Assessing LEO Satellite Networks for National Emergency Failover

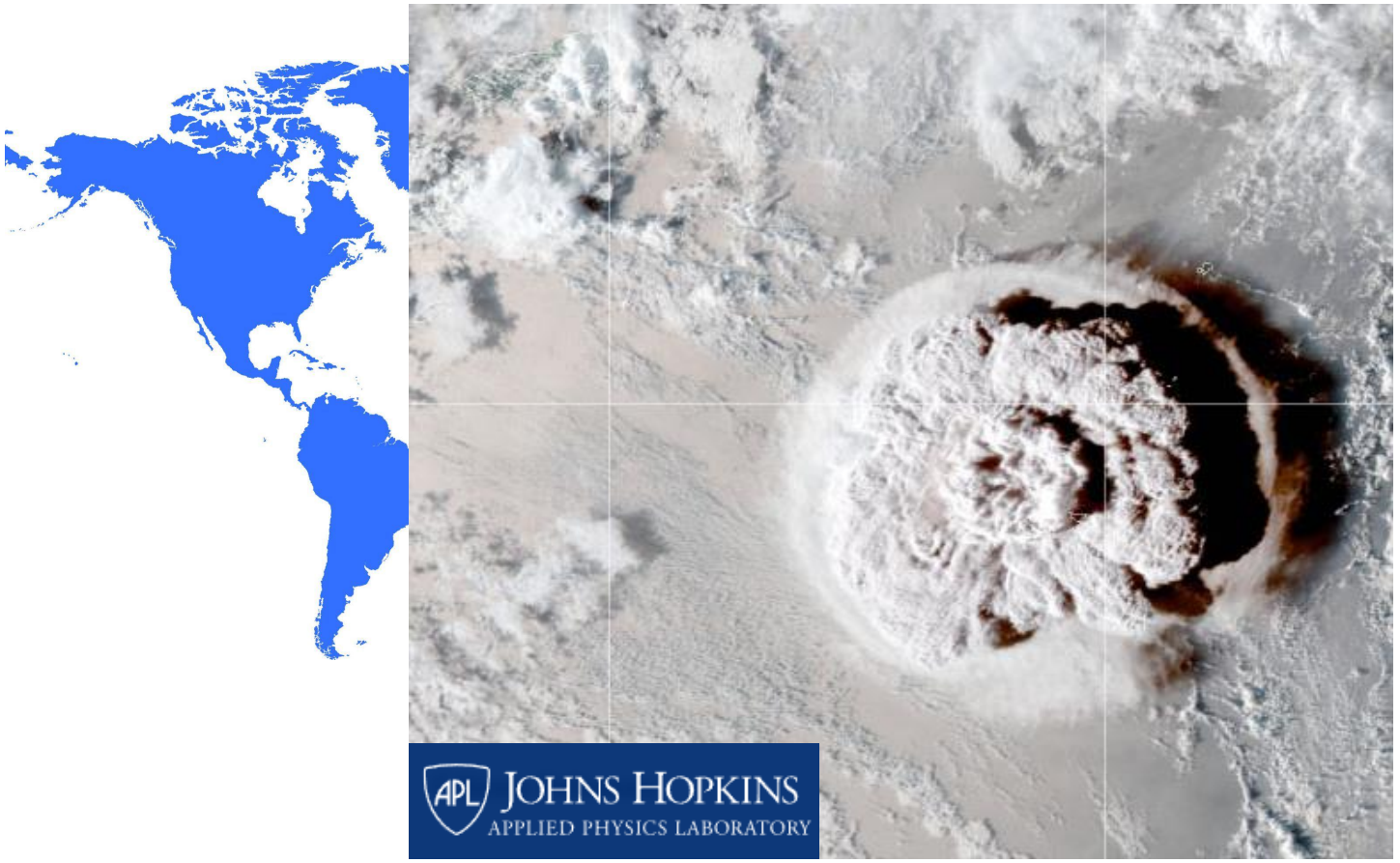
Vaibhav Bhosale, Ying Zhang, Sameer Kapoor, Robin Kim, Miguel Schlicht, Muskaan Gupta, Ekaterina Tumanova, Zachary S. Bischof, Fabián E. Bustamante, Alberto Dainotti, Ahmed Saeed

Georgia Institute of Technology

Northwestern University


TONGA
Tonga POCKET GUIDE

Volcanic Eruption on January 15, 2022



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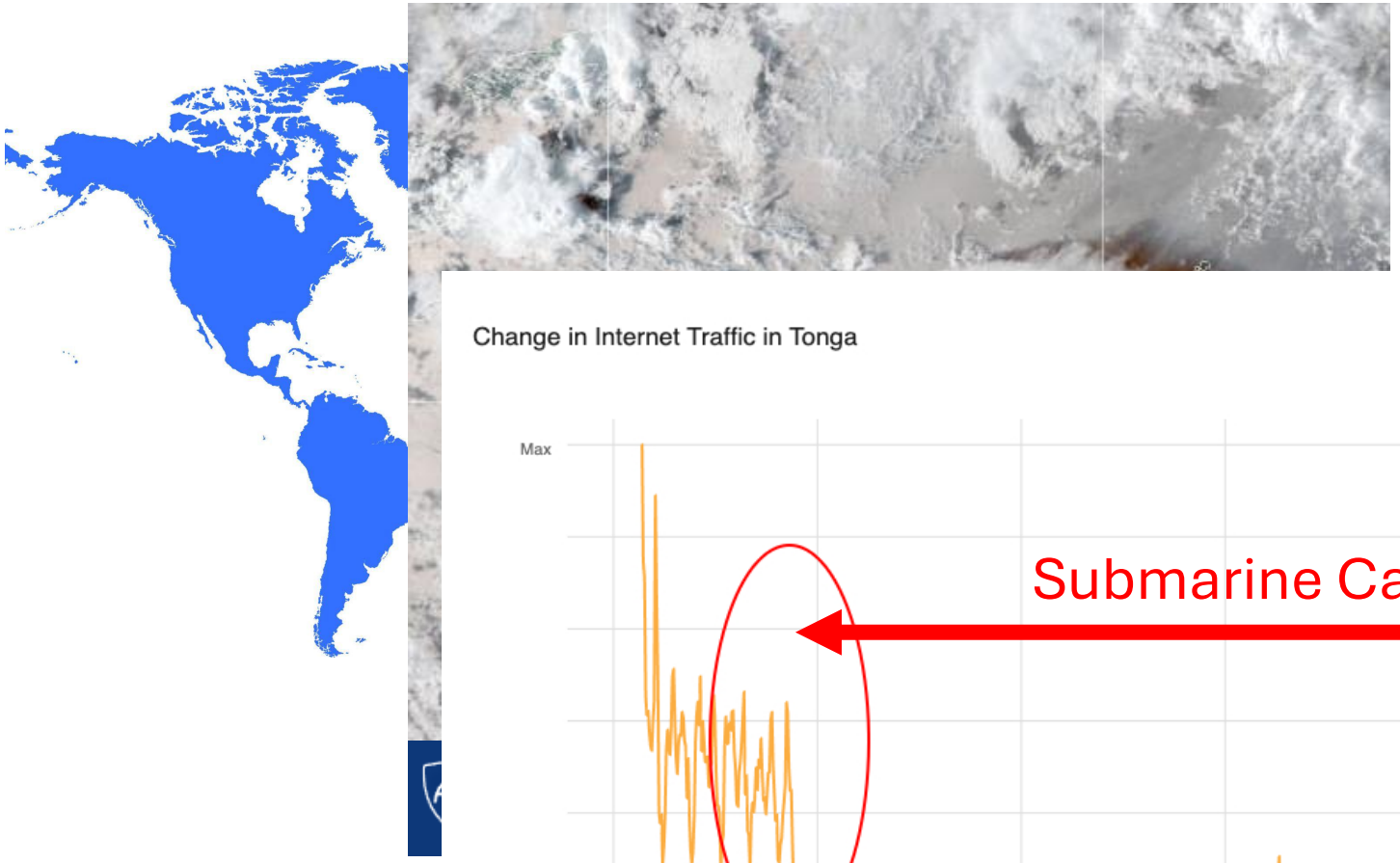
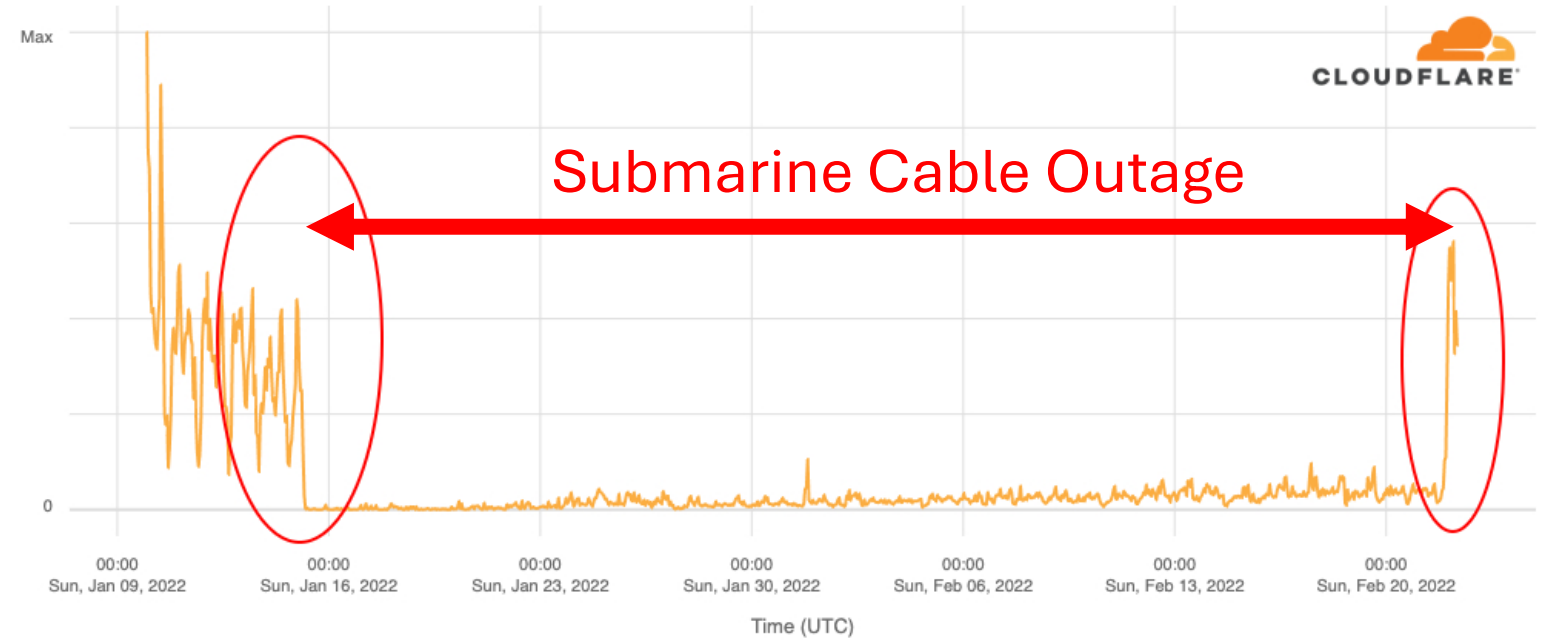


Severely damaged the submarine cable



Satellites to the Rescue!

BLOG

Restoration of Internet Connectivity in Tonga by SpaceX - Starlink Company

February 17th. 2022. CEO for MEIDECC and Department of Communications received, 50 VSAT Terminals kindly offered and donated by SpaceX and Starlink on Tuesday 15th February 2022, to the Government of Tonga for their relief efforts in response to the tsunami disaster that destroyed Tonga's only Submarine Fibre Cable.

Ministry of Communications
Government of the Kingdom of Tonga

Musk's Starlink connects remote Tonga villages still cut off after tsunami

By Kirsty Needham

February 23, 2022 3:05 AM EST · Updated February 23, 2022

Reuters

Satellite Operators Restore Critical Communications to Tonga After Volcanic Eruption

By Rachel Jewett | January 21, 2022

Via Satellite

Satellites to the Rescue!

Elon Musk's SpaceX sent thousands of Starlink satellite internet dishes to Ukraine, company's president says

PUBLISHED TUE, MAR 22 2022•5:10 PM EDT | UPDATED TUE, MAR 22 2022•6:05 PM EDT

Michael Sheetz
@IN/MICHAELJSHEETZ

CNBC

How Elon Musk's Starlink Got Battle-Tested in Ukraine

Fast-expanding satellite broadband services are proving decisive during war and other emergencies.

By Vivek Wadhwa, a columnist at *Foreign Policy*, entrepreneur, and author, and Alex Salkever, a technology writer and futu

FP

Proactive Measures by Governments

NATO-funded project to reroute internet to space in case of disruption to critical infrastructure

31 Jul. 2024 - | Last updated: 28 Aug. 2024 11:10

Ghana to licence Starlink in response to subsea cable cuts

Jack Haddon March 20, 2024 10:20 AM

Developing Taiwan's own 'Starlink' crucial for island-wide emergency, space agency says

By Eric Cheung, CNN

6 min read · Published 10:21 PM EDT, Sat May 4, 2024

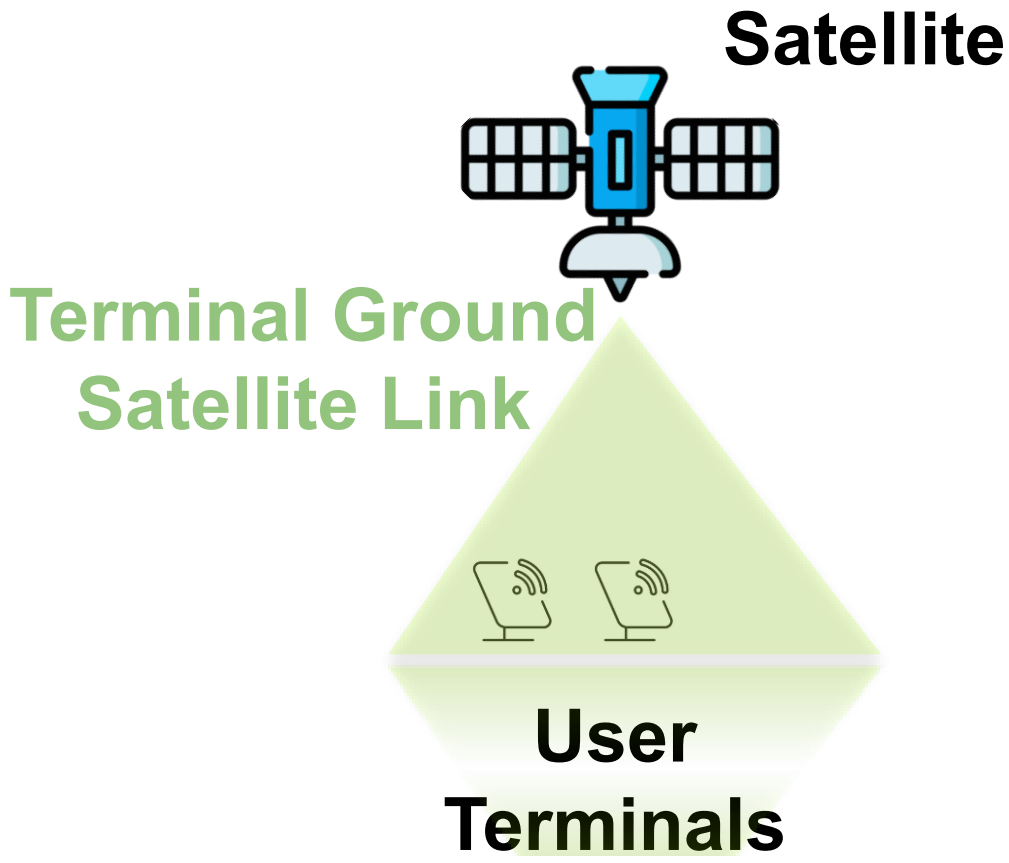
How Effective Can LEO Networks Be During Emergency Scenarios?

Key Takeaways

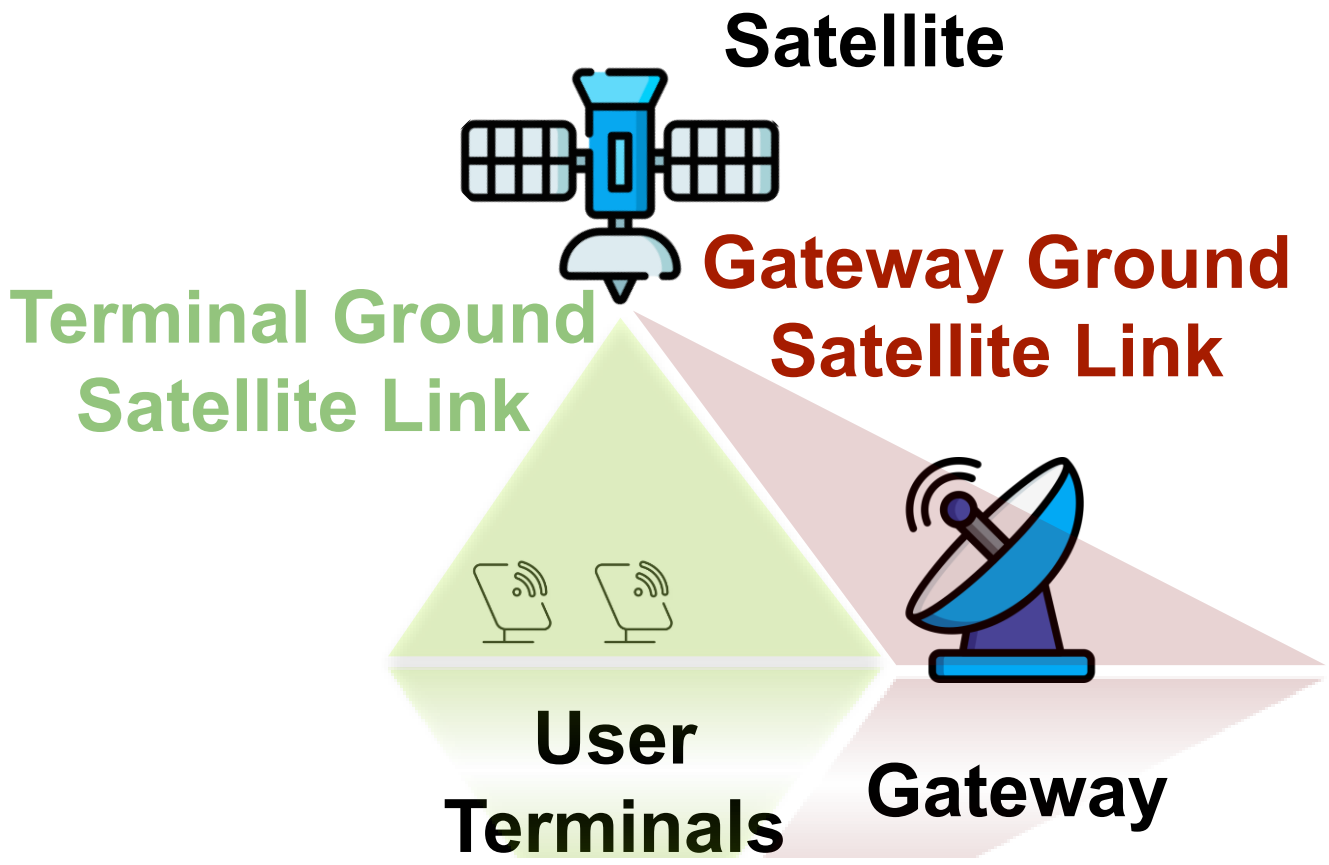
- LEO Networks cannot effectively substitute submarine cables
  - **Even with tens of thousands of satellites** -> Limited spectrum allocated
- Failover planning strongly shapes capacity
  - Terminal Distribution can **boost capacity by 1.5x**
  - Government-operator collaboration can **add 40% more capacity**
- Failover traffic can **significantly limit** global available bandwidth

Background on Satellite Networks

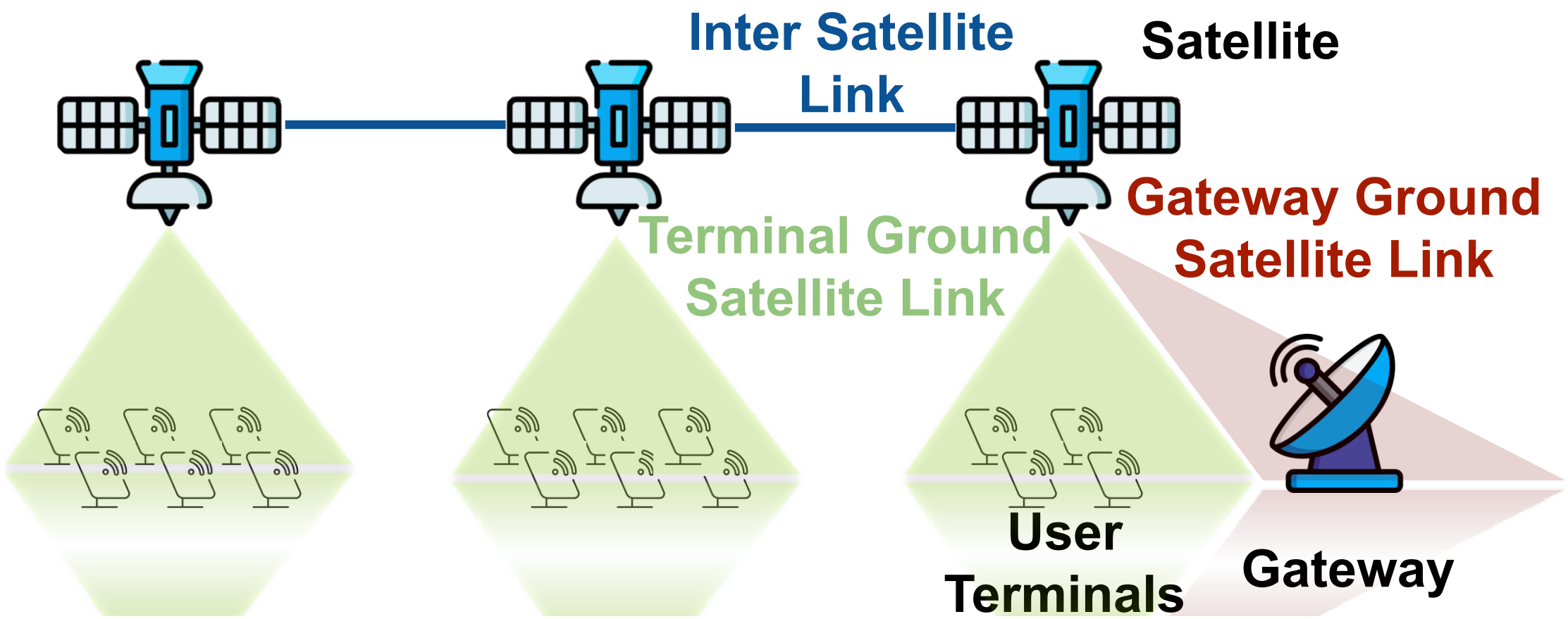
Satellite Network Architecture



Satellite Network Architecture



Satellite Network Architecture



Satellite Spectrum Management

- Large coverage area

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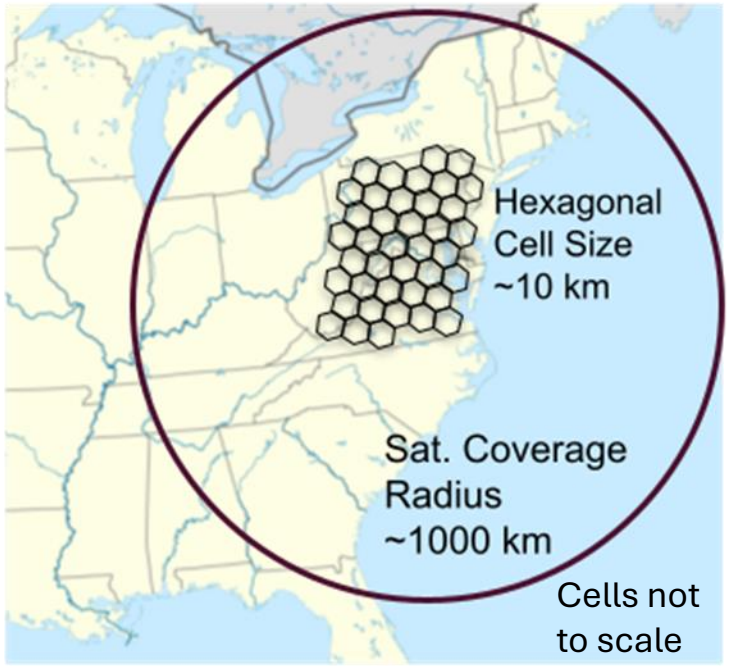
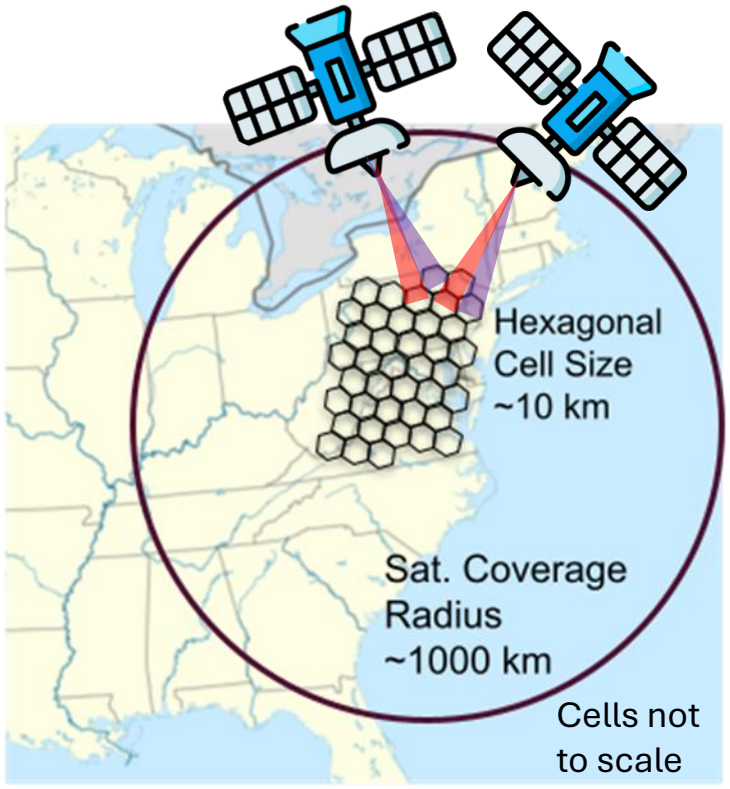


Satellite Spectrum Management

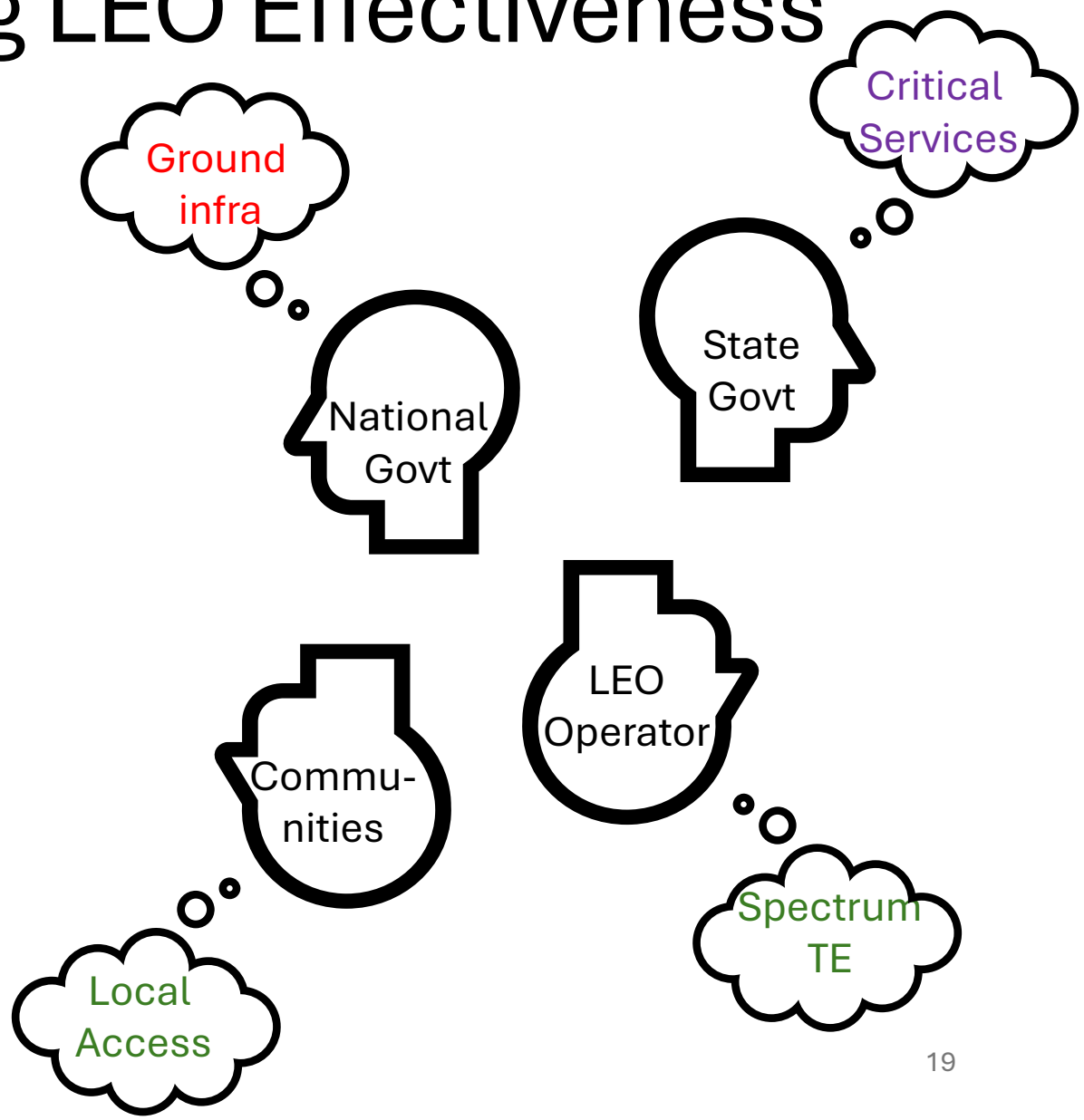
- Large coverage area
- Interference prevents satellite overlap
- Serve smaller “cells”
- Split spectrum into channels



How Effective Can LEO Networks Be During Emergency Scenarios?

Challenges in Assessing LEO Effectiveness

- Fragmented Control
  - Different levels of governments



Challenges in Assessing LEO Effectiveness

- Fragmented Control
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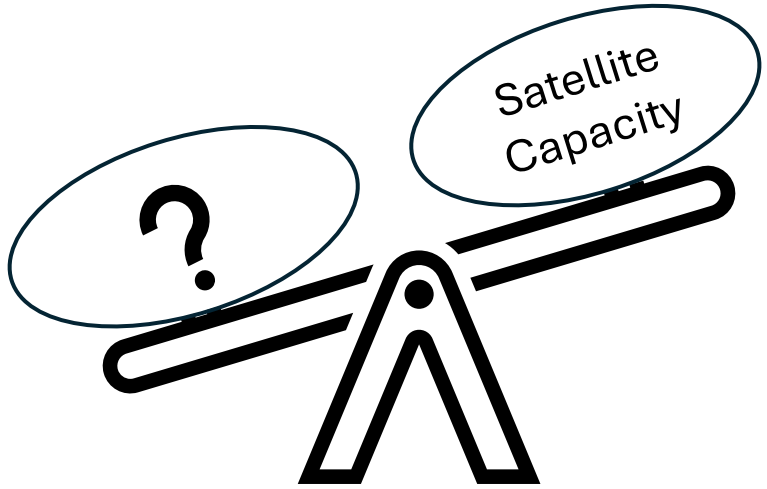
- No clear frame of reference

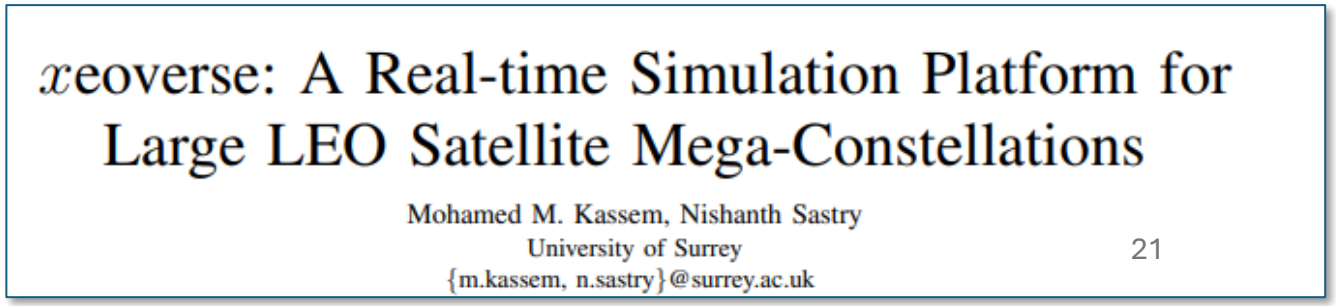


Challenges in Assessing LEO Effectiveness

- Fragmented Control
  - Different levels of governments
- No clear frame of reference
- Lack of tools to model large-scale LEO failover behavior

Exploring the "Internet from space" with HYPATIA

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



*x*eoverse: A Real-time Simulation Platform for Large LEO Satellite Mega-Constellations

Mohamed M. Kassem, Nishanth Sastry
University of Surrey
{m.kassem, n.sastry}@surrey.ac.uk

A National Perspective

- Leverage through licensing, regulatory control, ownership

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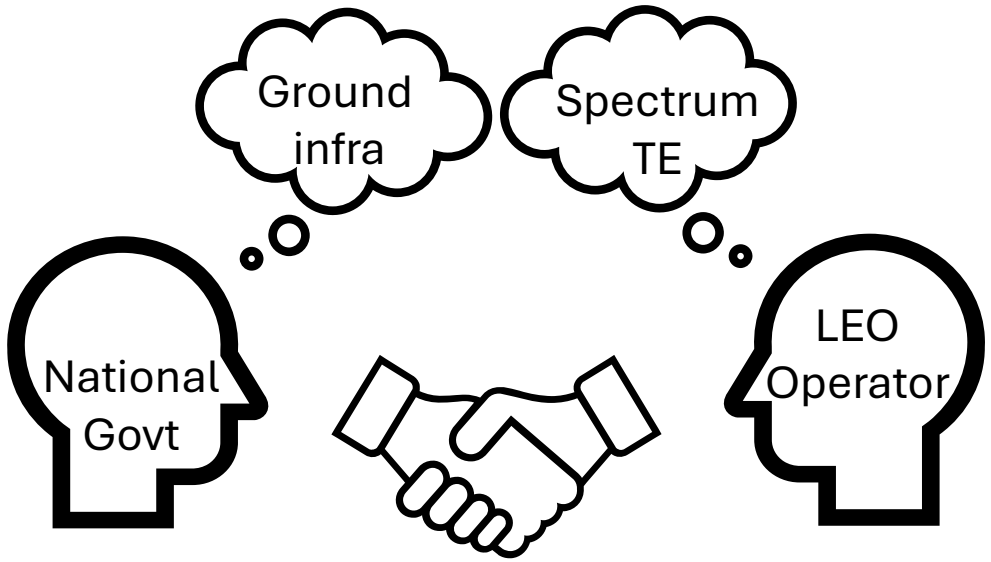
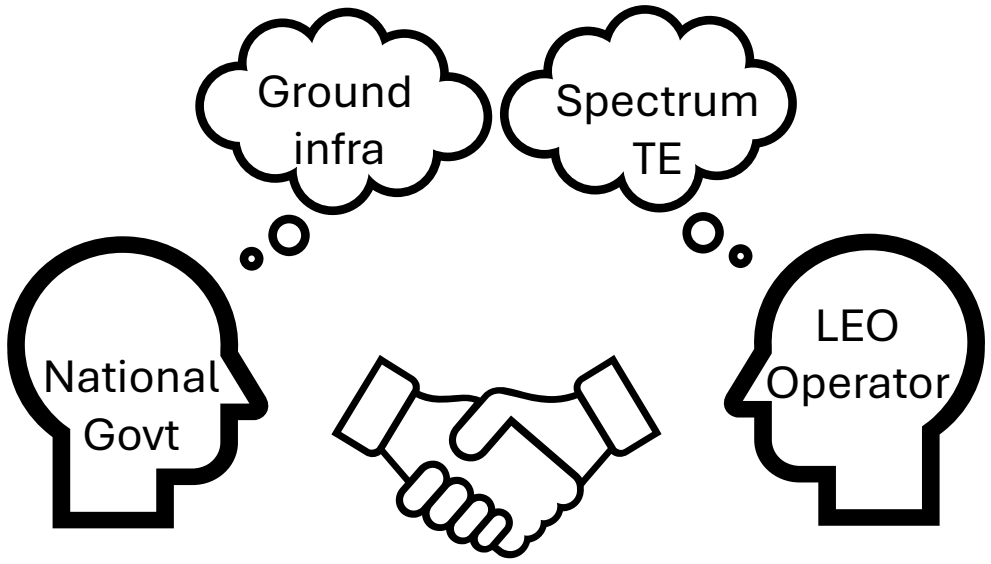
- Natural setting for cooperative planning



A National Perspective

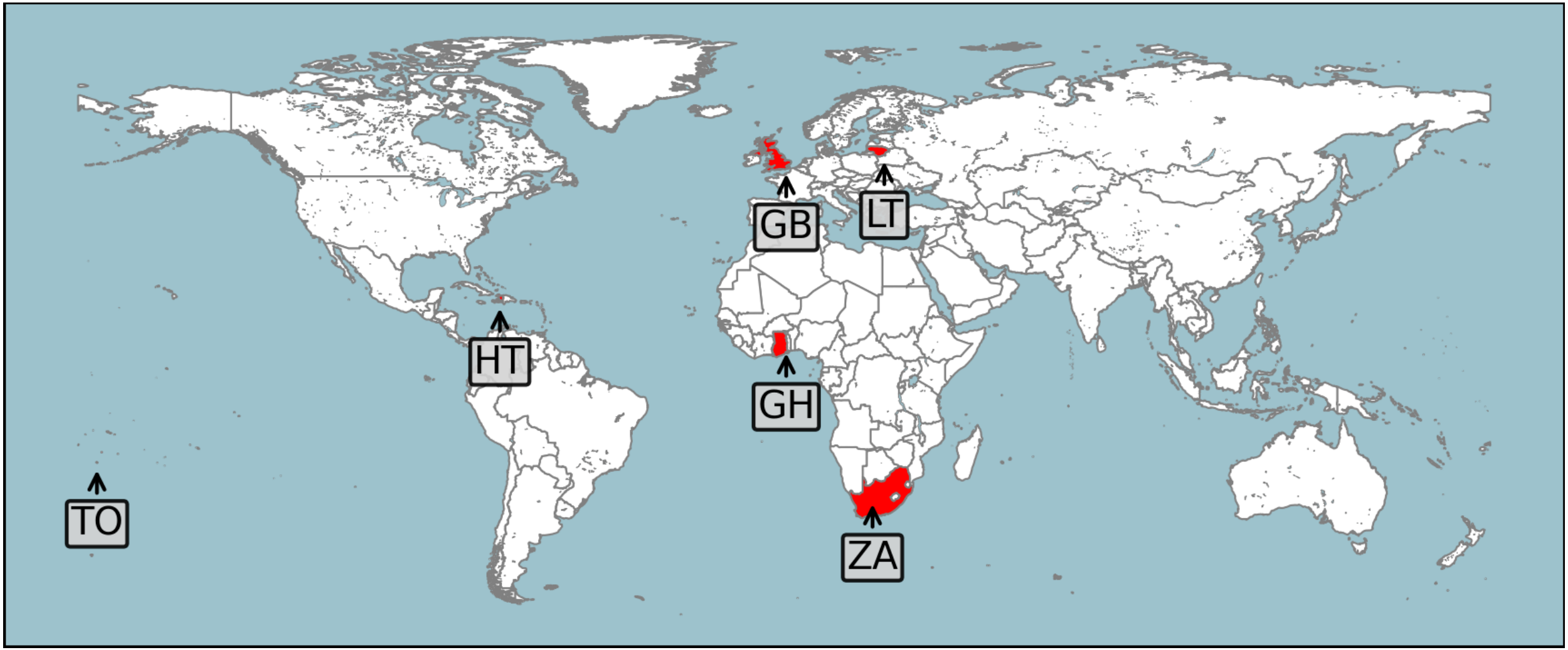
- Leverage through licensing, regulatory control, ownership
- Natural setting for cooperative planning
- Easier to model capacity



Submarine Cable Failures as a Reference

- Recent submarine cable disruptions
  - Diverse set of nations focusing on size, population, geography, etc.

Submarine Cable Failures as a Reference



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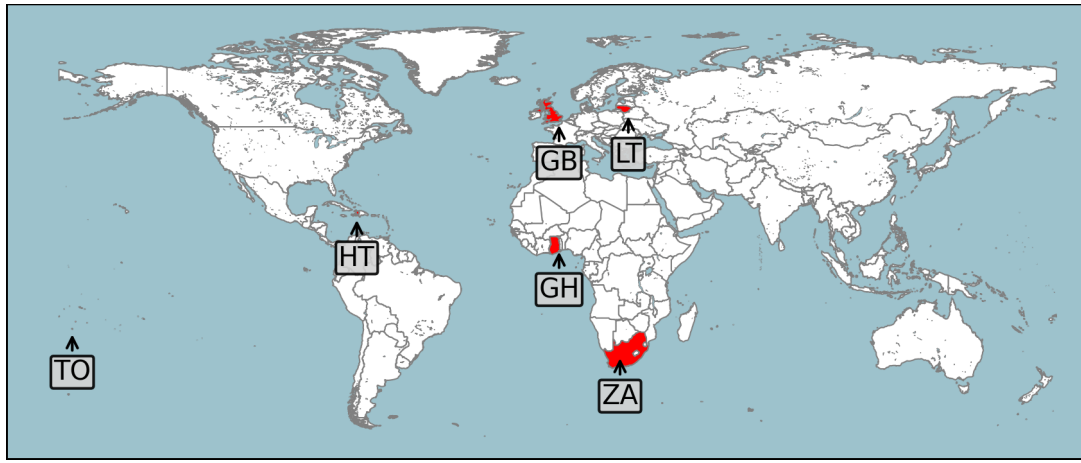
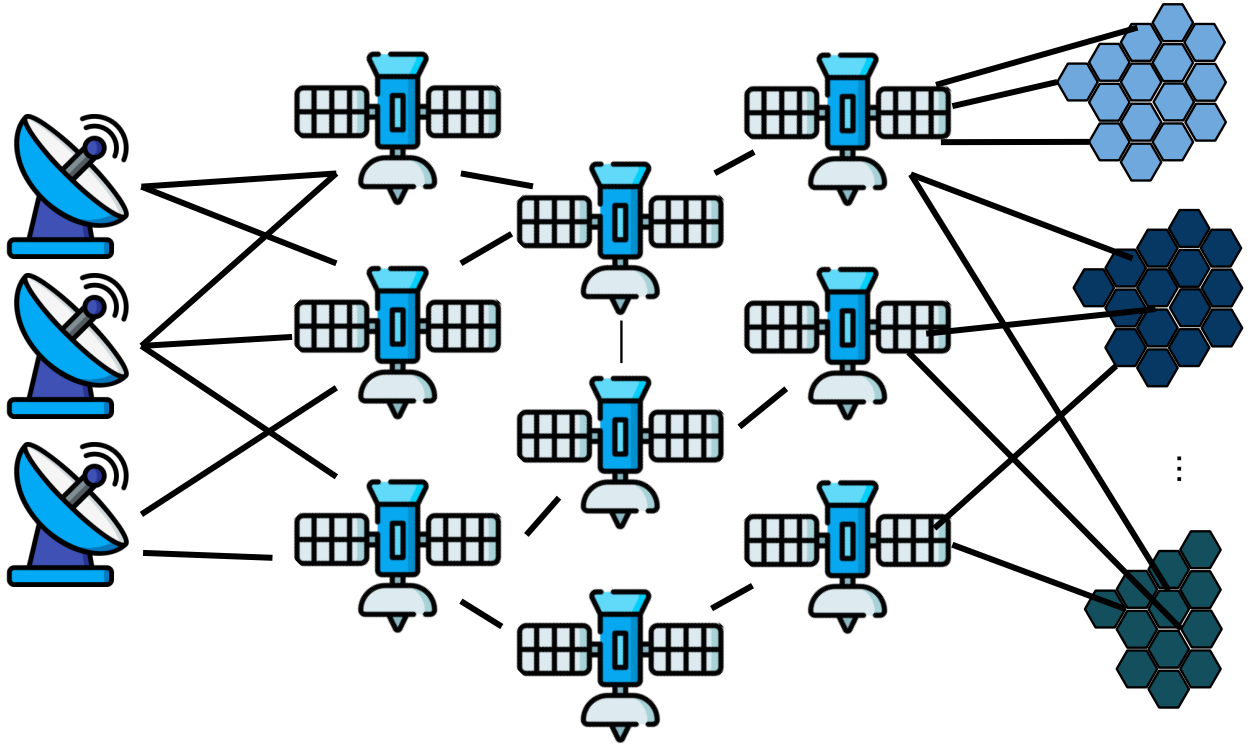
  - Diverse set of nations focusing on size, population, geography, etc.
- Map RIPE Atlas traceroutes to cables[1]



[1] Wang et al. Threading the Ocean: Mapping Digital Routes Across Submarine Cables using Calypso. *ACM SIGCOMM 2025*

CosmoSim Simulator

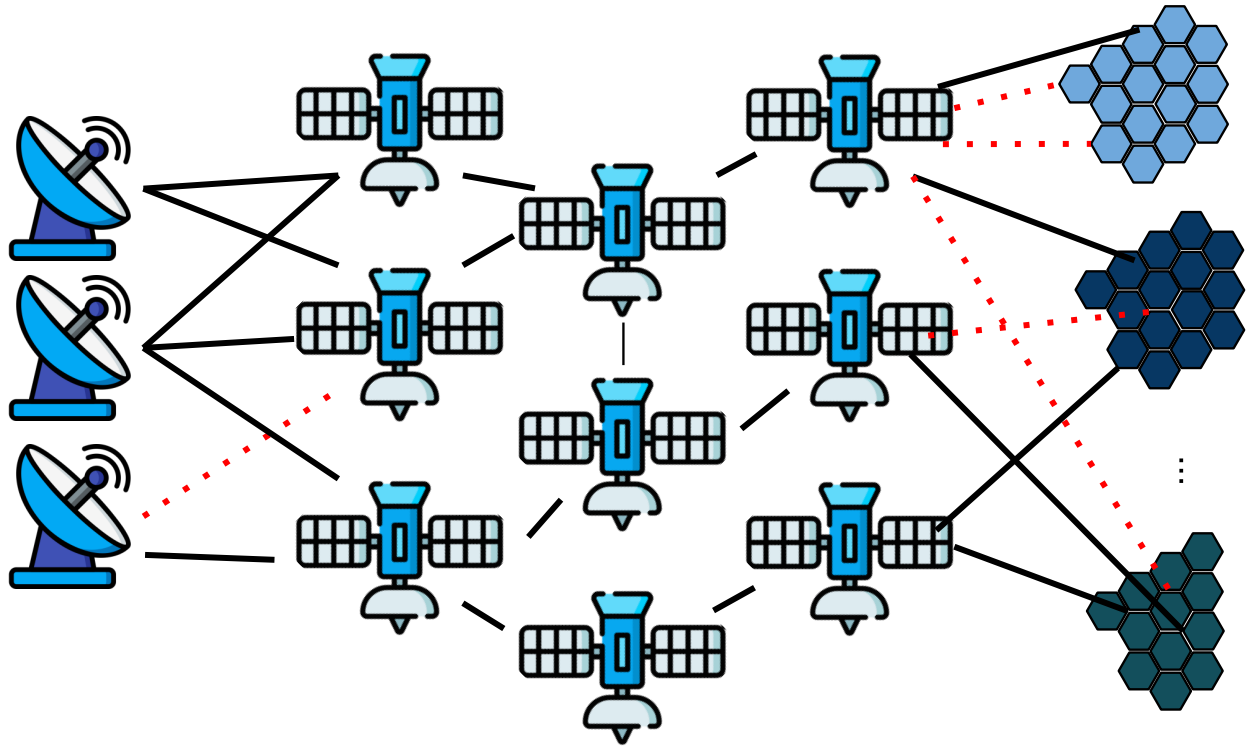
- Graph Generation



Gateway Nodes **Satellite Nodes** **Cell Nodes**

CosmoSim Simulator

- Graph Generation
- Spectrum Management



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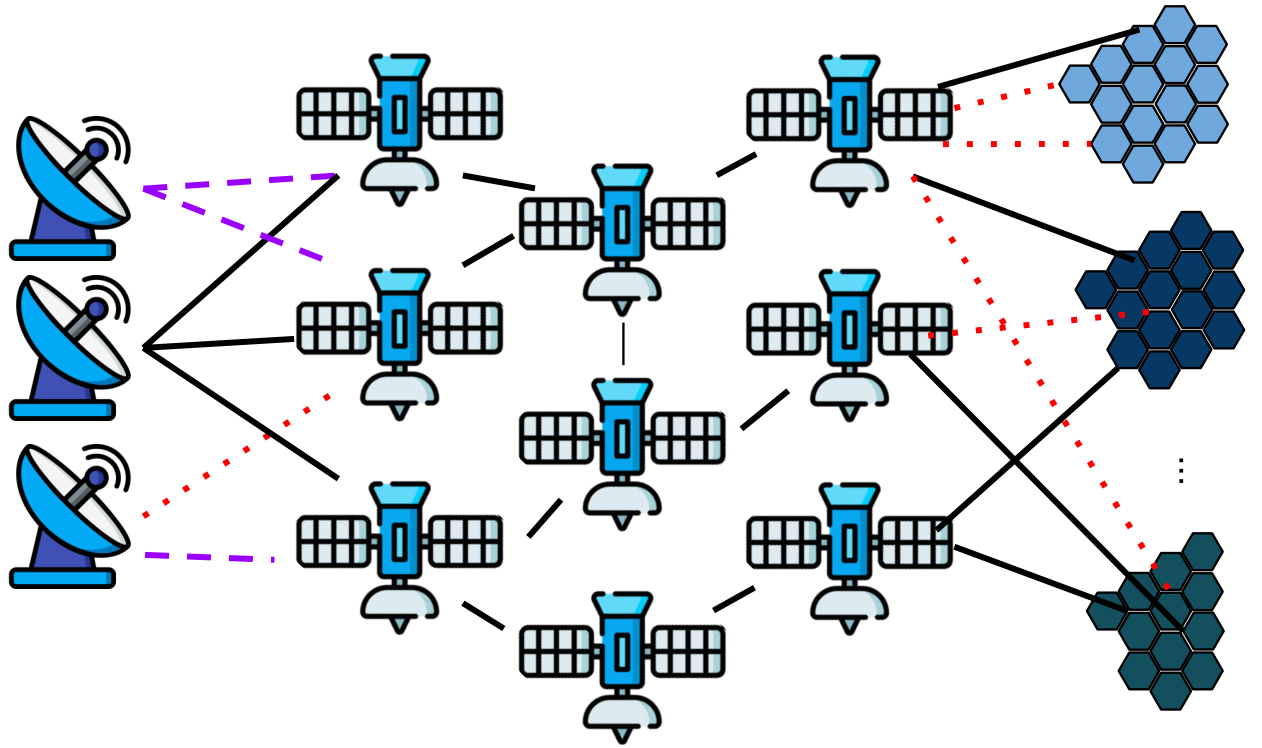

Gateway Nodes **Satellite Nodes** **Cell Nodes**

CosmoSim Simulator

- Graph Generation
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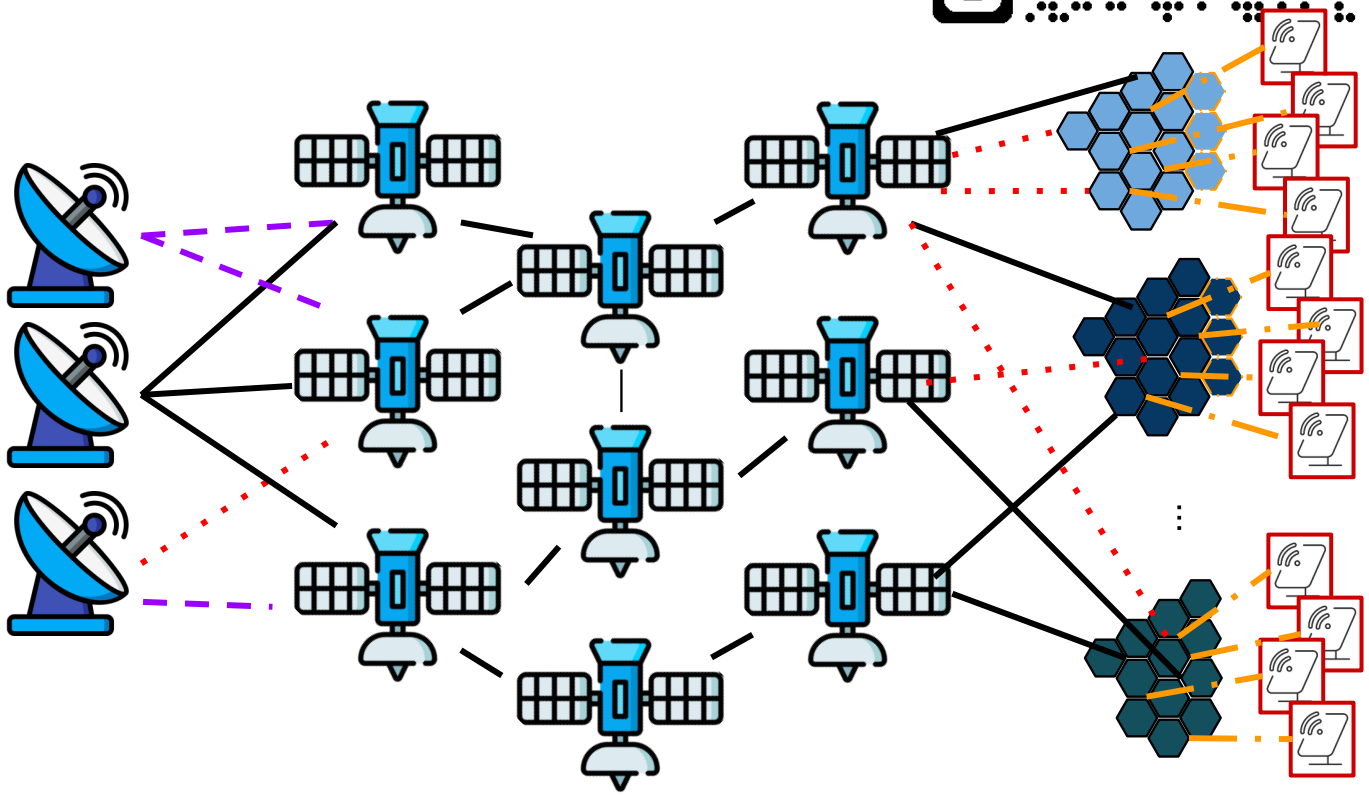
NEW!!



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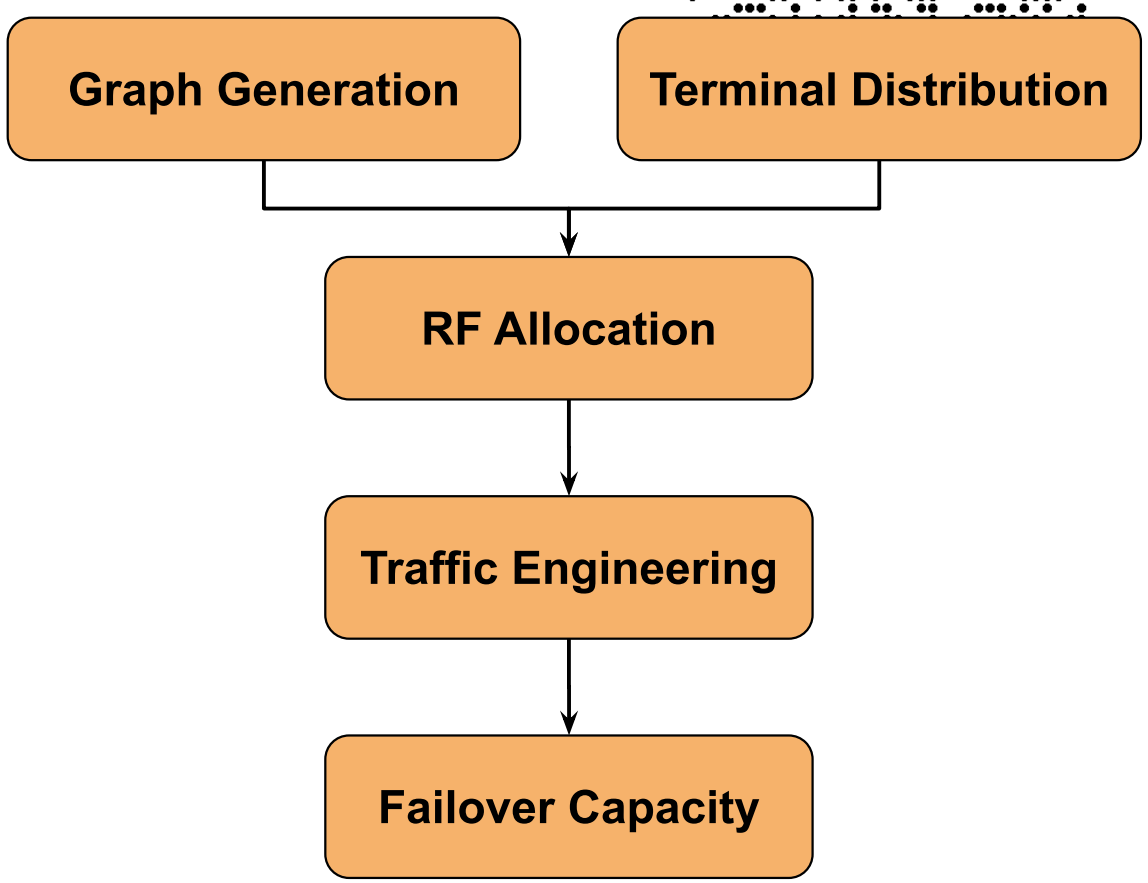

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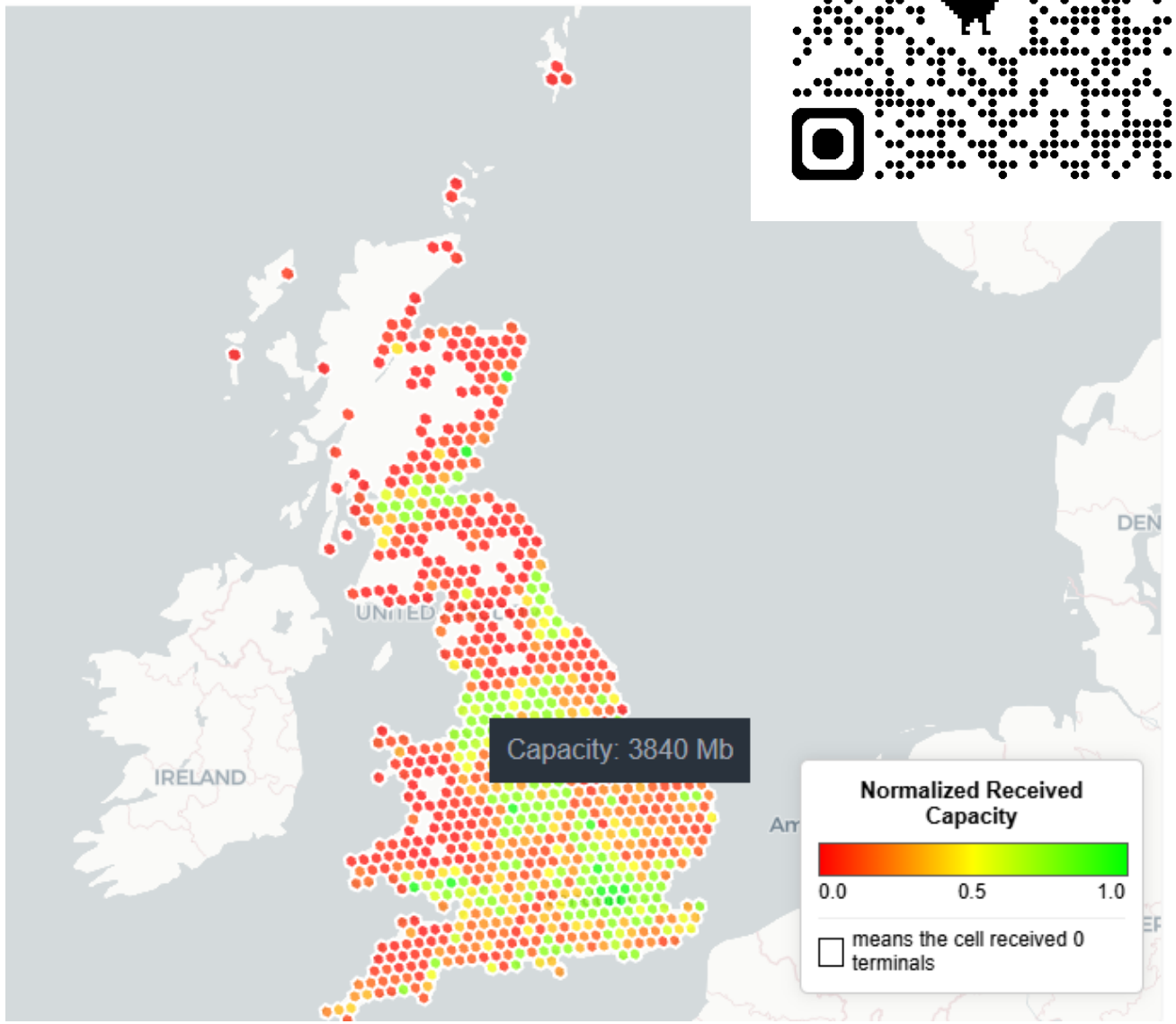
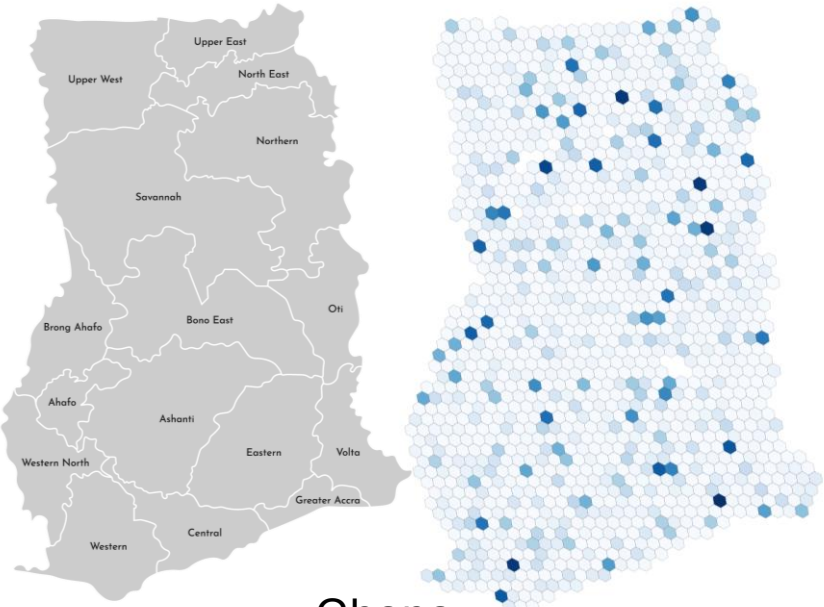


Terminal Distribution

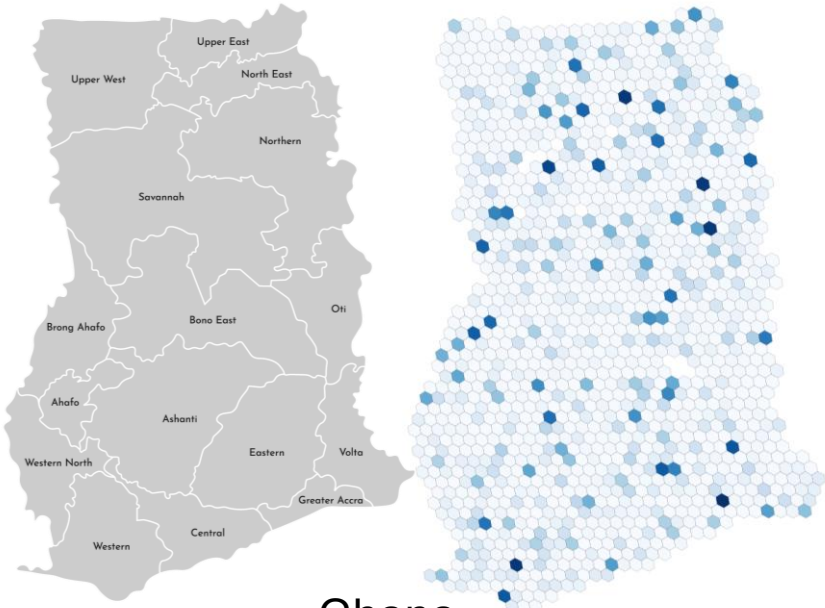
- Geographical deployment of terminals
  - Local vs National



Ghana

Terminal Distribution

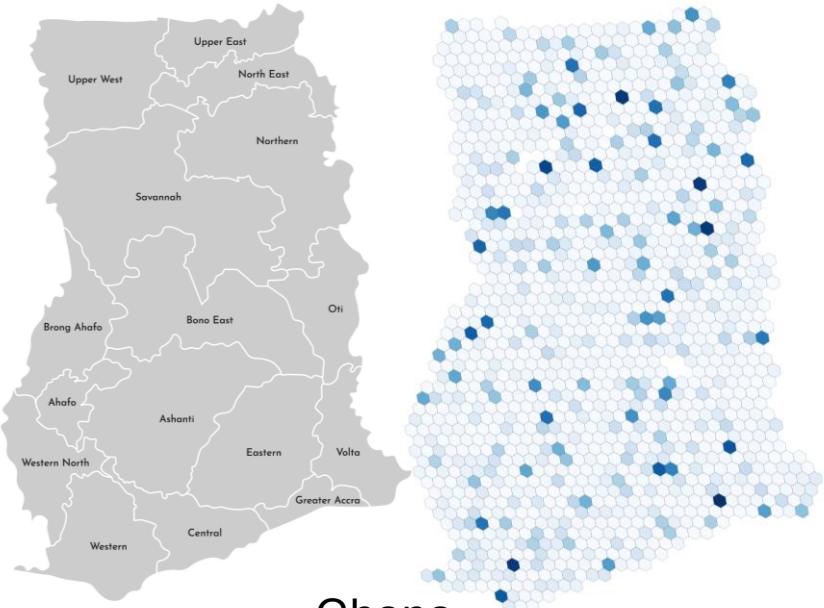
- Geographical deployment of terminals
  - Local vs National
- Naïve strategies ineffective
  - Uniform -> terminals in uninhabited areas
  - Population based -> underutilizes the network



Ghana

Terminal Distribution

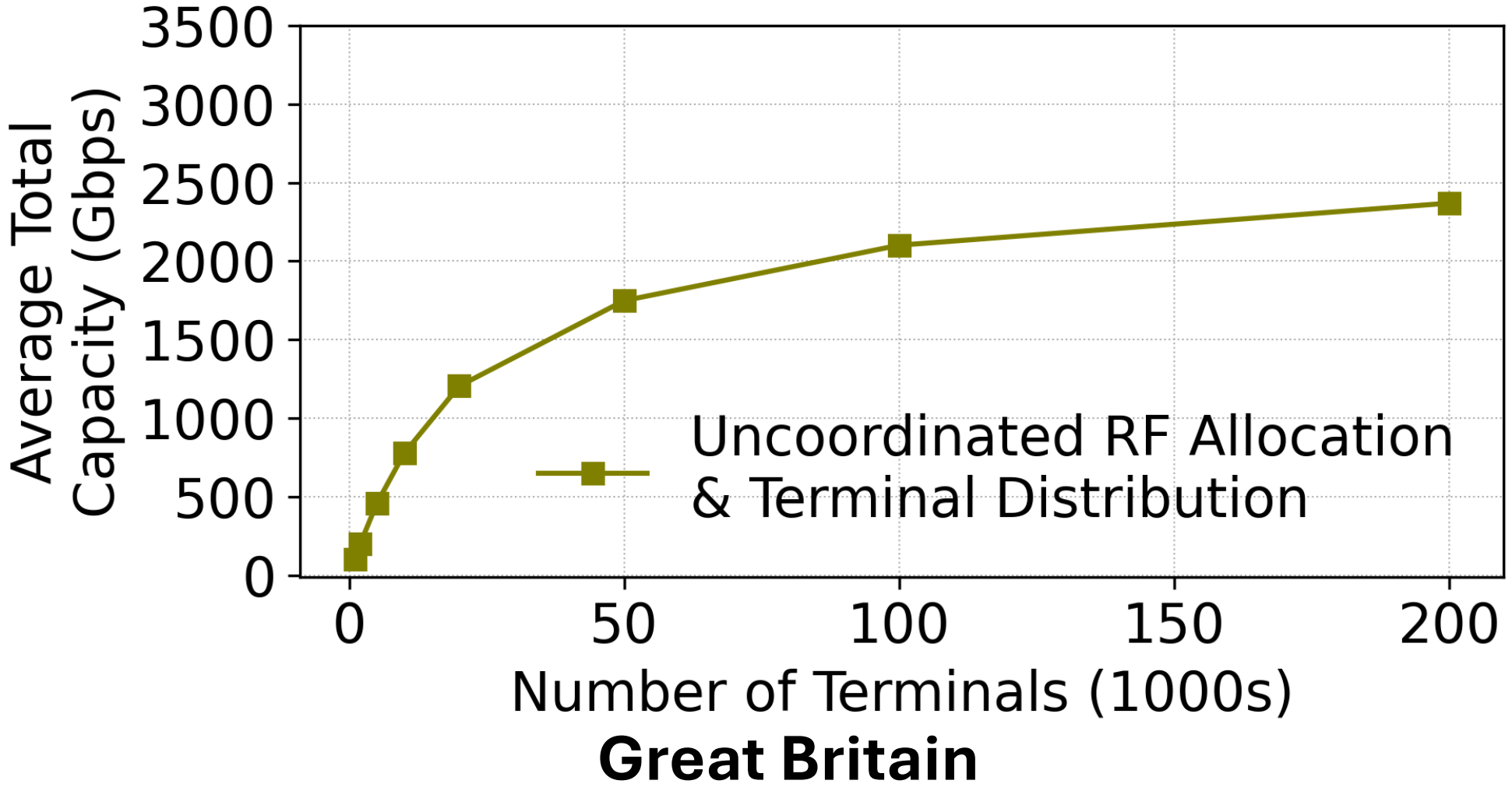
- Geographical deployment of terminals
  - Local vs National
- Naïve strategies ineffective
  - Uniform -> terminals in uninhabited areas
  - Population based -> underutilizes the network
- Greedy algorithm balancing these two
  - Uniformly spread terminals in high density cells



Ghana

Key Findings

Joint Failover Planning Benefits



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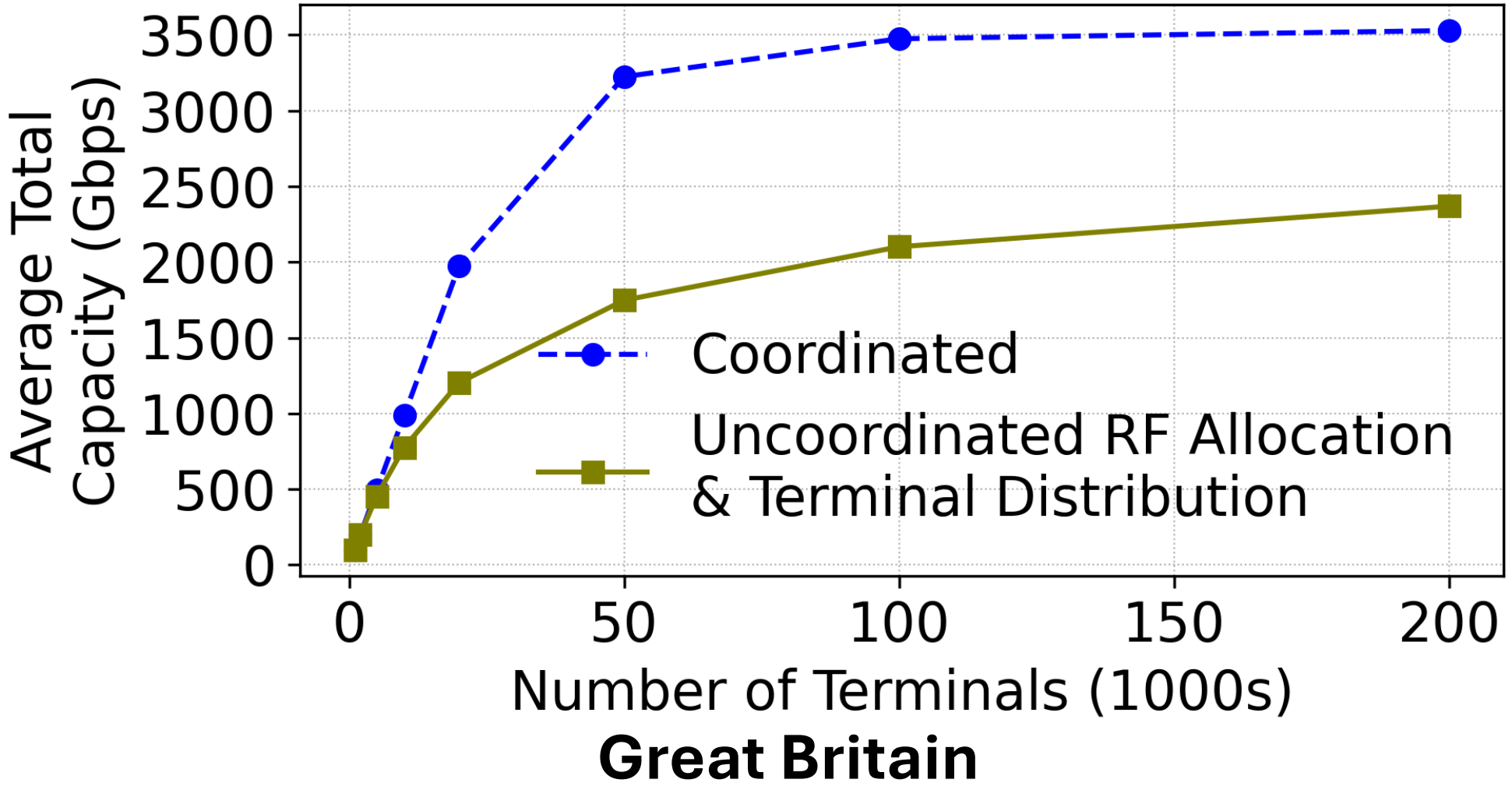

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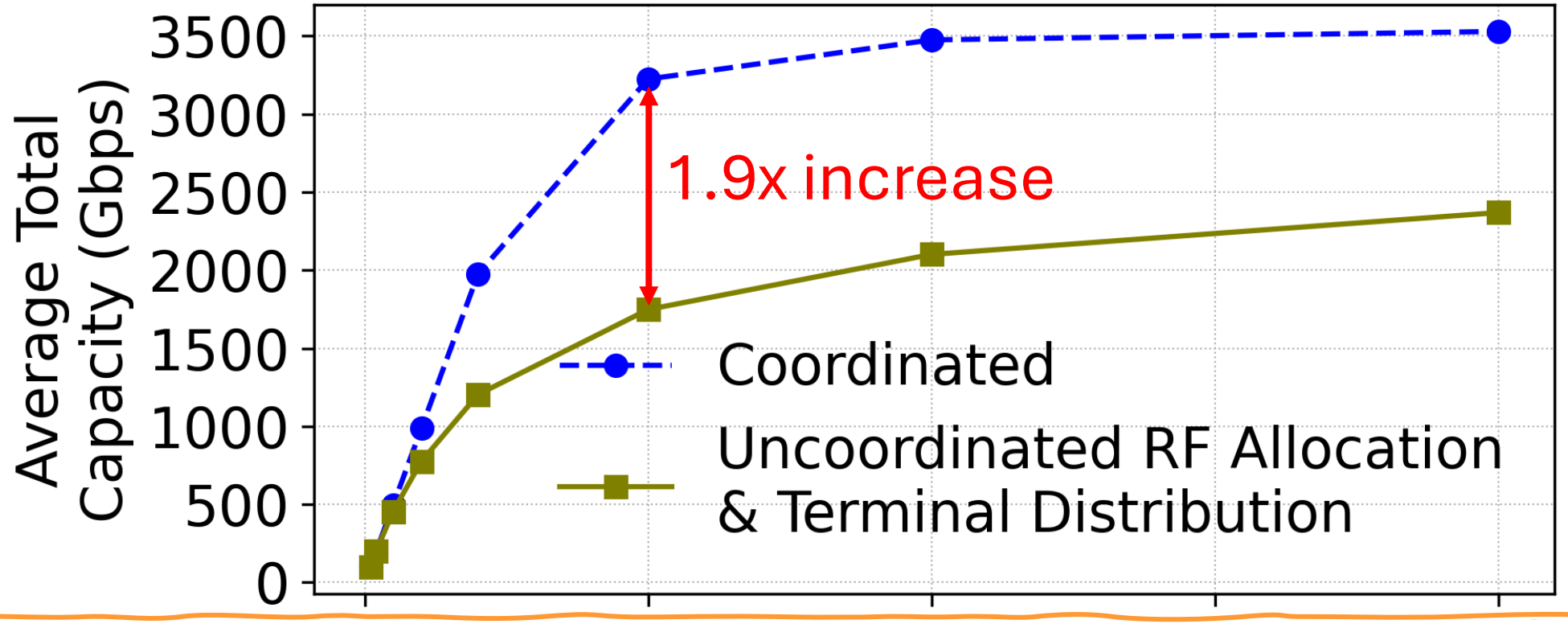
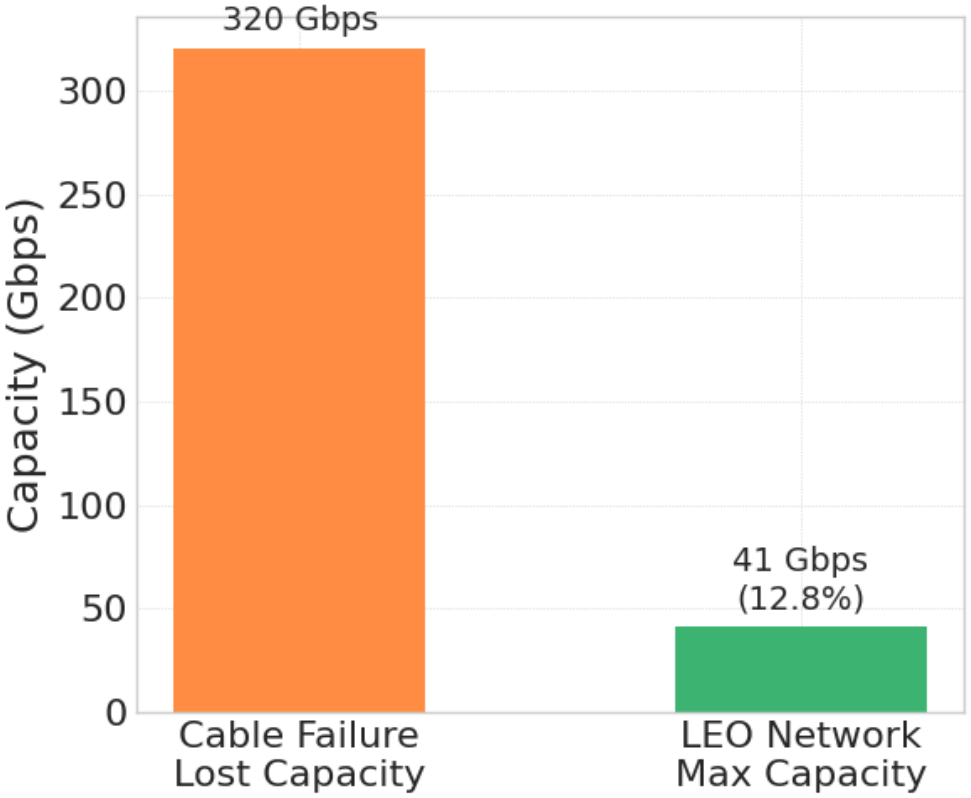


Joint planning can nearly double the capacity without extra resources.

Comparing Satellite vs Lost Cable Capacity



Tonga

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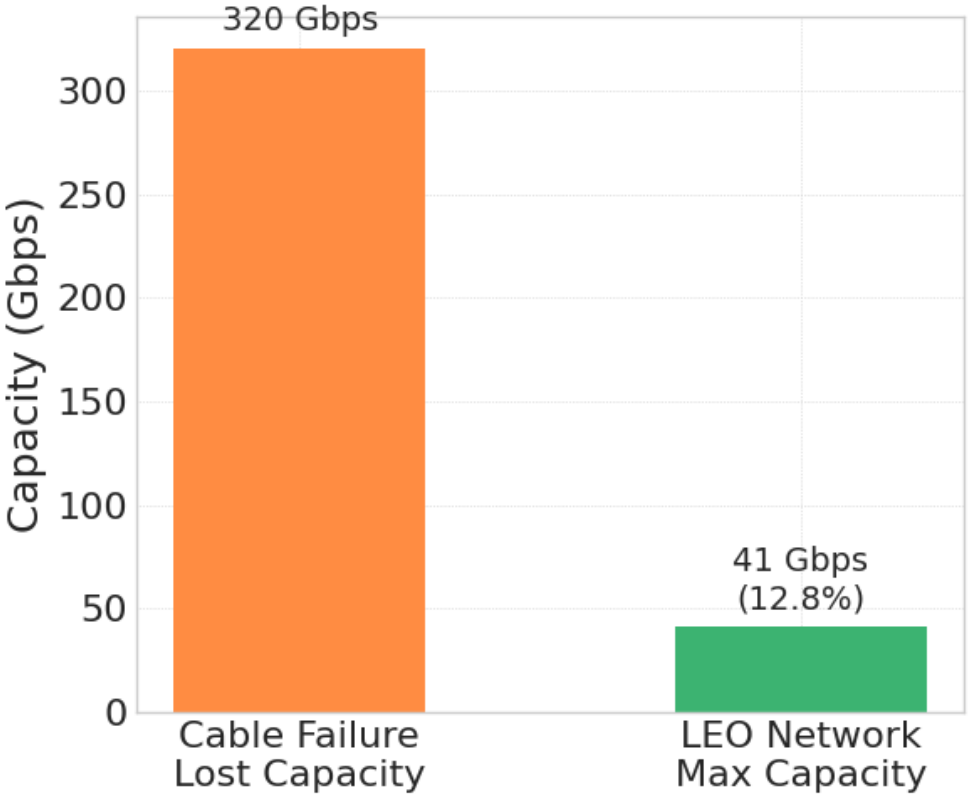

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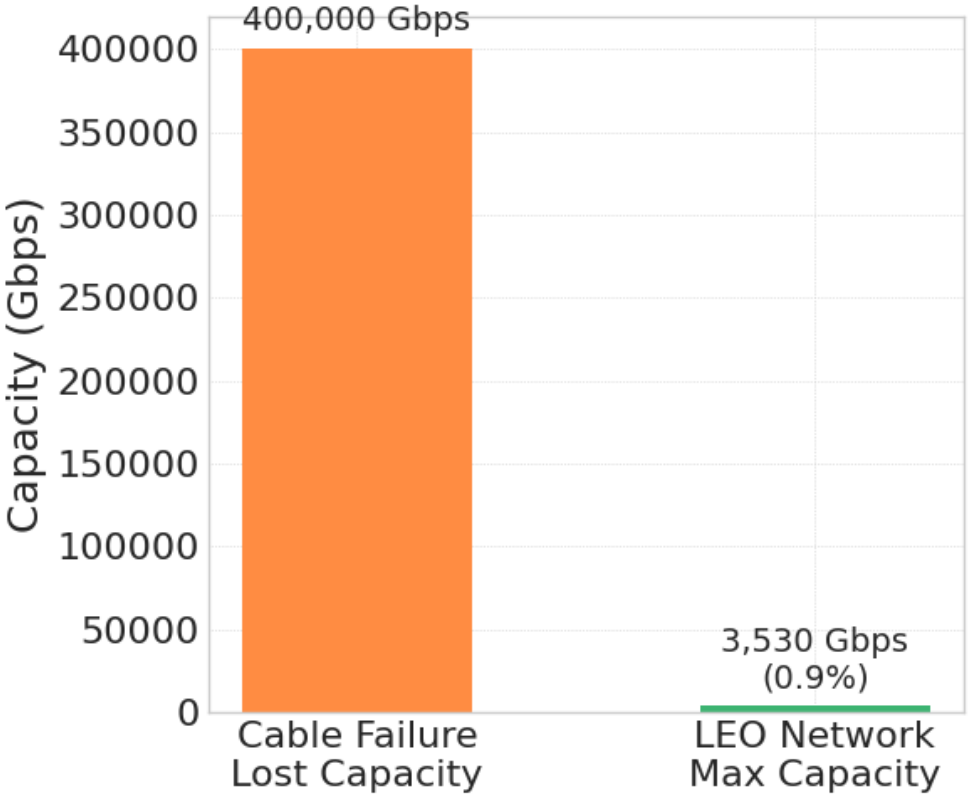

Great Britain

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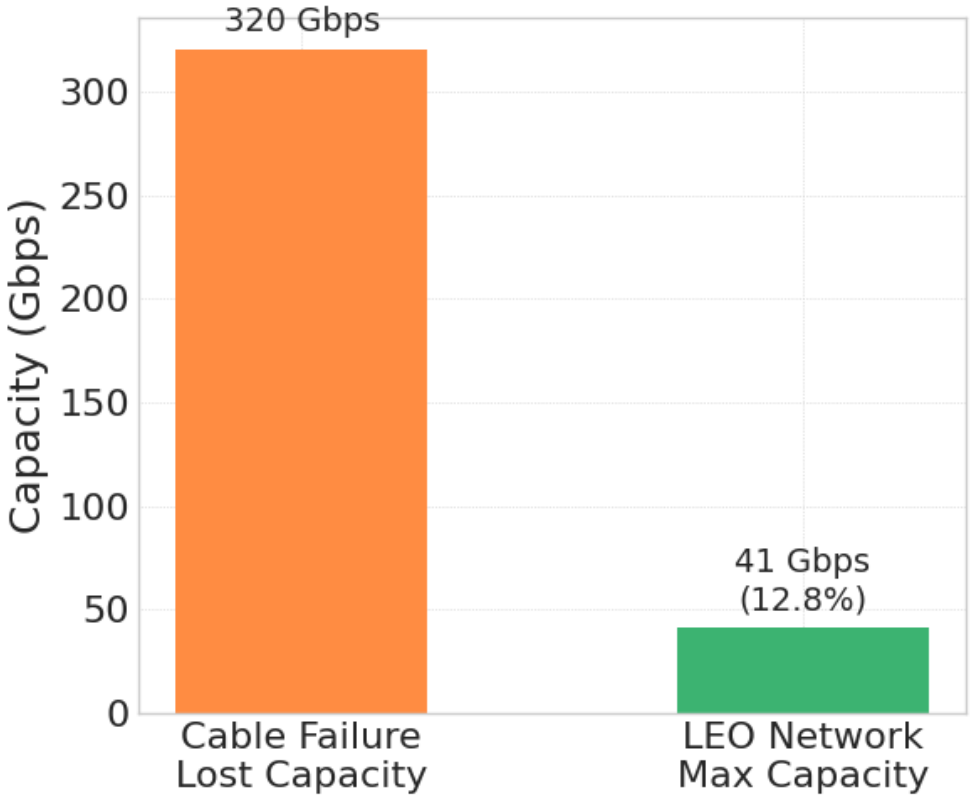
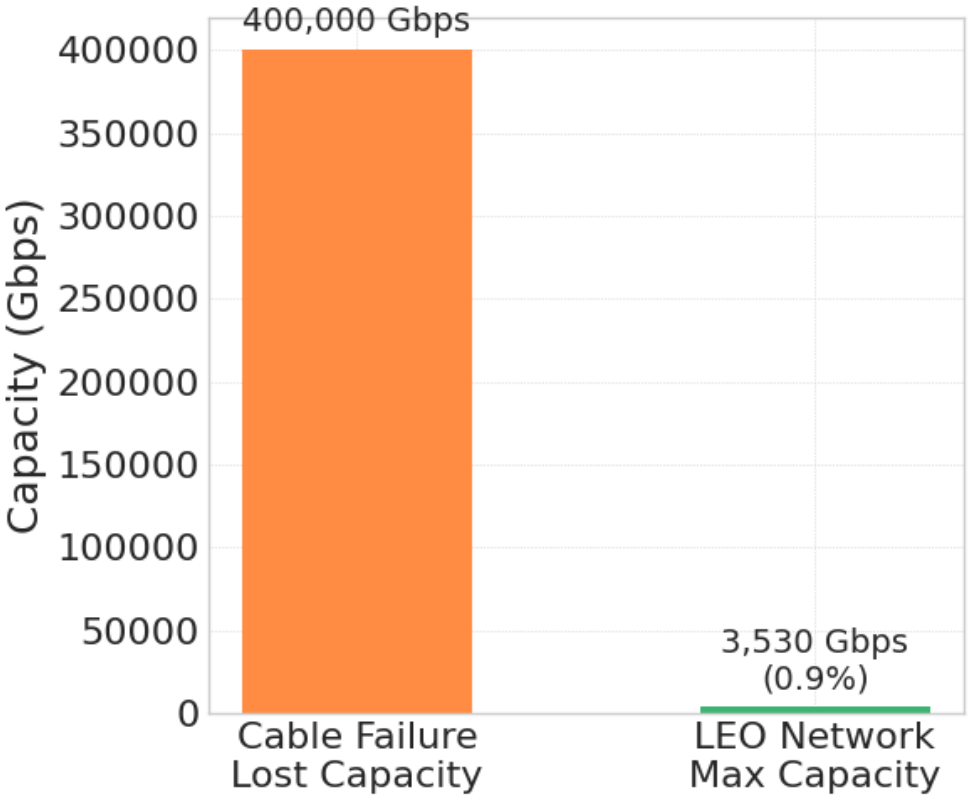


Tonga

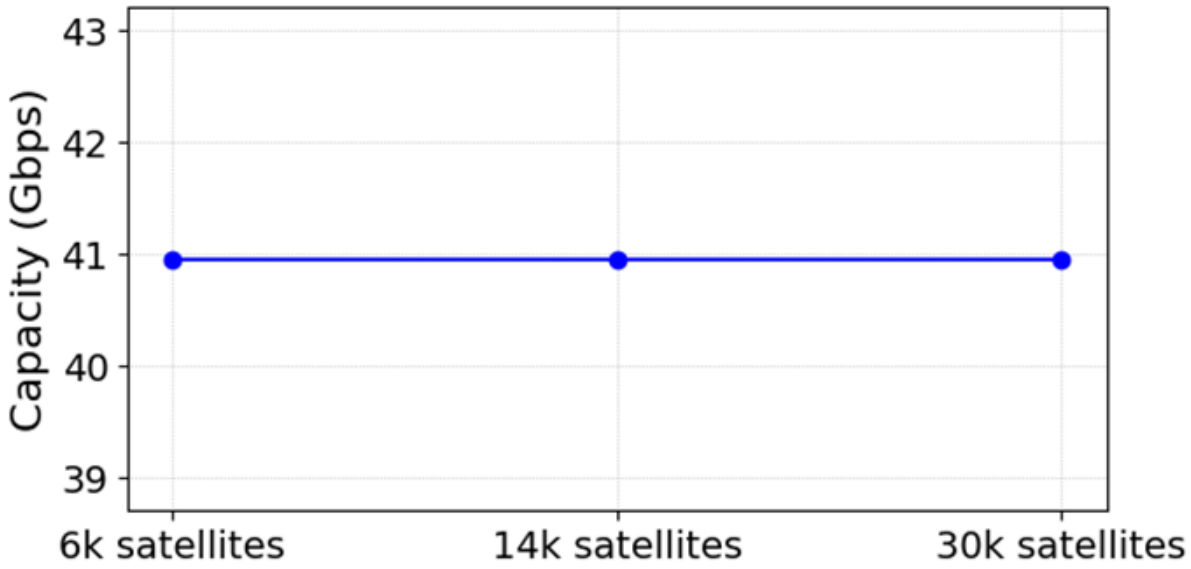
Limited Spectrum



Great Britain

Few Satellites

Do More Satellites Help?



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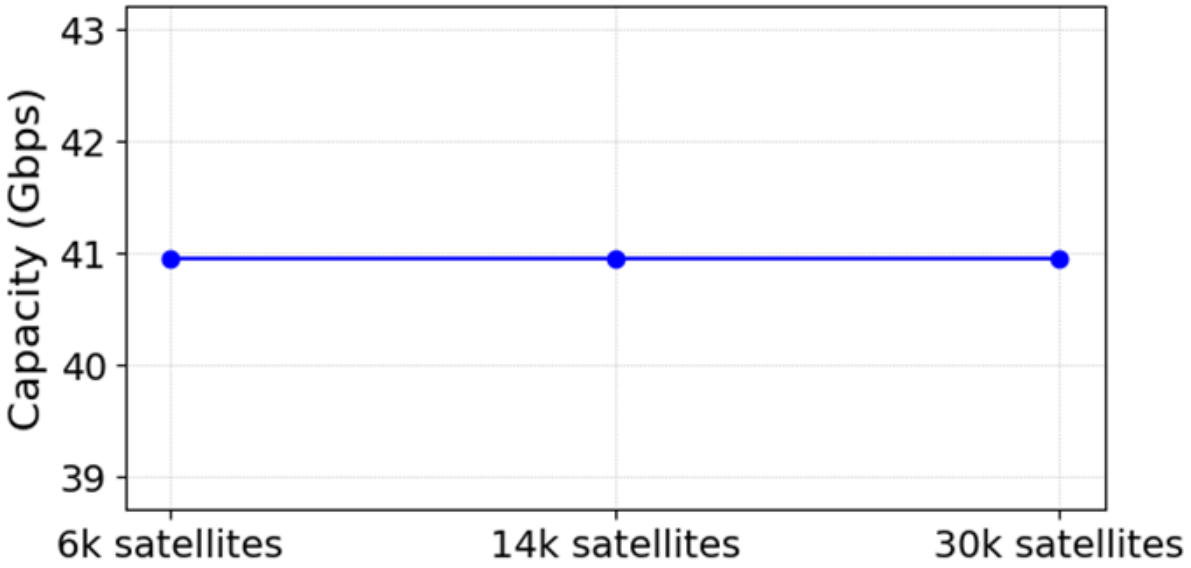
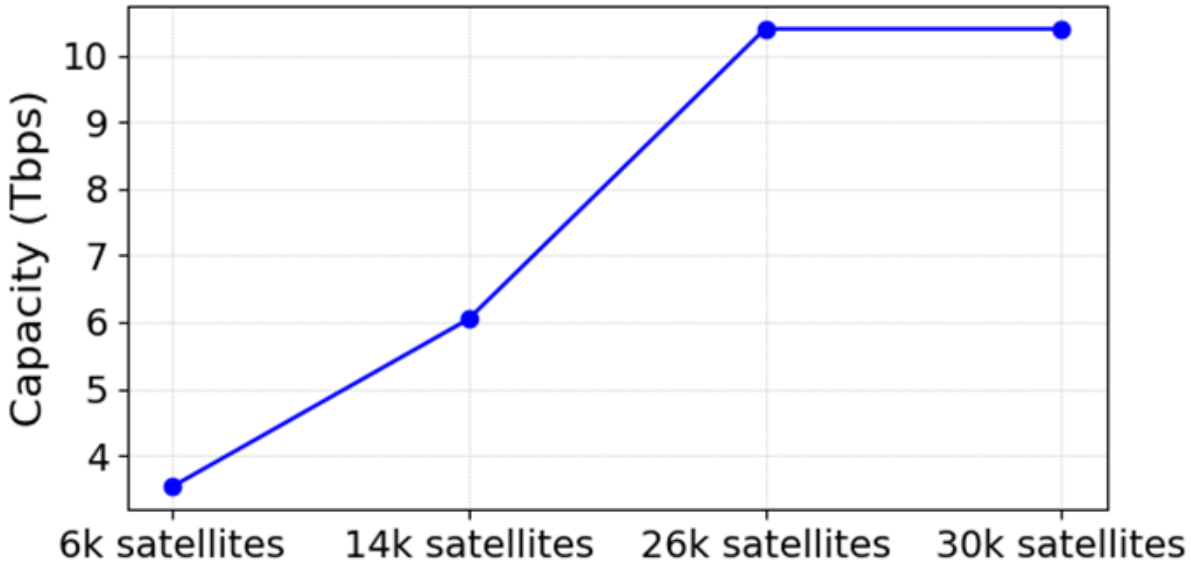


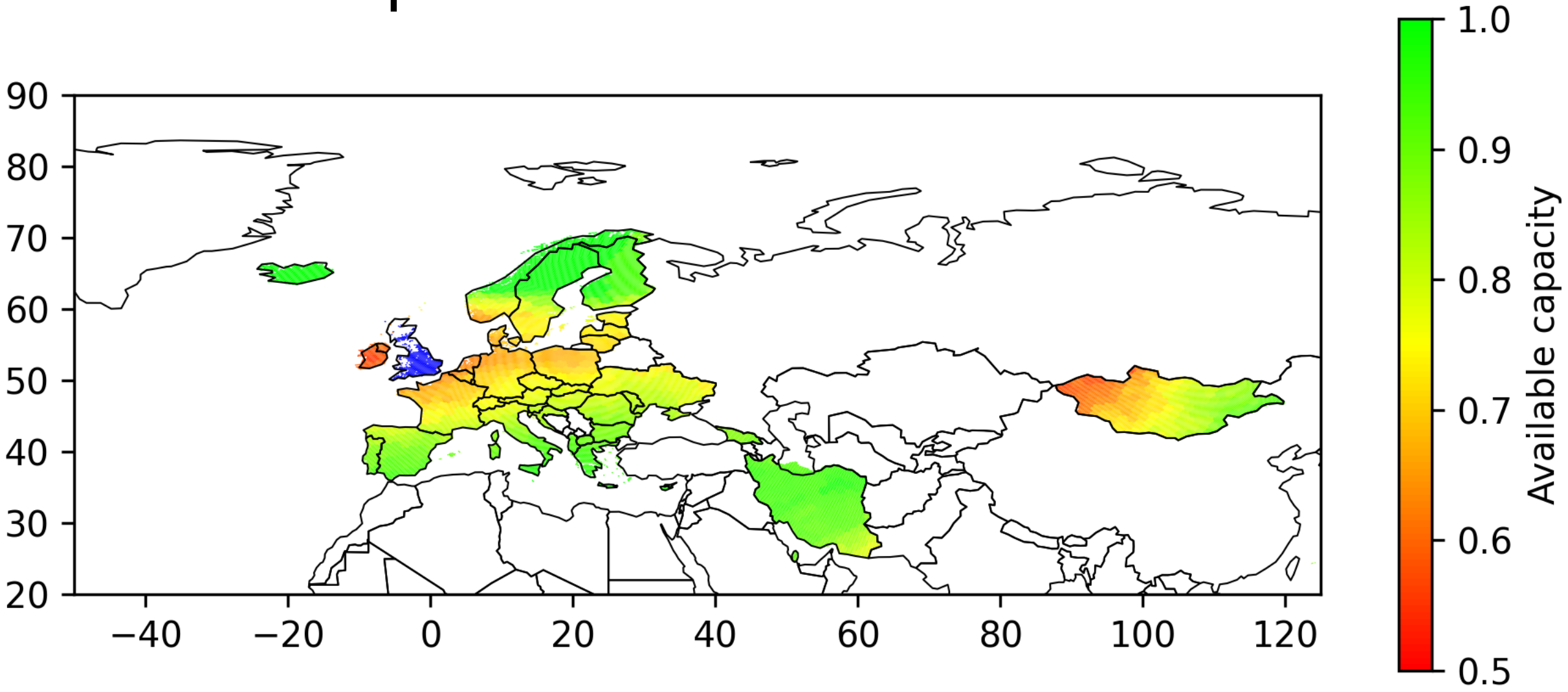
Tonga



Great Britain

Once the spectrum is fully used,
more satellites don't add capacity.

Global Impact of Failover Traffic



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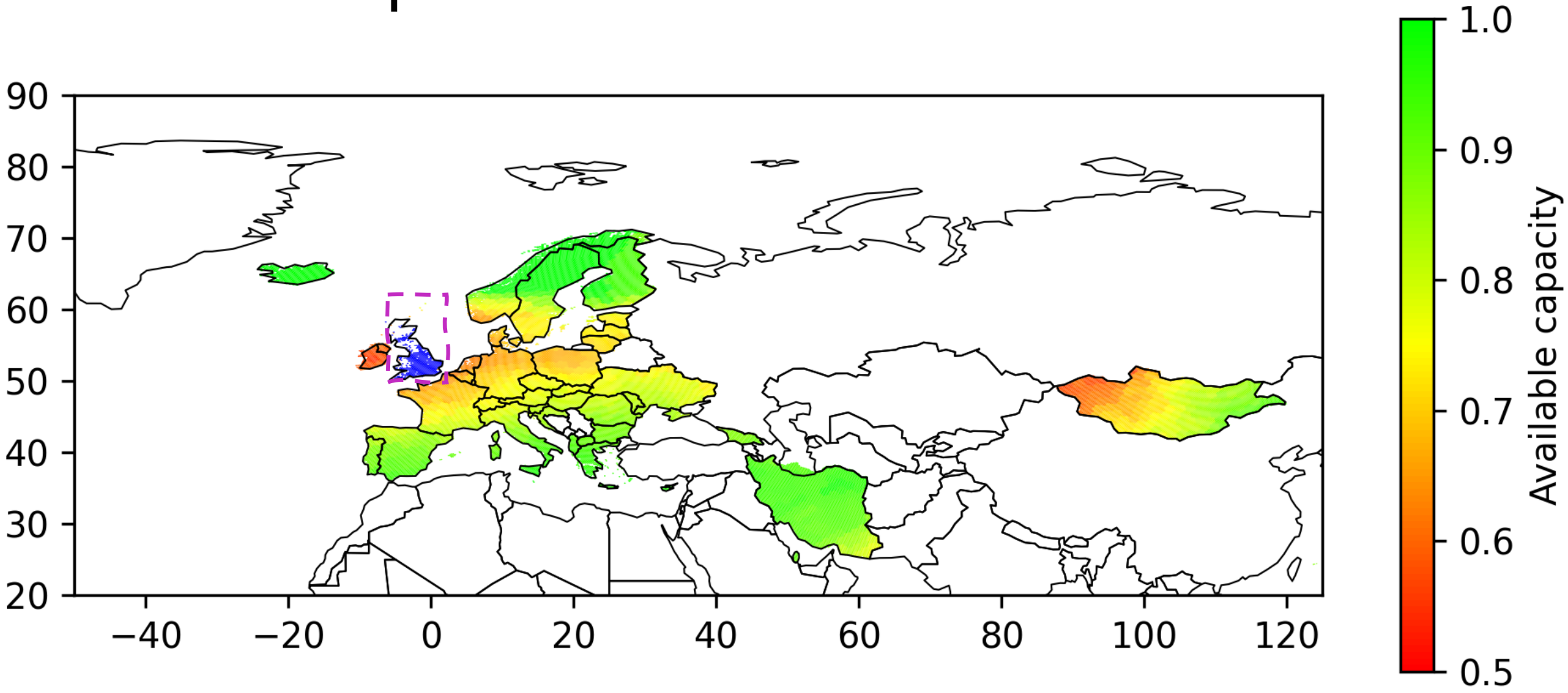

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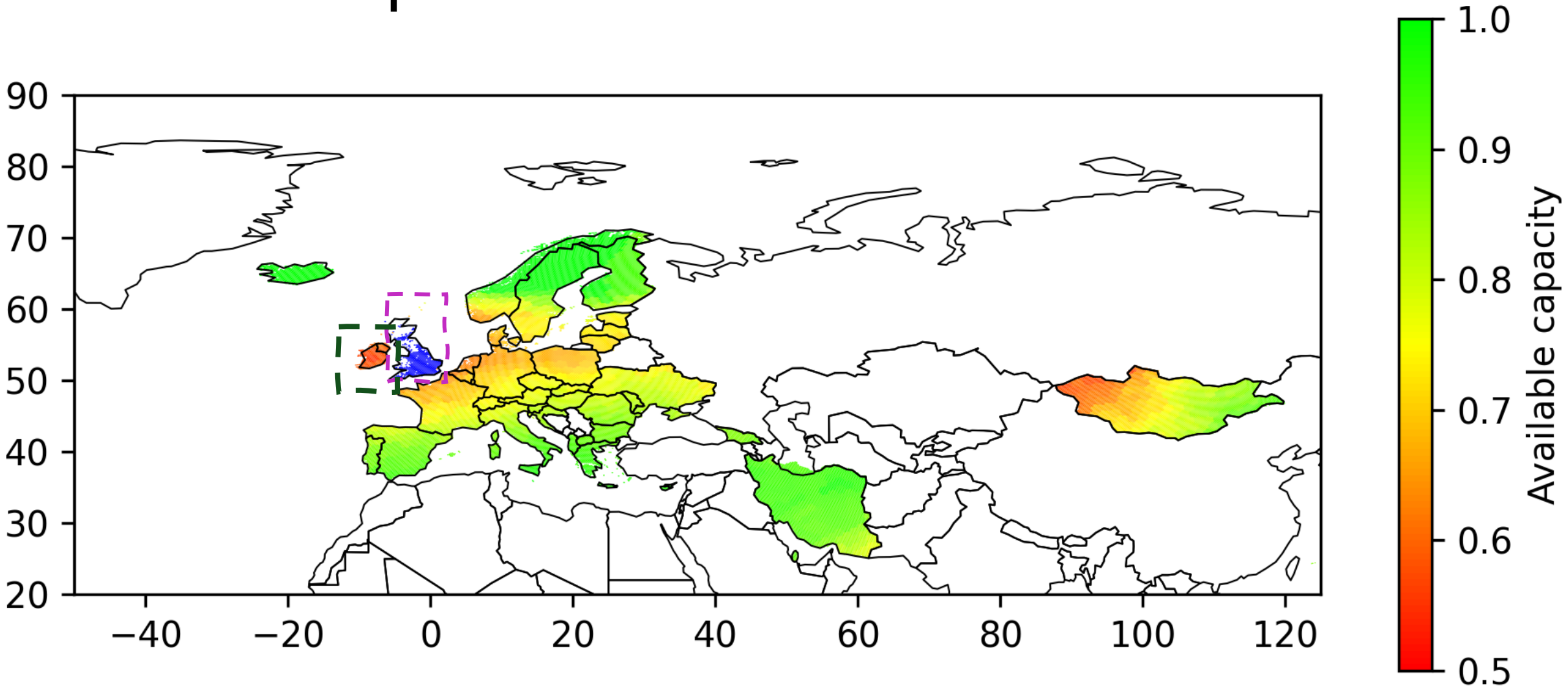

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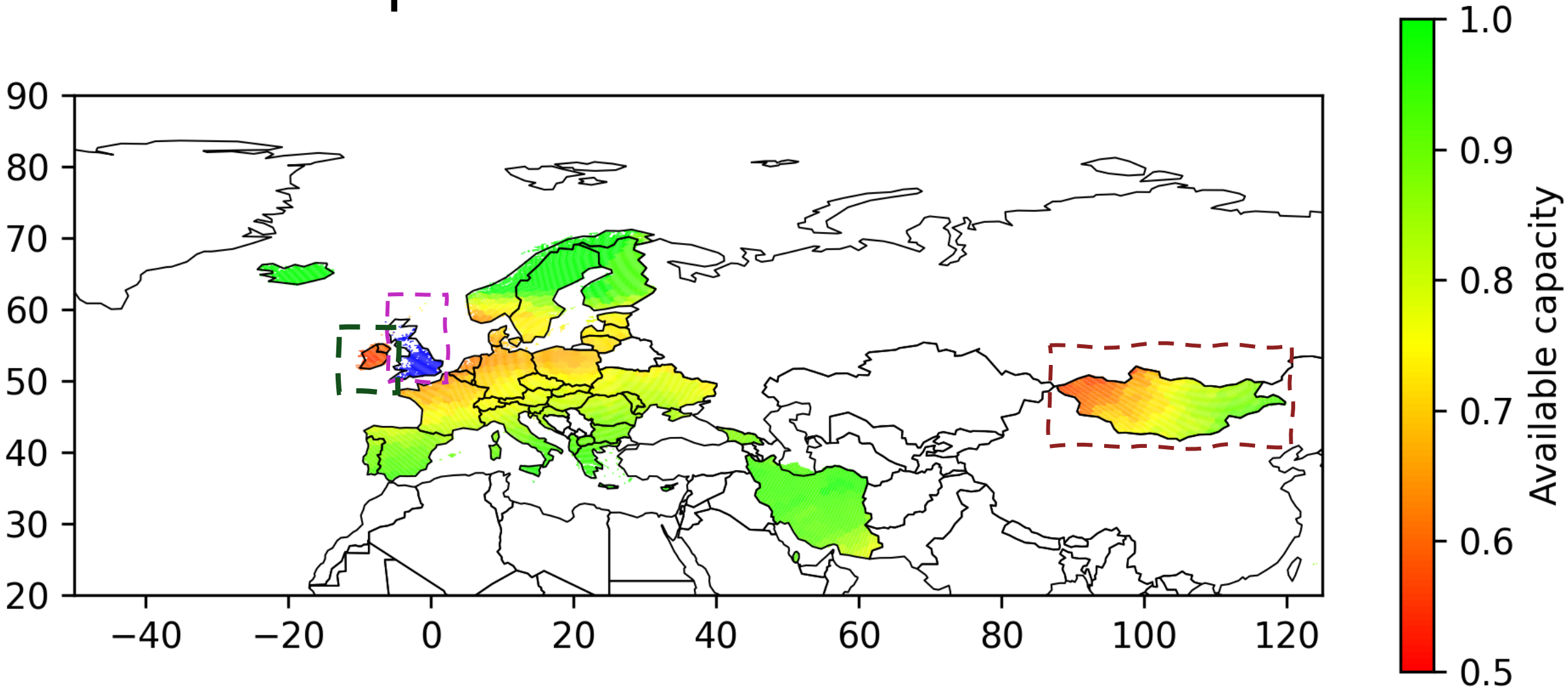

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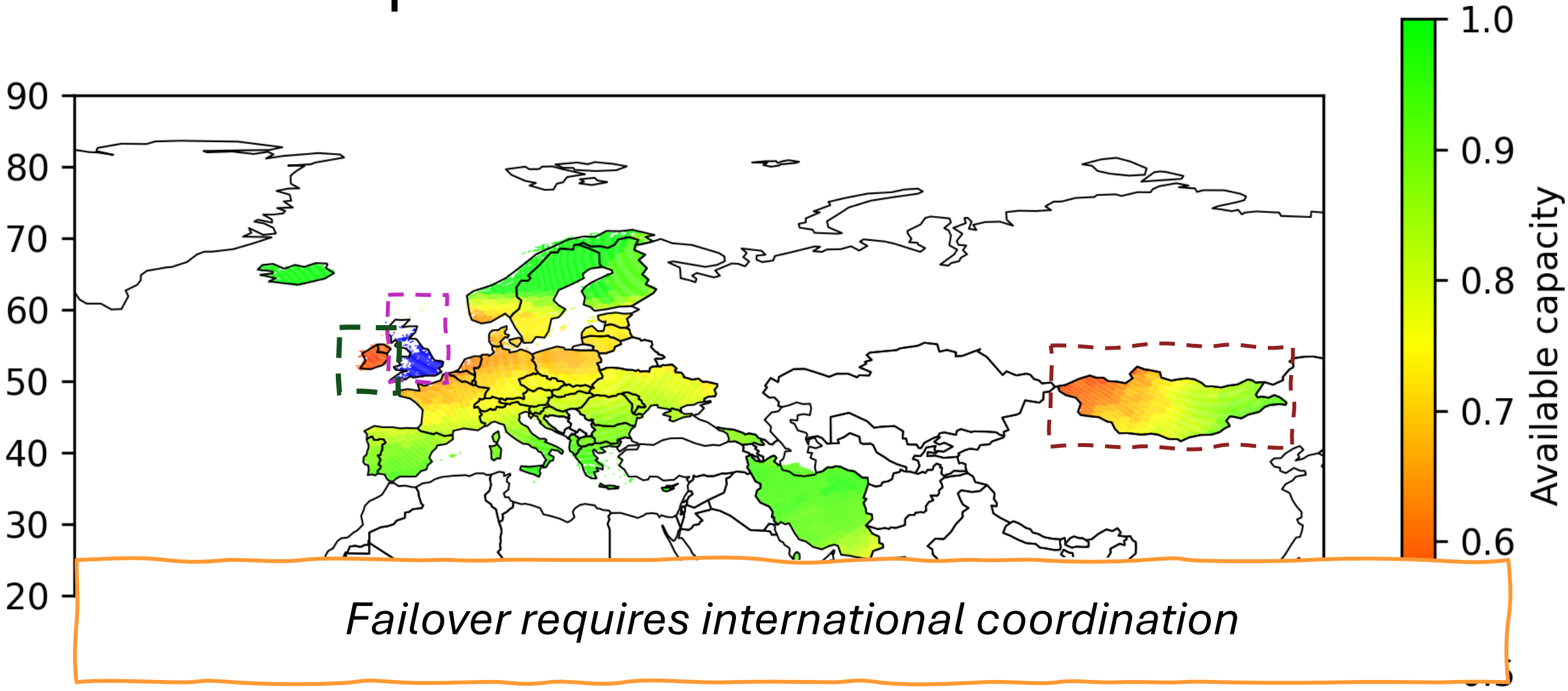

Failover requires international coordination

Key Takeaways

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- LEO Networks cannot effectively substitute submarine cables
  - **Even with tens of thousands of satellites** -> Limited spectrum allocated
- Poor failover planning may **reduce capacity by 50%**
- Failover traffic can **significantly limit** global available bandwidth