Technische Universität Berlin

CELESTIAL: Virtual Software System Testbeds for the LEO Edge

Tobias Pfandzelter, David Bermbach | 23rd ACM/IFIP International Middleware Conference

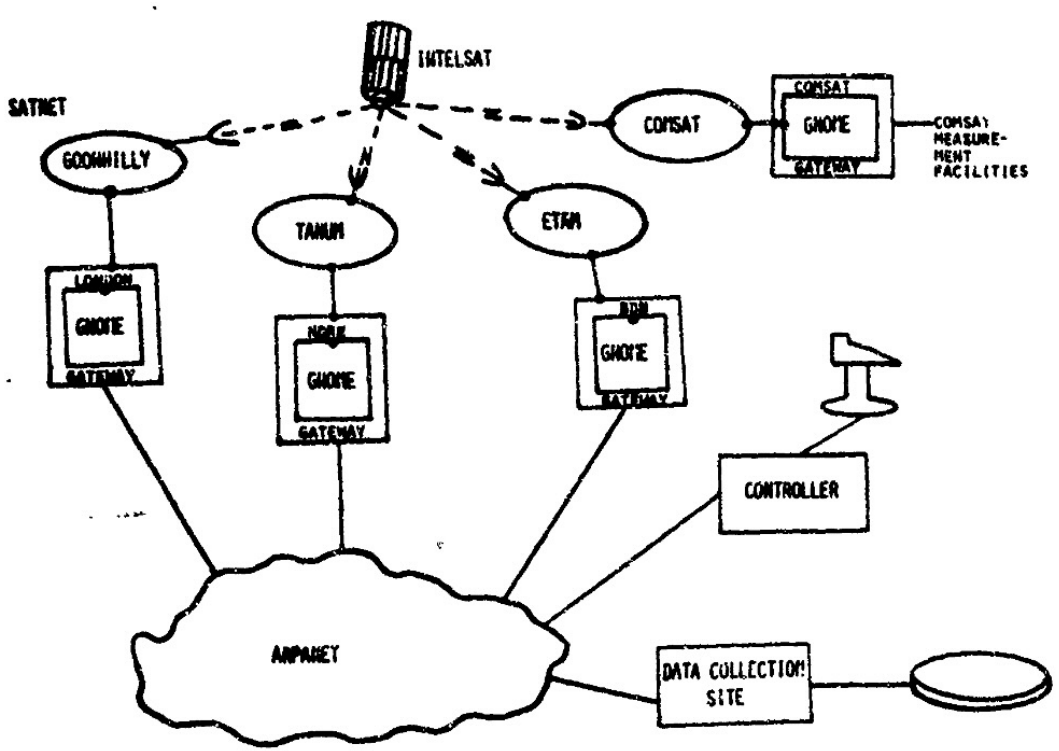
1. Why LEO satellite edge computing matters

2. Virtual software system testbeds with CELESTIAL

1. Why LEO satellite edge computing matters

2. Virtual Software System Testbeds with CELESTIAL

Internet from Space



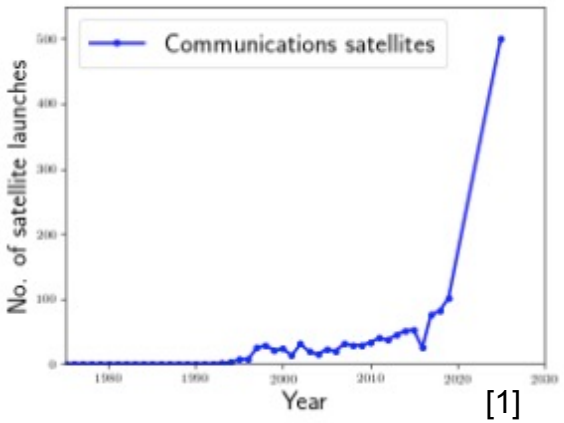
[14] P. Kirstein, “University College London ARPANET Project, Annual Report 1977,” Apr. 1978.

Internet from Space

NASA awards millions to SpaceX and Amazon's Project Kuiper for satellite communications

BY ALAN BOYLE on April 20, 2022 at 3:24 pm

https://www.geekwire.com/2022/nasa-awards-millions-to-spacex-and-amazons-project-kuiper-for-satellite-communications/



[1]

Arianespace Soyuz rocket launches 34 OneWeb internet satellites into space

By Mike Wall published August 22, 2021

Arianespace has now lofted a total of 288 OneWeb satellites.

https://www.space.com/arianespace-sozyuz-launches-oneweb-9-internet-satellite-mission

North

Elon Musk's Starlink high-speed satellite internet service begins northern rollout

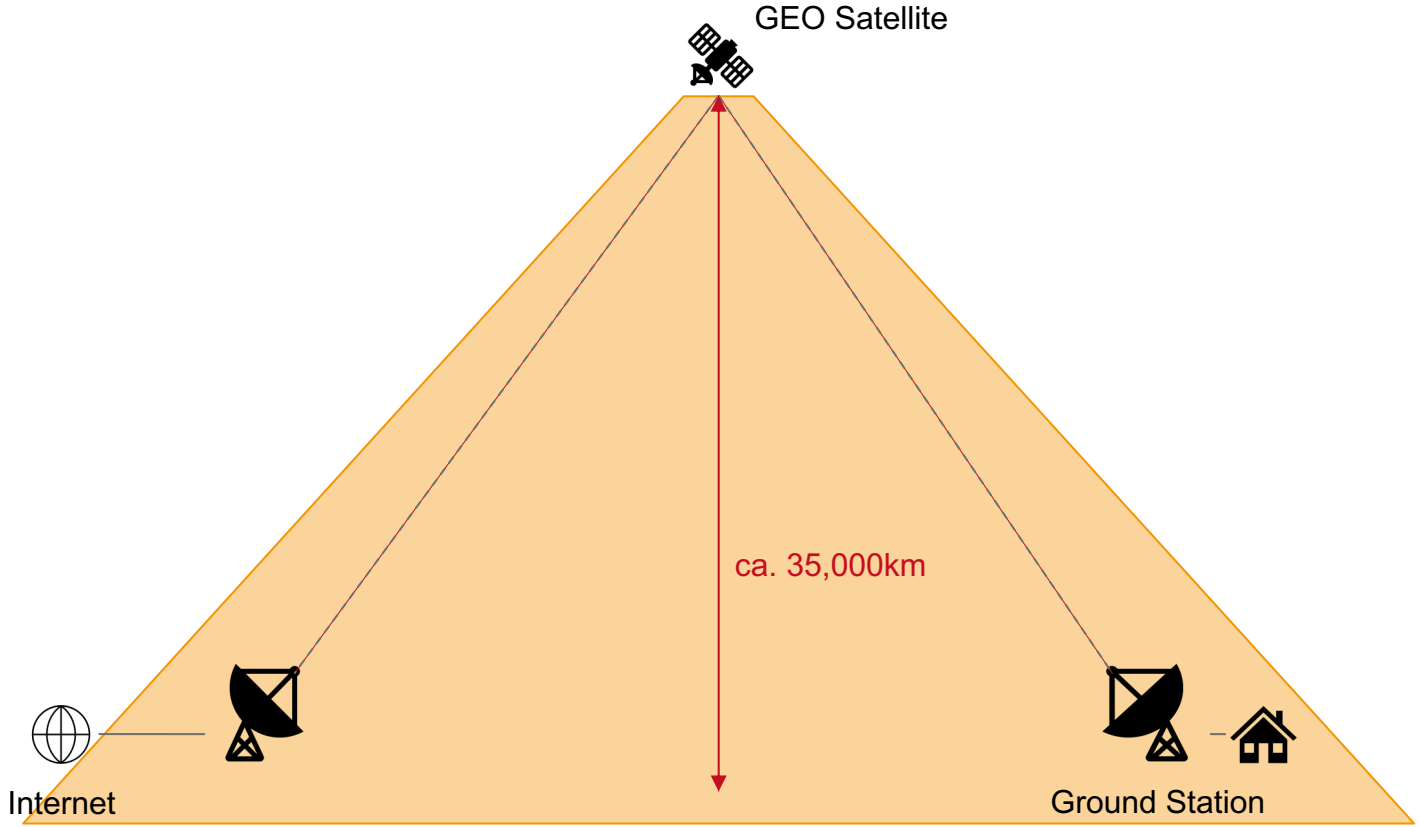
https://www.cbc.ca/news/canada/north/starlink-in-the-north-1.6640989

SpaceX deploys more Starlink satellites, aims for higher launch cadence

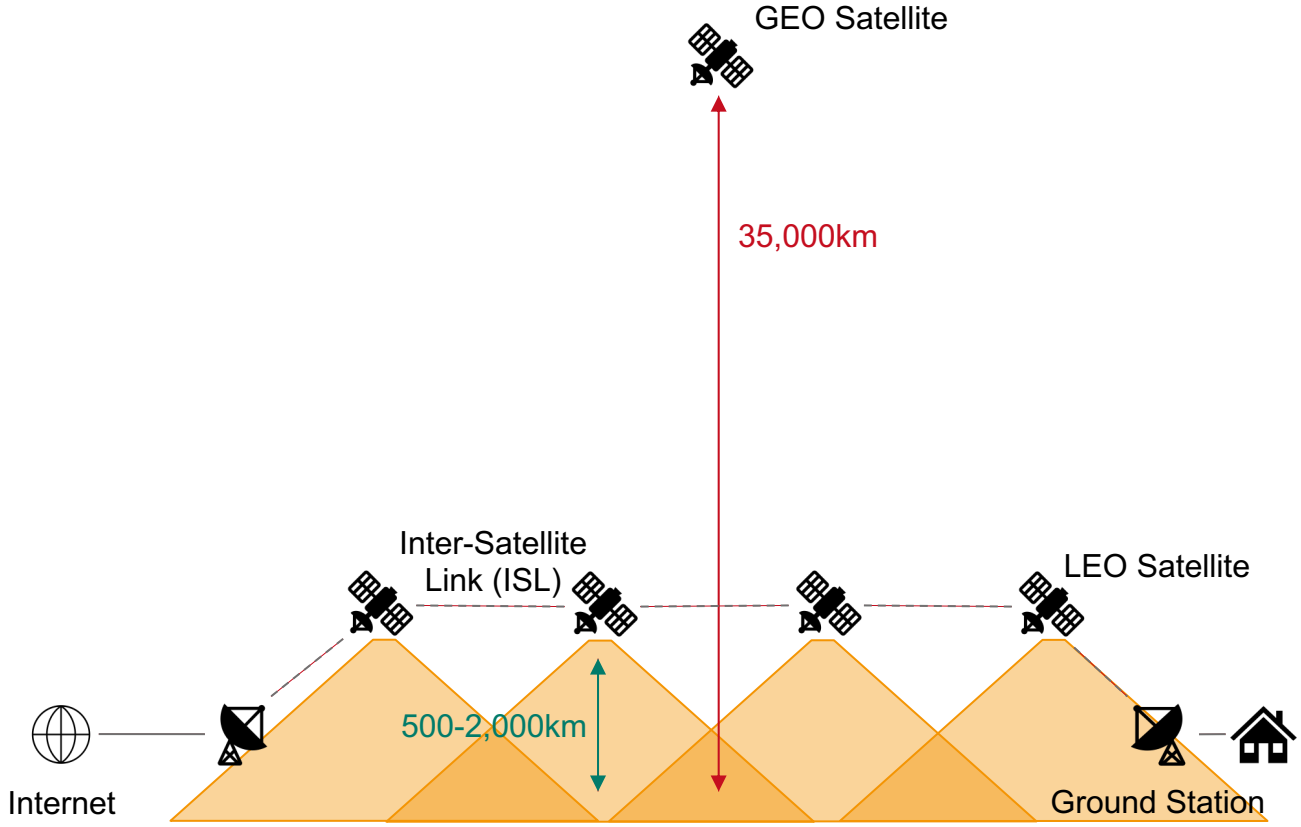
April 21, 2022 Stephen Clark

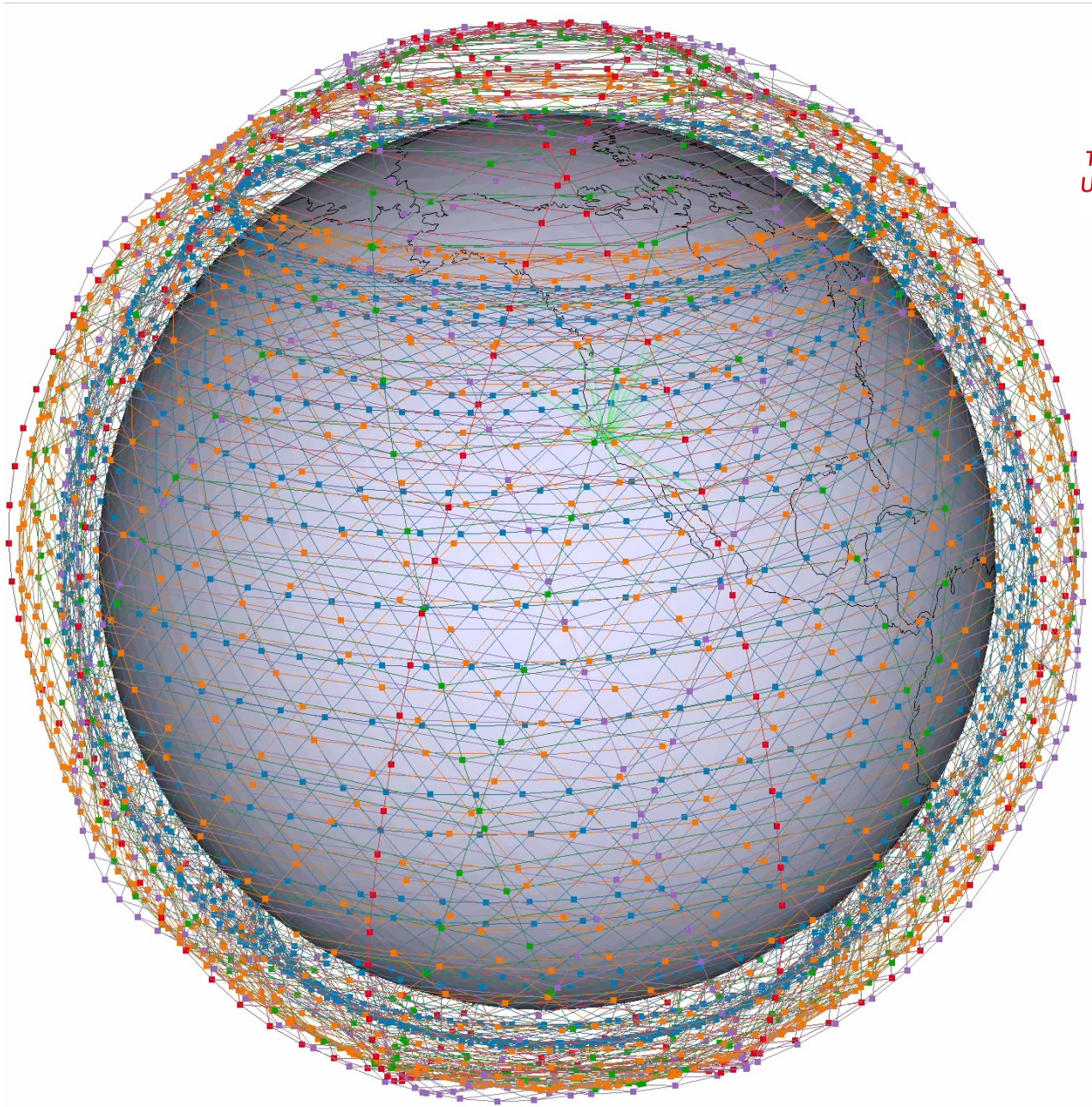
https://spaceflightnow.com/2022/04/21/spacex-deploys-more-starlink-satellites-aims-for-higher-launch-cadence/

Internet from Space – The Old, Boring Way

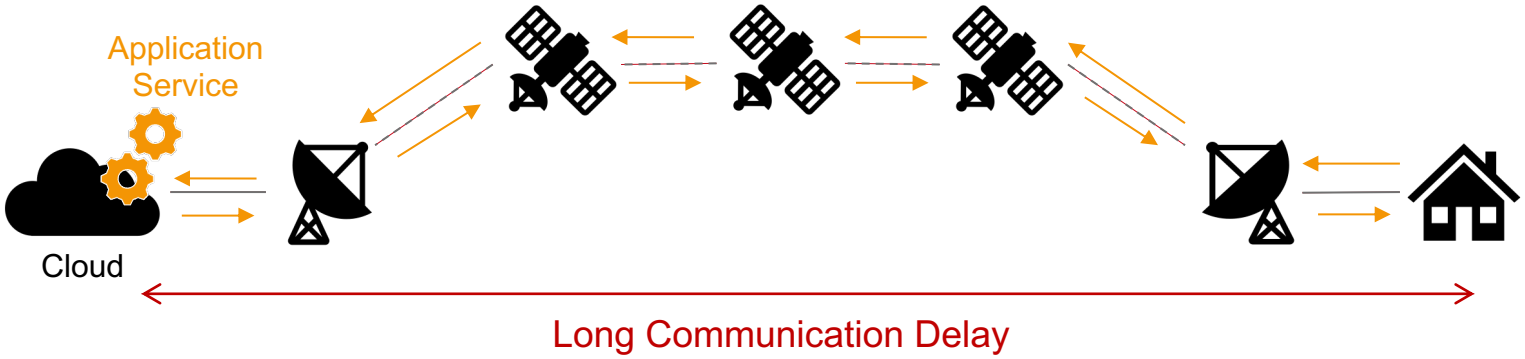


Internet from Space – The New, Exciting Way

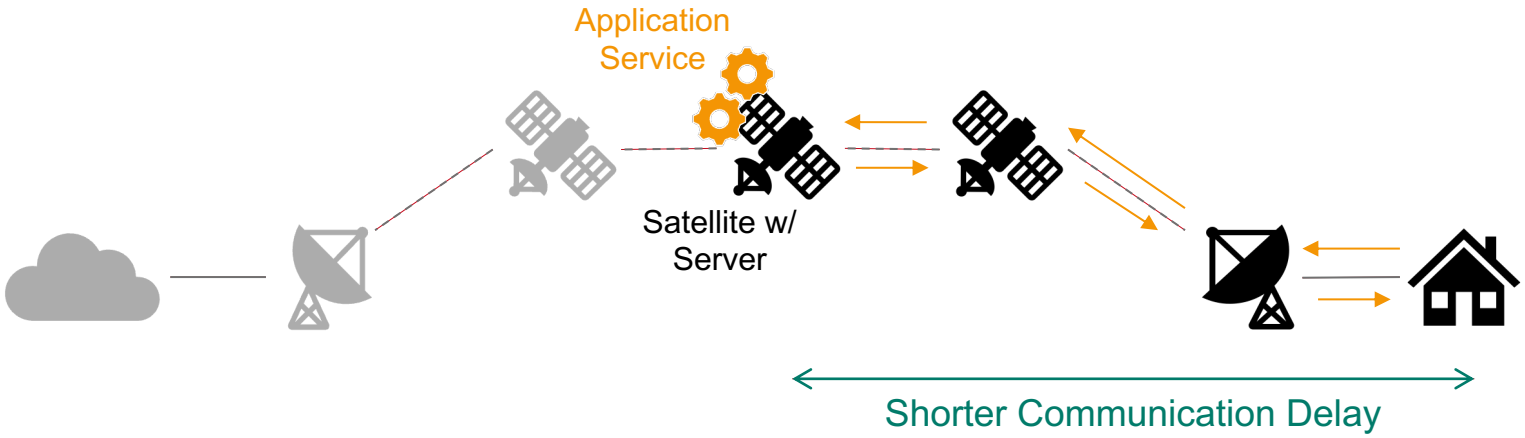




Computing and LEO Networks

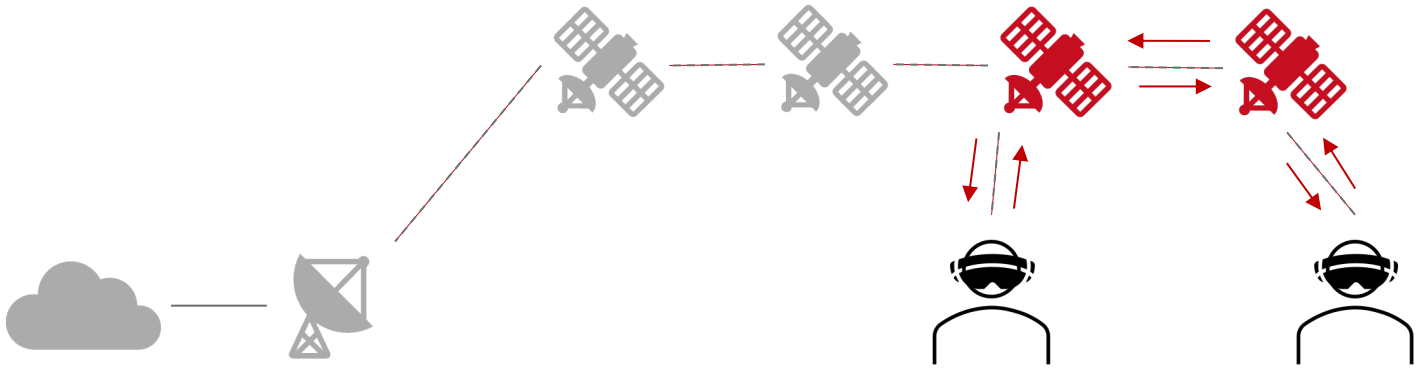


LEO Satellite Edge Computing



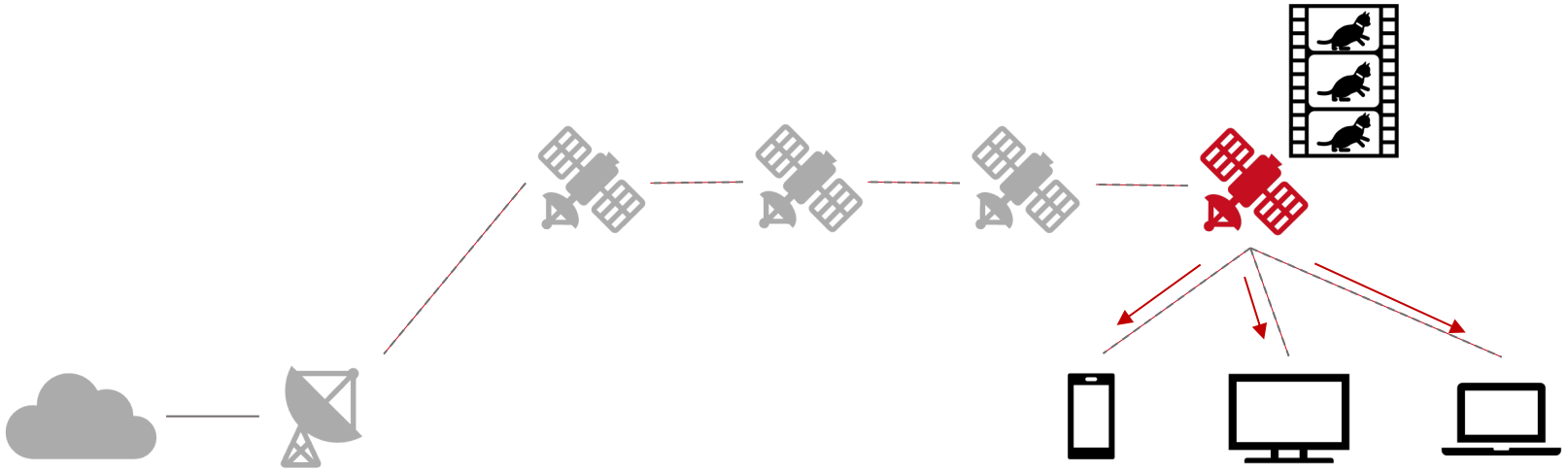
[2] D. Bhattacherjee et al., “In-orbit computing: An outlandish thought experiment?” in *Proceedings of the 19th ACM Workshop on Hot Topics in Networks (HotNets 2019)*, Nov. 2020, pp. 197–204.

LEO Edge: Multi-User Interaction



[2] D. Bhattacherjee et al., “In-orbit computing: An outlandish thought experiment?” in *Proceedings of the 19th ACM Workshop on Hot Topics in Networks (HotNets 2019)*, Nov. 2020, pp. 197–204.

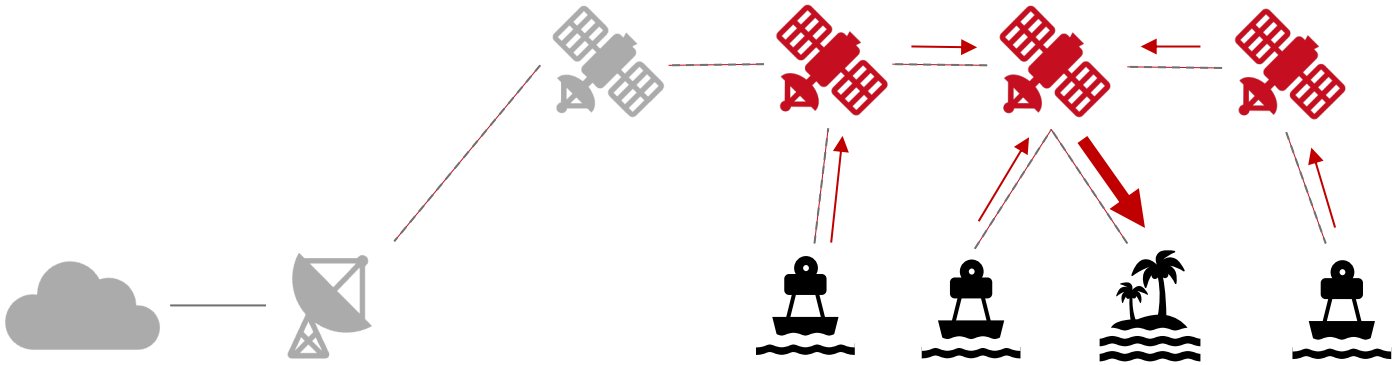
LEO Edge: CDNs



[3] T. Pfandzelter et al., “Edge (of the Earth) Replication: Optimizing Content Delivery in Large LEO Satellite Communication Networks” in *Proceedings of the 21st IEEE/ACM International Symposium on Cluster, Cloud and Internet Computing (CCGrid 2021)*, May. 2021, pp. 565–575.

[4] U. Speidel, “LEO mega-constellations - where the challenges lie” in *LEOCONN 2022*, Oct. 2022.

LEO Edge: Remote Internet of Things



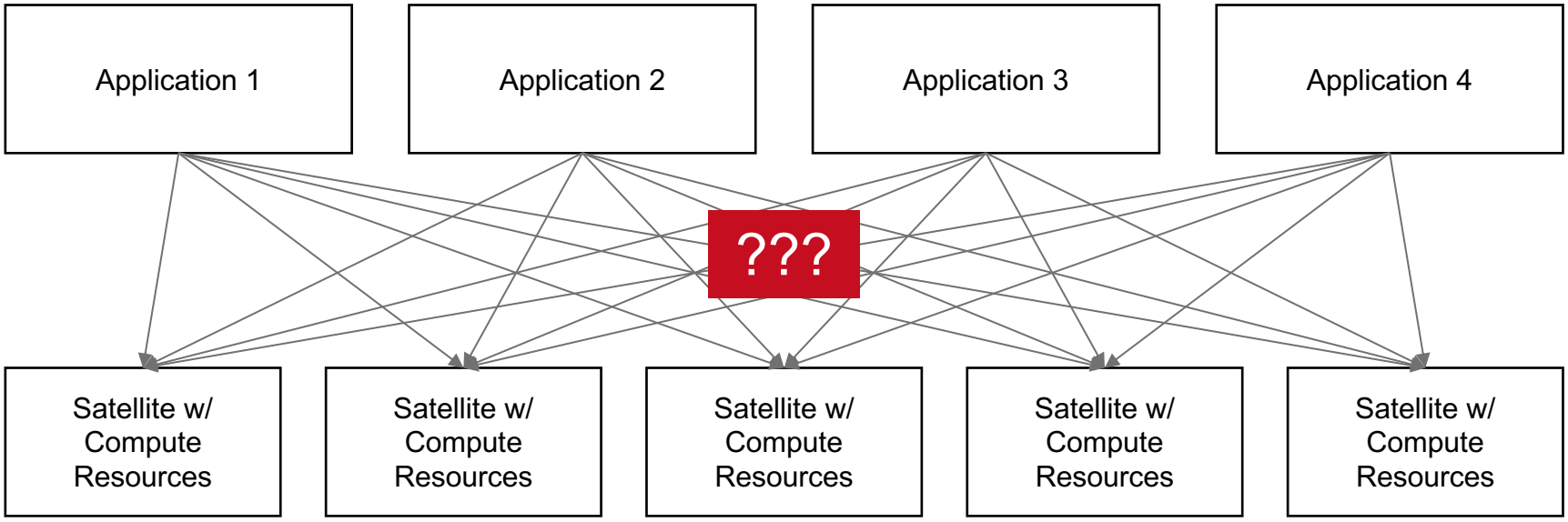
Easy Enough?

Consider…

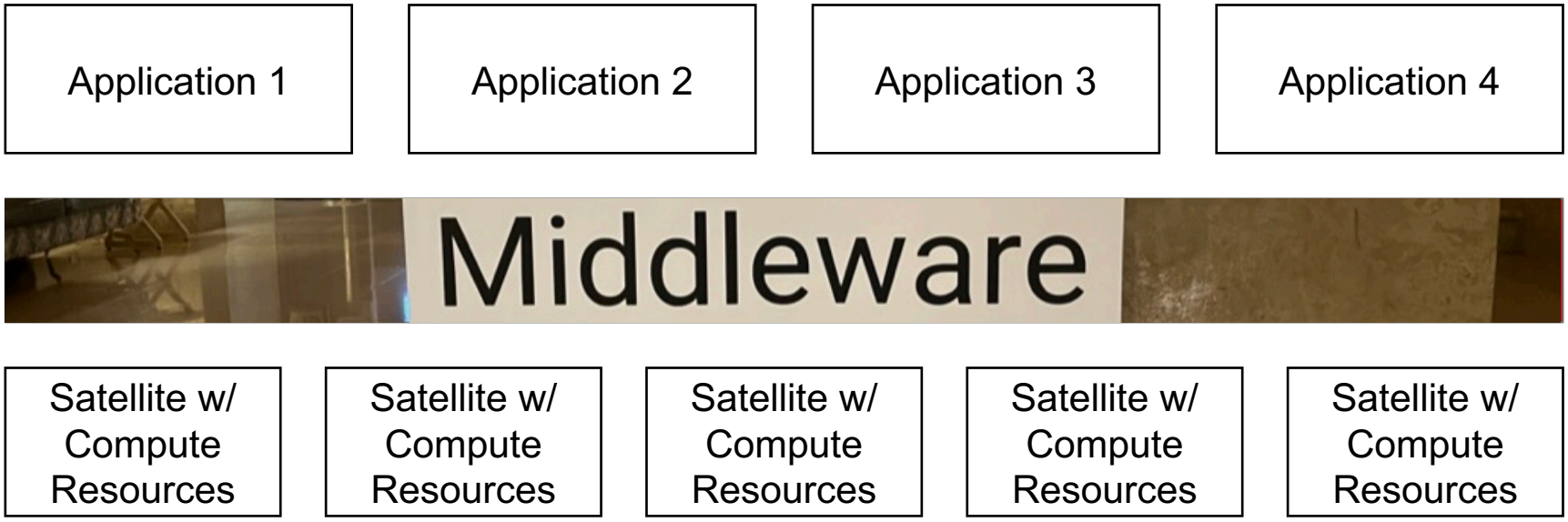
- **Mobility**: 90-minute orbital period
- **Coverage**: satellite handover every 1-2 minutes
- **Resource Constraints**: a server in space?
- **Fault Tolerance**: *a server in space???*
- **Multi-Tenancy**: different applications for different geographies
- **Scalability**: thousands of satellites

[5] T. Pfandzelter et al., “Towards a Computing Platform for the LEO Edge” in *Proceedings of the 4th International Workshop on Edge Systems, Analytics and Networking (EdgeSys 2021)*, Apr. 2021, pp. 43–48.

Easy Enough?


Application 1
Application 2
Application 3
Application 4
???
Satellite w/ Compute Resources
Satellite w/ Compute Resources
Satellite w/ Compute Resources
Satellite w/ Compute Resources
Satellite w/ Compute Resources

We'll need a compute platform



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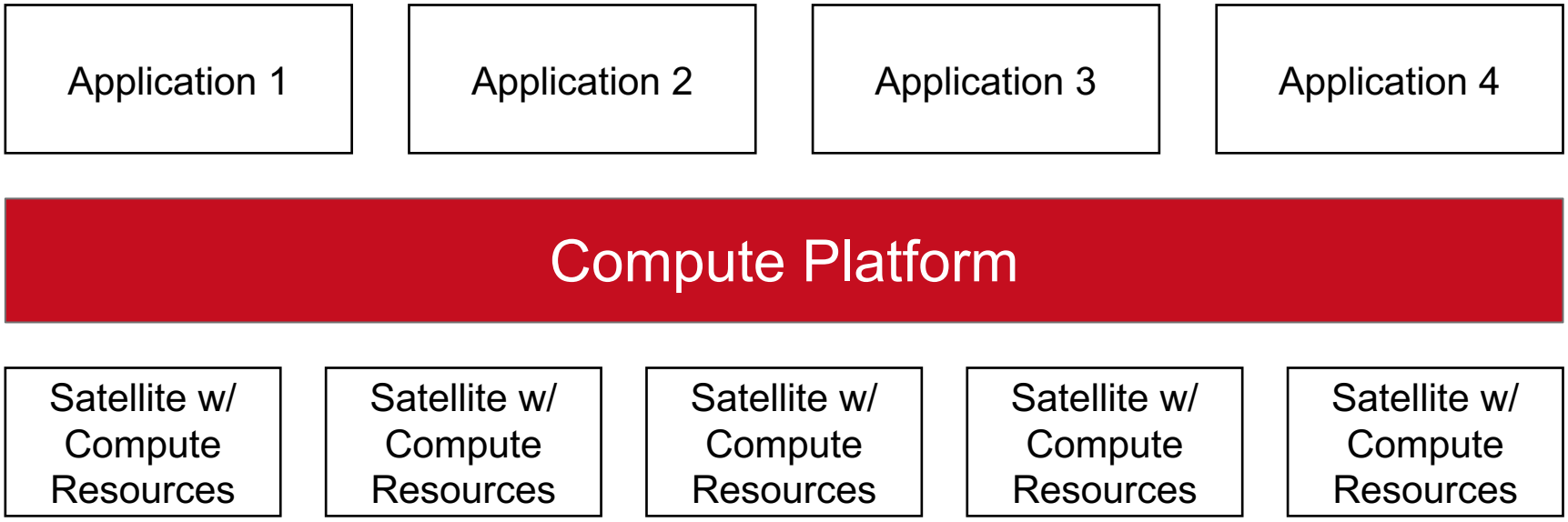

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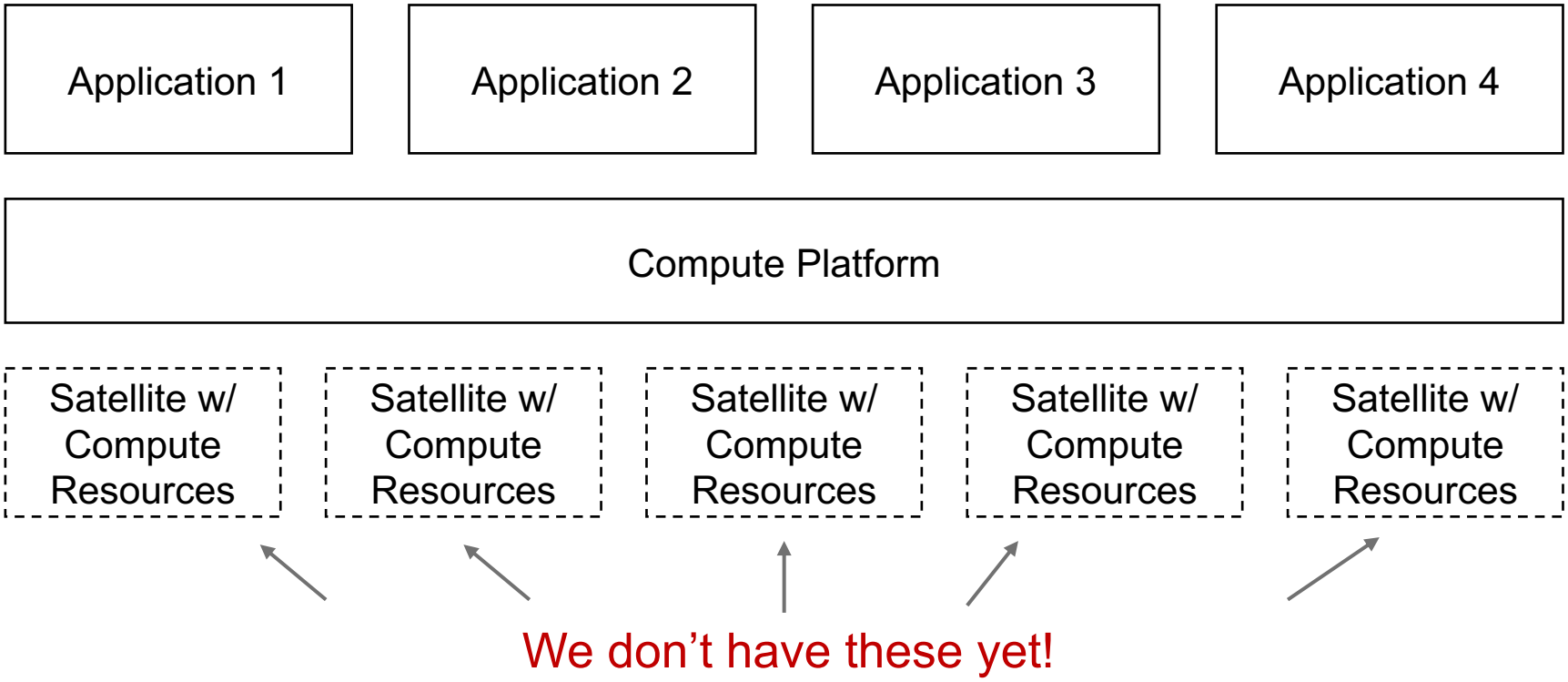

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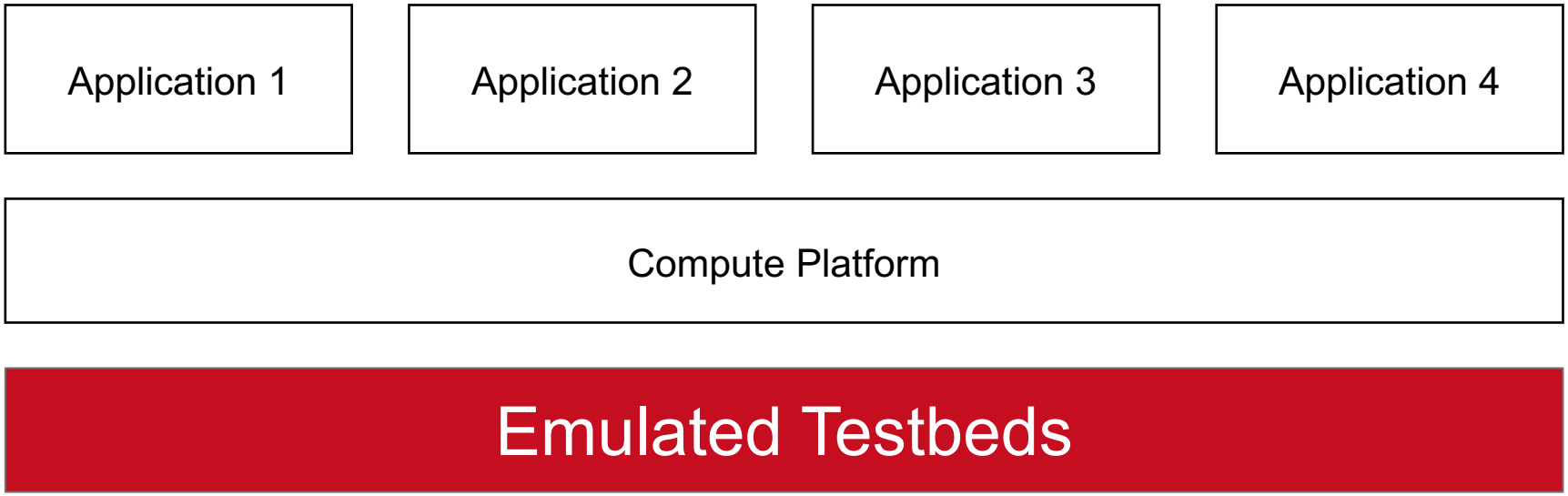

1. Why LEO satellite edge computing matters

2. Virtual software system testbeds with CELESTIAL

CELESTIAL

- Run **cheap** testbeds of LEO edge constellations in the cloud
- Provide isolated computing resources for each satellite in a scalable manner
- Support arbitrary software systems, including platforms
- Reliable efficiency, accuracy, reproducibility, repeatability

CELESTIAL

- Run **cheap** testbeds of LEO edge constellations in the cloud
- Provide isolated computing resources for each satellite in a scalable manner
- Support arbitrary software systems, including platforms
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This seems hard!

Thousands of Isolated Compute Resources in the Cloud vs. “Cheap”

	VMs		Containers
Cost	High		Low
Isolation	High		Low
Software Support	High		Medium
Overhead	High		Low

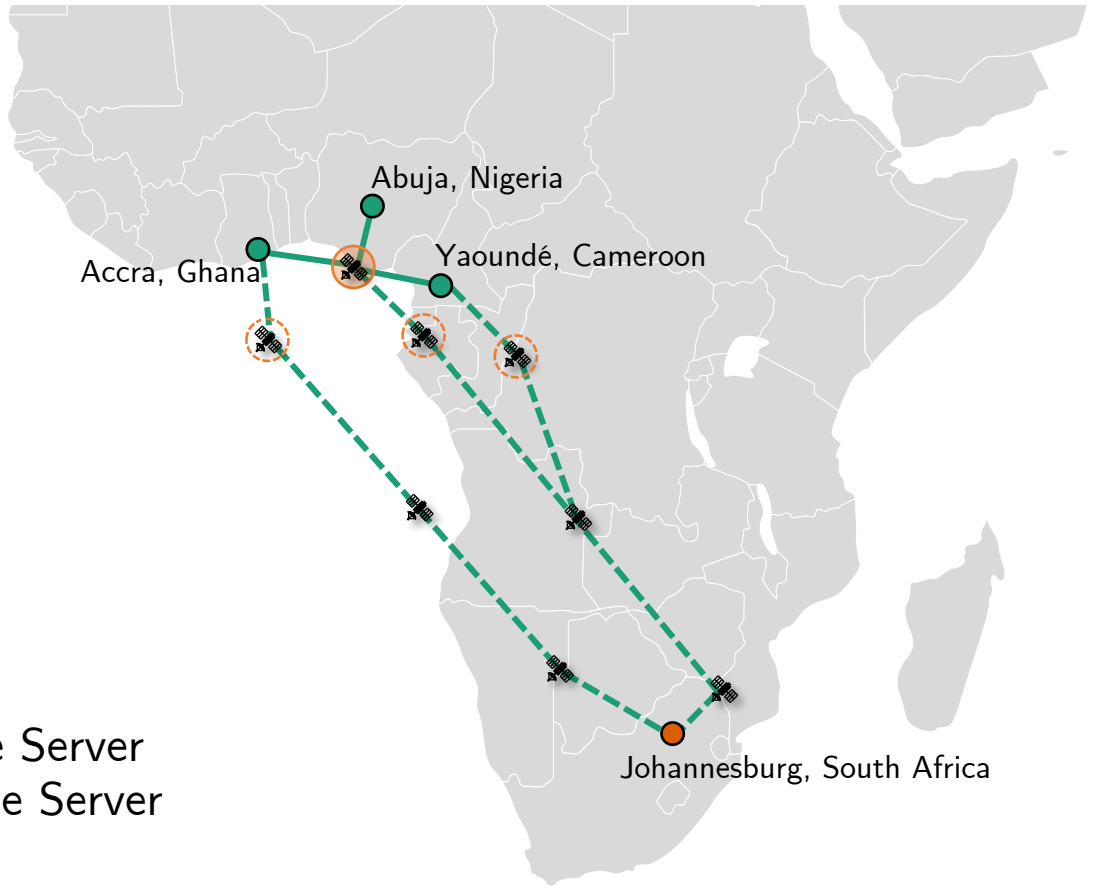
Thousands of Isolated Compute Resources in the Cloud vs. “Cheap”

	VMs	MicroVMs	Containers
Cost	High	**Low**	Low
Isolation	High	**High**	Low
Software Support	High	**High**	Medium
Overhead	High	**Low**	Low

[6] A. Agache et al., “Firecracker: Lightweight Virtualization for Serverless Applications” in *Proceedings of the 17th USENIX Symposium on Networked Systems Design and Implementation (NSDI ’20)*, Feb. 2022, pp. 419–434.

1. Efficient virtualization with microVMs

Thousands?



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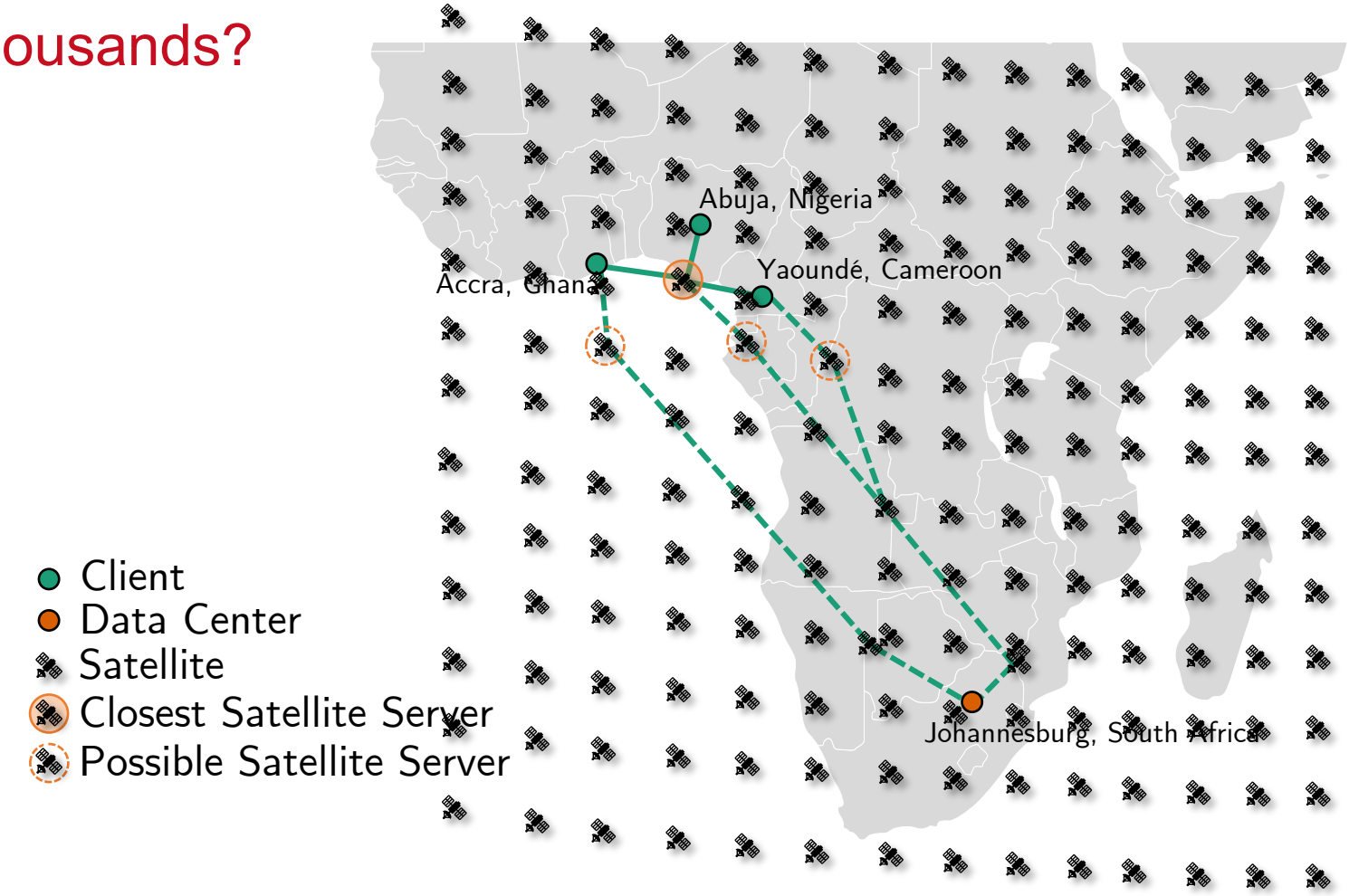
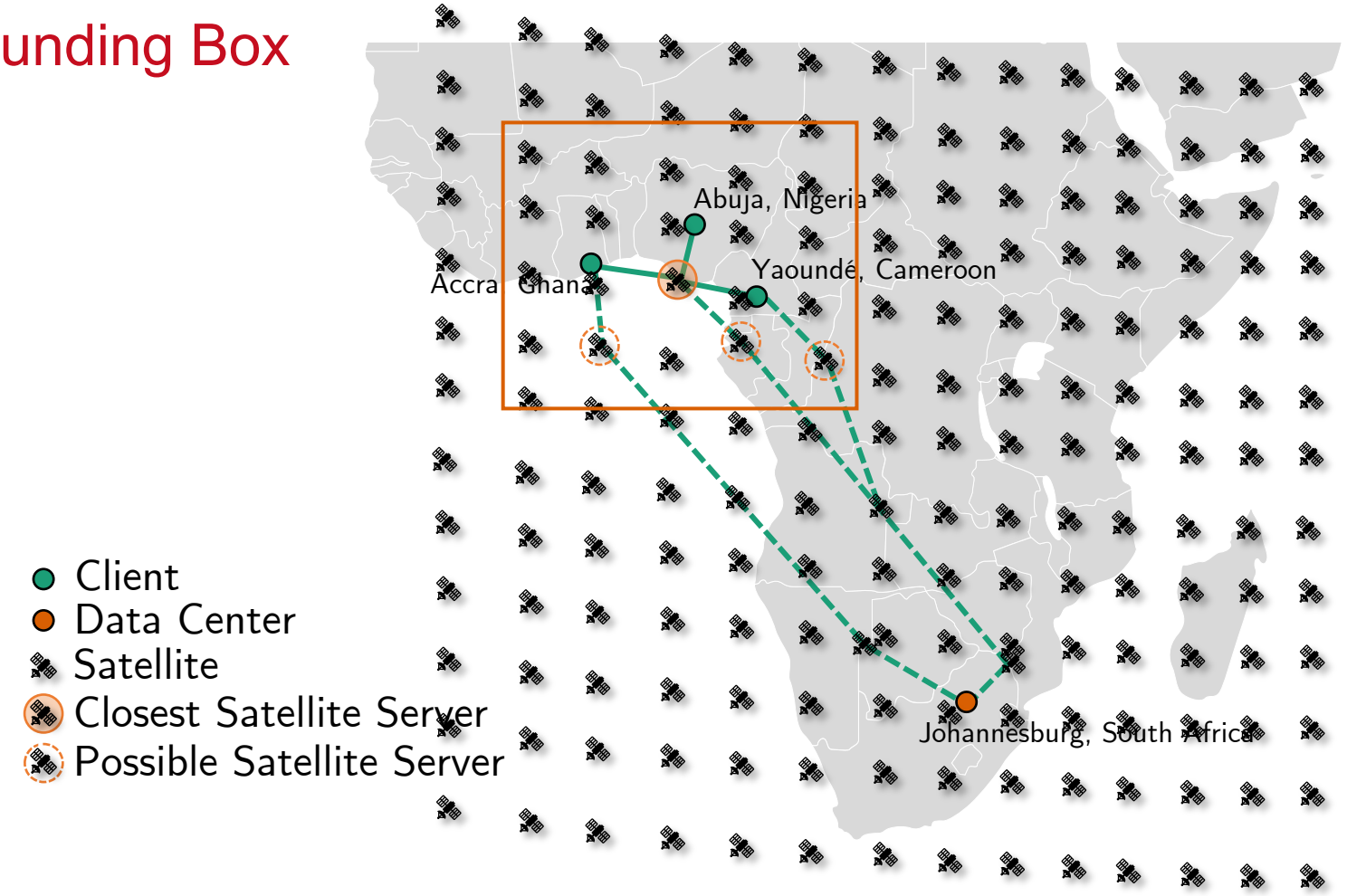
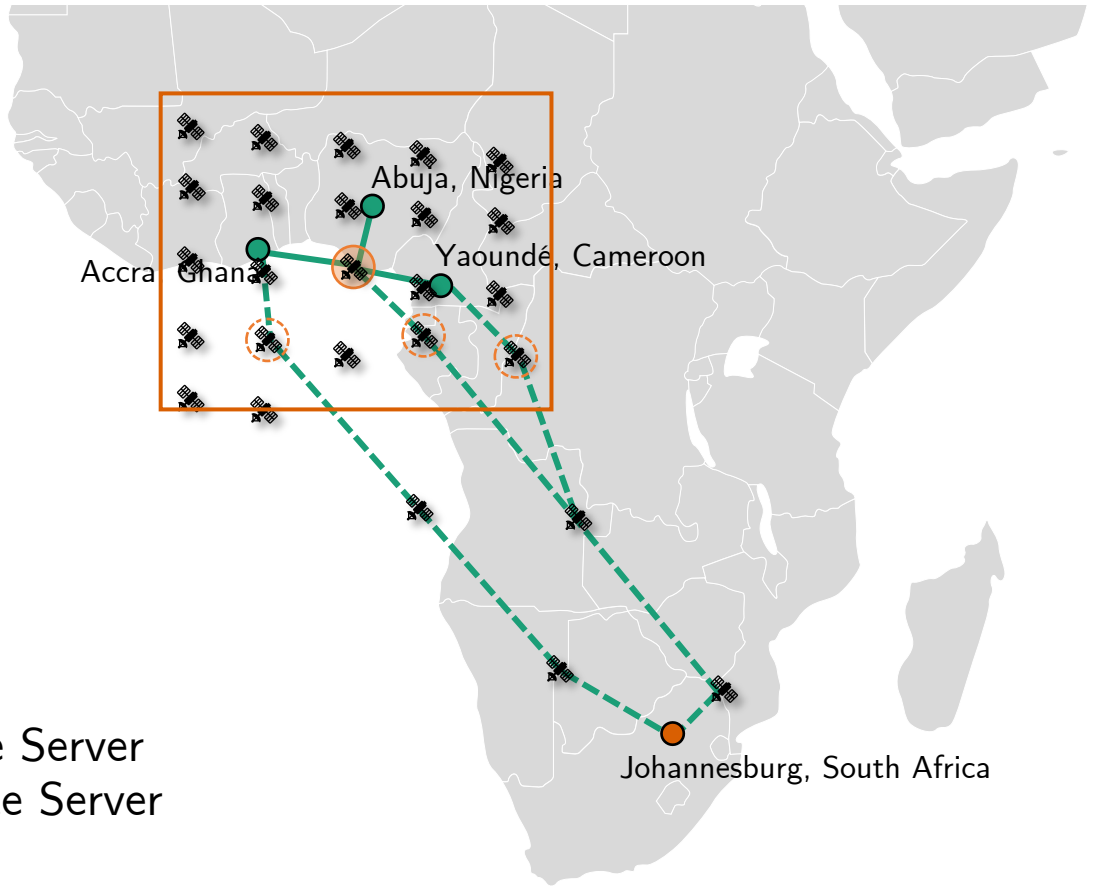
Thousands?


Abuja, Nigeria
Accra, Ghana
Yaoundé, Cameroon
Johannesburg, South Africa
Client
Data Center
Satellite
Closest Satellite Server
Possible Satellite Server

Bounding Box



Bounding Box

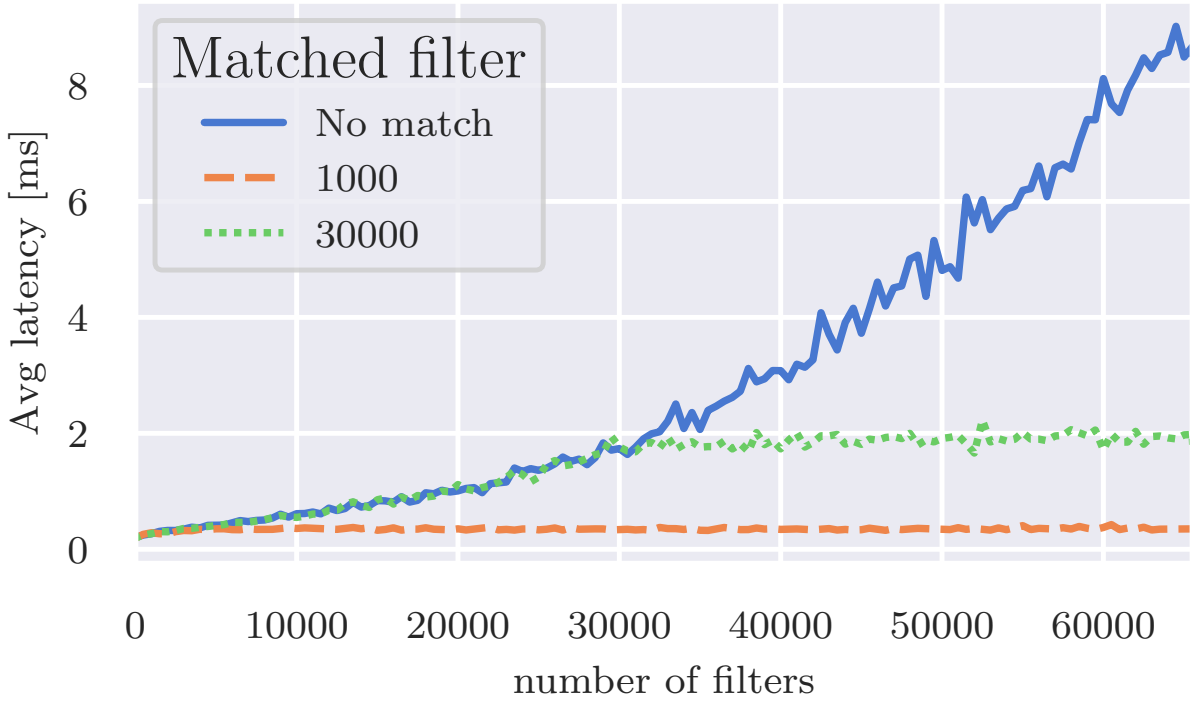


- Client
- Data Center
- Satellite
- Closest Satellite Server
- Possible Satellite Server

1. Efficient virtualization with microVMs

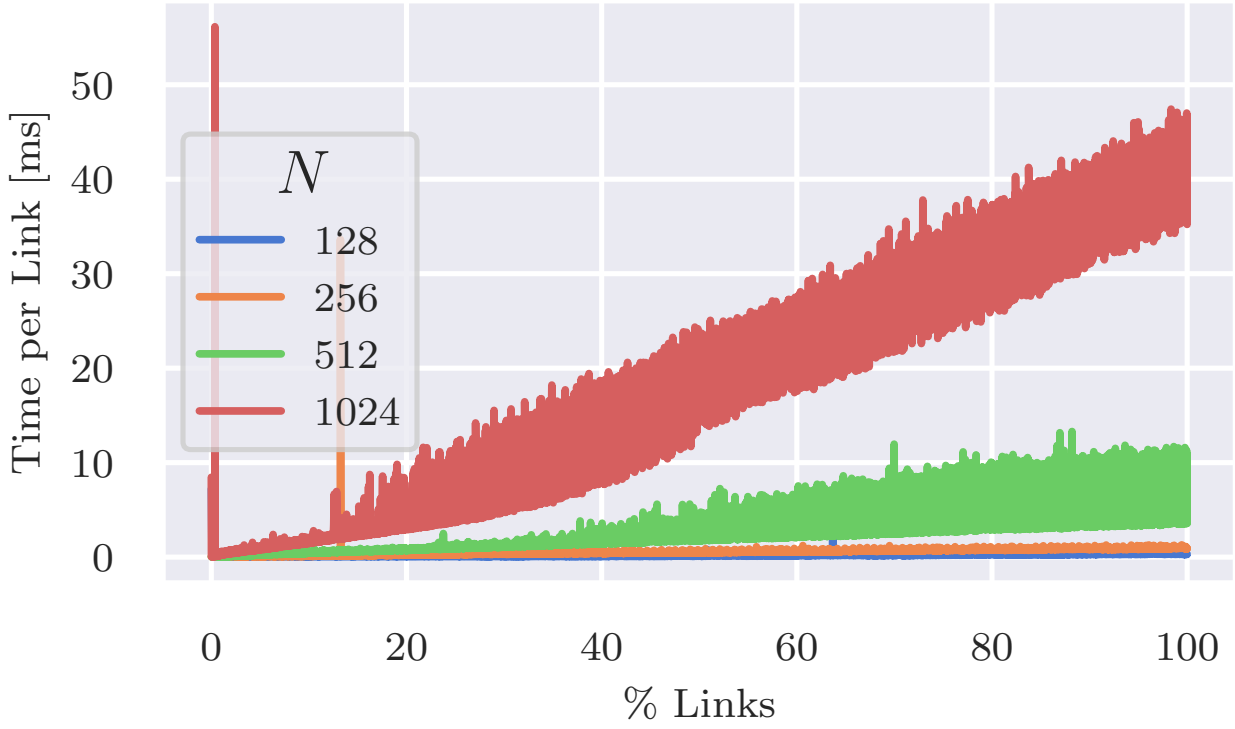
2. Bounding box

Scalable Network Emulation



[13] S. Becker et al., “Network Emulation in Large-Scale Virtual Edge Testbeds: A Note of Caution and the Way Forward ” in *Proceedings of the 2nd International Workshop on Testing Distributed Internet of Things Systems (TDIS 2022)*, Sep. 2022.

Scalable Network Emulation



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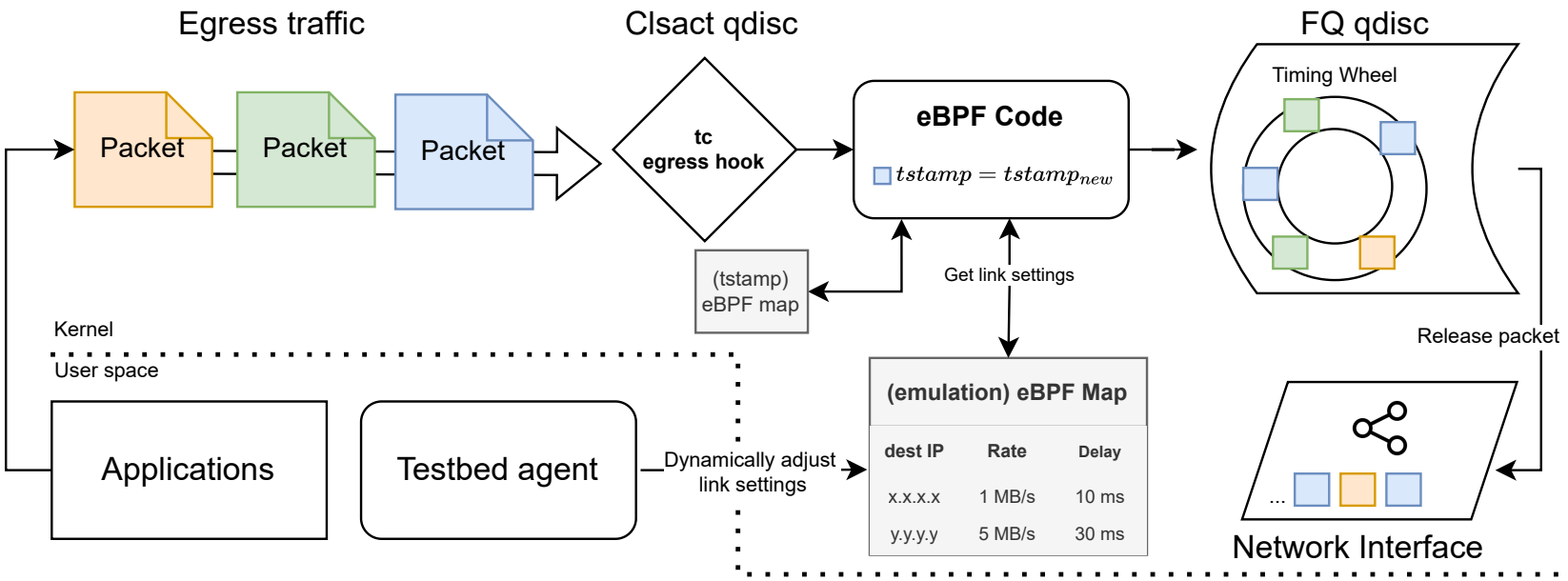

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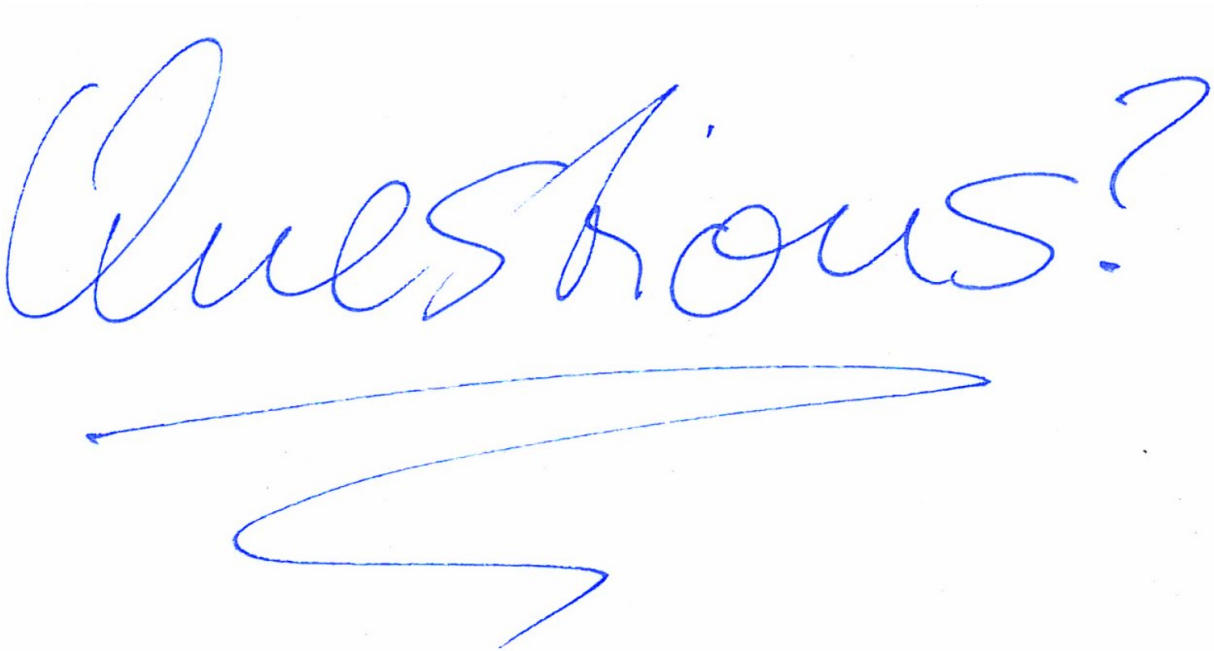
1. Efficient virtualization with microVMs
2. Bounding box
3. Scalable network emulation

Conclusion

- LEO satellite networks are coming – join our research area!
- Have a cool technology or prototype for edge computing? See if it fits the LEO edge!
- When you're ready, get prototyping on CELESTIAL! It's scalable, easy to use, and cheap (even your students can run it)

© D. Bhattacherjee



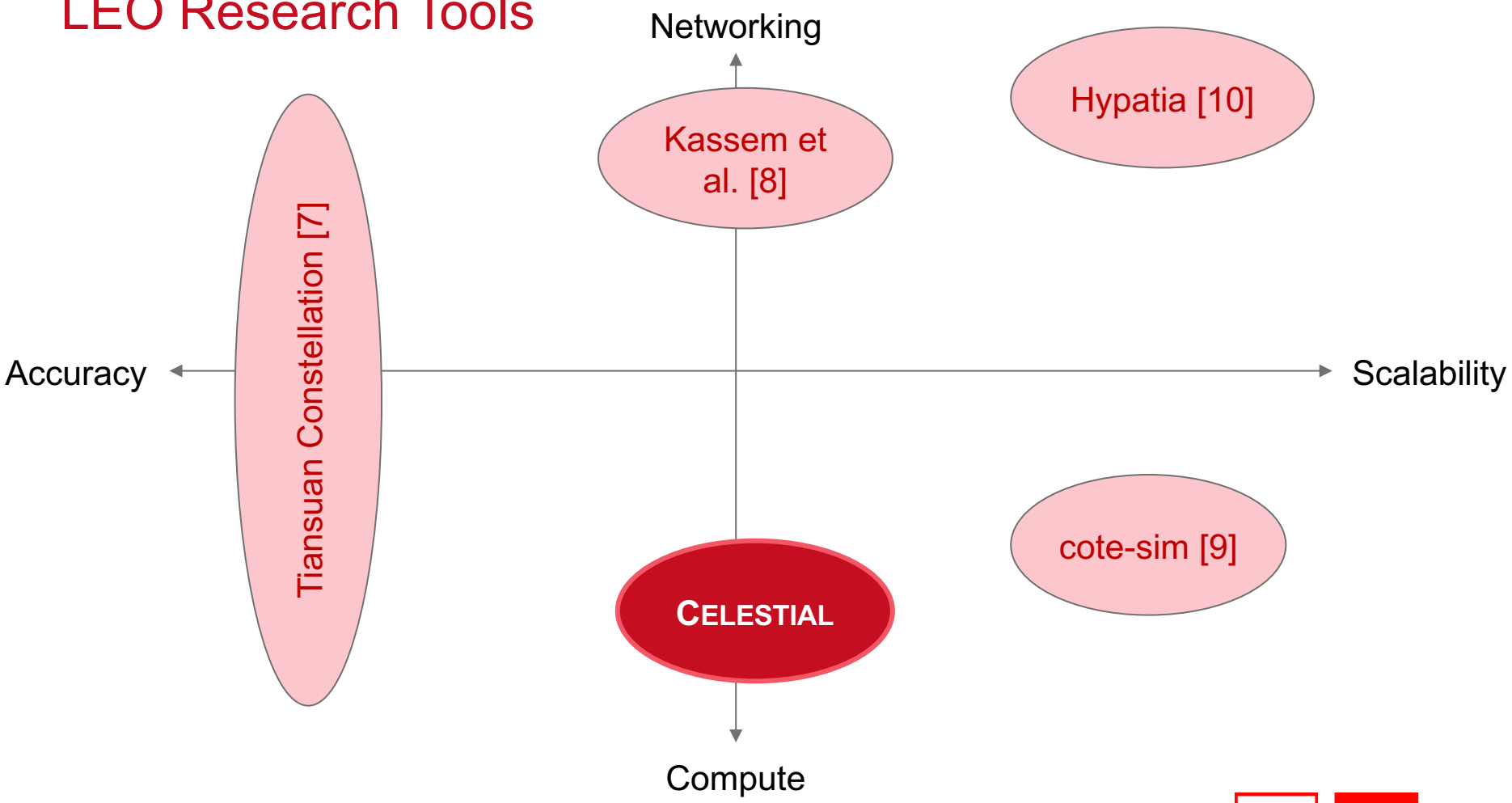
Contact: tp@mcc.tu-berlin.de

LEOCONN Mailing List: aka.ms/subscribe_LEOCONN

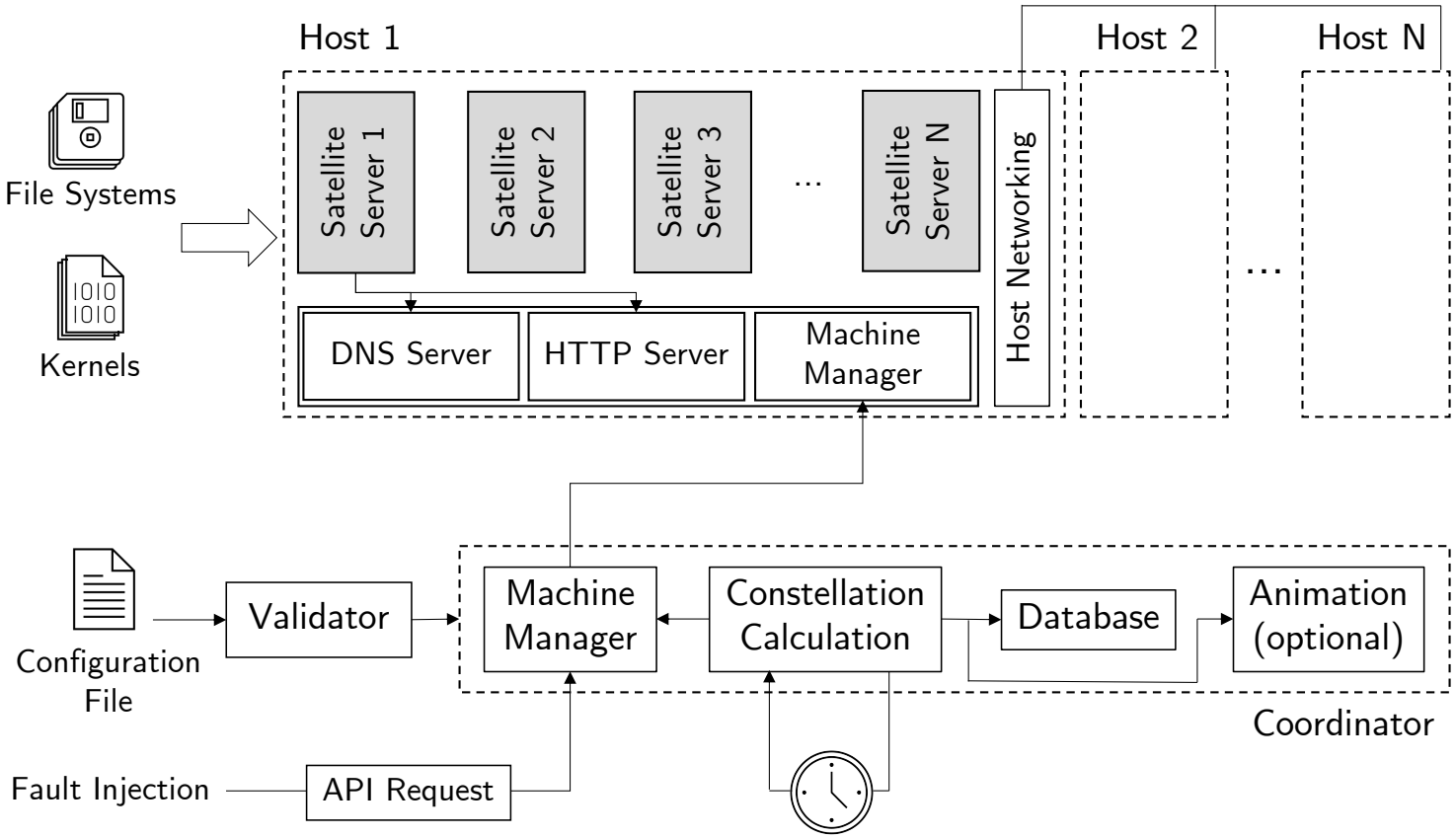
Code: github.com/OpenFogStack/celestial

Docs: openfogstack.github.io/celestial/

LEO Research Tools



CELESTIAL: Overview



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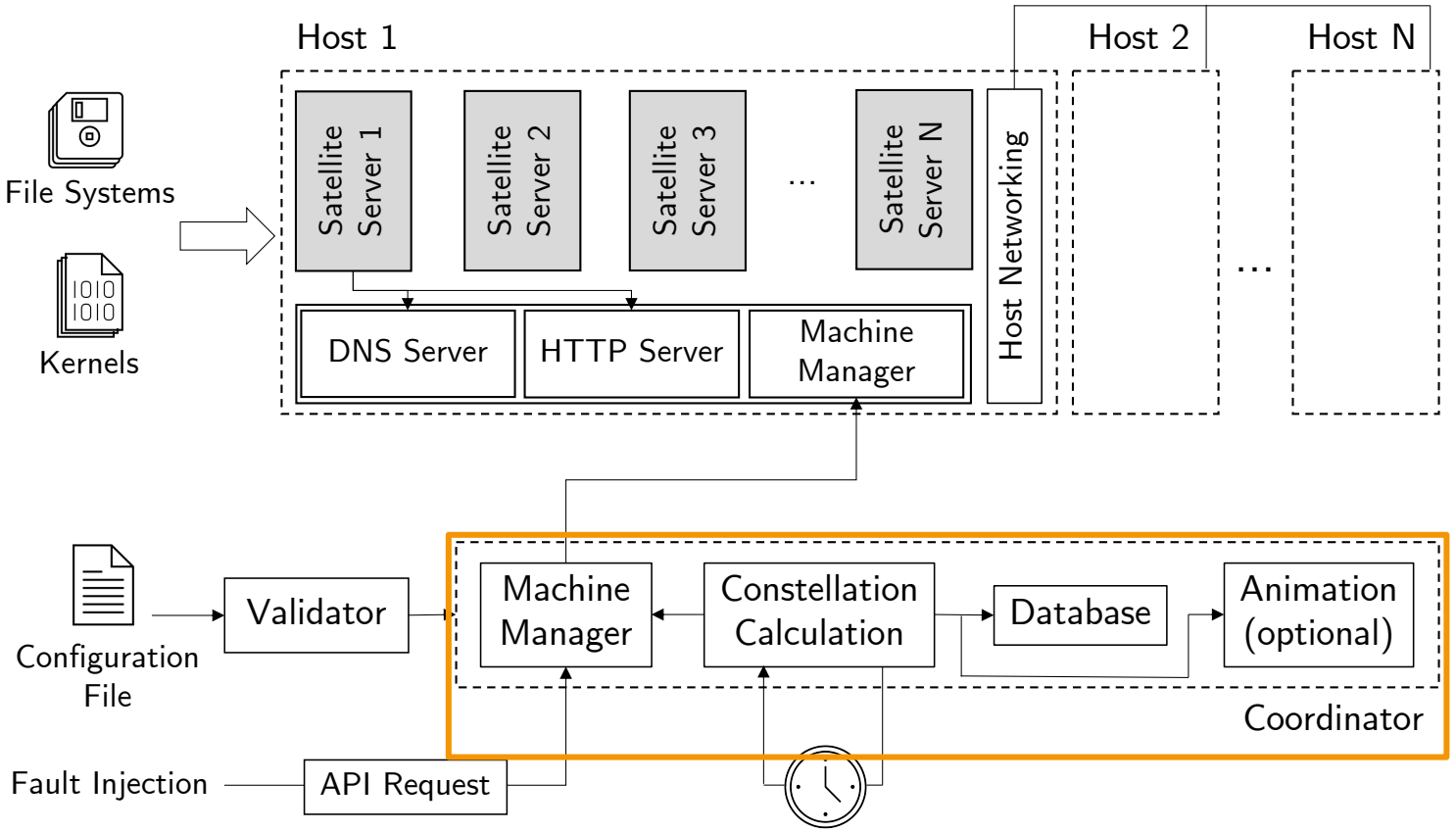

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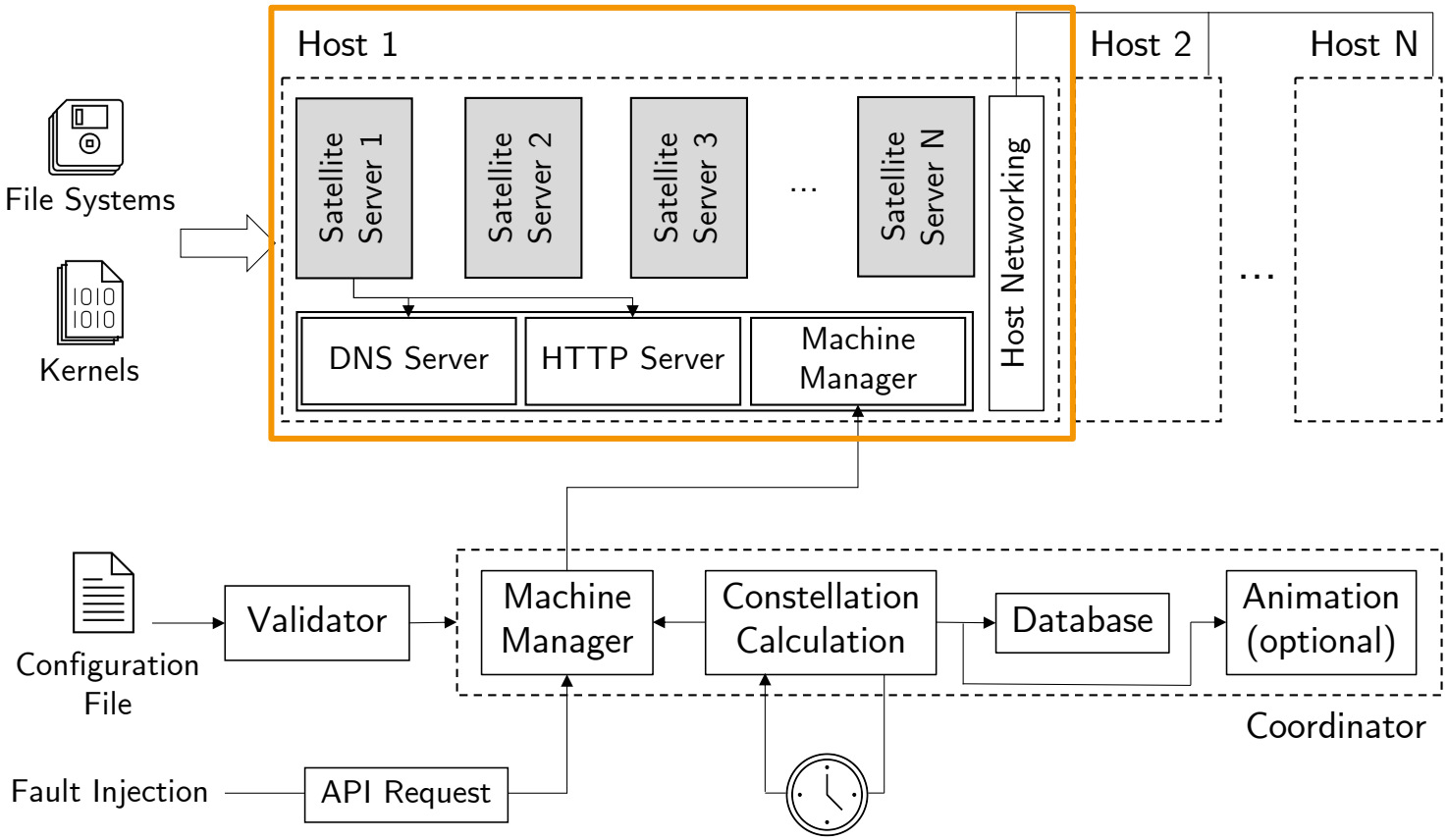

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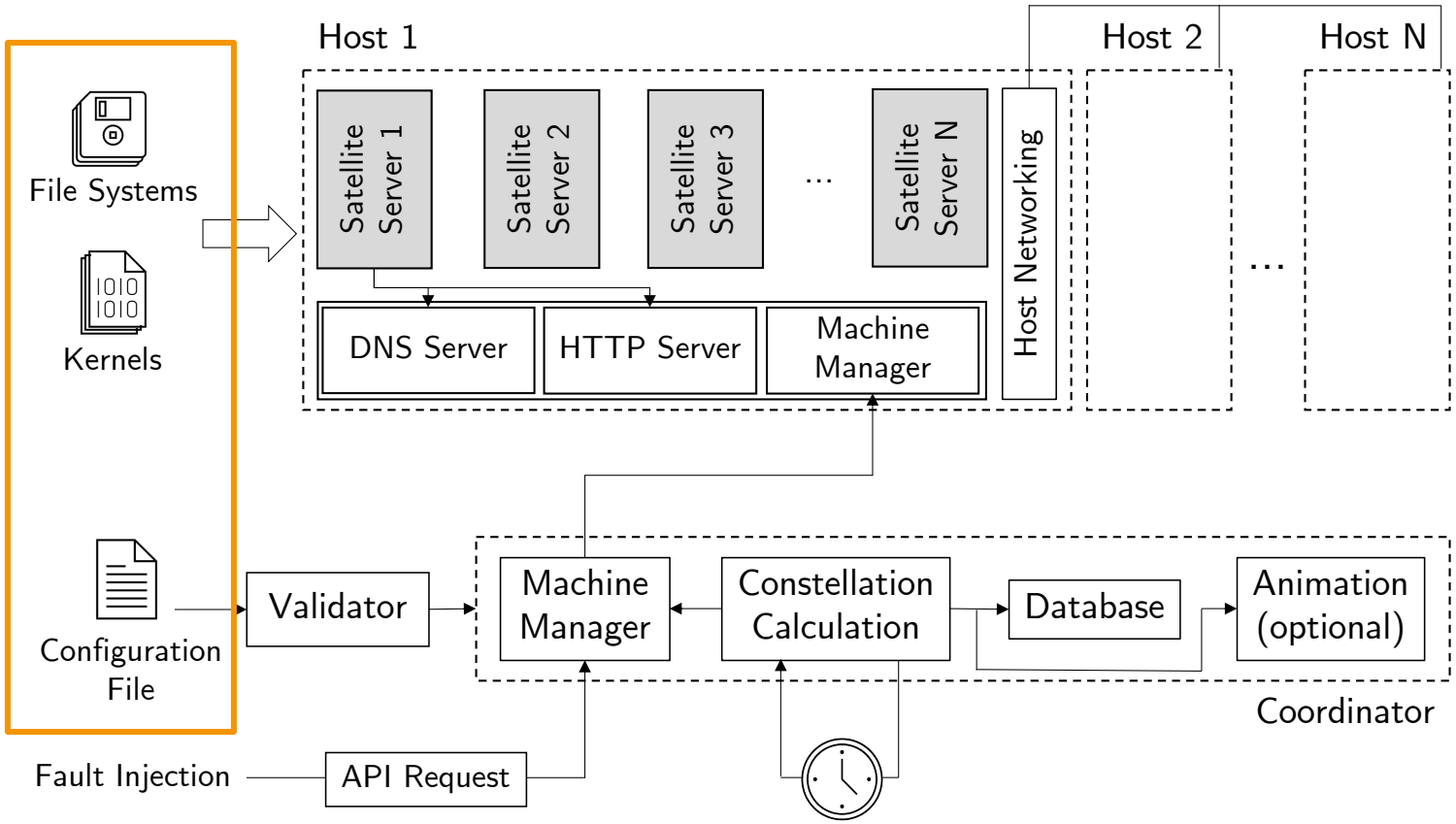
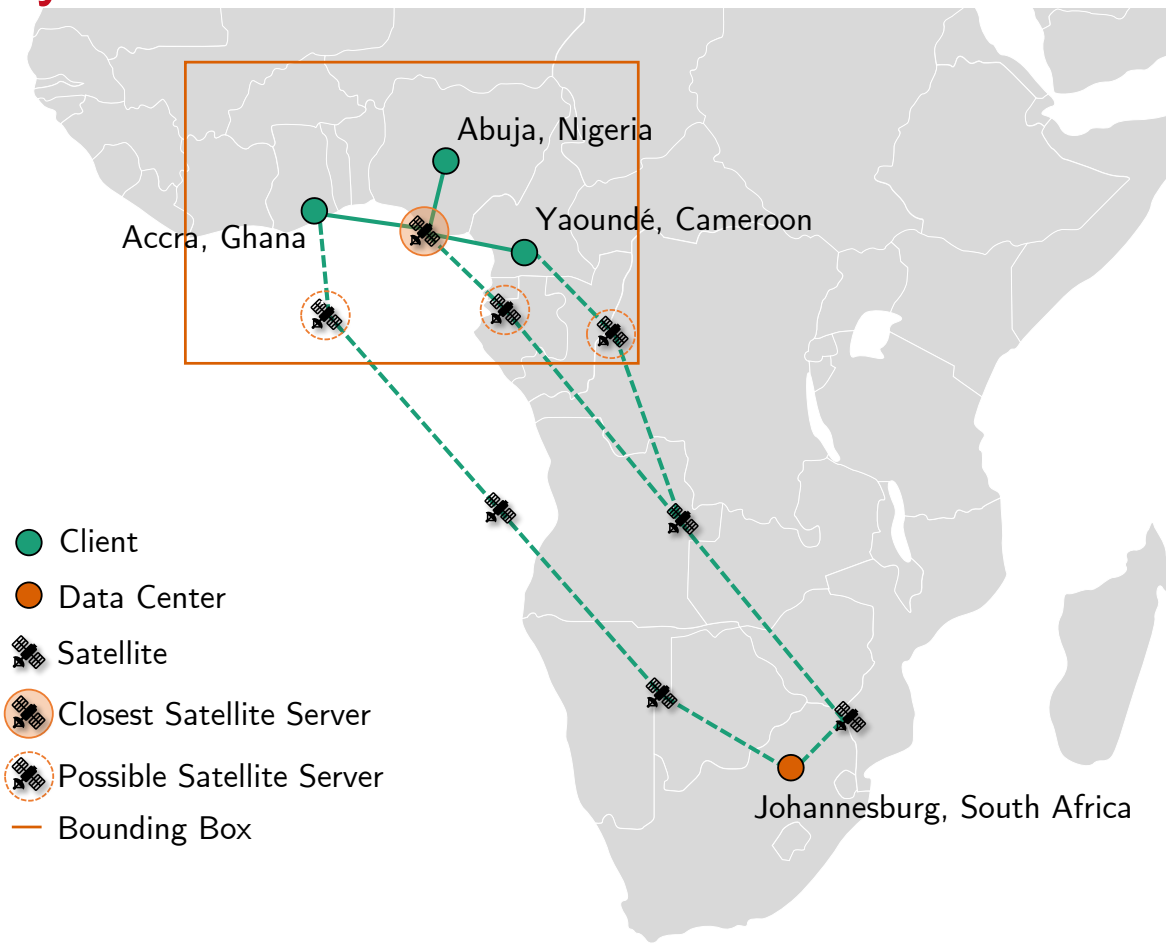


Case Study 1: Multi-User Interaction



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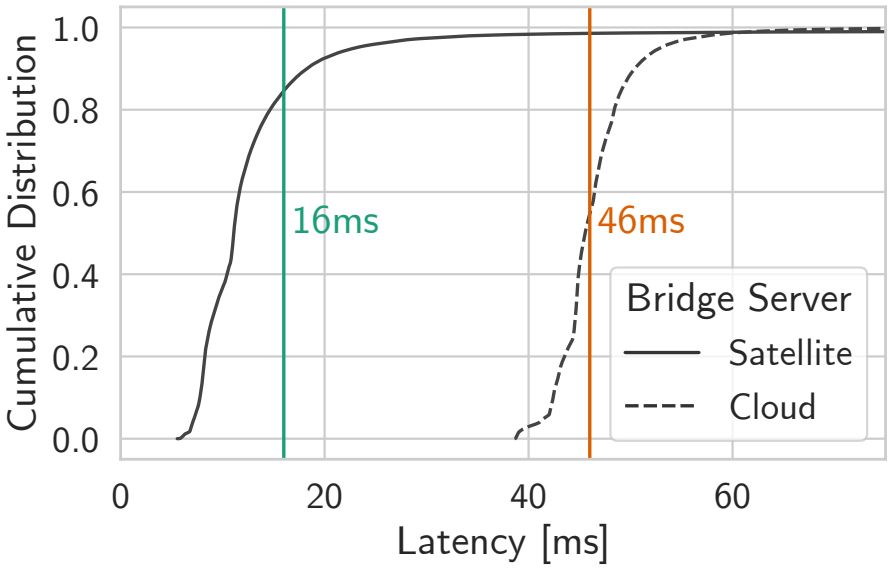
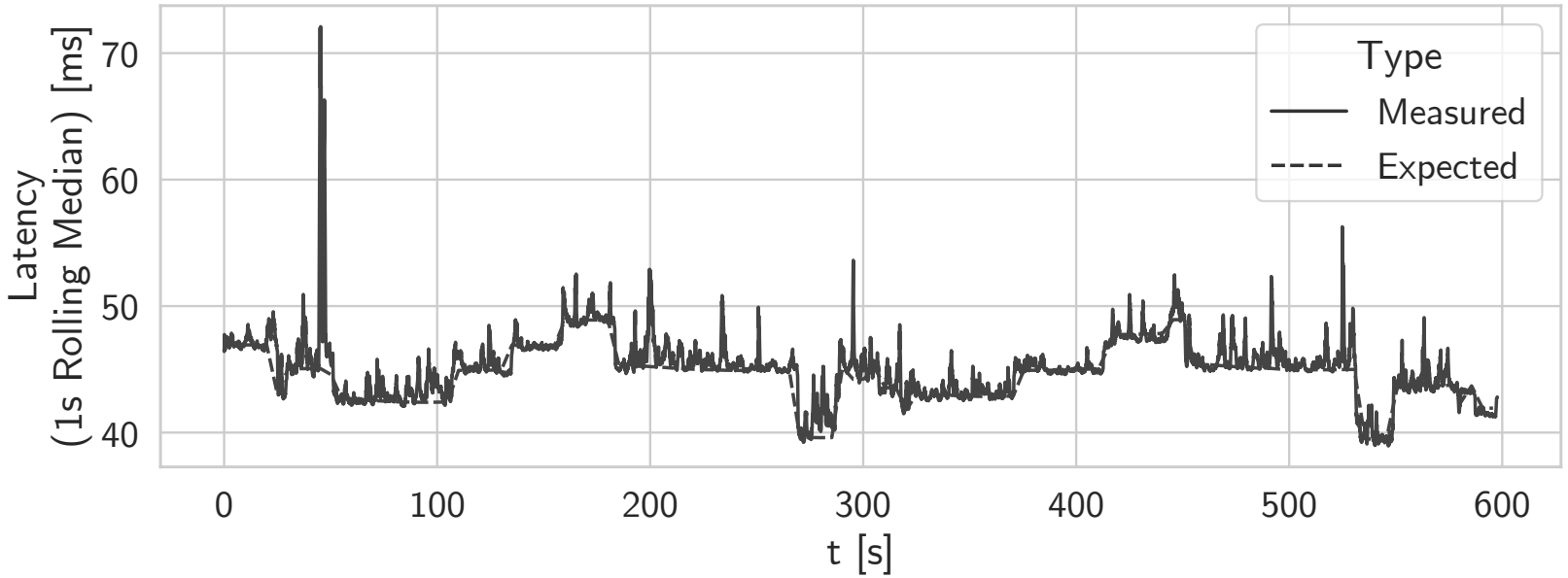


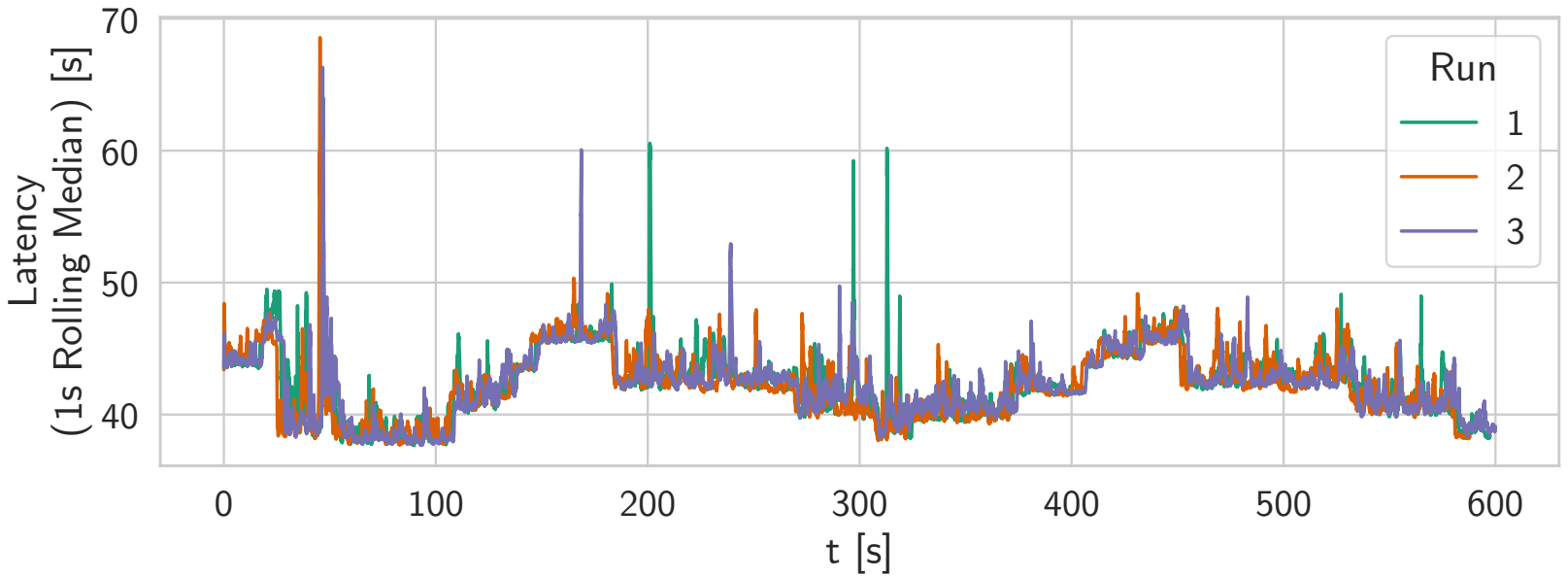
Stream Latency between Accra and Abuja

Case Study 1: Multi-User Interaction



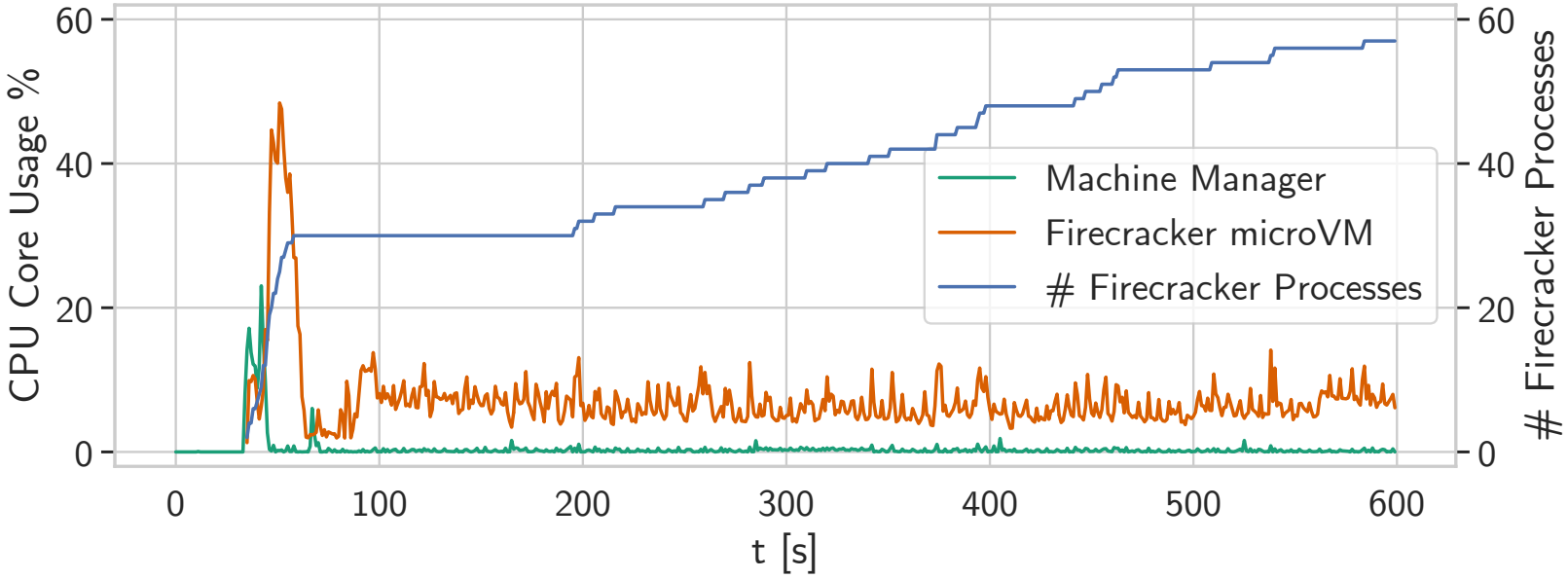
Measured and Expected Network Latency Between Two Users

Case Study 1: Multi-User Interaction



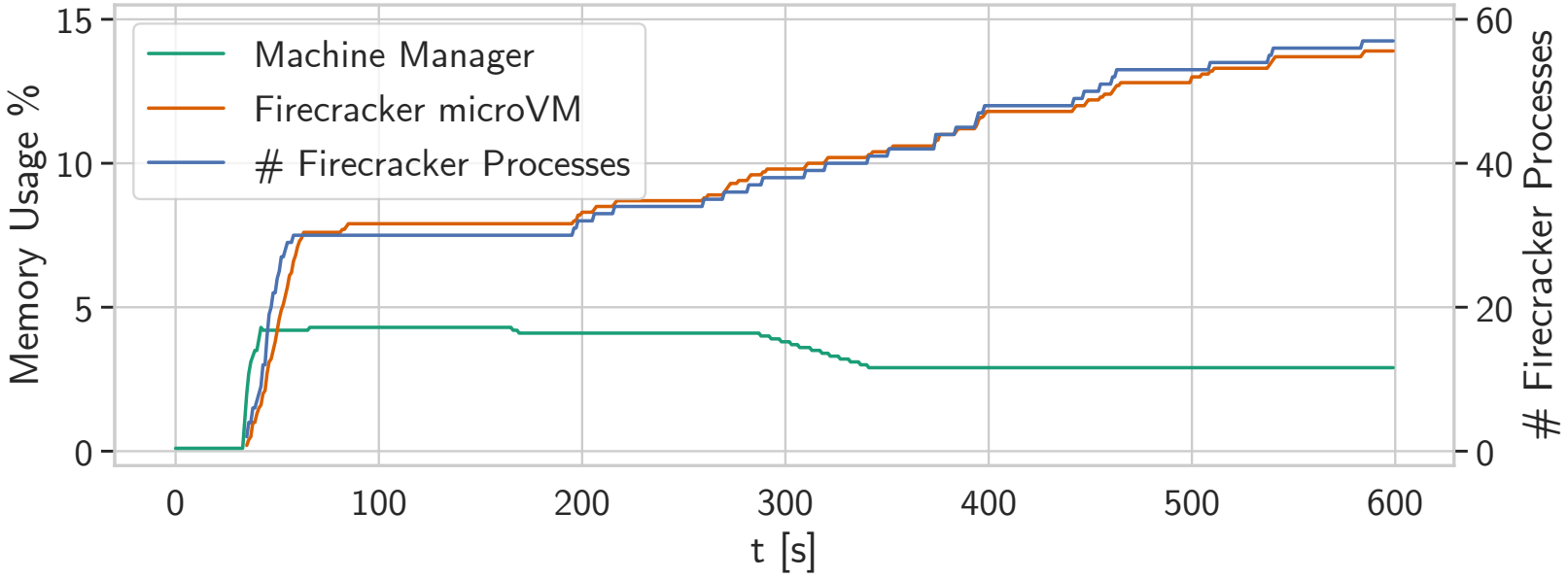
Reproducibility

Case Study 1: Multi-User Interaction



Host CPU Usage

Case Study 1: Multi-User Interaction

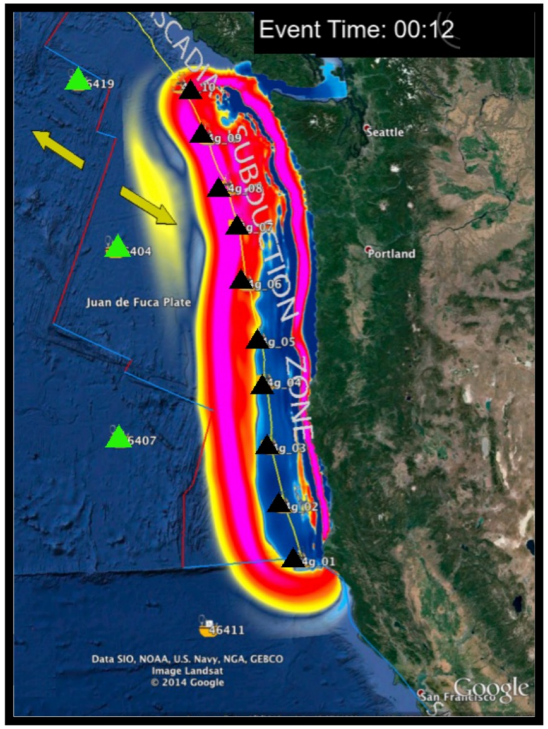


Host Memory Usage

Case Study 2: DART

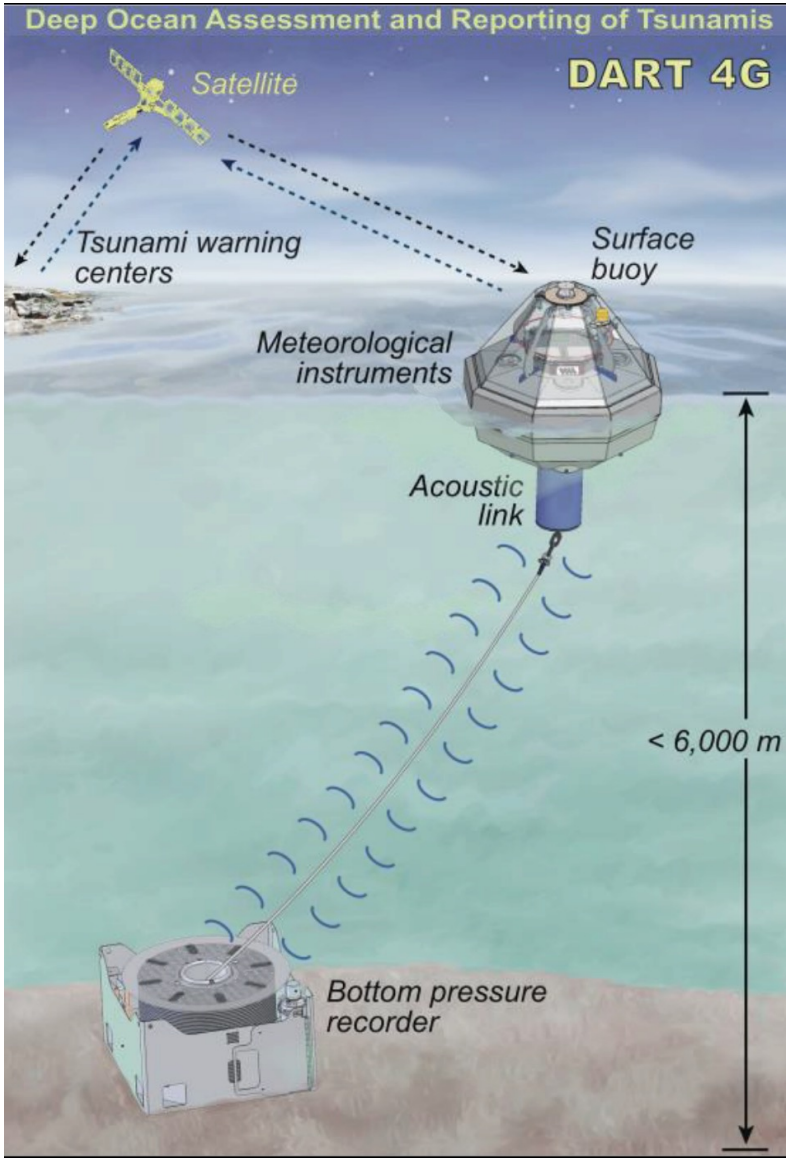
A Cascadia subduction rupture scenario with a 4G network (black triangles) envisioned close to the trench along the length of potential rupture. Time of tsunami detection by nearest 4G is expected to be on order of 10 minutes.

Three currently deployed DART II systems are identified by bright green triangles.



[12] NOAA Center for Tsunami Research, “DART 4G: Deep-ocean Assessment and Reporting of Tsunami - 4th Generation Tsunami Measurement System,” May. 2016.

Case Study 2: DART



[12] NOAA Center for Tsunami Research, “DART 4G: Deep-ocean Assessment and Reporting of Tsunami - 4th Generation Tsunami Measurement System,” May. 2016.

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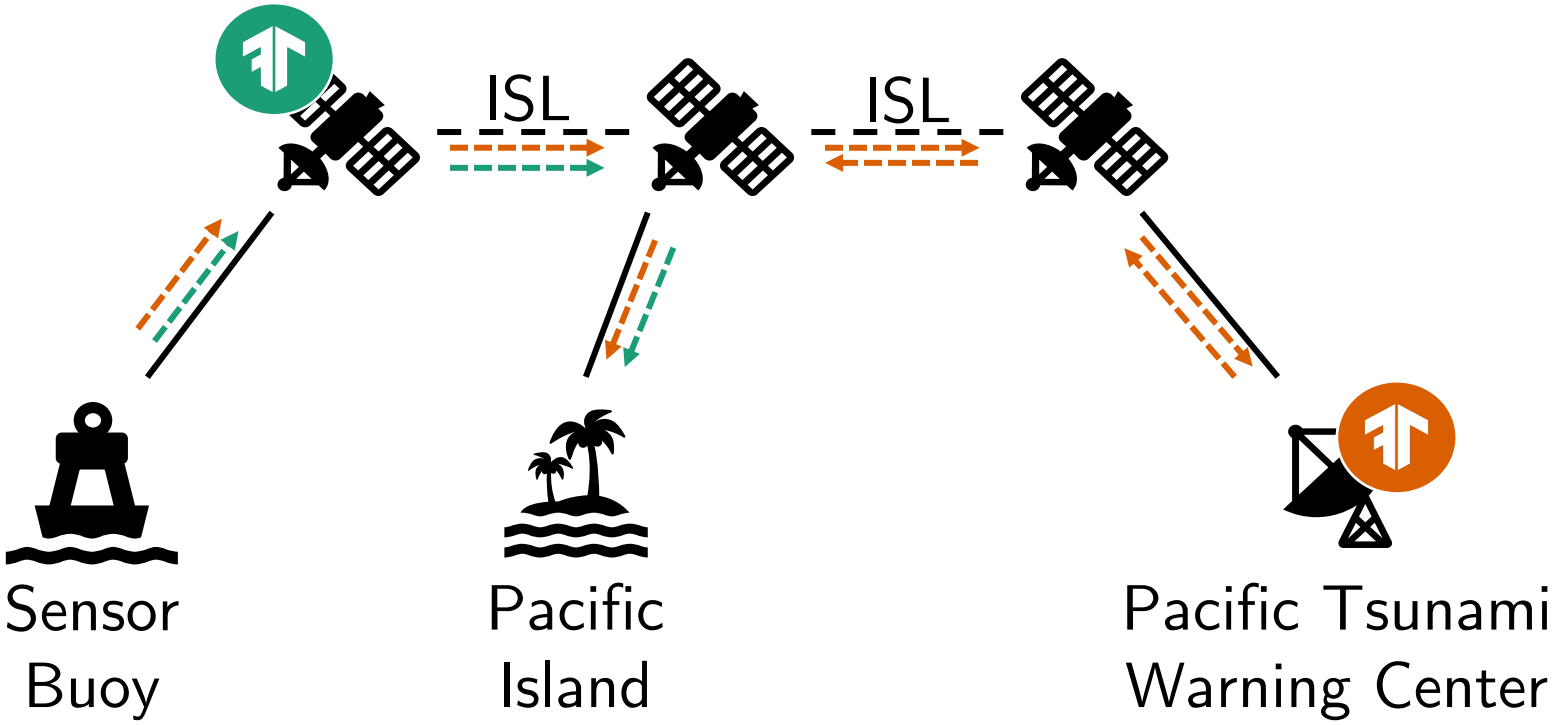

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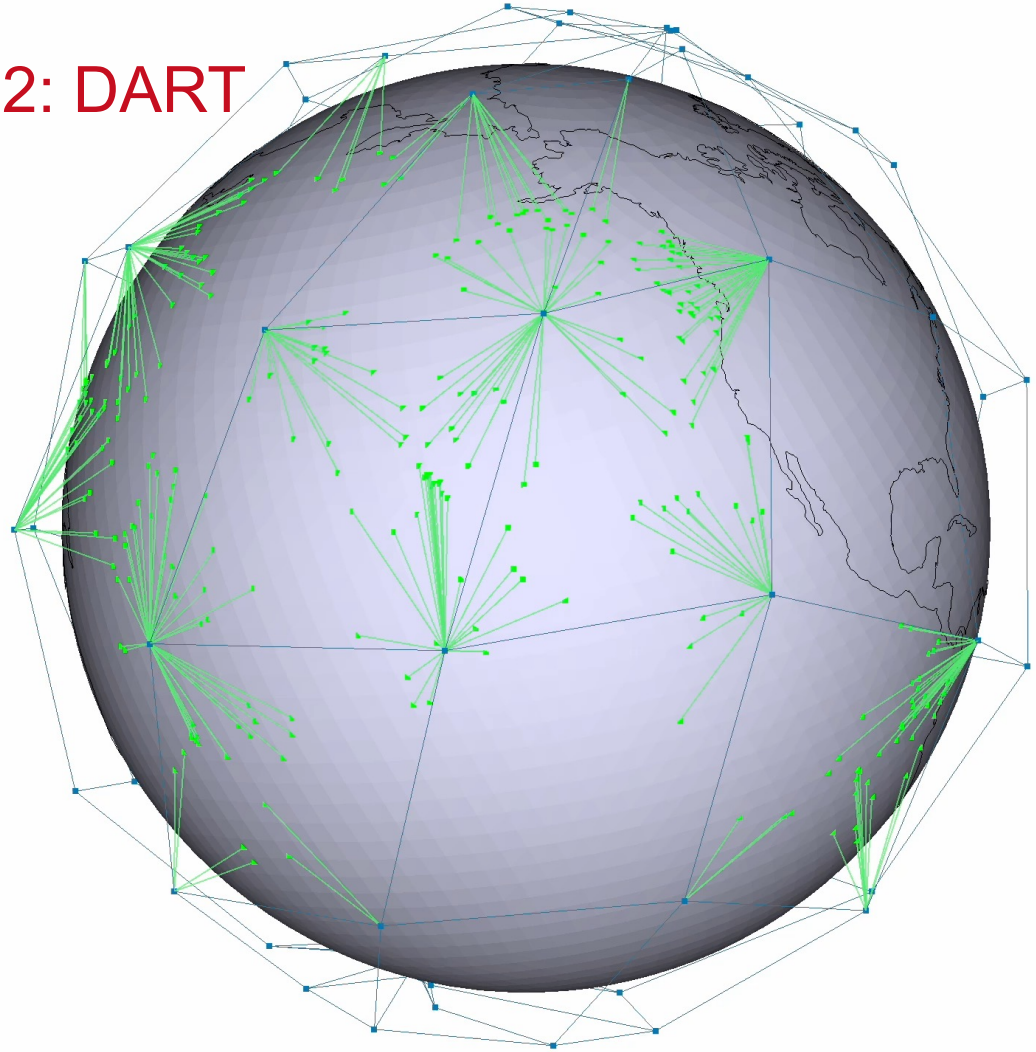

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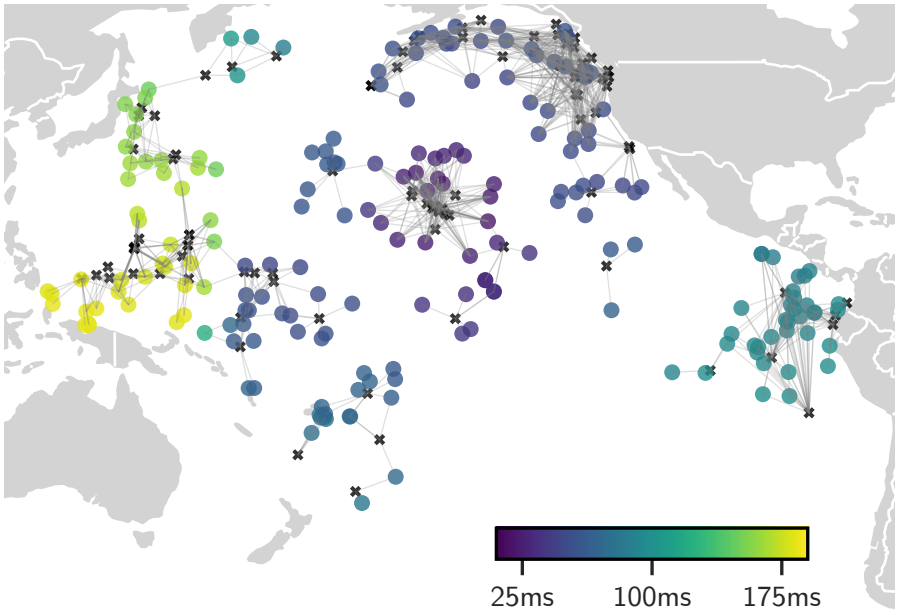
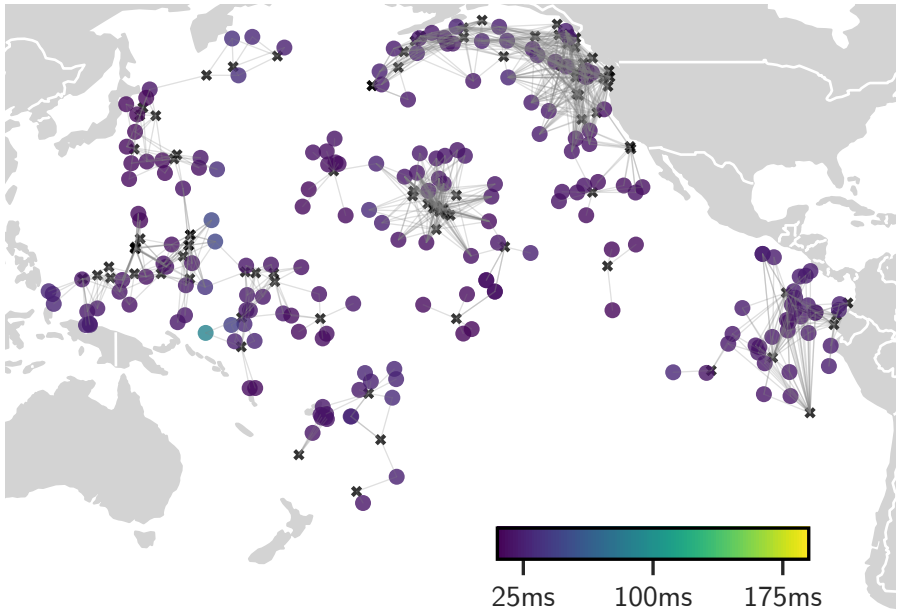


Central Server



Satellite Servers

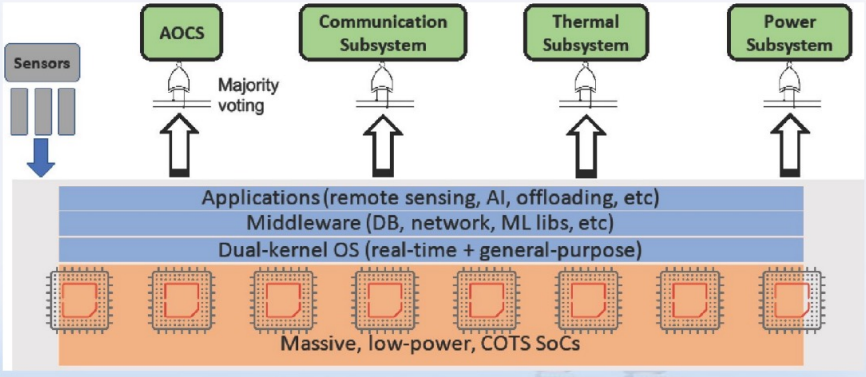
Sensor Reading Notification Latency

Computers in Space

Research plan

In-space Computing Server (2022 –)

- A satellite-borne server design with massive ARM SoCs
- High computing density, high reliability, and high energy efficiency



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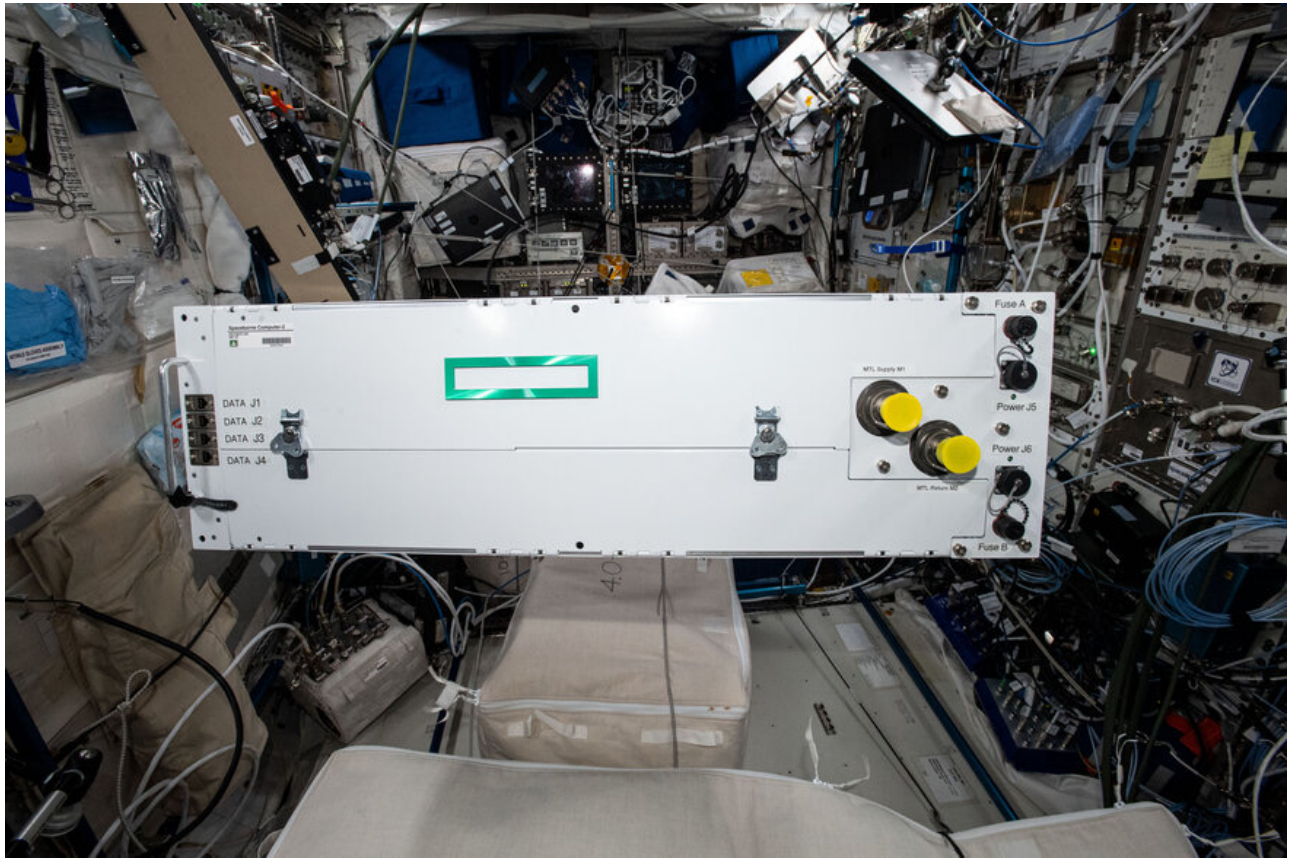
[7] S. Wang, "Tiansuan Constellation: An Open Research Platform for Satellite Network and Computing" in *LEOCONN 2022*, Oct. 2022.

Computers in Space



[11] Hewlett Packard Enterprise, “HPE Spaceborne Computer”, Online: https://www.hpe.com/us/en/compute/hpc/supercomputing/spaceborne.html

References (I)

[1] V. Bhosale, K. Bhardwaj, and A. Gavrilovska, “Toward loosely coupled orchestration for the LEO satellite edge,” in *Proceedings of the 3rd USENIX Workshop on Hot Topics in Edge Computing (HotEdge ‘20)*, Jun. 2020.

[2] D. Bhattacherjee, S. Kassing, M. Licciardello, and A. Singla, “In-orbit computing: An outlandish thought experiment?” in *Proceedings of the 19th ACM Workshop on Hot Topics in Networks (HotNets ’19)*, Nov. 2020, pp. 197–204.

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