A Characterization of Route Variability in LEO Satellite Networks

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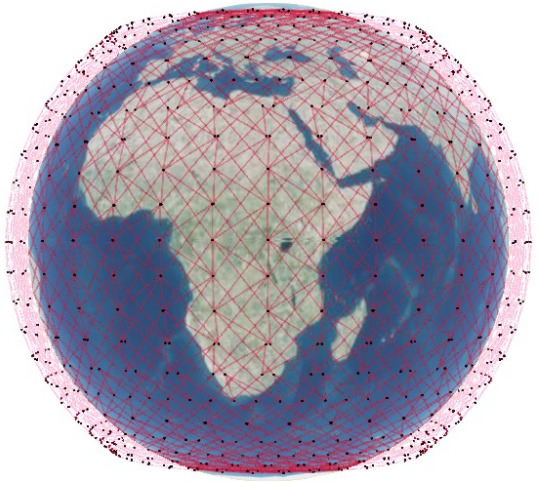
Low Earth Orbit (LEO) Satellite

- >10,000 LEO satellites planned in the next decade
- High bandwidth and low cost in rural and disaster-affected areas
- Potential to outperform terrestrial networks
- Satellites form a network using Inter Satellite Links (ISLs) routing data through these links to the destination ground station


POLITICO

UkraineX:
How Elon Musk's space satellites changed the war on the ground

JUNE 8, 2022 | 9:00 AM



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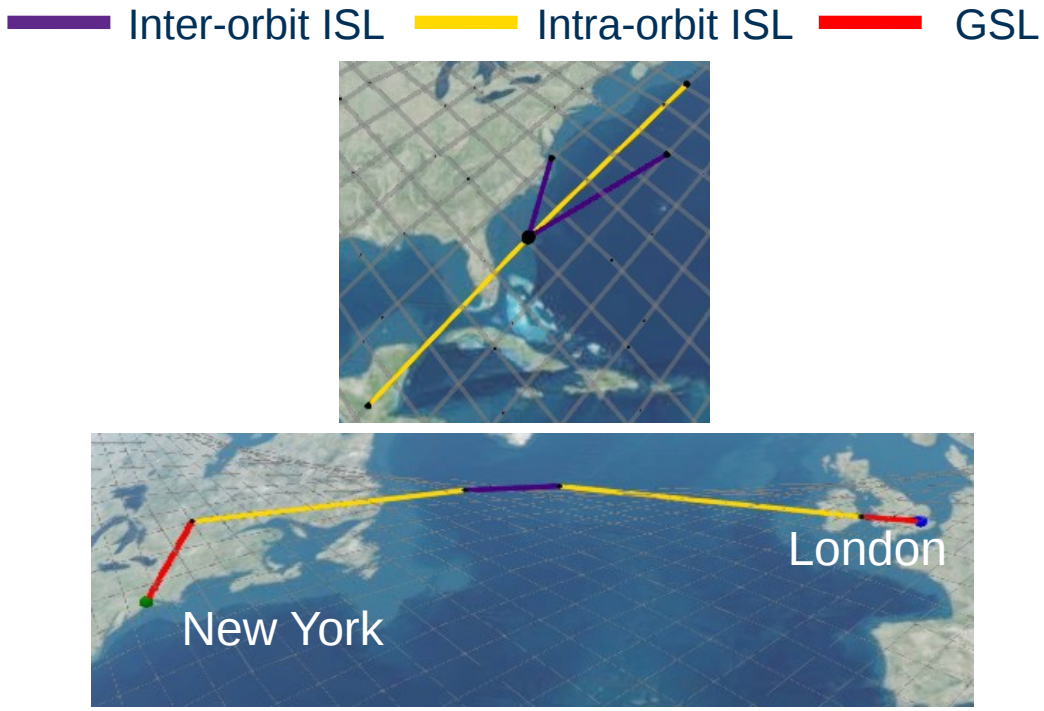
A LEO Satellite Networks Primer

- +Grid ISL Topology
- Paths made up of two Ground-Satellite Links (GSLs) and zero or more ISLs
- Highly dynamic infrastructure with satellites moving at 27,000 km/h
- A satellite accessible for maximum 4.5 minutes



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How does this impact networking algorithms?

- Networking algorithms assume stable paths and RTTs
  - Congestion control and adaptive video streaming attempt to converge to the capacity of the selected path
  - Traffic engineering algorithms assume a stable ranking of available paths between two points

A characterization of variability needed to check if current networking algorithms need to be modified.

What is the extent of Variability in LEO Satellite Networks?

Objectives of our Study

- How much route churn exists?
  - Is this route churn necessary?

Route churn is a measure of the frequency of change in routes between a source-destination pair.

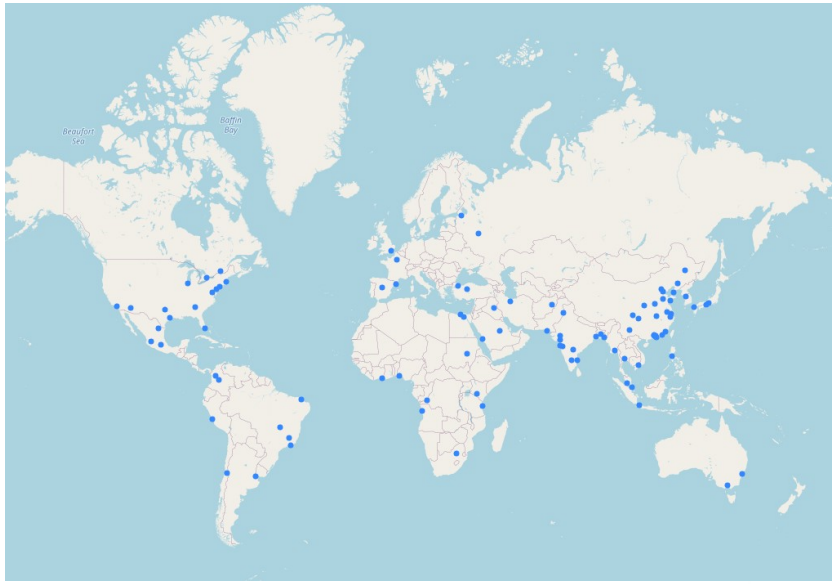
- How much RTT variability exists?
  - Can we explain this variability?

RTT Variability is a measure of the RTT variation between a source-destination pair.

Simulation Methodology

- Simulate **Starlink**, Kuiper, Telesat based on public FCC filings
  - Predict satellite locations using path models
- Use shortest-path routing to minimize RTT
- Measure route characteristics for 100 minutes
  - Recompute routes every second
- 100 most populous cities as ground stations
  - 4950 src-dst pairs
  - ~600k routes observed

	Altitude	Inclination	Orbits	Satellites
Starlink	550	53	72	1584



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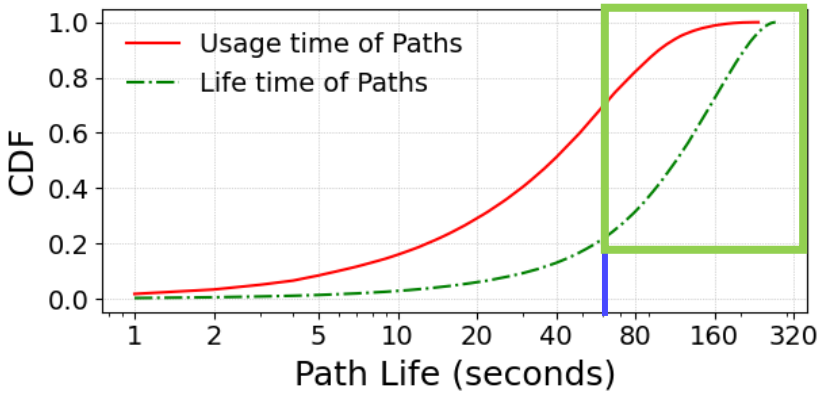
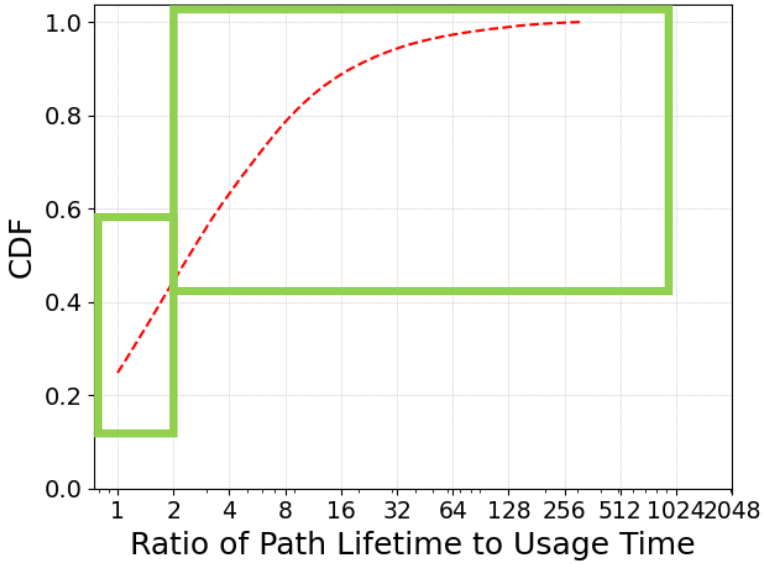
How much Route Churn is Observed?

- All paths studied are shortest paths
  - Compare the usage time and lifetime of a path
- More than 80% paths exist for more than a minute, but just ~30% are used for more than a minute
- Two reasons for route churn
  - Path ceasing to exist
  - Rerouting between valid paths





>50% paths are used for less than half their lifetime

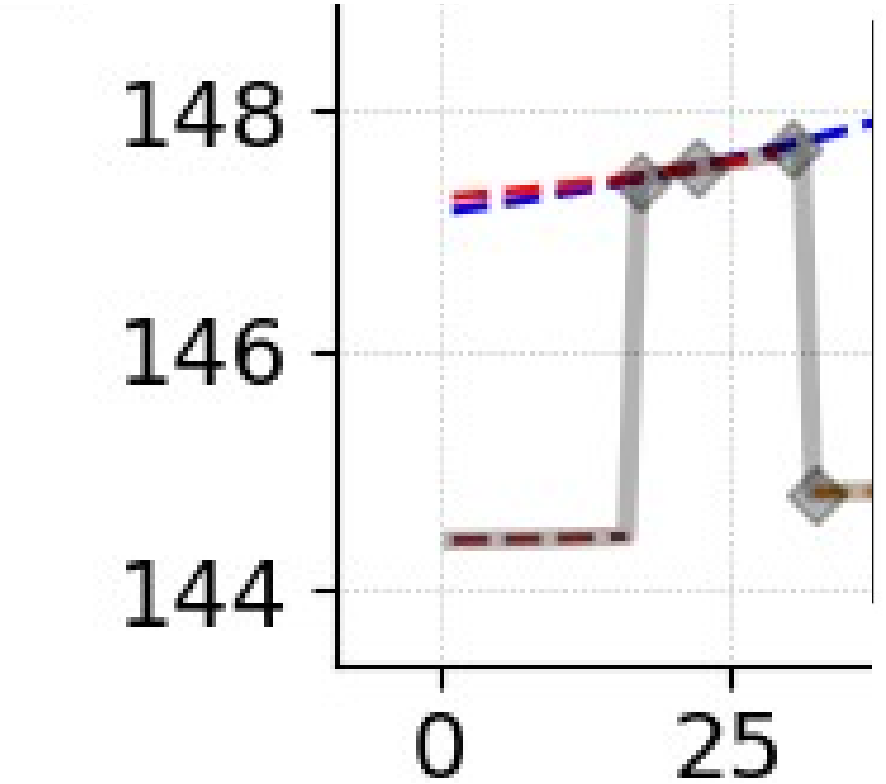
Is this Route Churn Necessary?

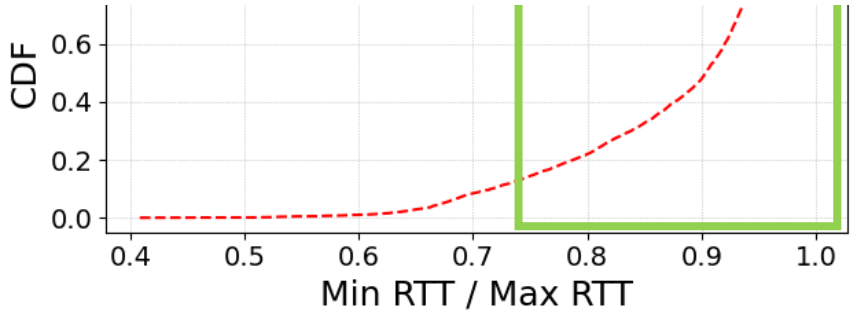
- Jakarta-Bogotá as an example
  - Multiple path switches with RTT varying by ~6-8 ms
  - Second switch due to 0.005 ms latency gain only to switch back to the earlier path in a few seconds

- Compa RTT and the minimu

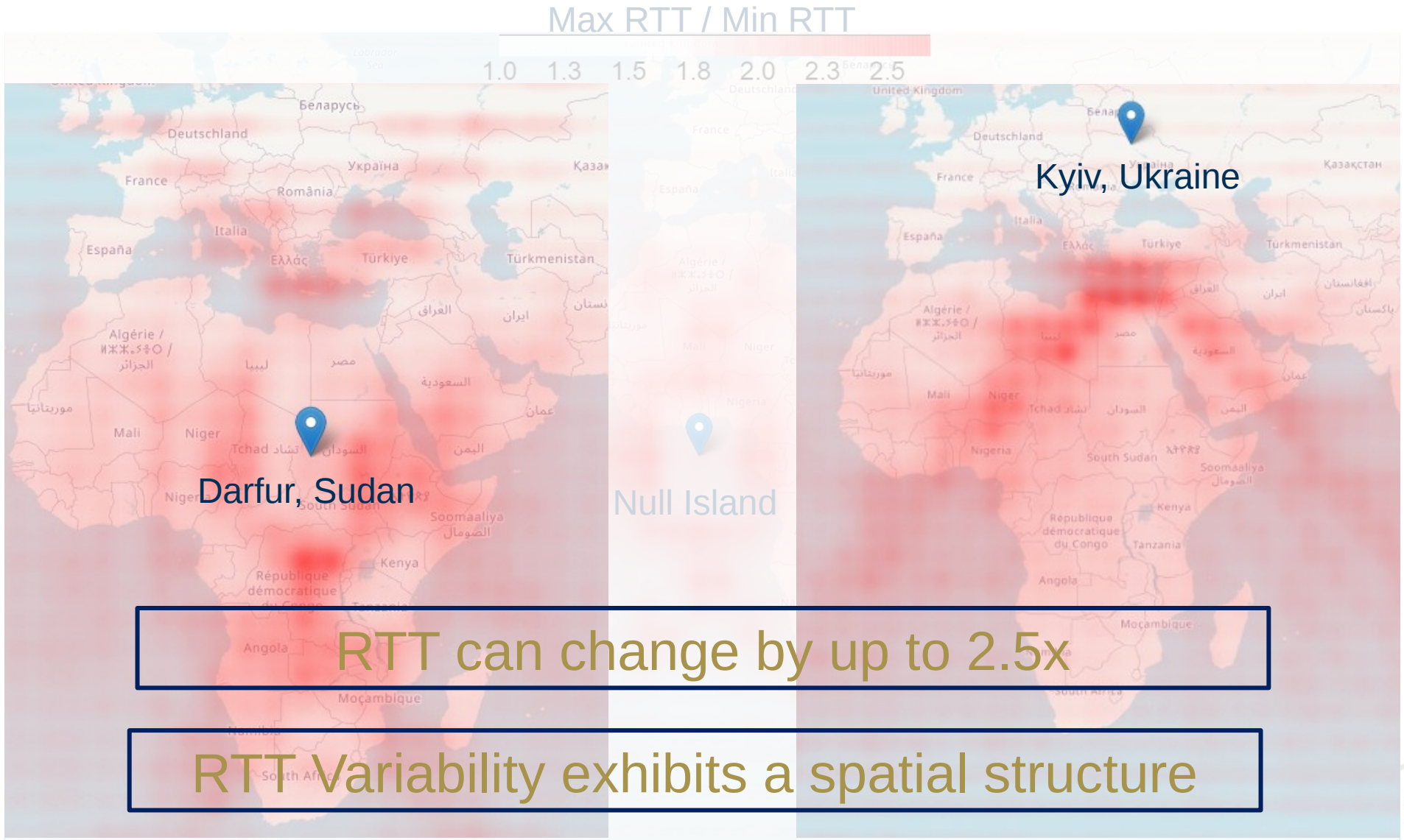
>8 d for less

Dotted Lines – Individual paths
Solid line - Actual RTT selected
Diamonds – Path switches





How much RTT variability exists?



RTT can change by up to 2.5x

RTT Variability exhibits a spatial structure

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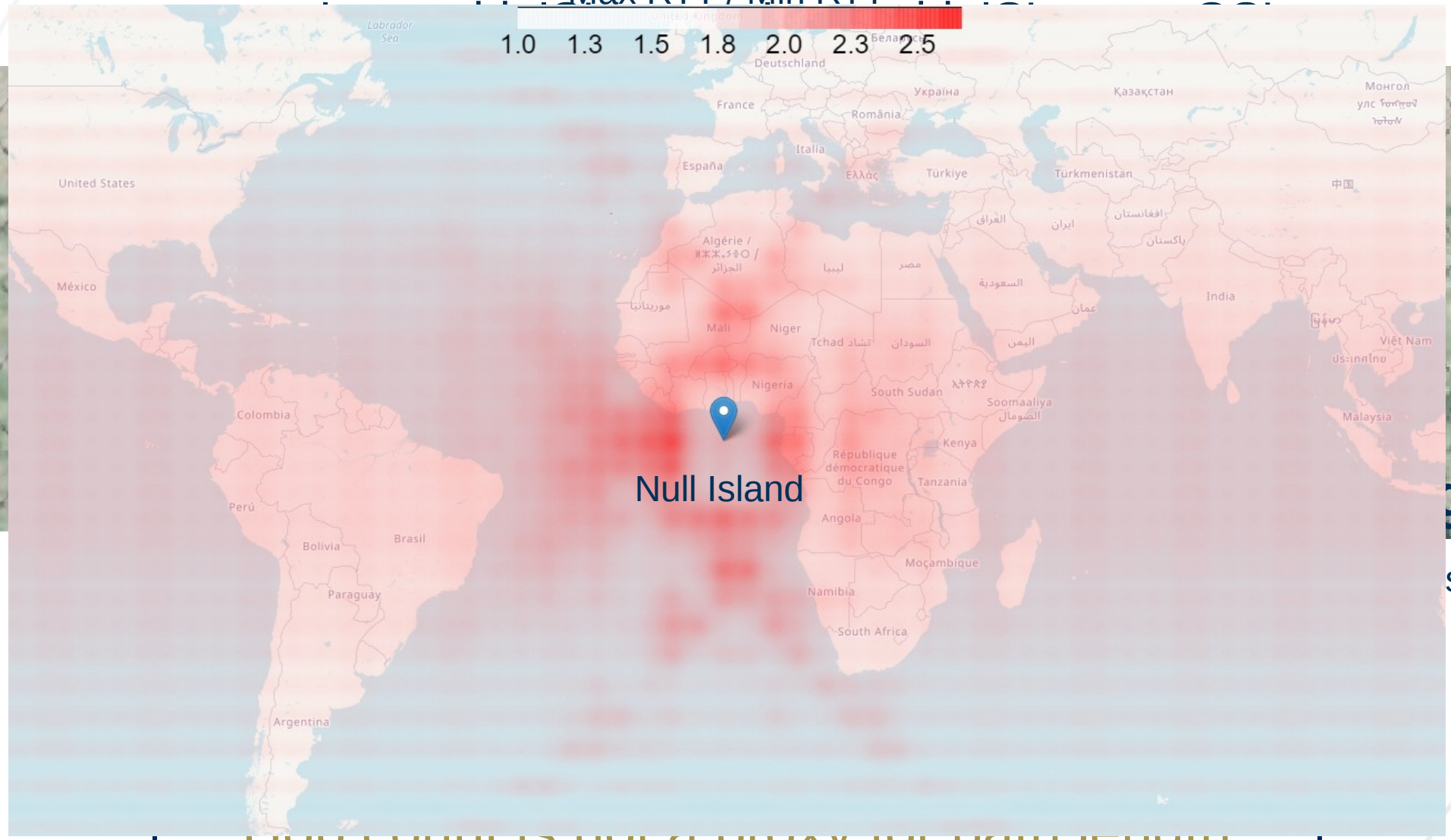
Can we explain this RTT Variability?



3 paths over
6 seconds

Hop count is not a proxy for path length

Warning!!! 2D representation of 3D paths

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Summary

- How much route churn exists?
  - Is this route churn necessary?

>50% paths are used for less than half their lifetime
>80% paths are abandoned for less than 25% gain

- How much RTT variability exists?
  - Can we explain this variability?

RTT can change by up to 2.5x
RTT Variability exhibits a spatial structure

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