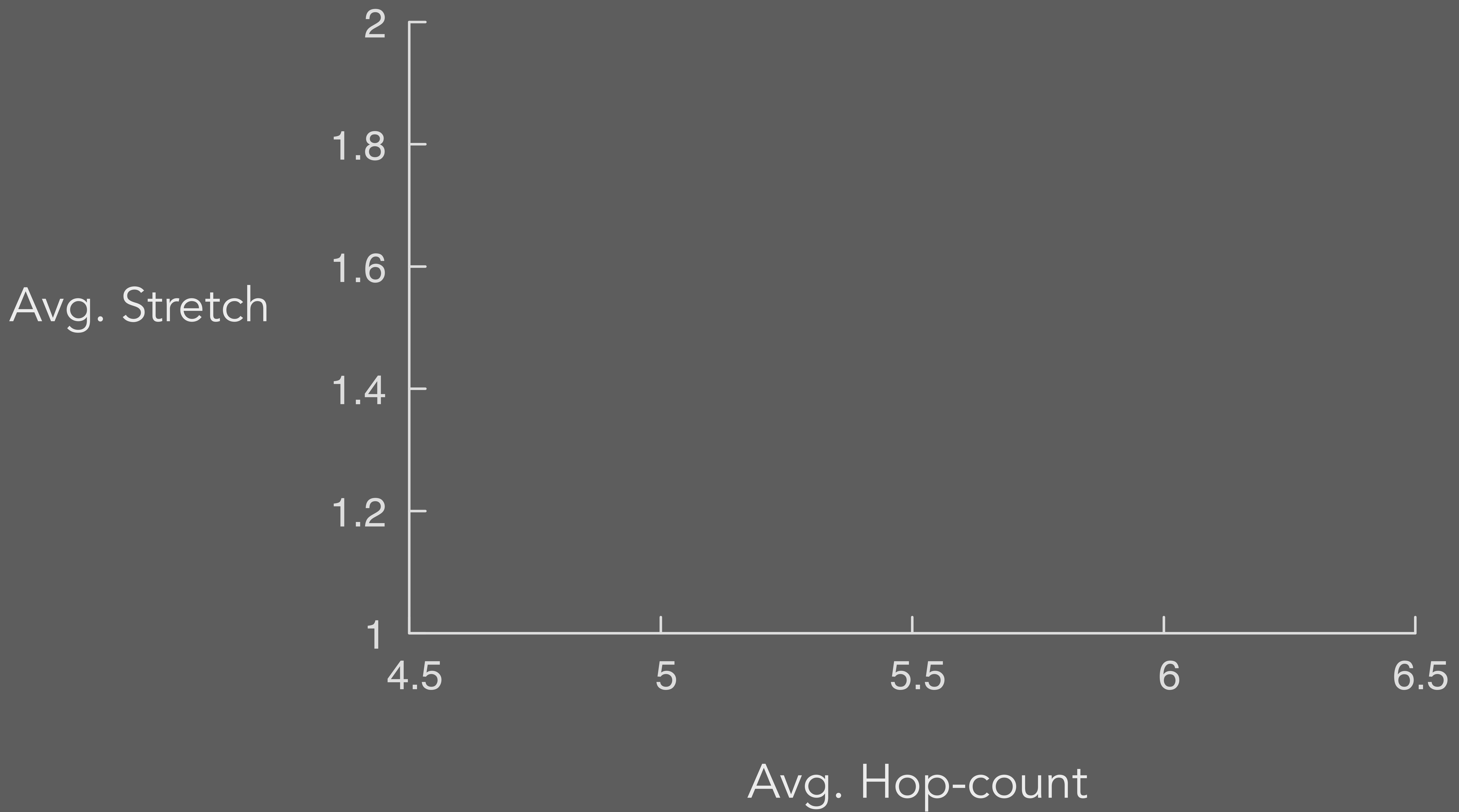
Our approach


pexels.com

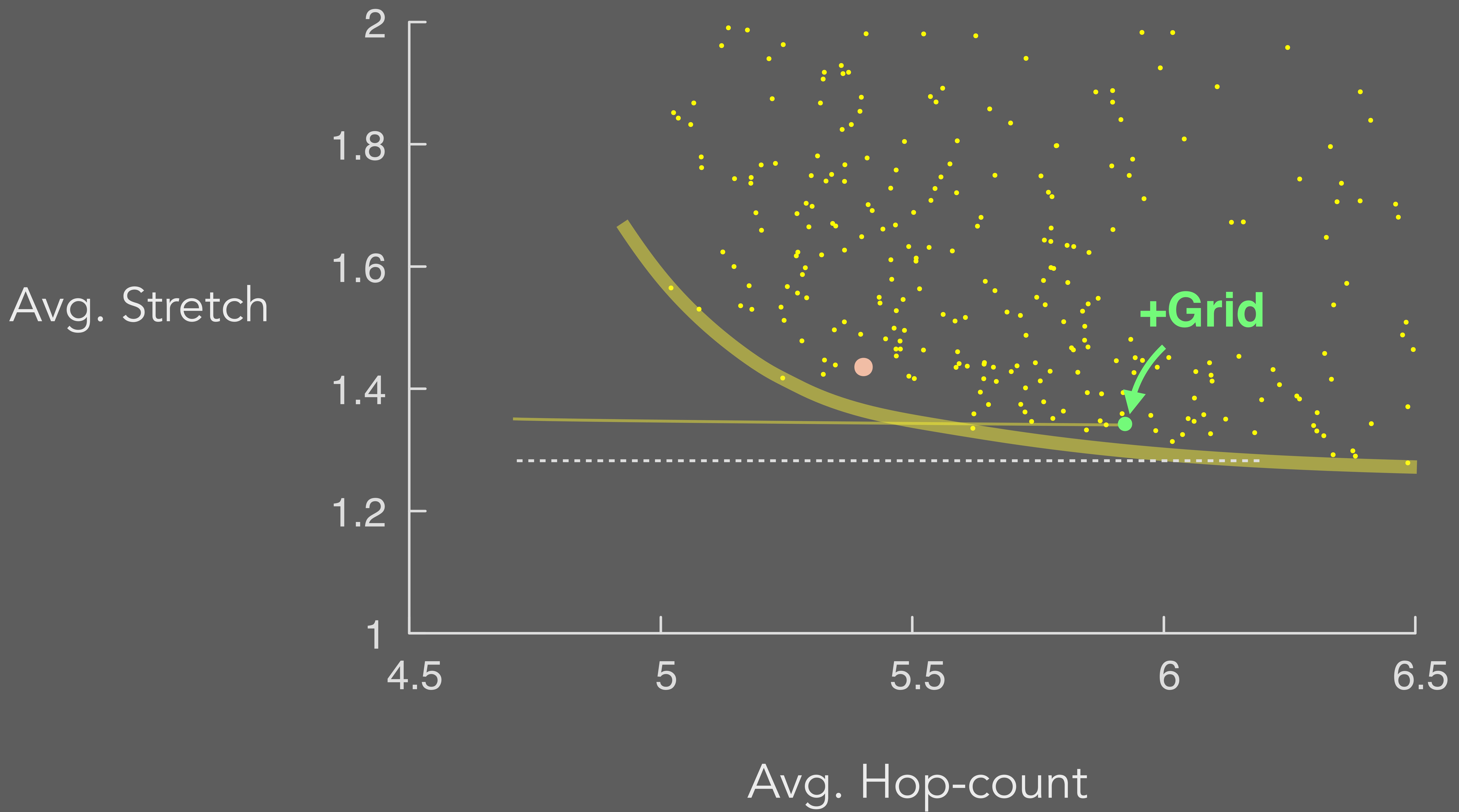
Constellations explored

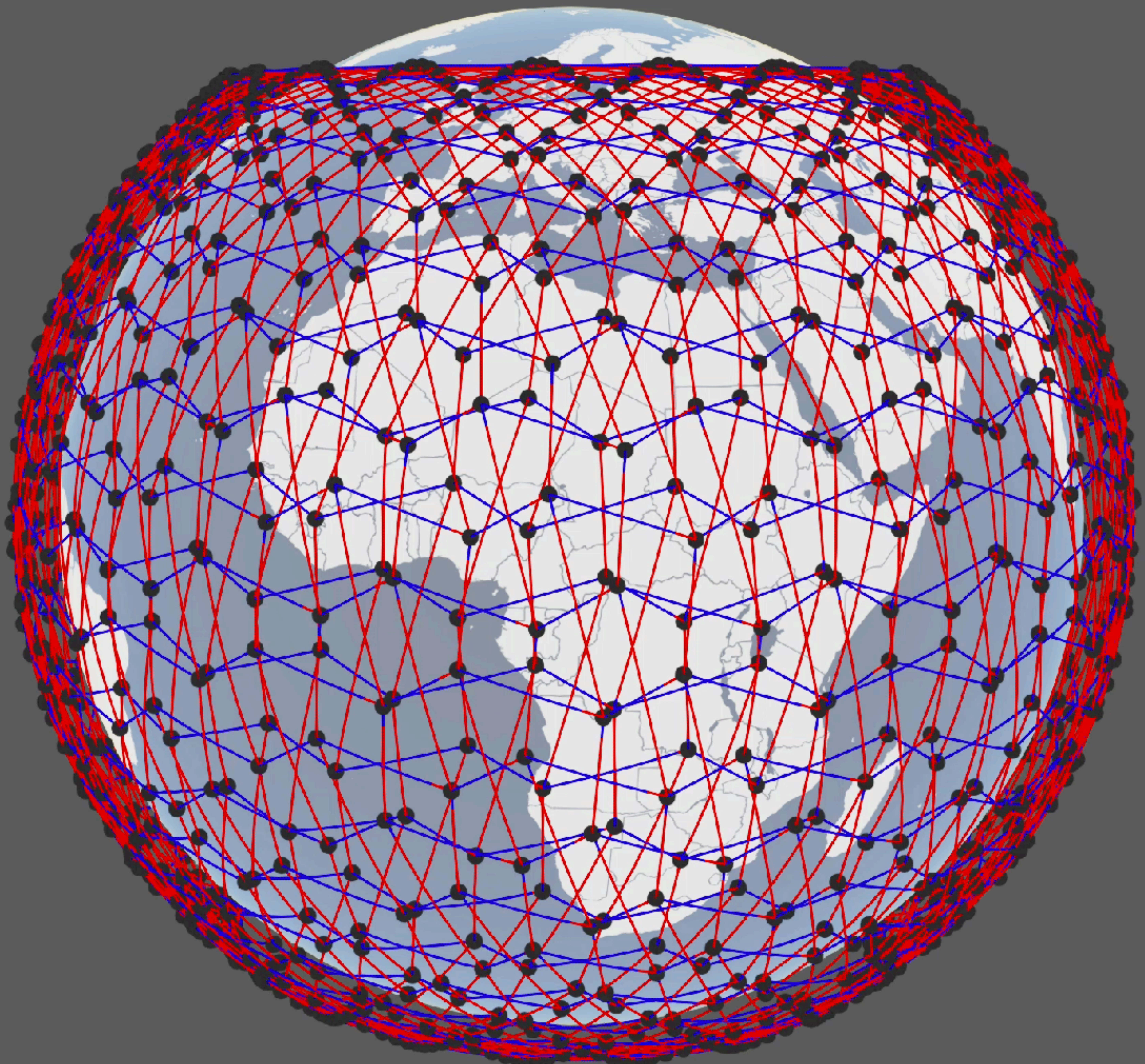
- Uniform 40x40 (40^2) 53° inclination, 550 km altitude
- SpaceX **Starlink** Phase 1 (24x66, 53°, 550 km)
- Amazon **Kuiper** Phase 1 (34^2, 51.9°, 630 km)

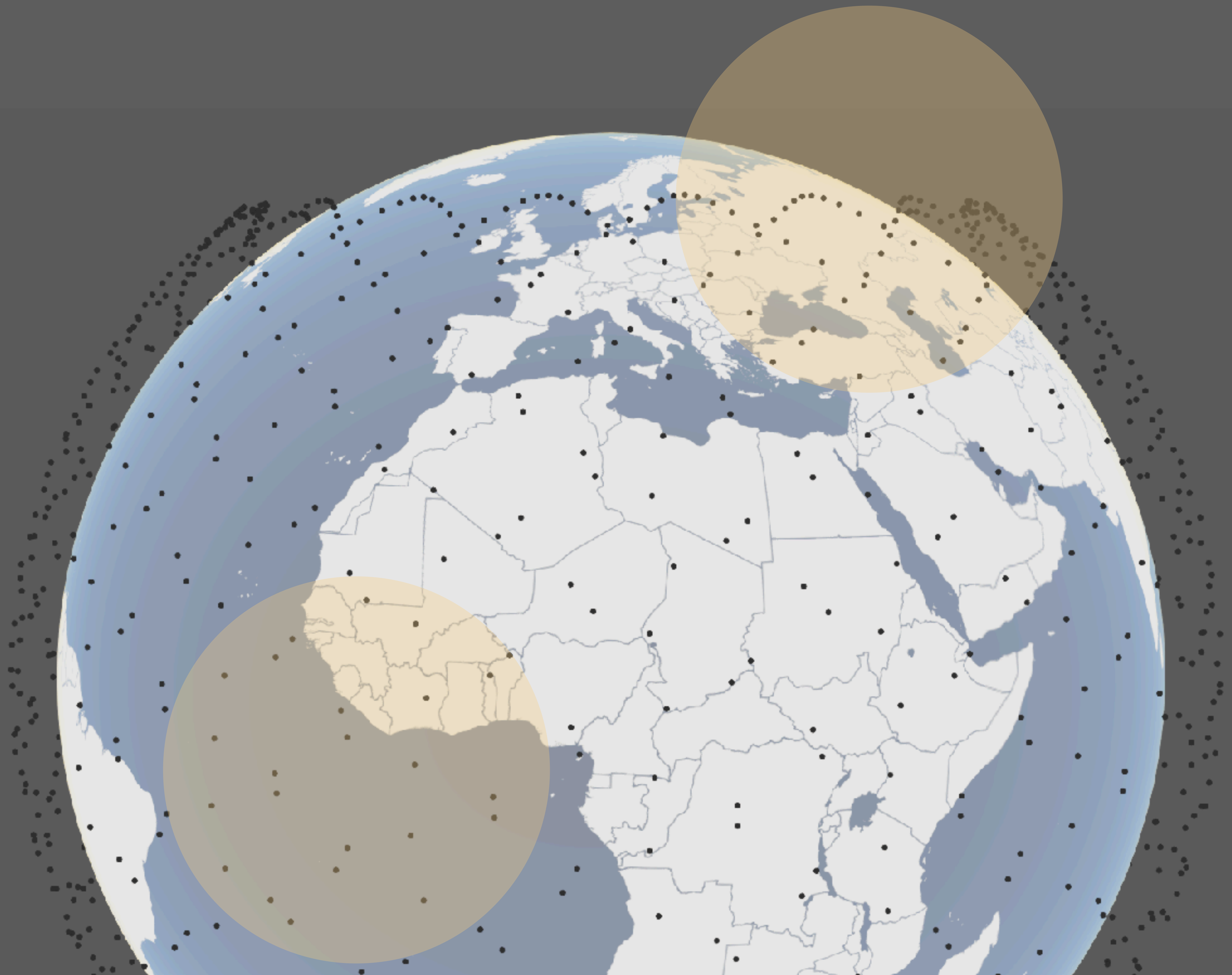
A large number of design points



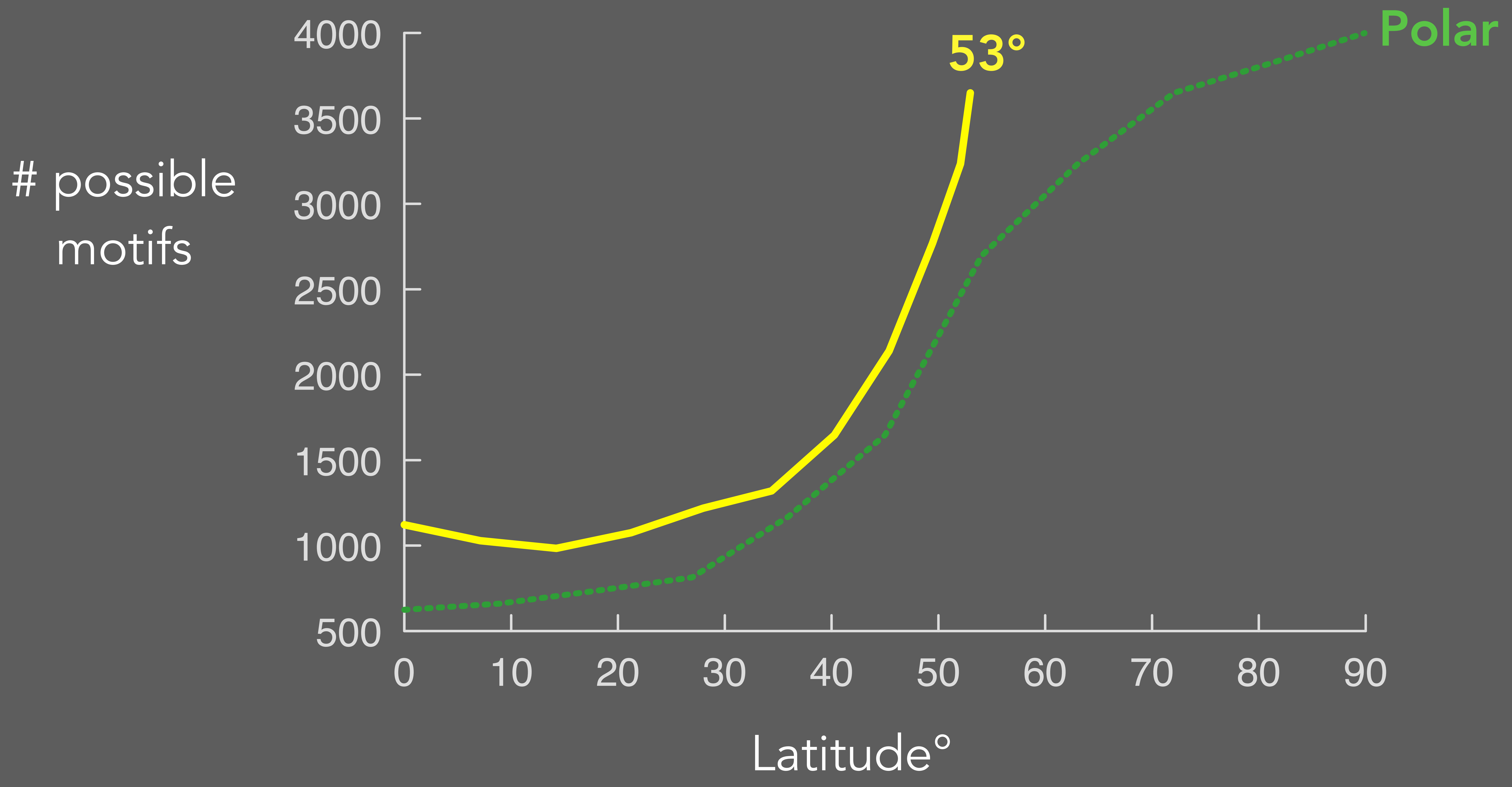
+Grid is a low-efficiency motif

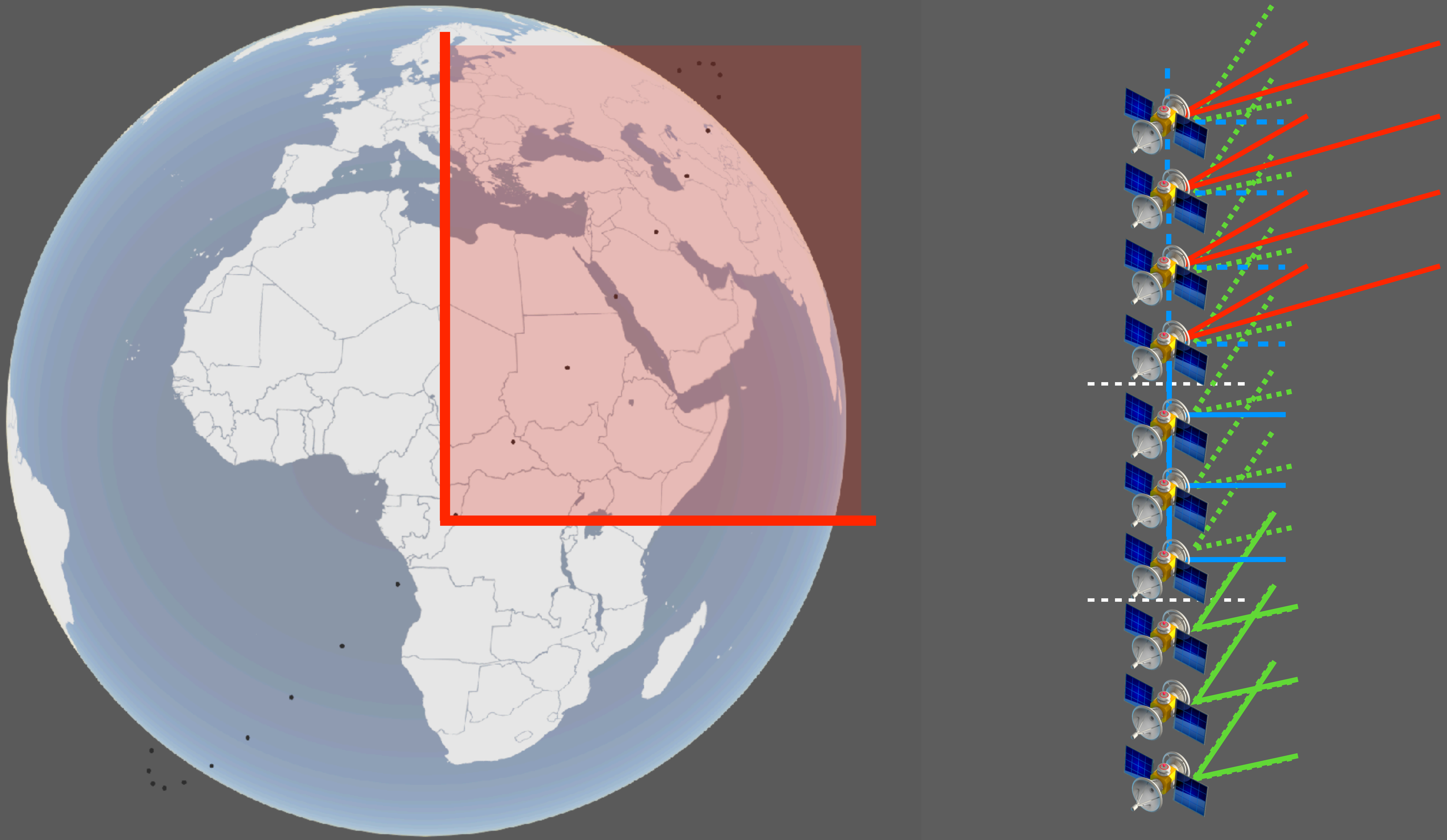


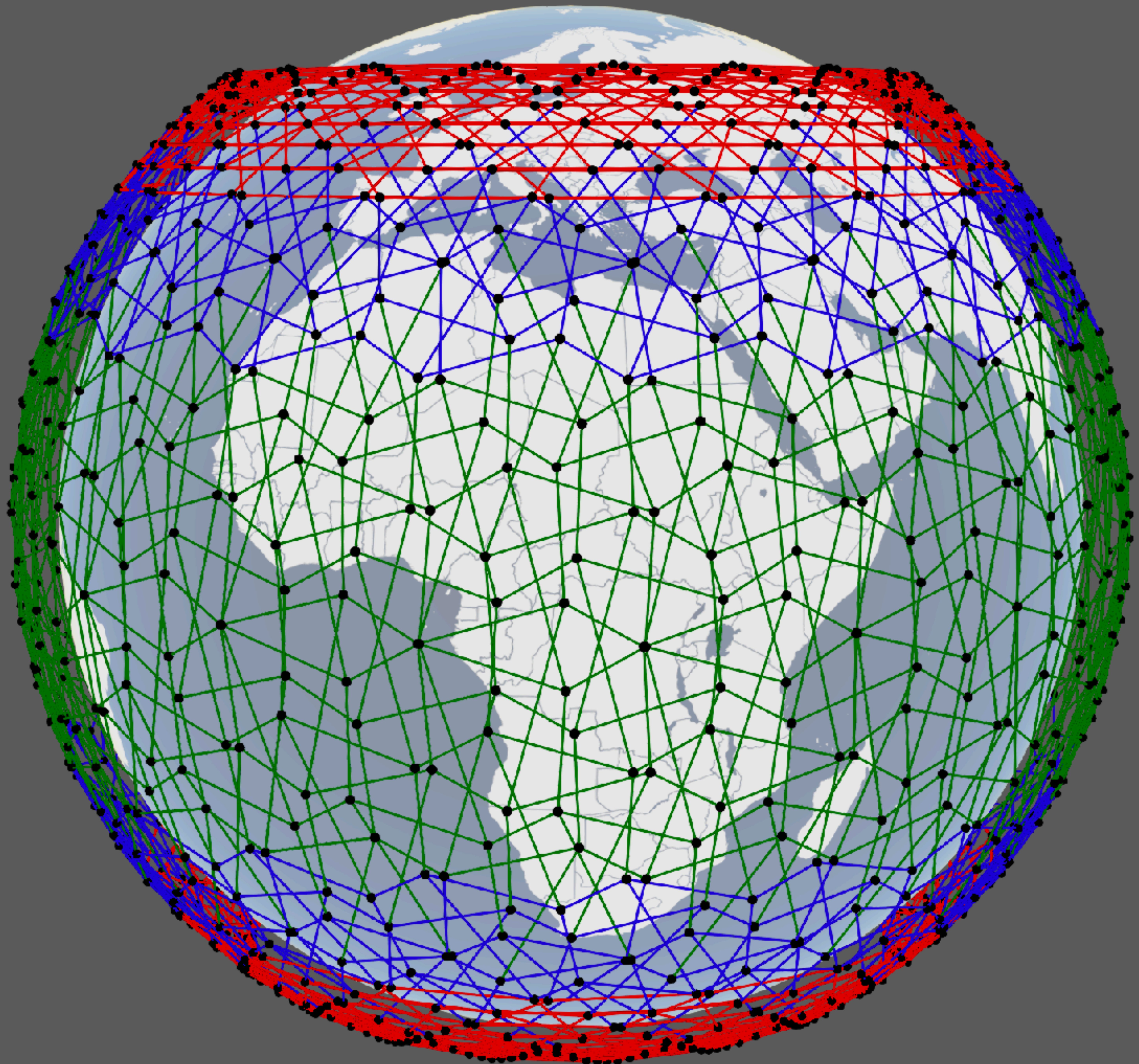




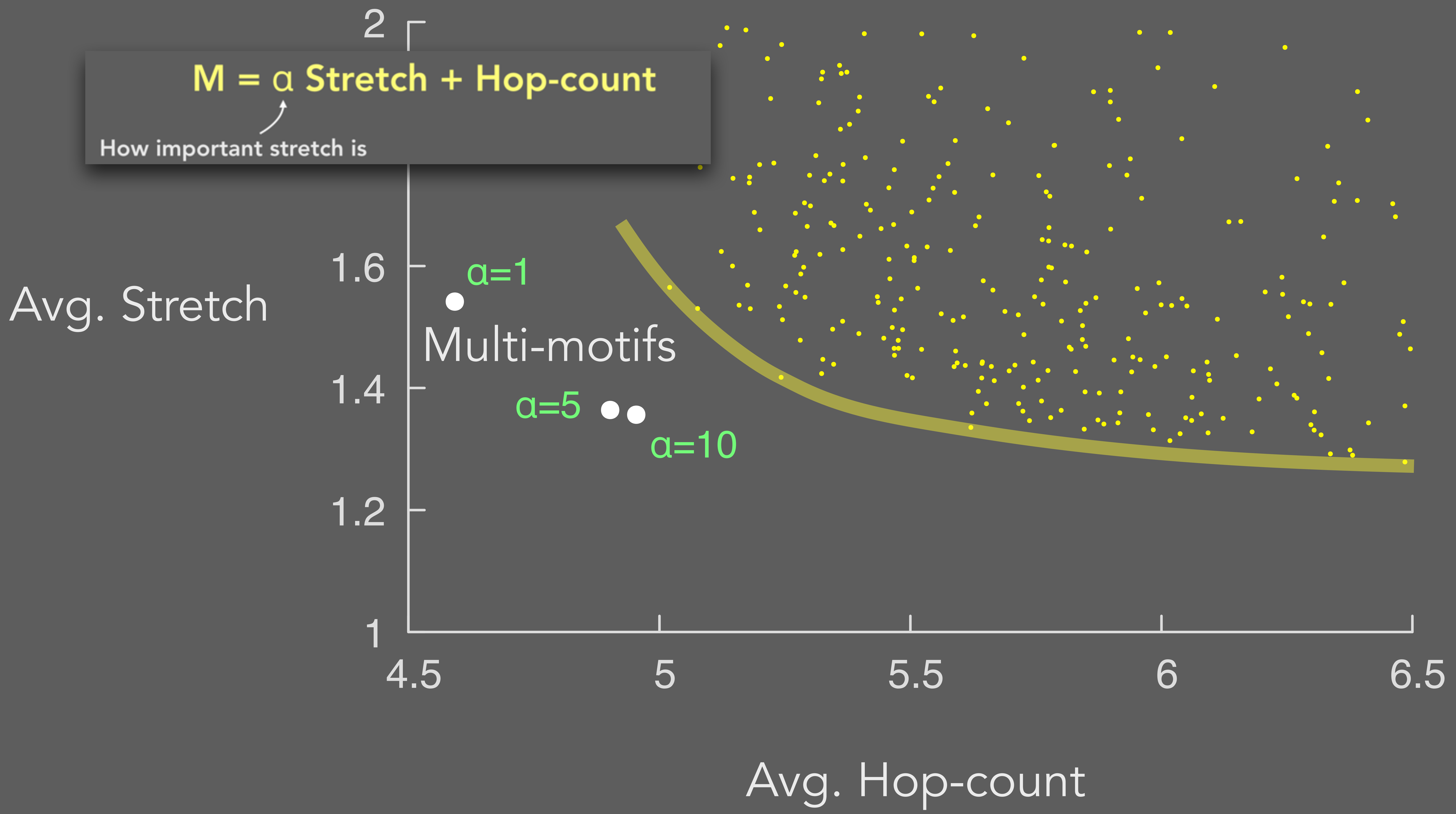
More options at higher latitudes







Beyond single motif frontier



Performance improvements

		Severely power-limited links
Starlink	54%	40%
Kuiper	45%	4%
40^2	48%	7%

How do we

… pick satellite trajectories to serve target areas?

… connect satellites to offer high network performance?

Trajectory & topology design

… route efficiently within a constellation?

… integrate such networks into Internet routing?

Routing

… do efficient congestion control on such networks?

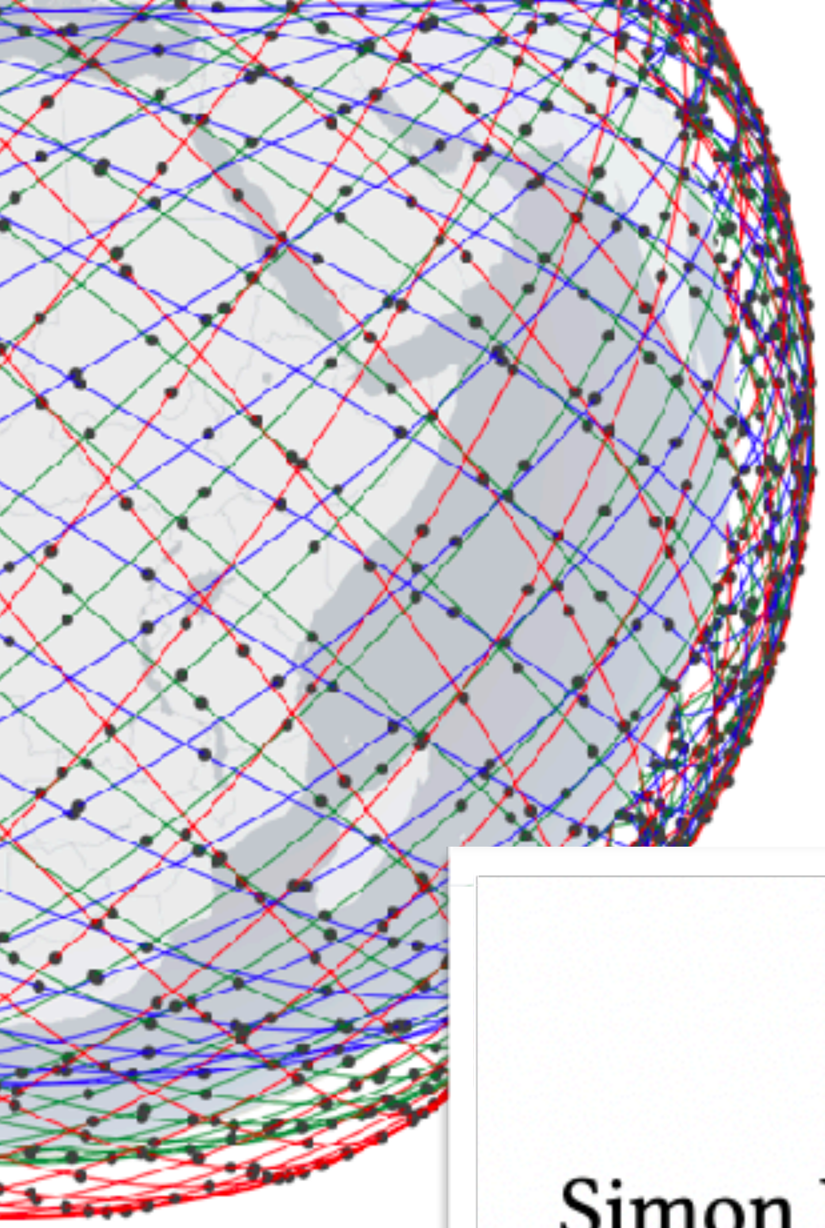
Transport

… design applications that run on top?

Apps

Agenda

- What is the LEO hype about?
- Understanding LEO networks
- **LEO simulations**
- A global testbed & beyond



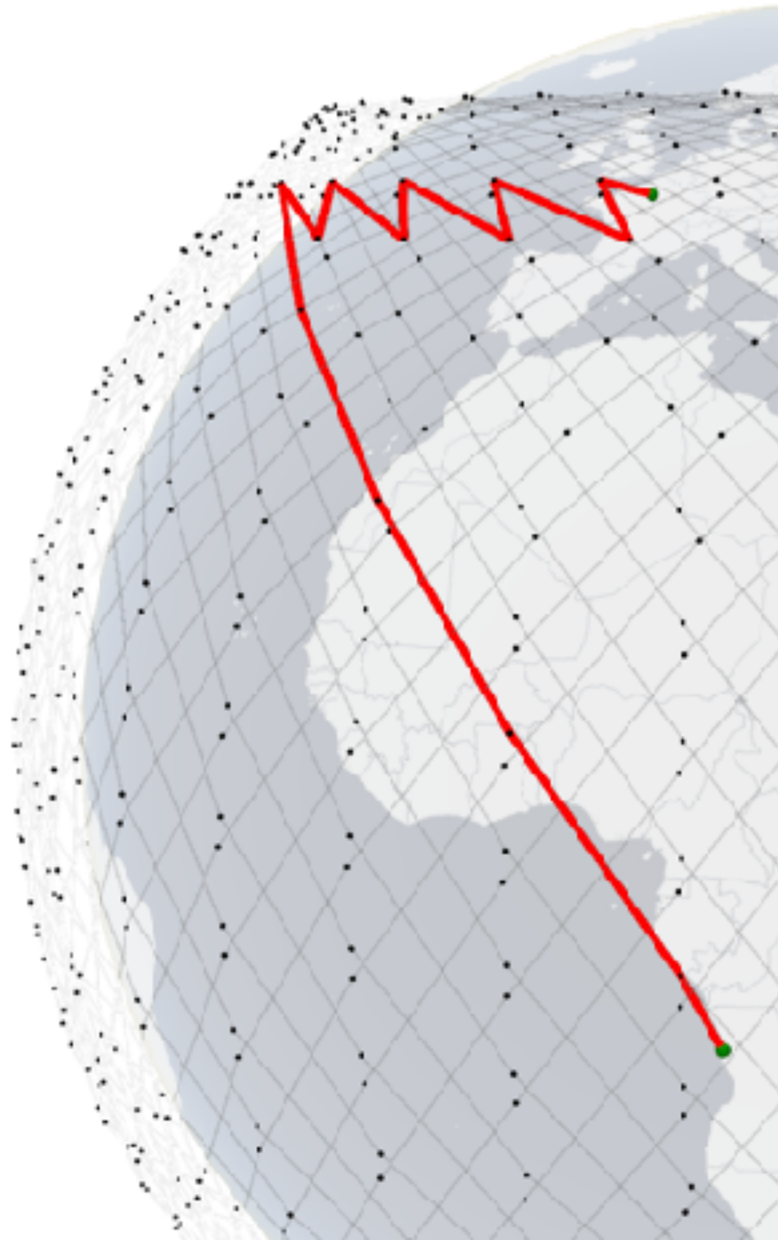
Exploring the "Internet from space" with HYPATIA

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

IMC'20,
Best Paper

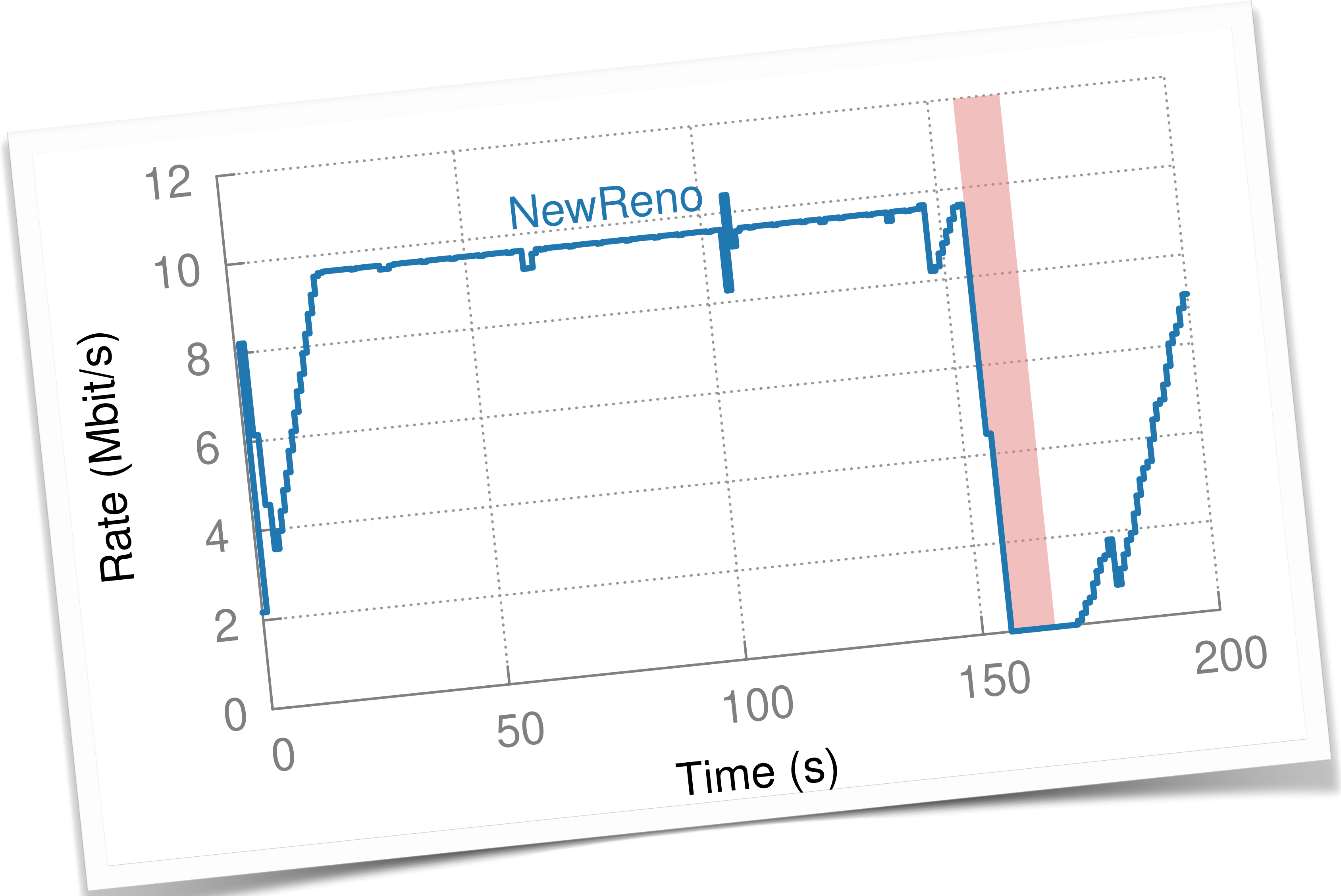
Hypatia

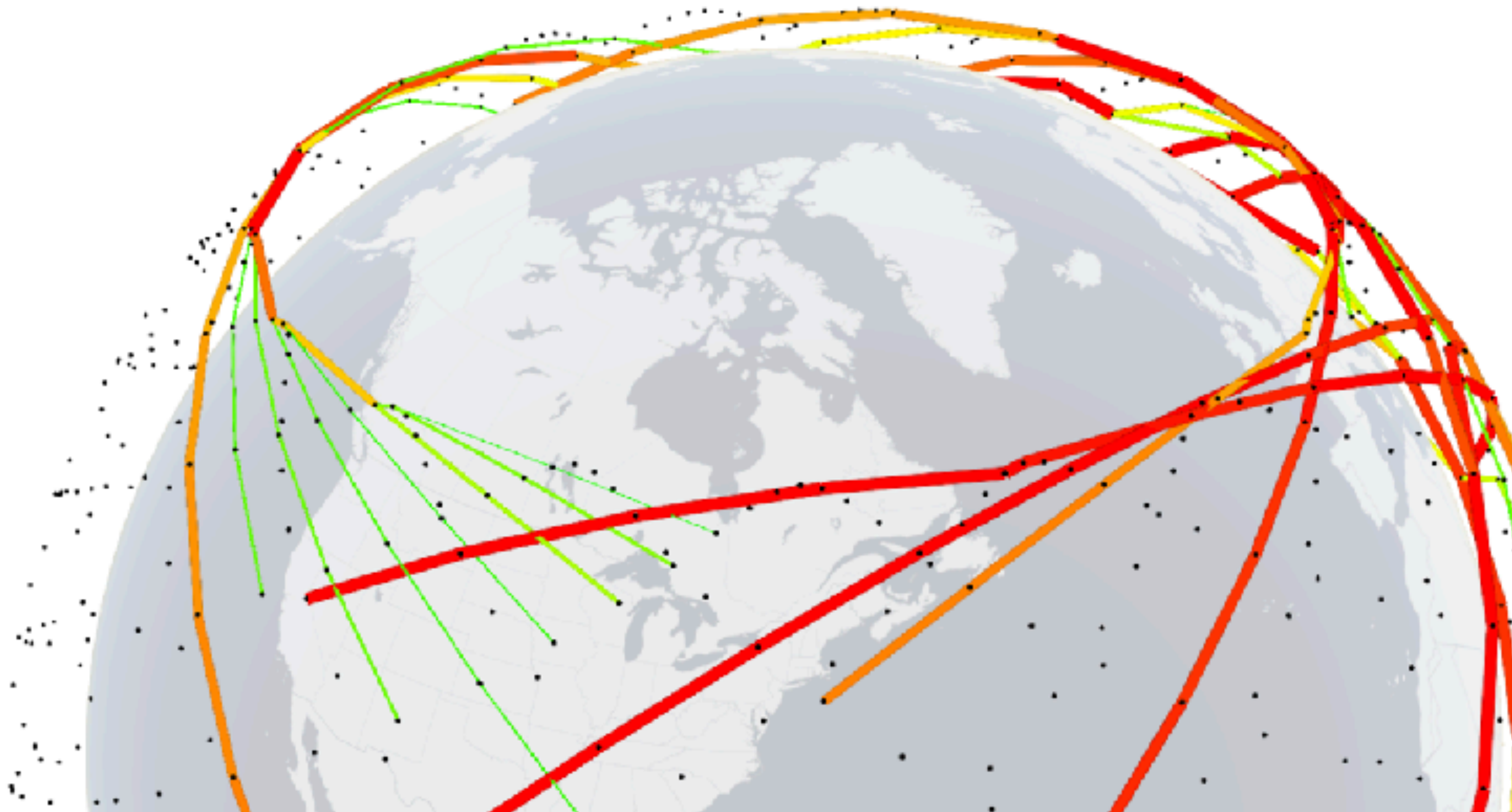
A simulation and visualization tool for satellite networks



*equal contribution

Satellite trajectories
Network topology
Ground stations
Traffic flows





Extends ns-3
LEO dynamics
Precomputed states
Cesium 3D library

Experiment setup

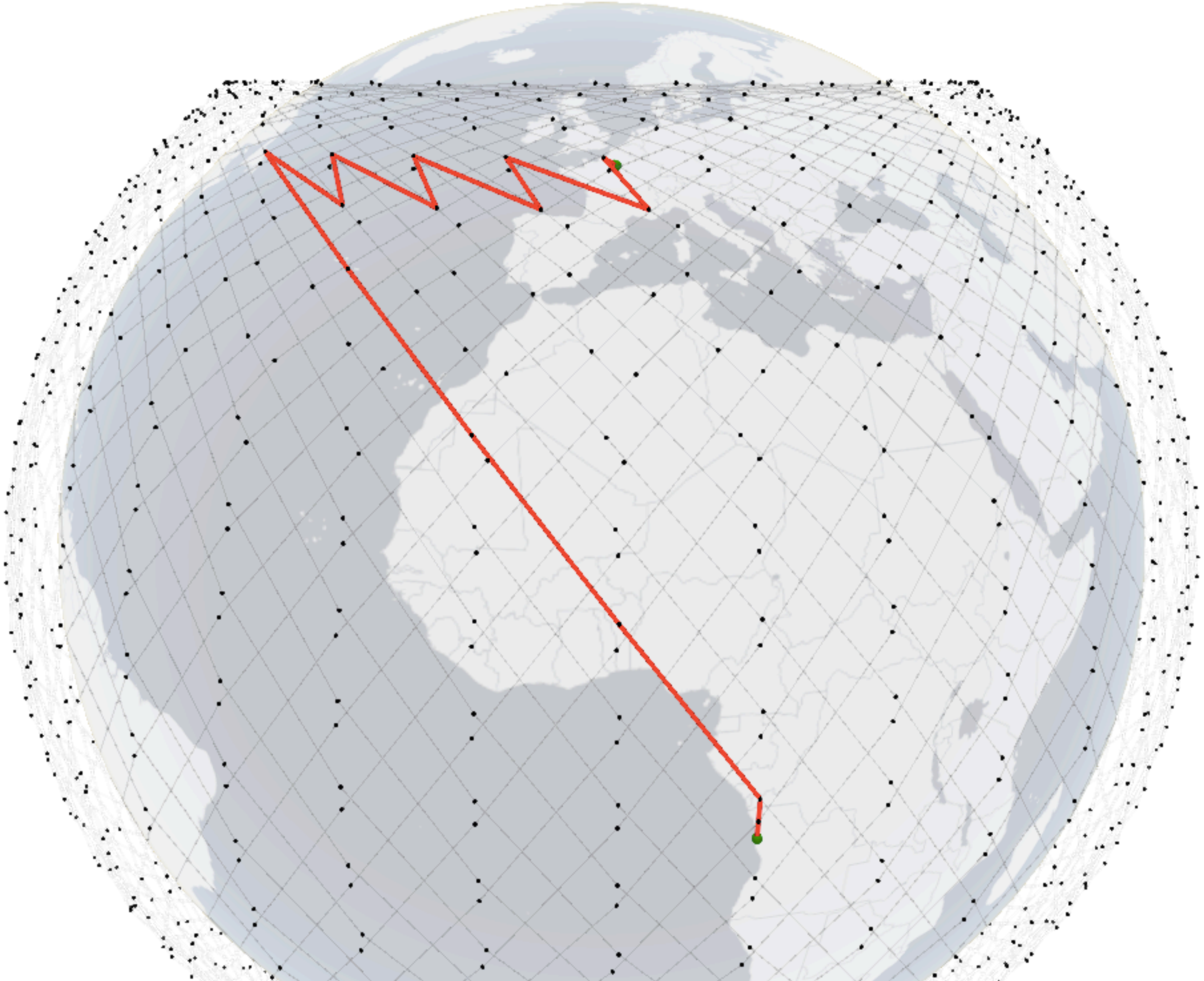
First shell of Kuiper

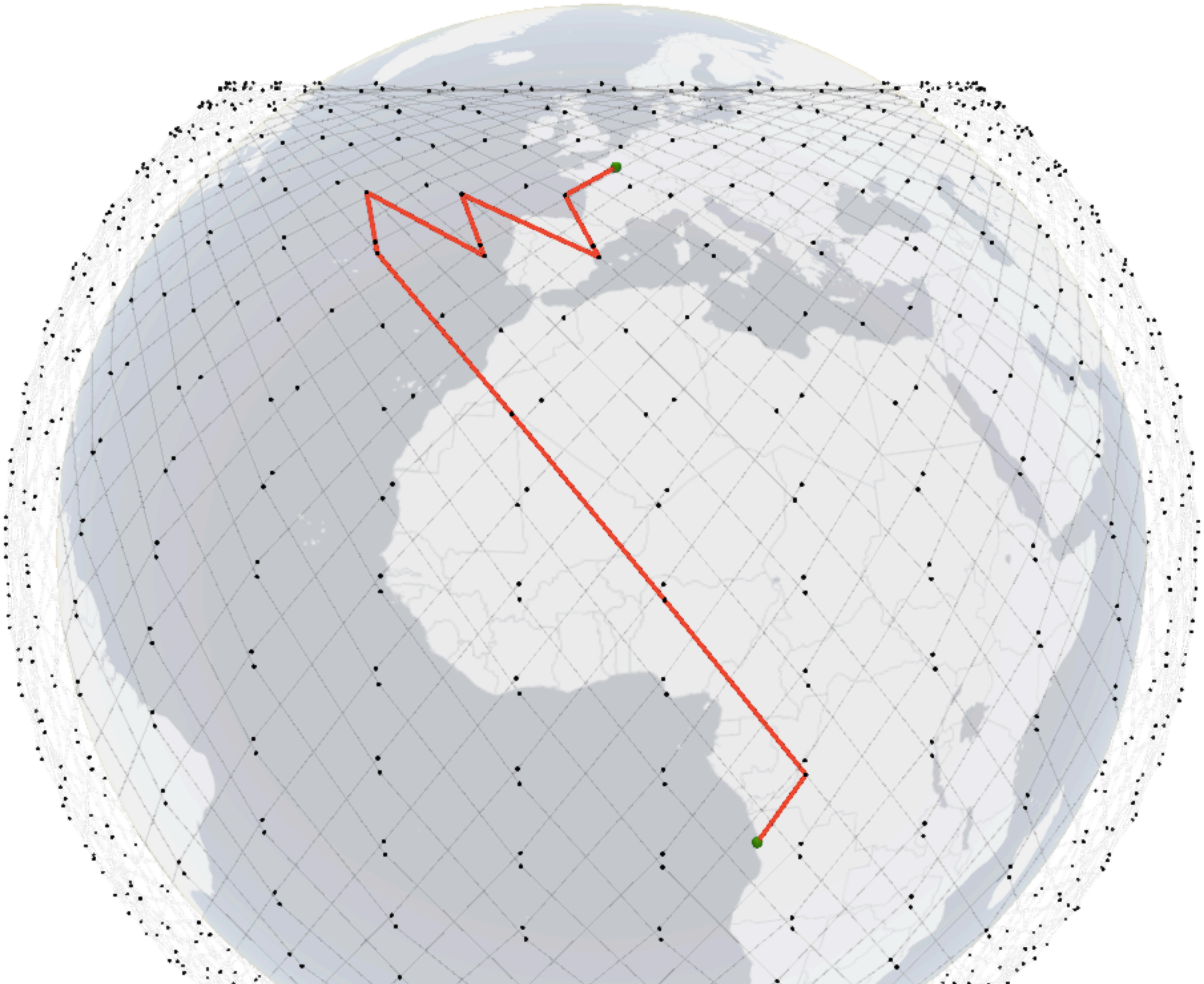
- 630 km height
- 34 orbits, each with 34 satellites
- 51.9° inclination

Connectivity is +Grid, routing is shortest path

Ground stations in top-100 most populous cities

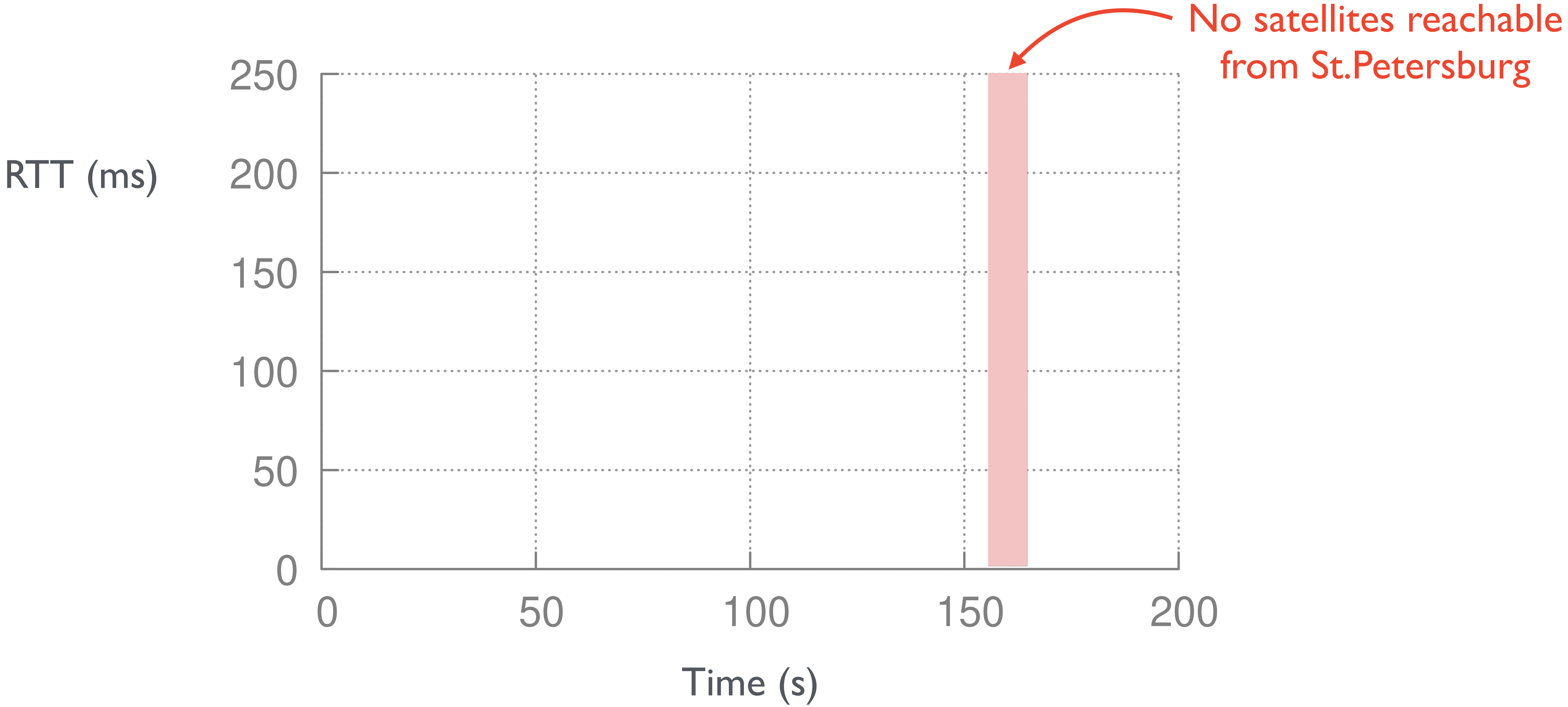
All links are 10 Mbps





RTT fluctuation: Rio de Janeiro to St. Petersburg

This is without any other traffic in the network



RTT fluctuation: Rio de Janeiro to St. Petersburg

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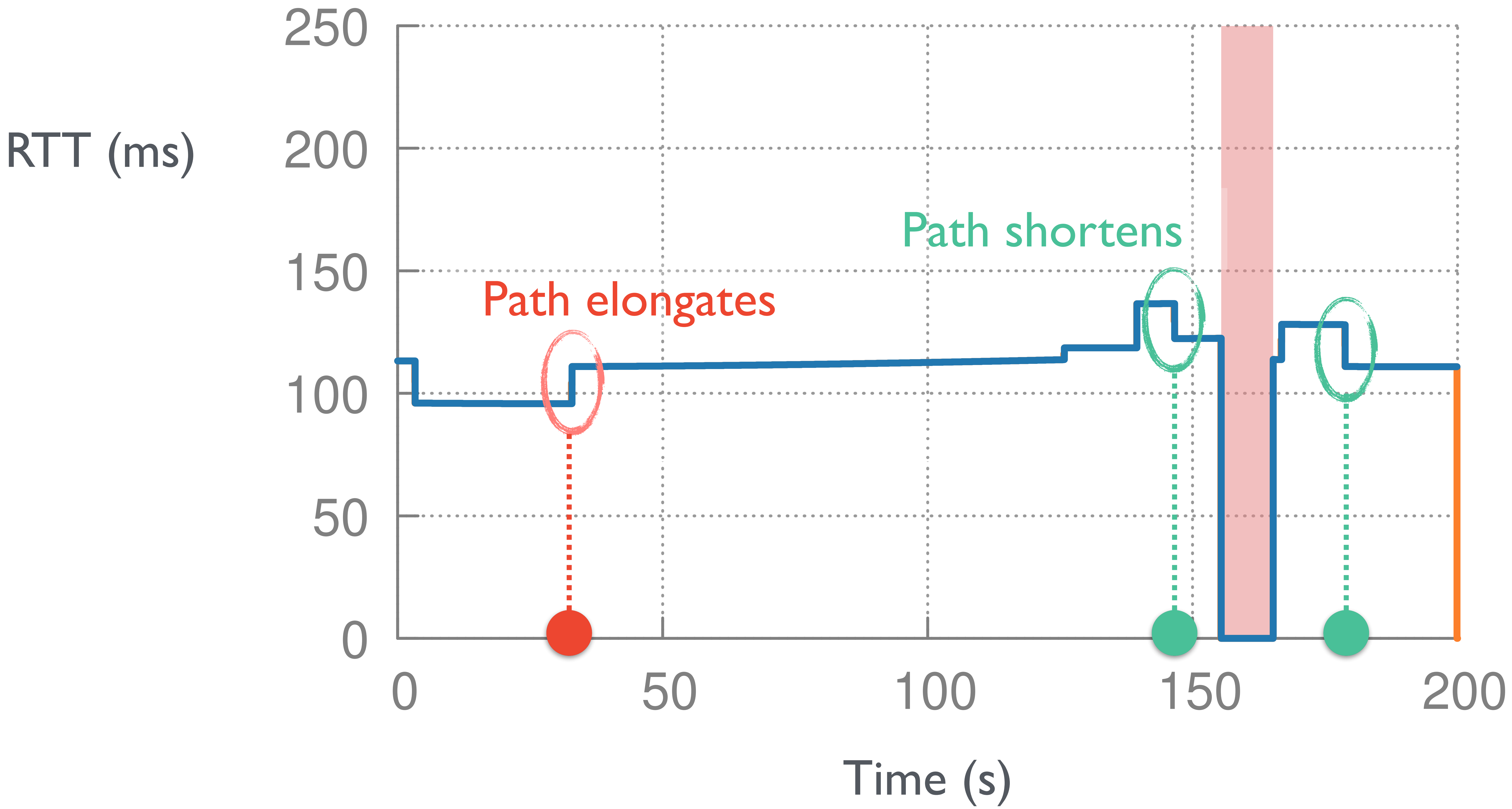
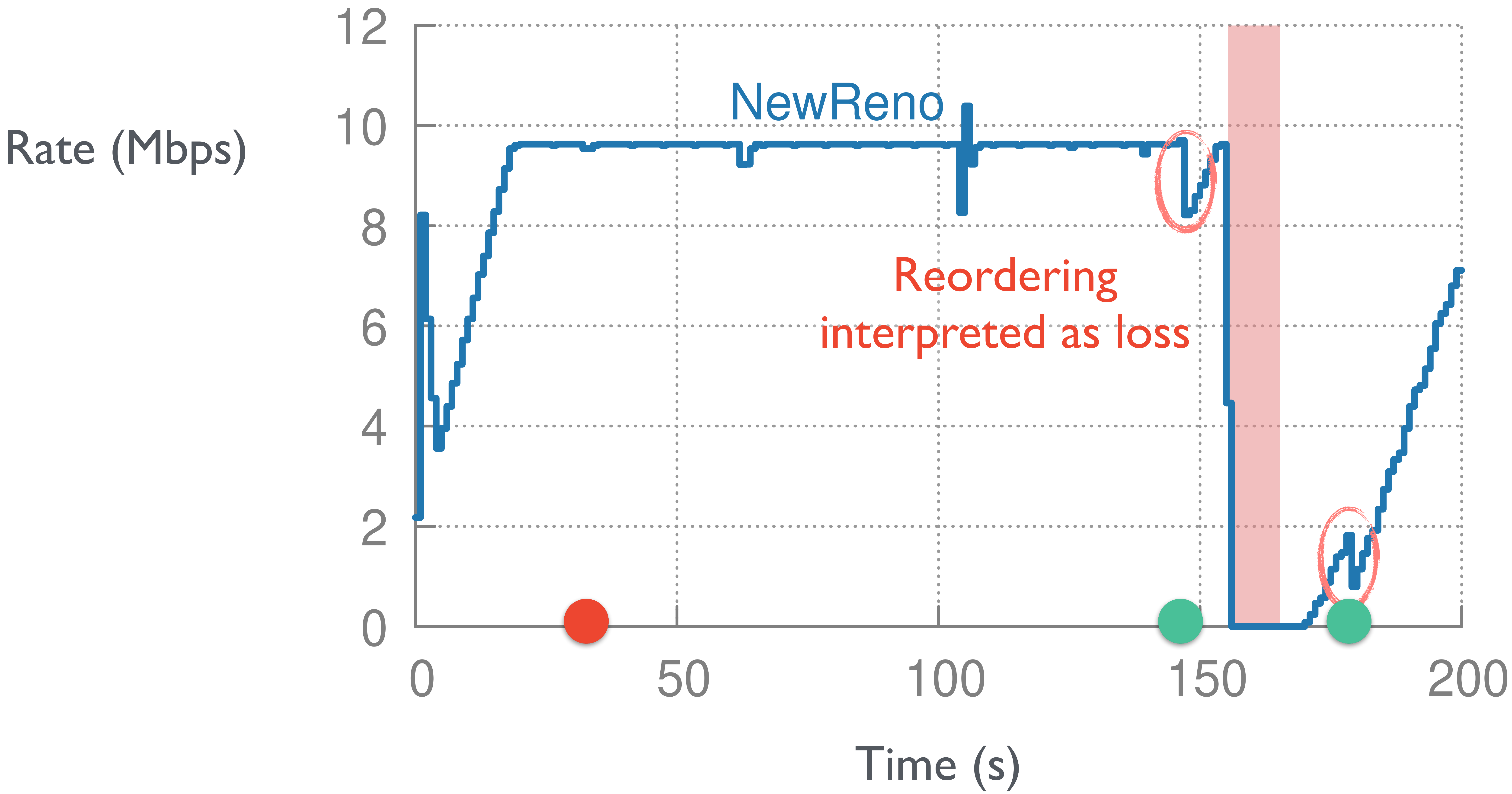


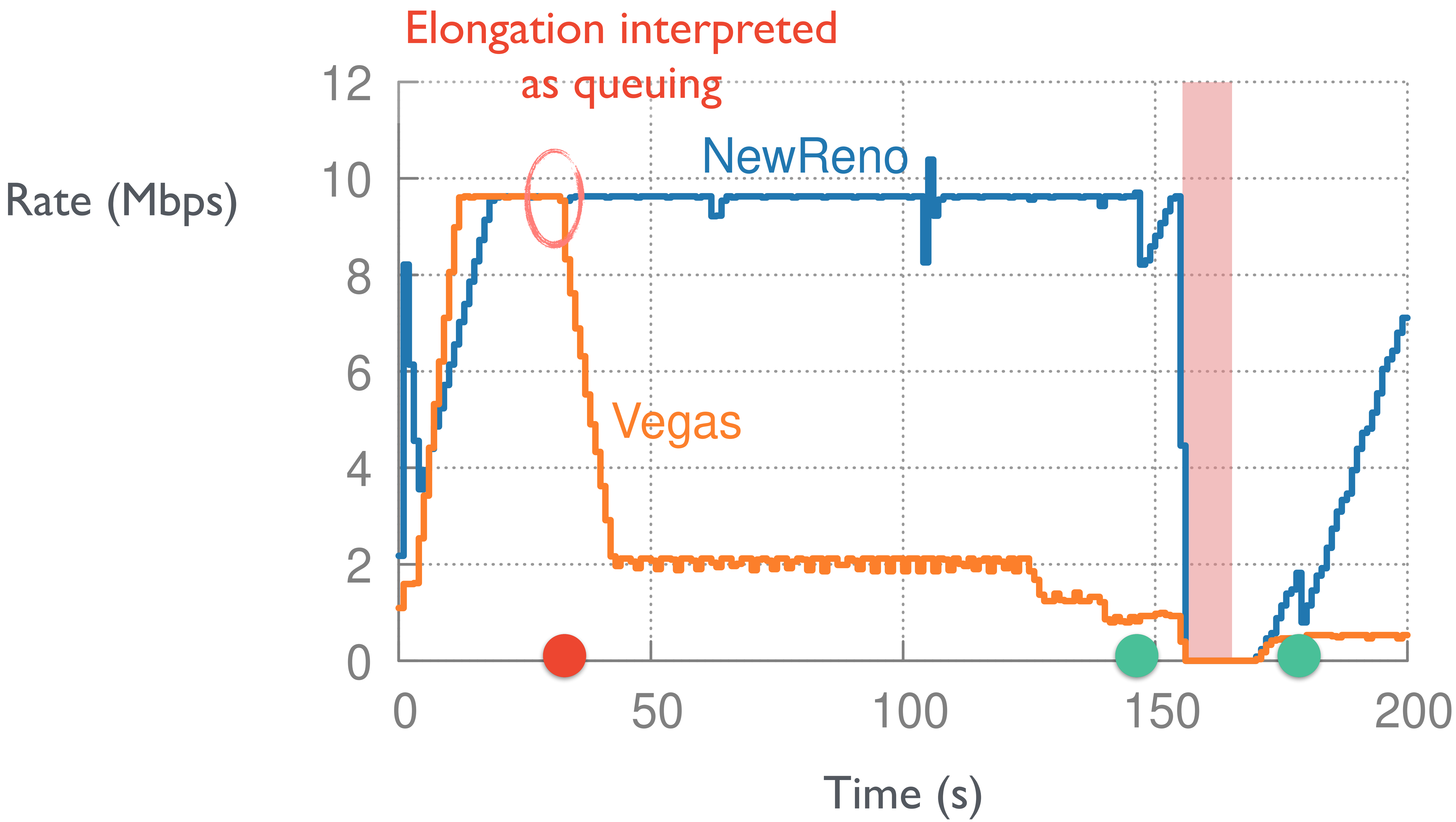
Impact on loss-based CC is small

This is without any other traffic in the network



Delay-based CC suffers

This is without any other traffic in the network



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 flows can suffer

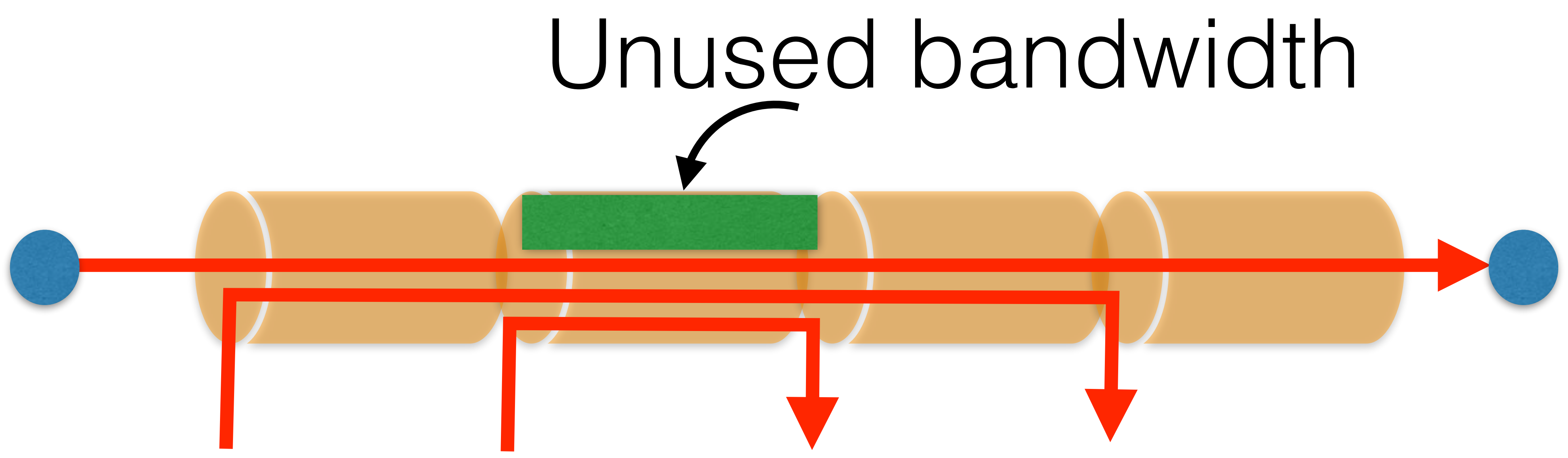
Path structure change has network-wide impact

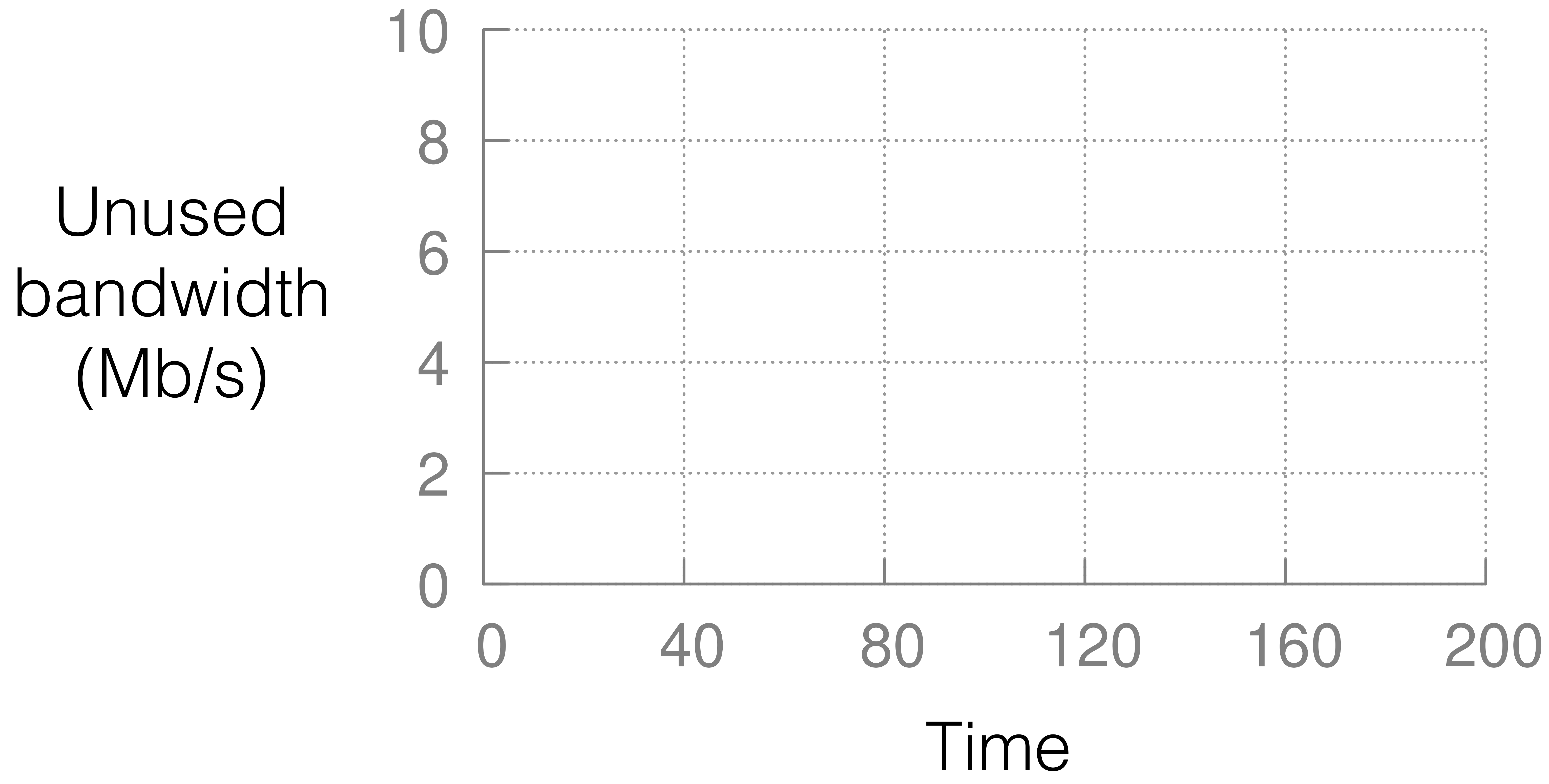
Few link changes per city-pair per minute

But large number of changes network-wide

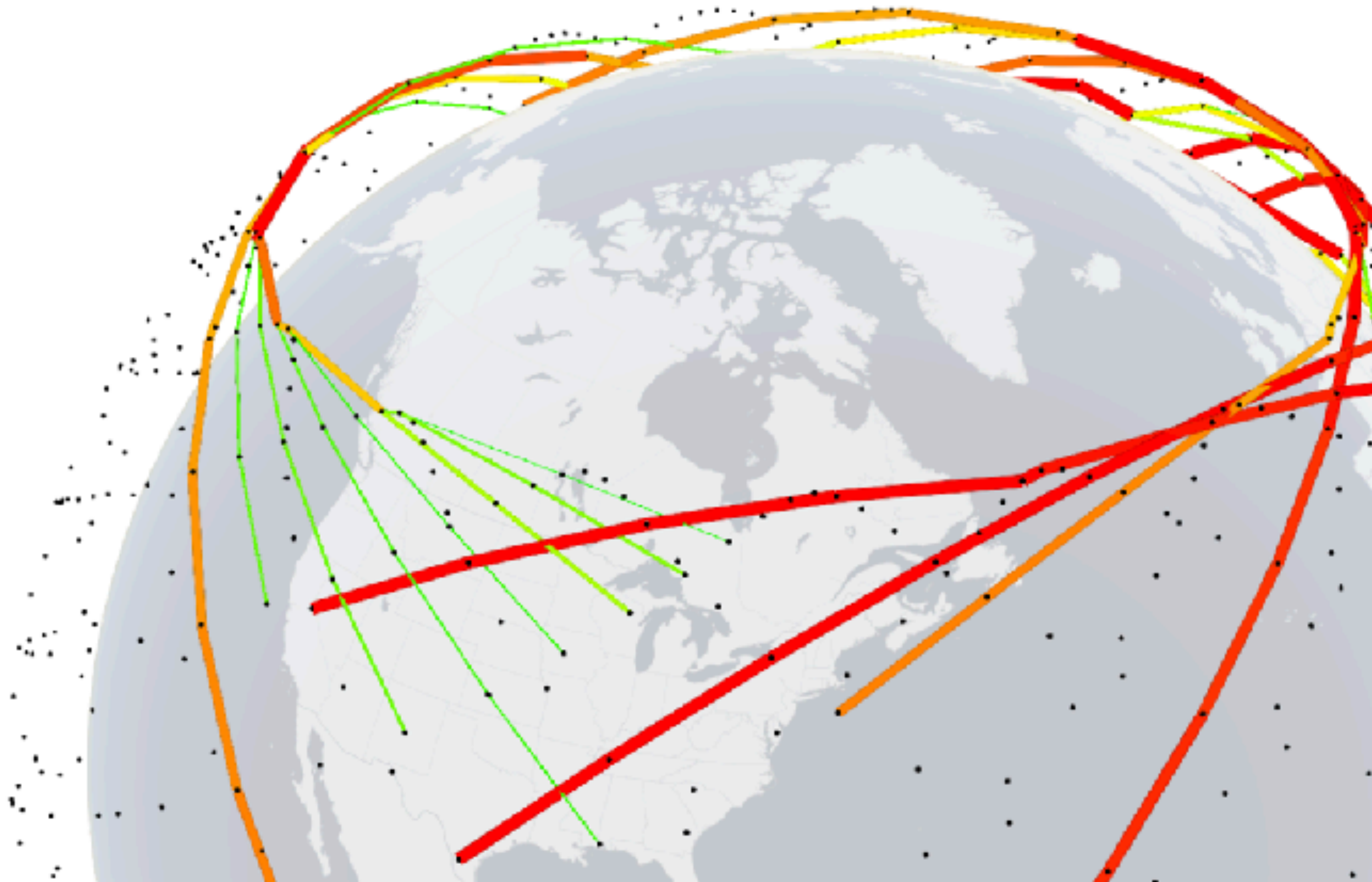
An uncongested link can suddenly see added traffic

Cross-traffic

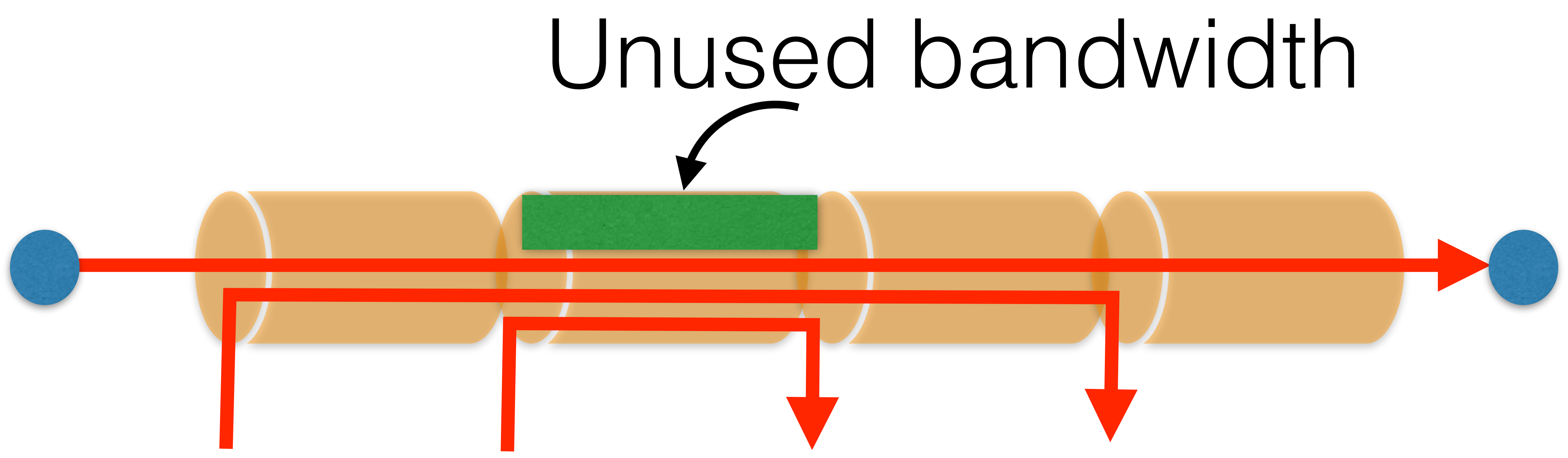


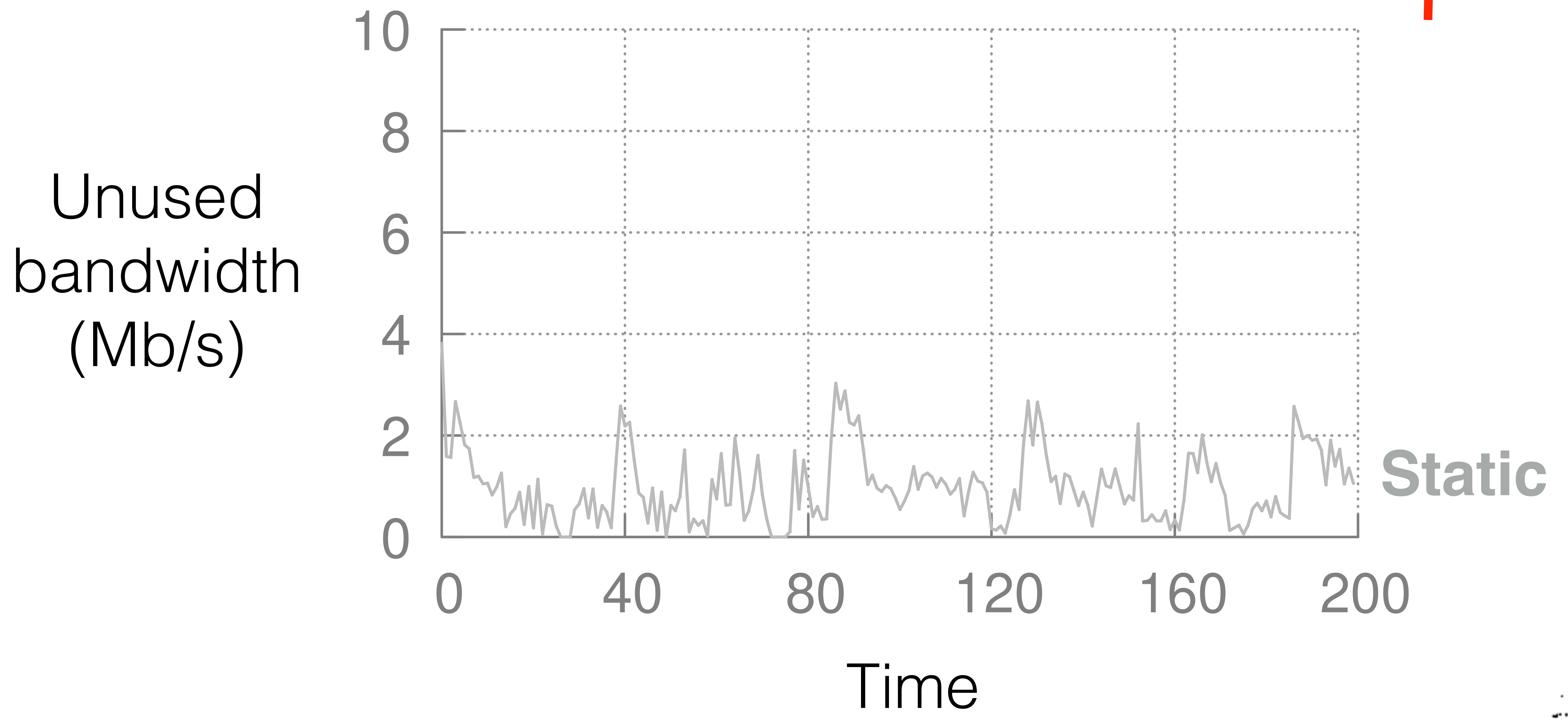


Kuiper K1

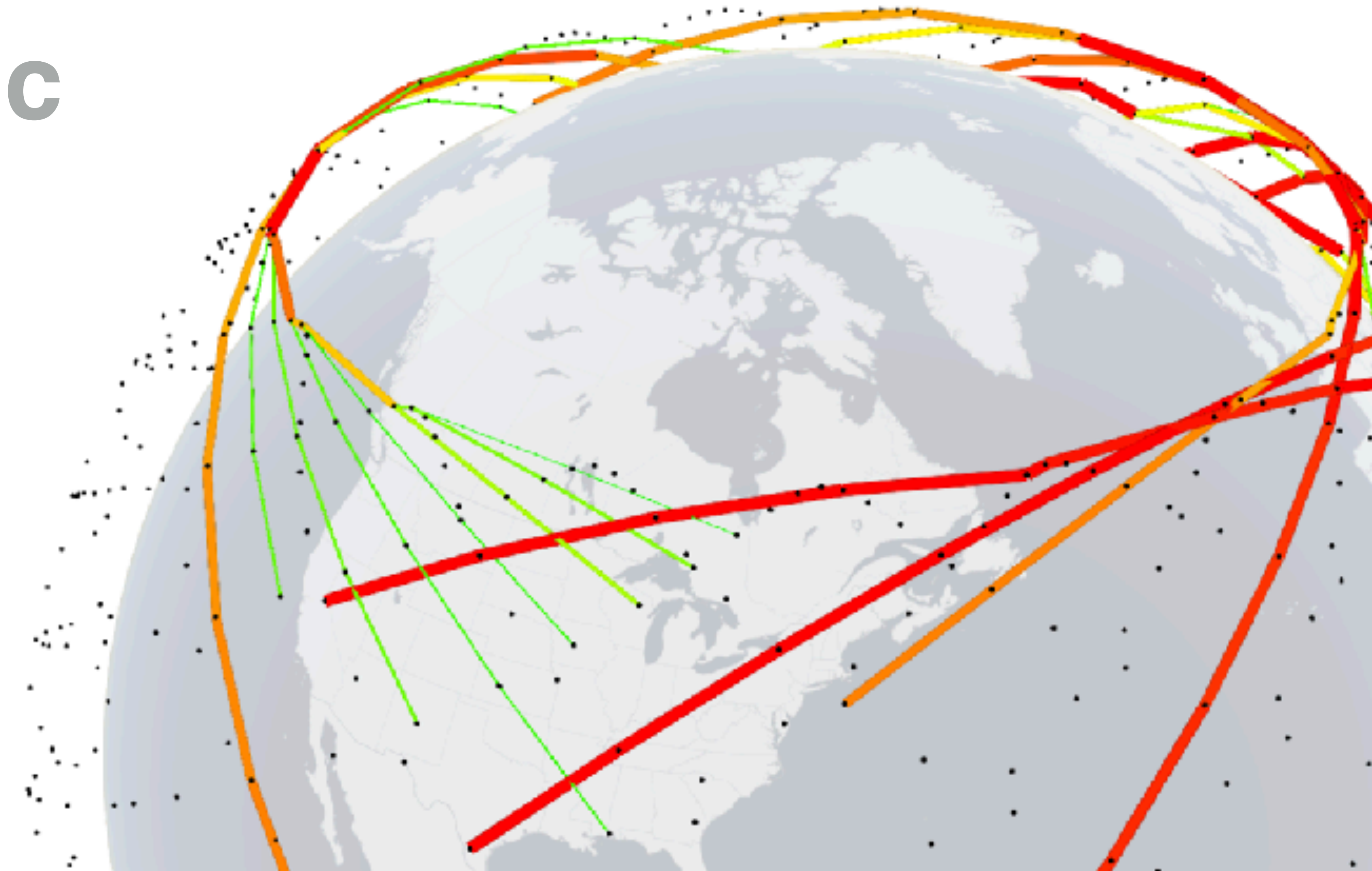


Cross-traffic

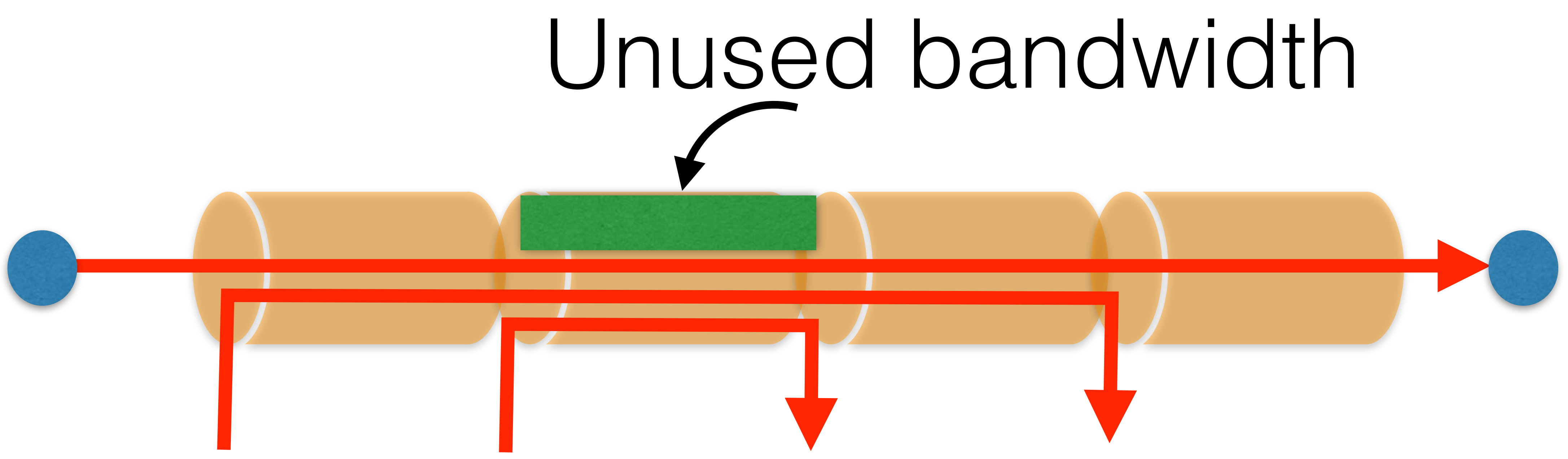


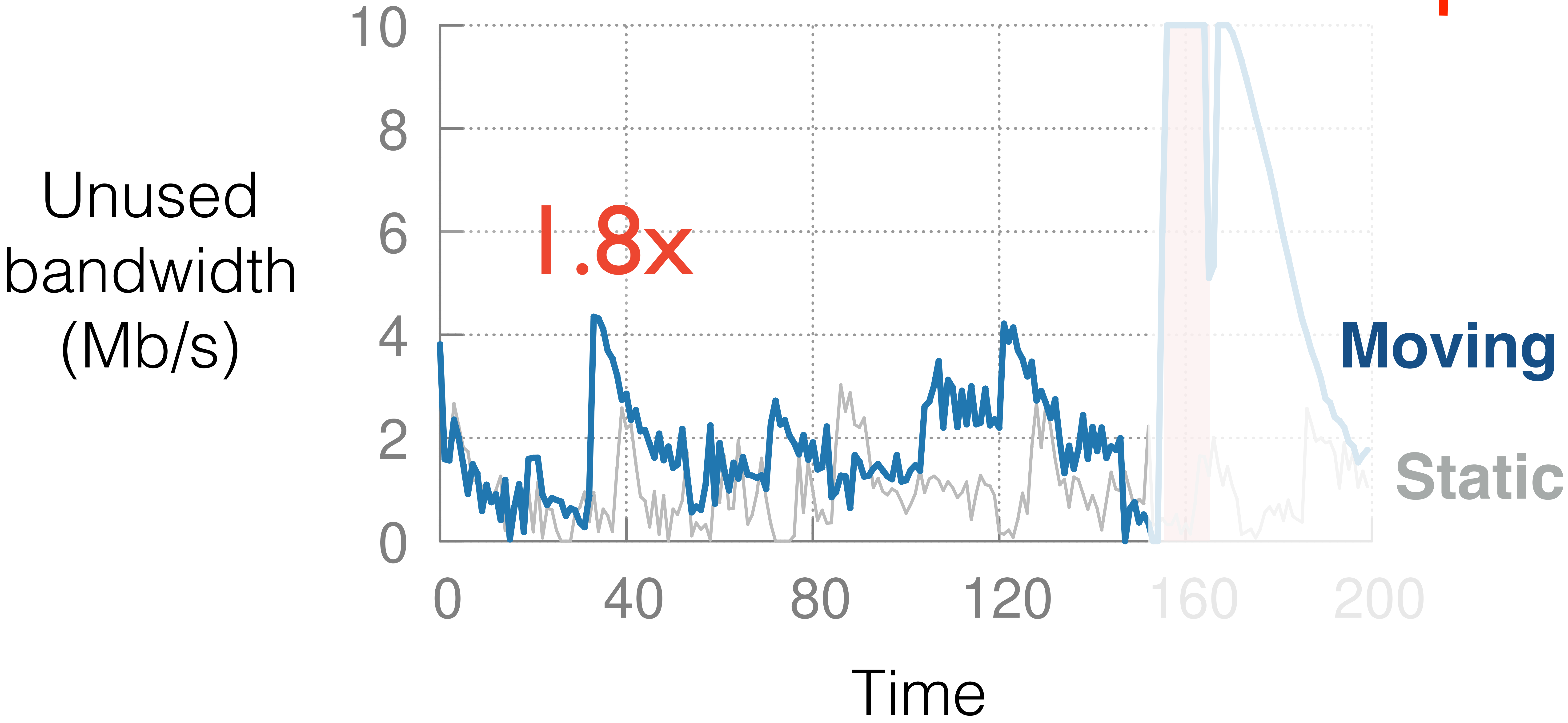


Kuiper K1

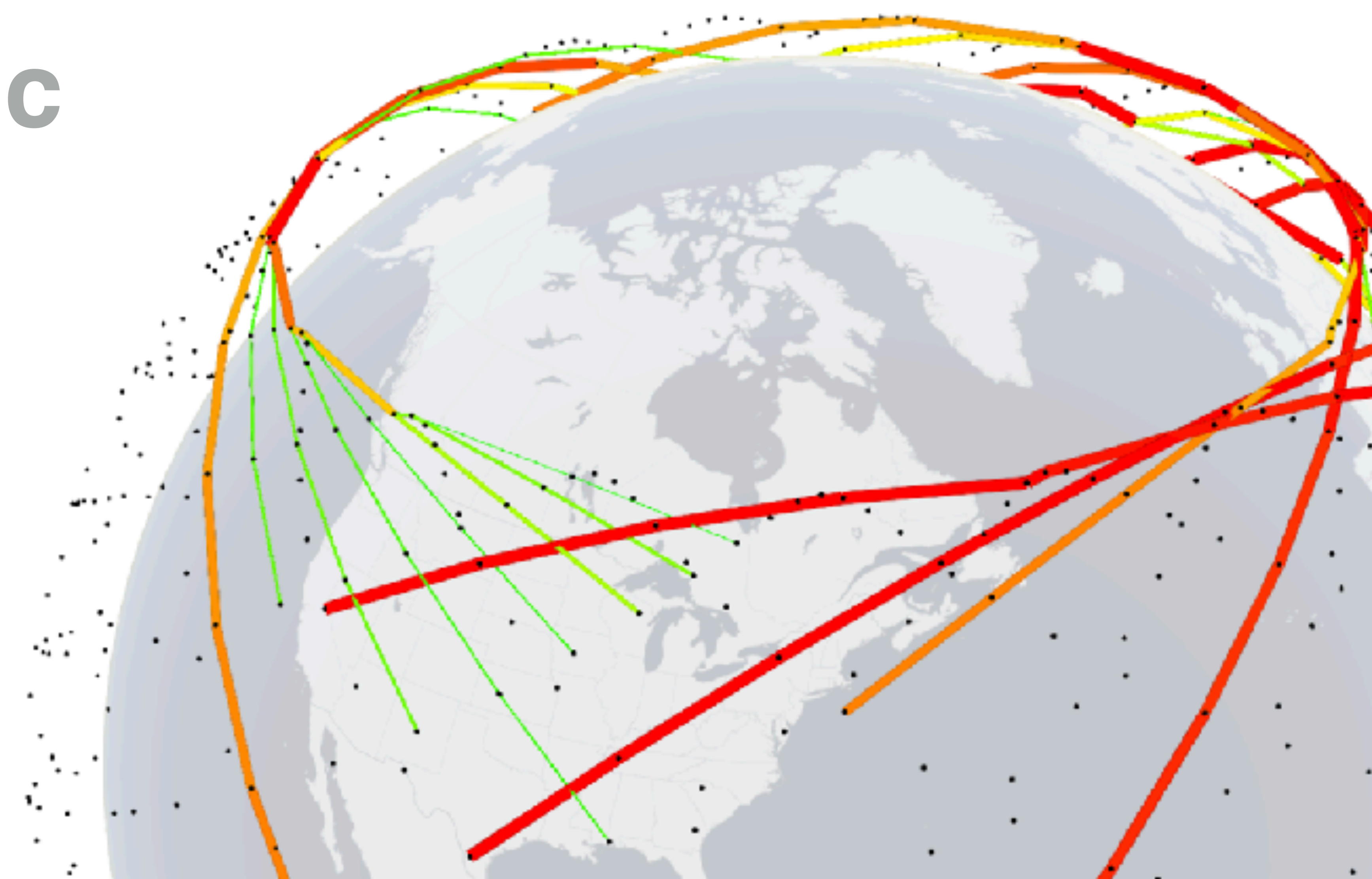


Cross-traffic

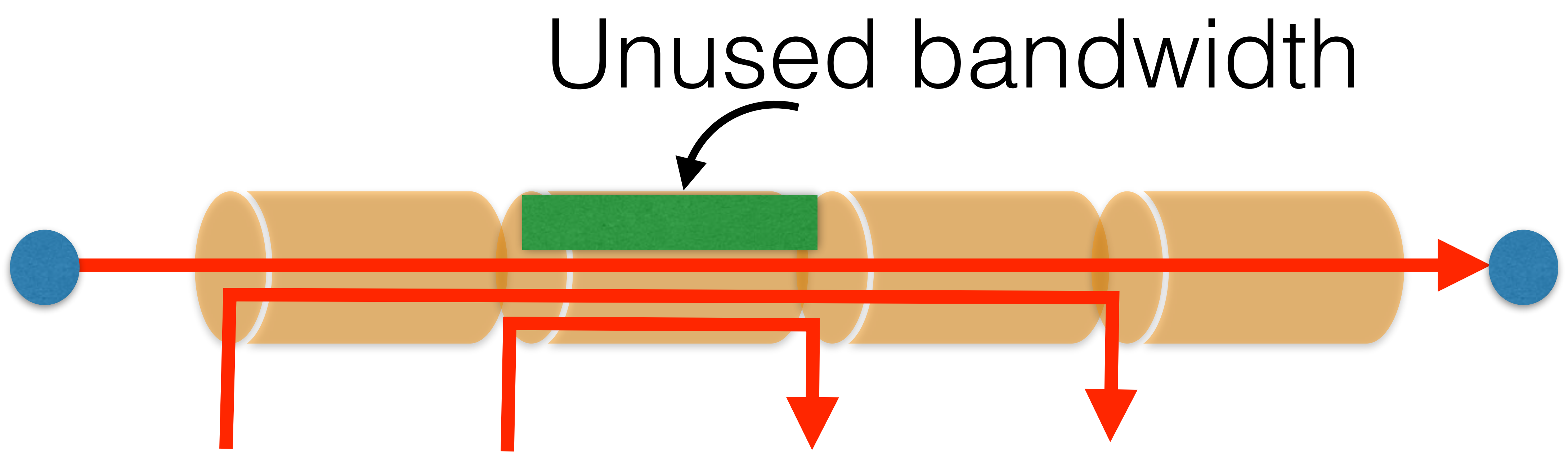


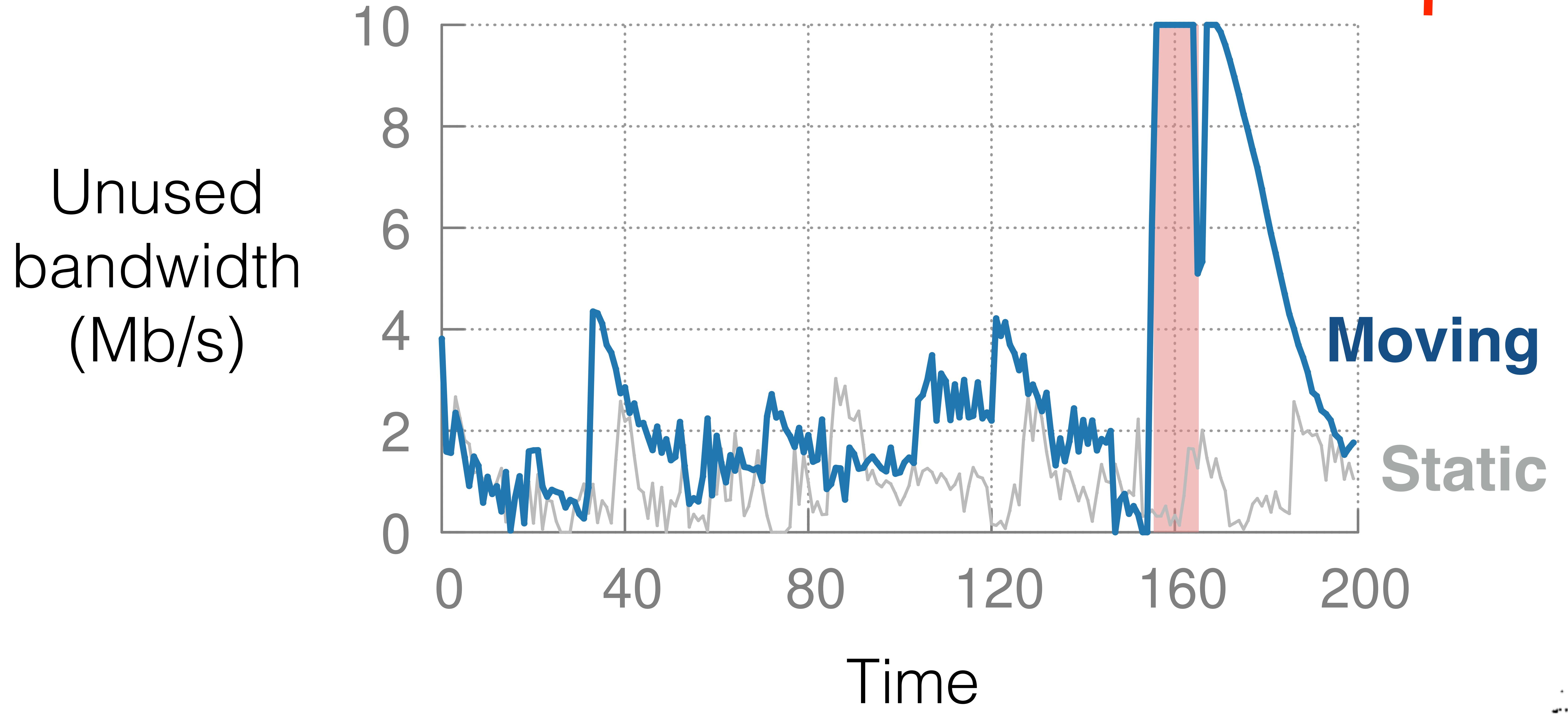


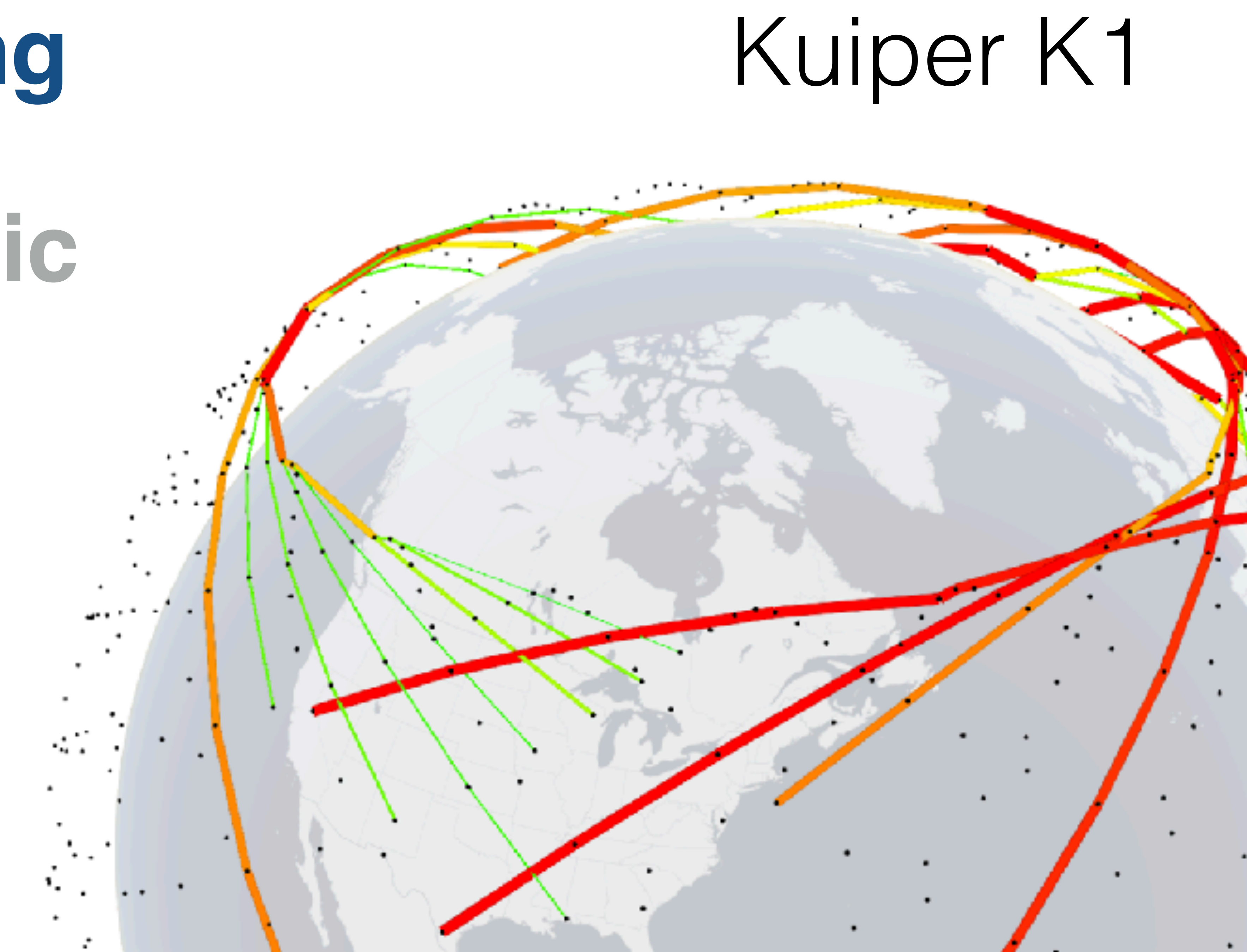
Kuiper K1



Cross-traffic







Challenge for transport: fast convergence

Challenge for TE: planning across time

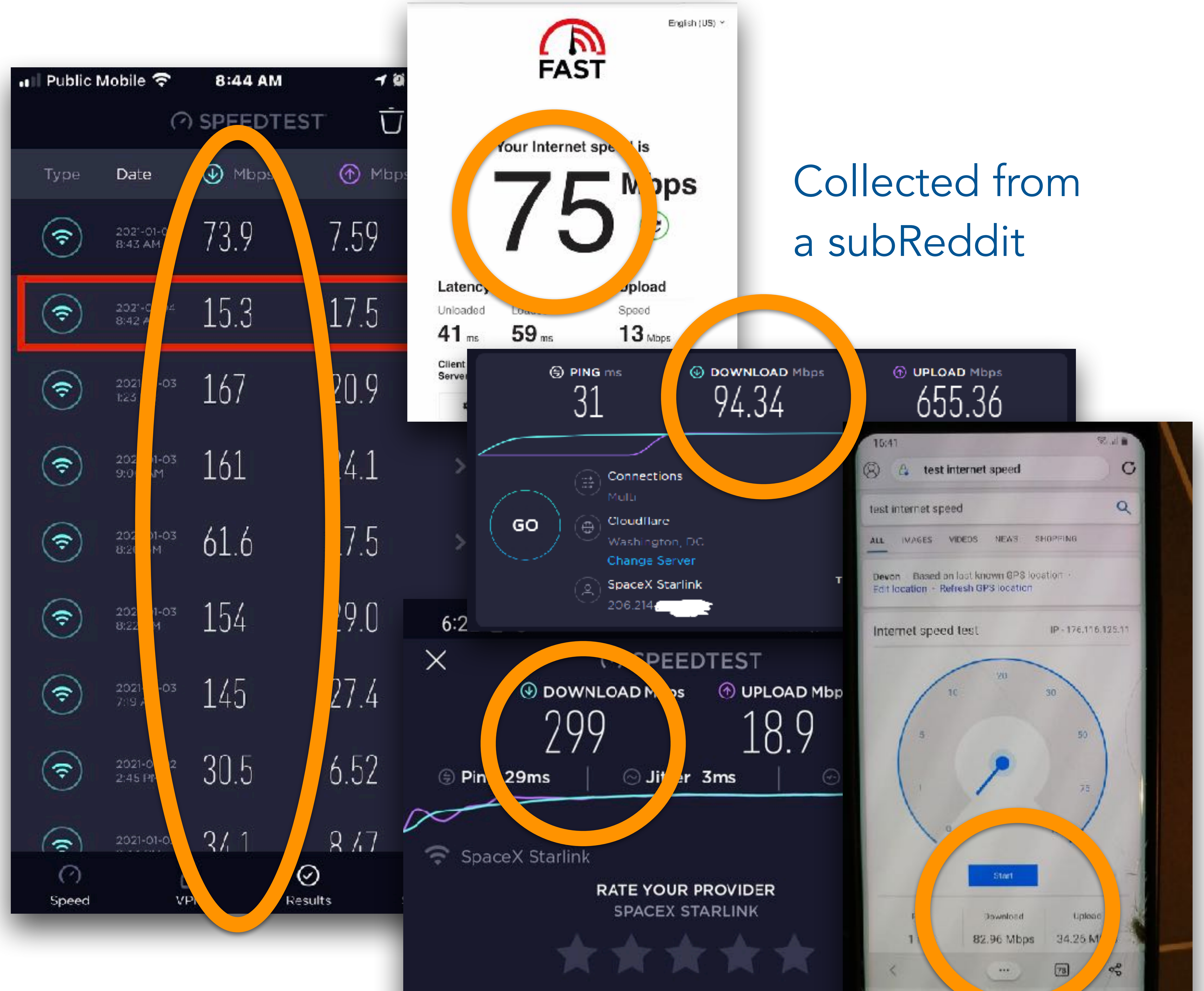
Hypatia is only the first step

in building up research infrastructure for a new breed of networks

Agenda

- What is the LEO hype about?
- Understanding LEO networks
- LEO simulations
- **A global testbed & beyond** [CCR’21; A Singla]

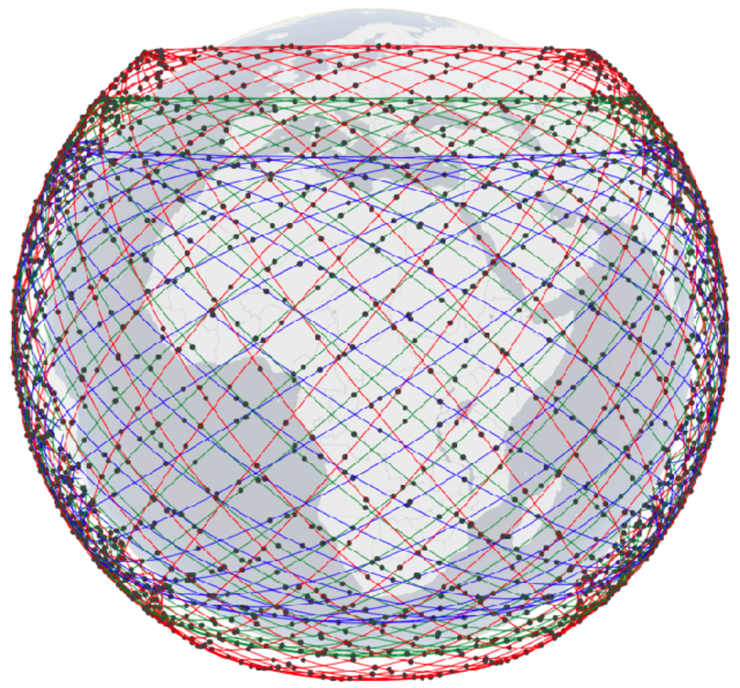
Starlink Beta performance reports



Collected from a subReddit

Performance varies with

Time



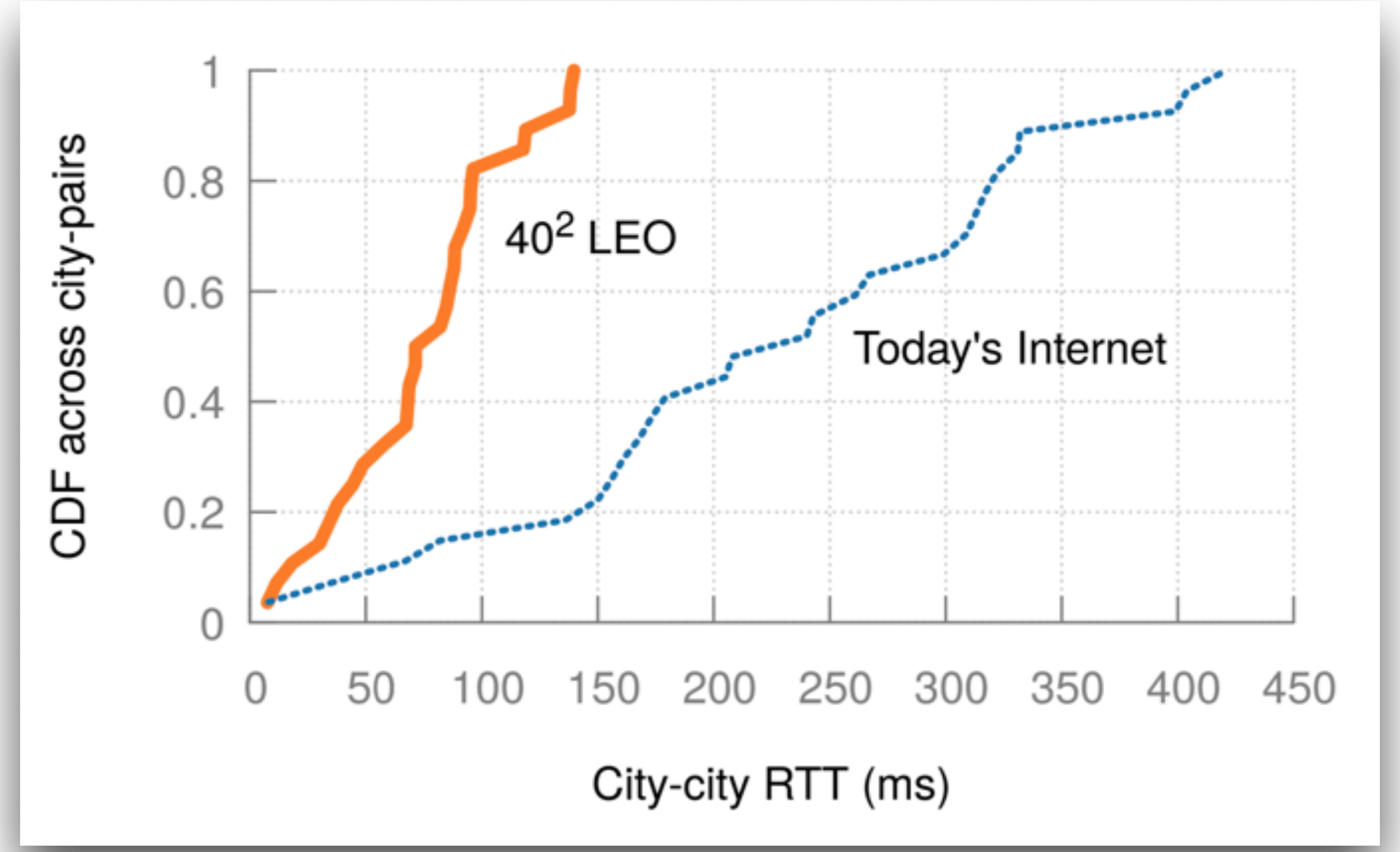
Location

Deployments

A global LEO measurement testbed

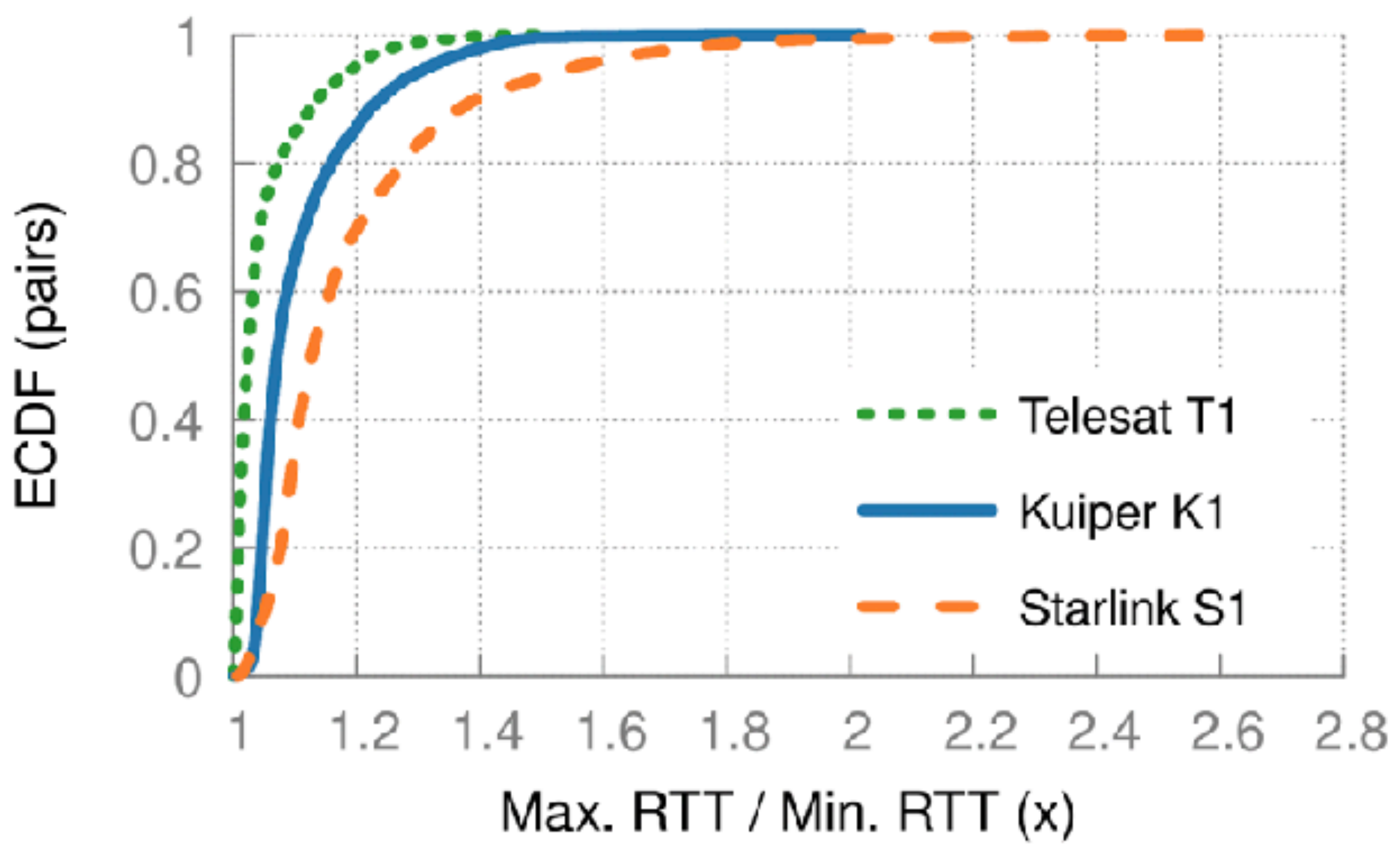
A global LEO measurement testbed

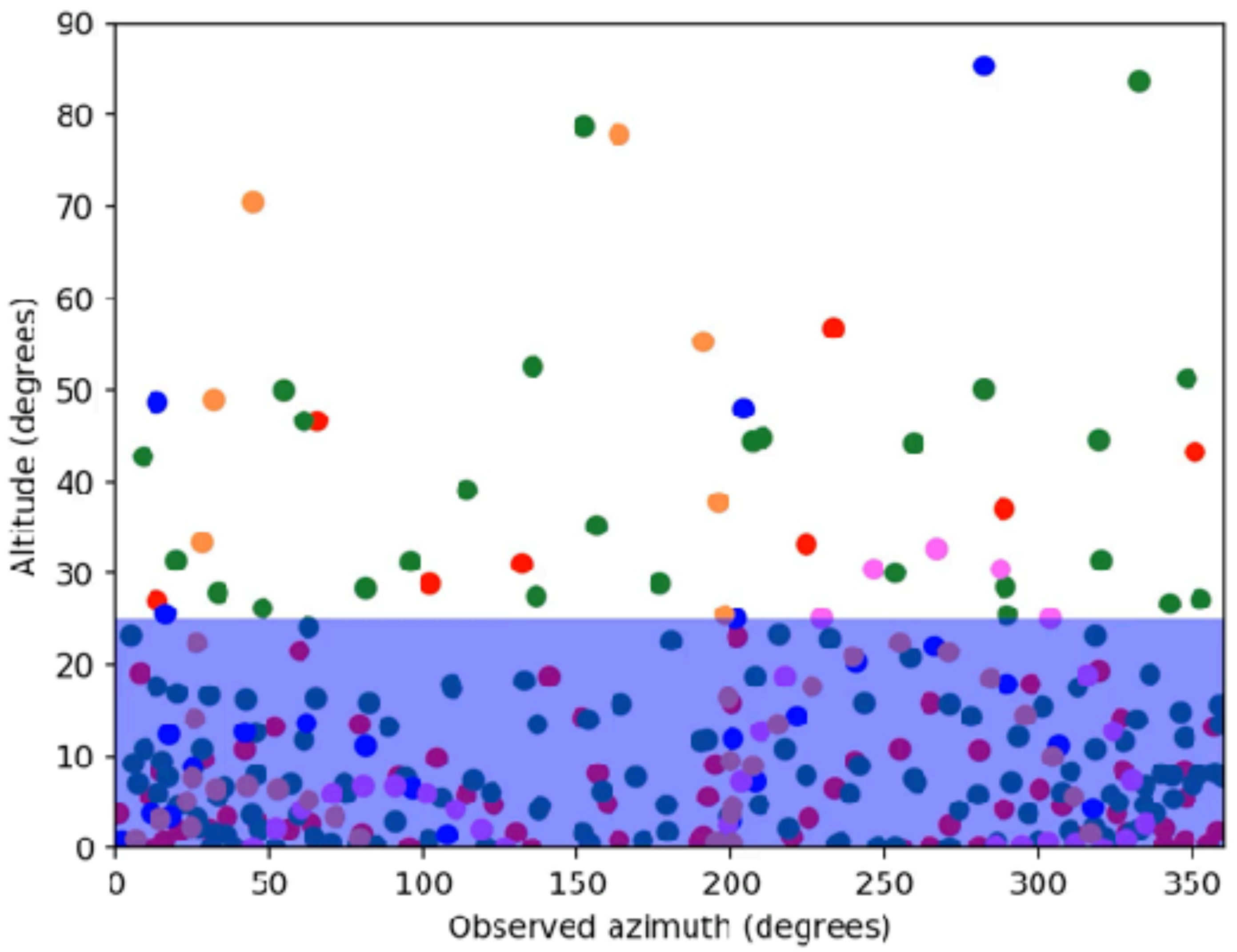
- Low-latency application QoE



A global LEO measurement testbed

- Low-latency application QoE
- Latency fluctuations due to LEO dynamics



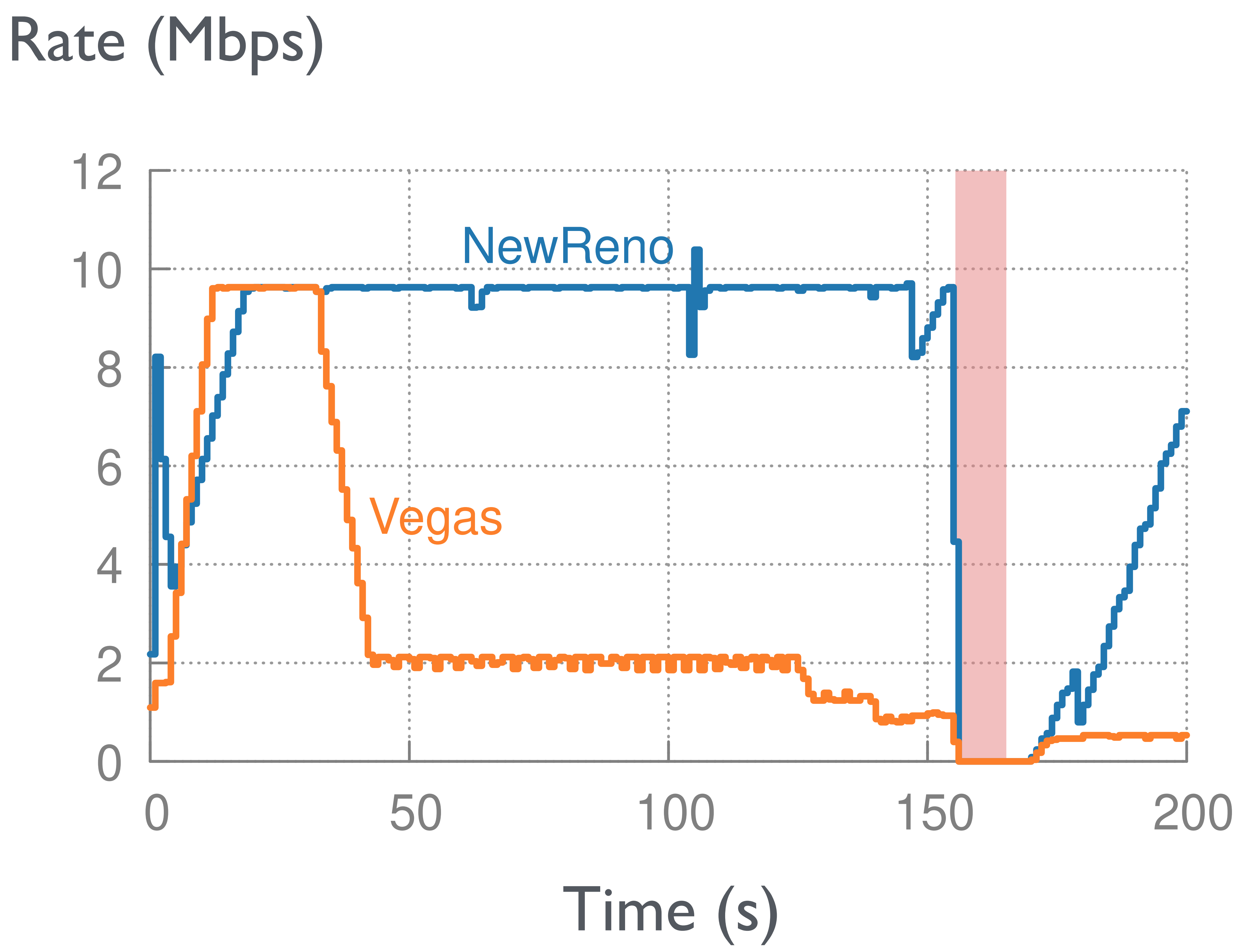


Starlink S1 from Delhi

50x faster than real-time

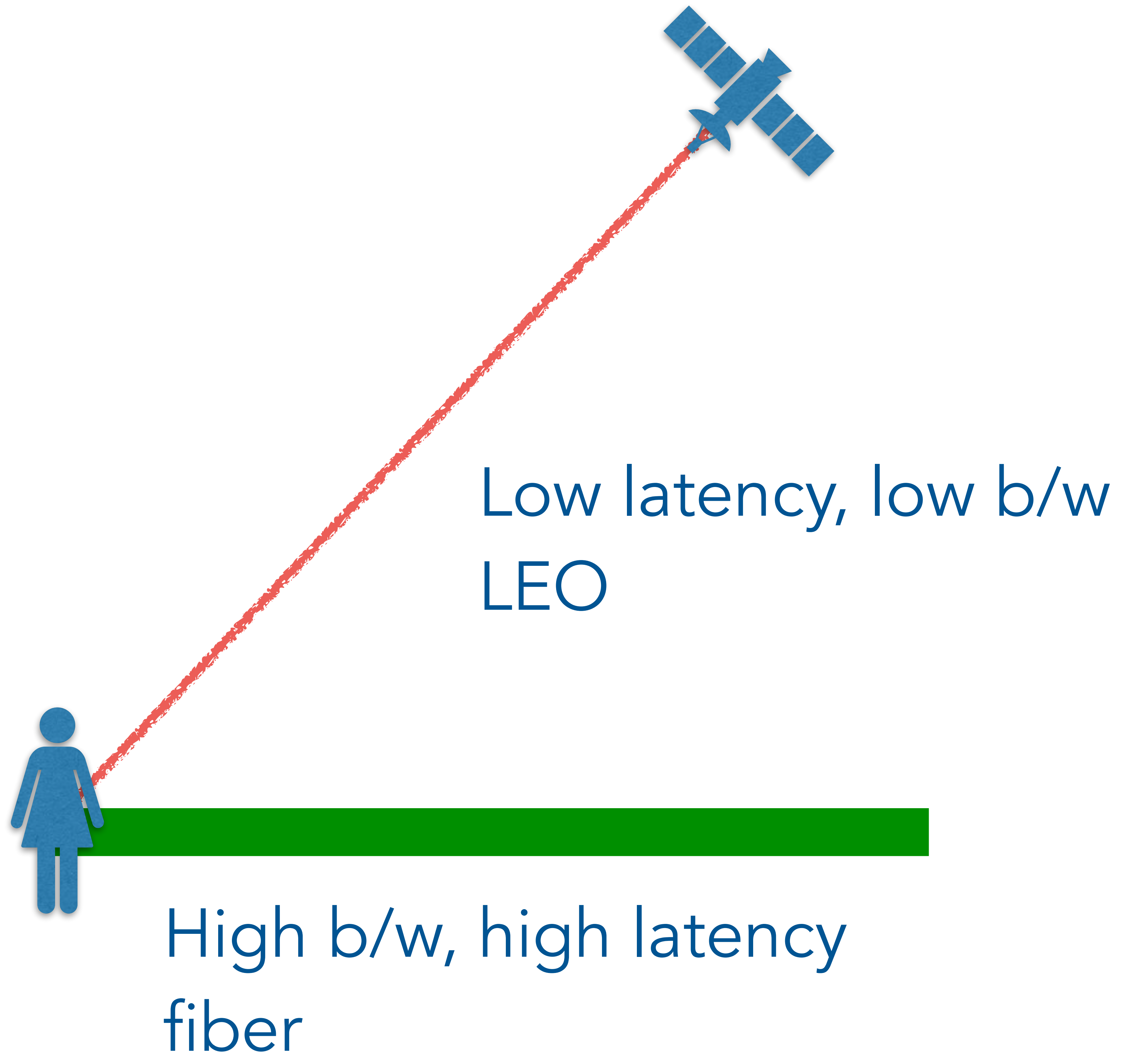
A global LEO measurement testbed

- Low-latency application QoE
- Latency fluctuations due to LEO dynamics
- Congestion control evaluation



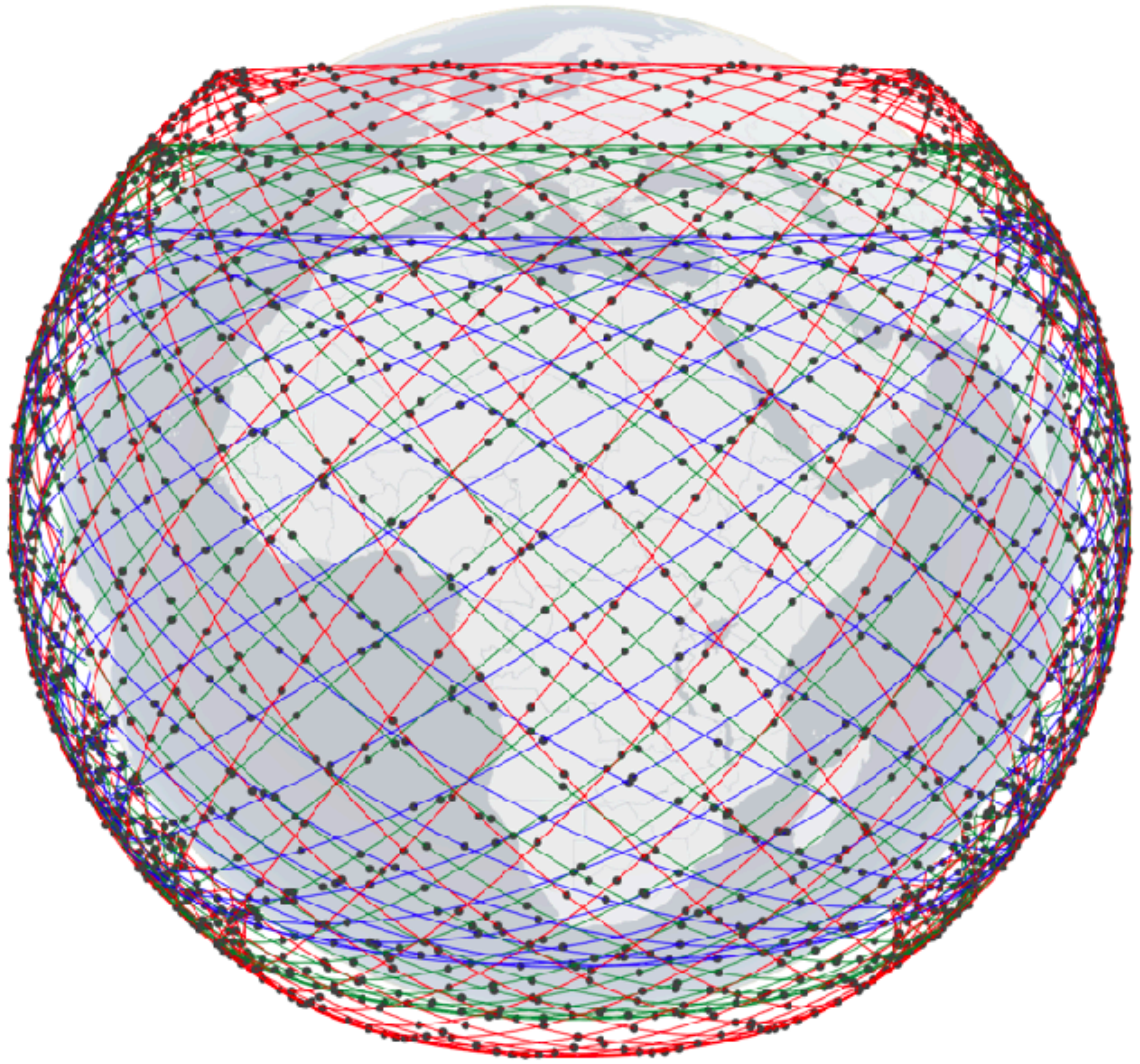
A global LEO measurement testbed

- Low-latency application QoE
- Latency fluctuations due to LEO dynamics
- Congestion control evaluation
- Multi-access connectivity



A global LEO measurement testbed

- Low-latency application QoE
- Latency fluctuations due to LEO dynamics
- Congestion control evaluation
- Multi-access connectivity
- Impact of weather, geometry, long-term evolution, etc.



Current participation

- Microsoft Research
- Azure Space
- Univ. Surrey
- Telefonica

Let’s join hands!

- Reach me at debopamb@microsoft.com
- For LEOCONN WS, subscribe mailing list: https://aka.ms/subscribe_LEOCONN