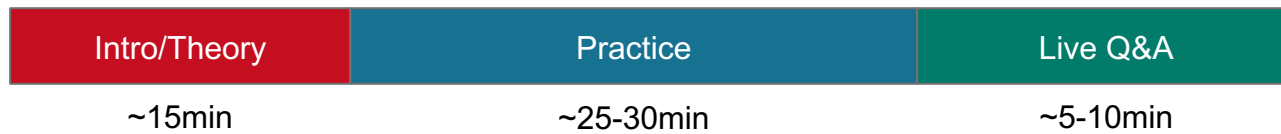




Testing LEO Edge Software Systems in Virtual Testbeds

Tobias Pfandzelter | Mobile Cloud Computing | LEOCONN 2022 @ MobiCom 2022

Outline



LEO Satellites

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/>

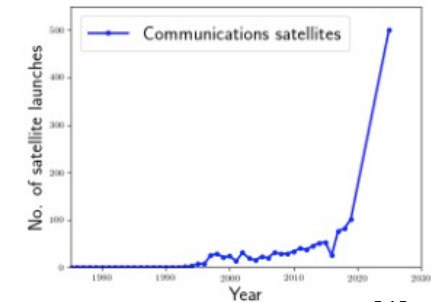
Arianespace Soyuz rocket launches 34 OneWeb internet satellites into space

By Mike Wall published August 22, 2021

Arianespace has now lofted a total of 288 OneWeb satellites.



<https://www.space.com/arianespace-soyuz-launches-oneweb-9-internet-satellite-mission>



[1]

INVESTING IN SPACE

About 150,000 people in Ukraine are using SpaceX's Starlink internet service daily, government official says

PUBLISHED MON, MAY 2 2022-12:03 PM EDT | UPDATED MON, MAY 2 2022-1:25 PM EDT

<https://www.cnn.com/2022/05/02/ukraine-official-150000-using-spacexs-starlink-daily.html>

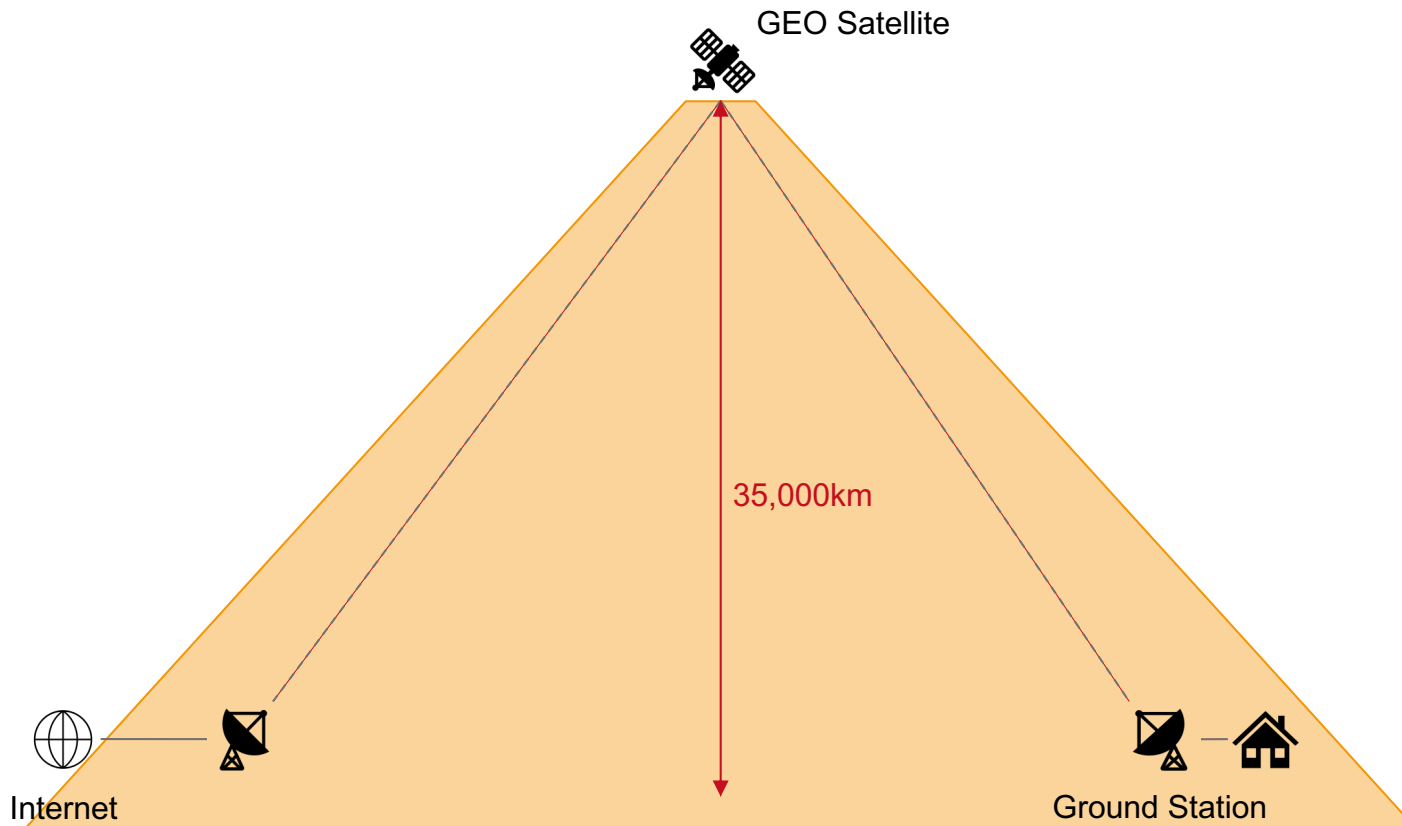
SpaceX deploys more Starlink satellites, aims for higher launch cadence

© April 21, 2022 Stephen Clark

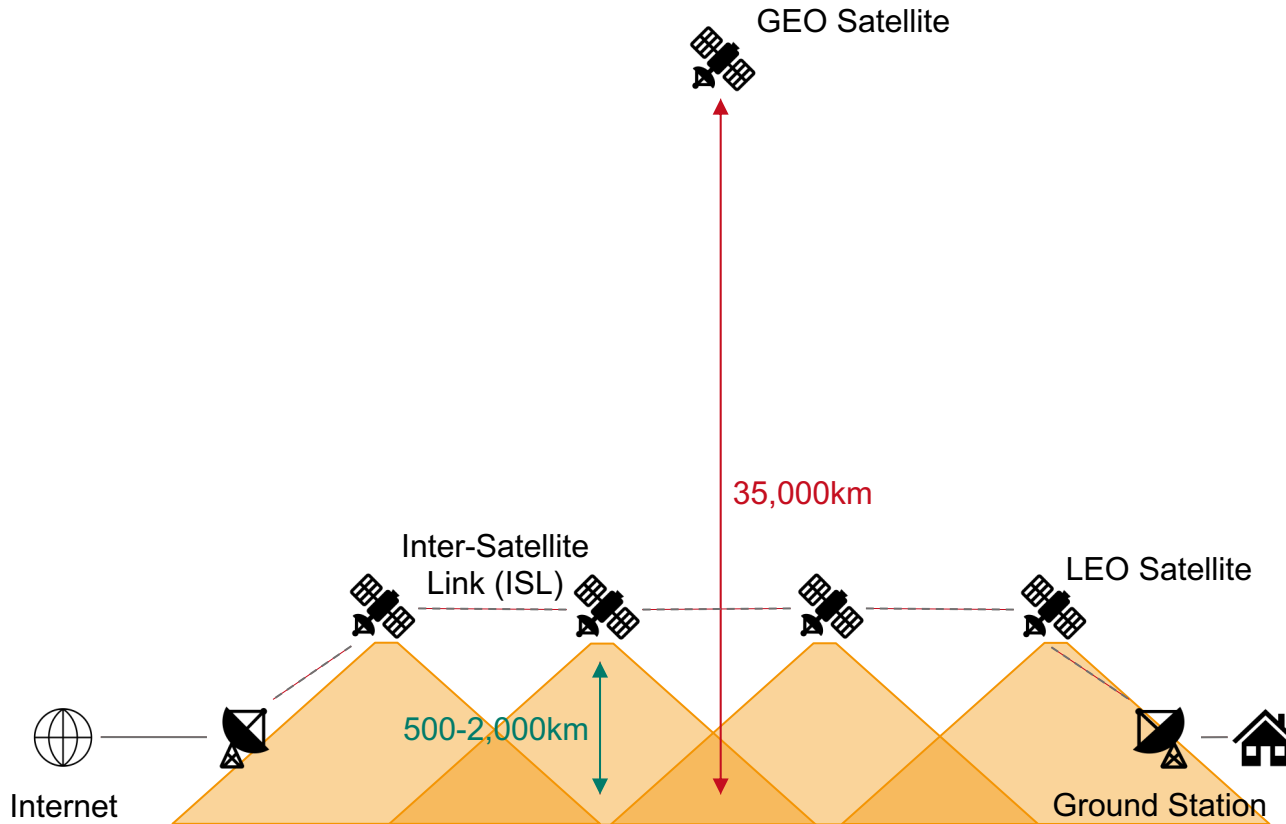
<https://spaceflightnow.com/2022/04/21/spacex-deploys-more-starlink-satellites-aims-for-higher-launch-cadence/>



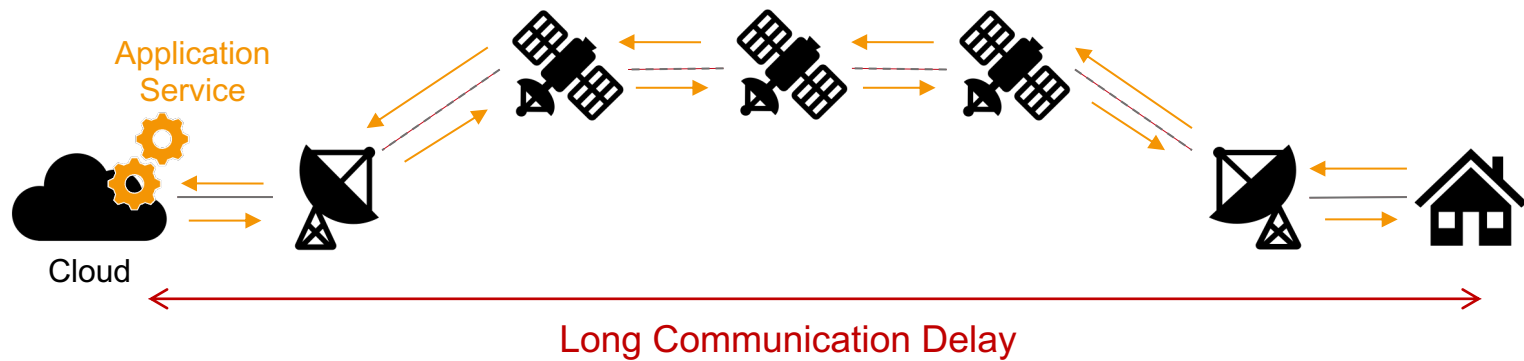
LEO Satellites



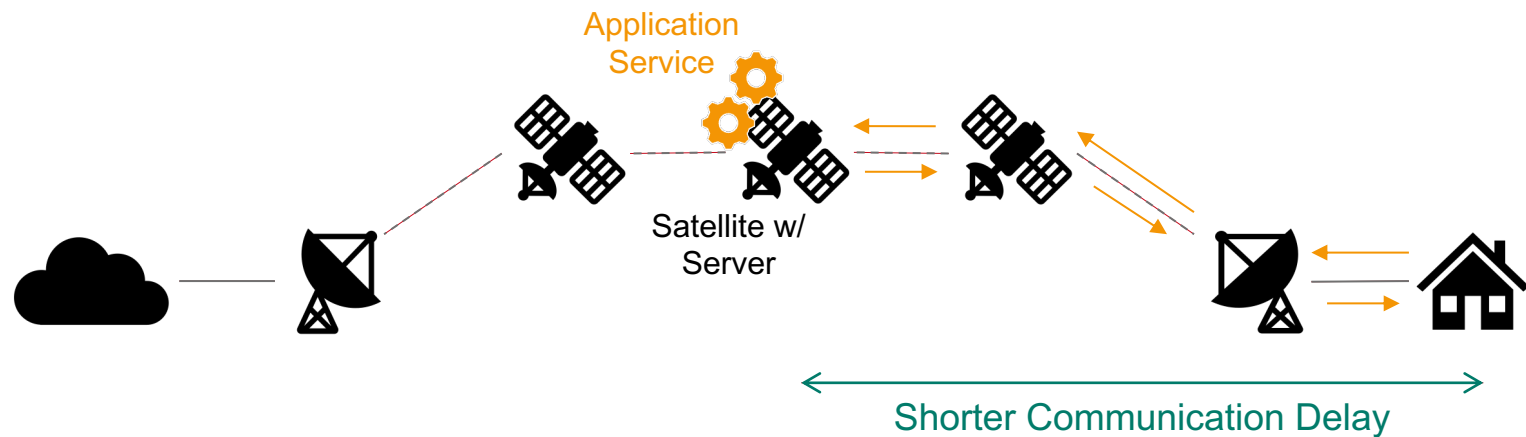
LEO Satellites



LEO Satellite Edge Computing



LEO Satellite Edge Computing



[2] D. Bhattacharjee, 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 2019)*, Nov. 2020, pp. 197–204.

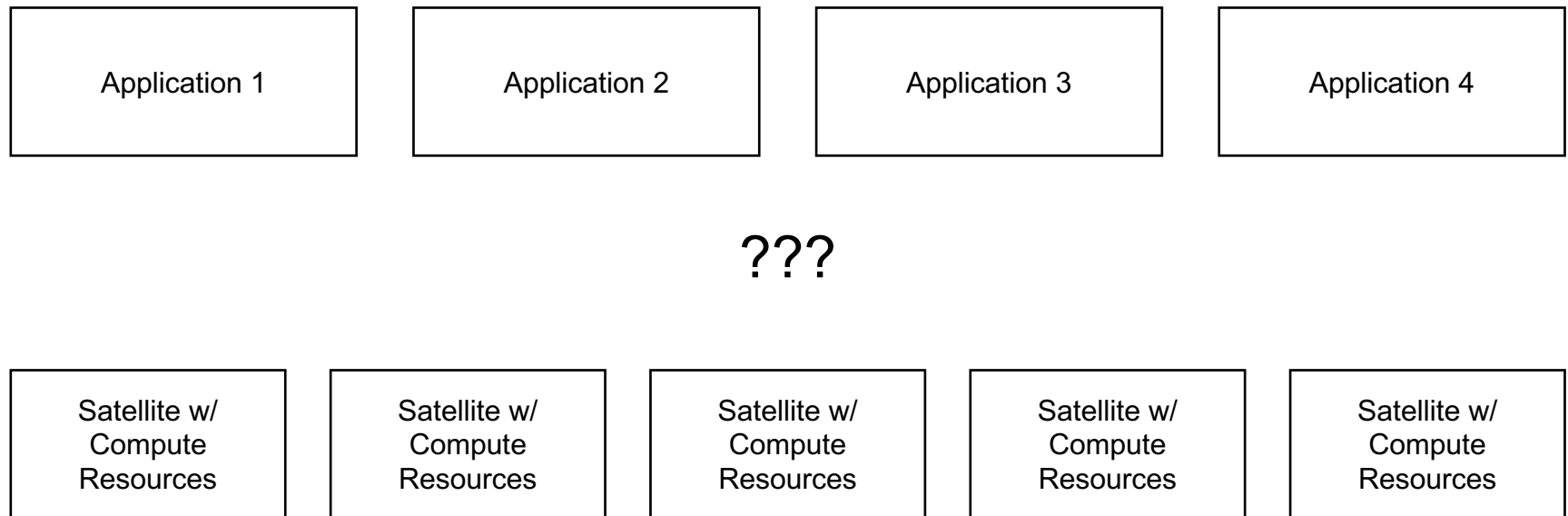
Easy Enough?

Consider...

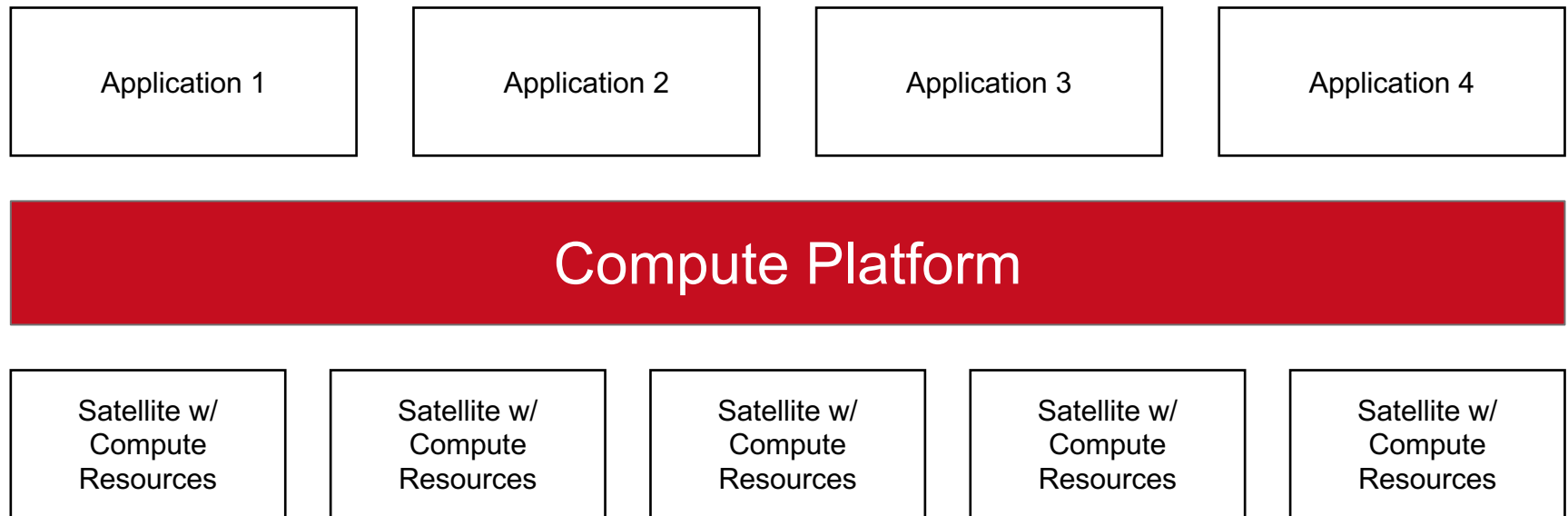
- Mobility
- Coverage
- Resource Constraints
- Fault Tolerance
- Multi-Tenancy
- Scalability

[3] T. Pfandzelter, J. Hasenburg, and D. Bermbach, “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.

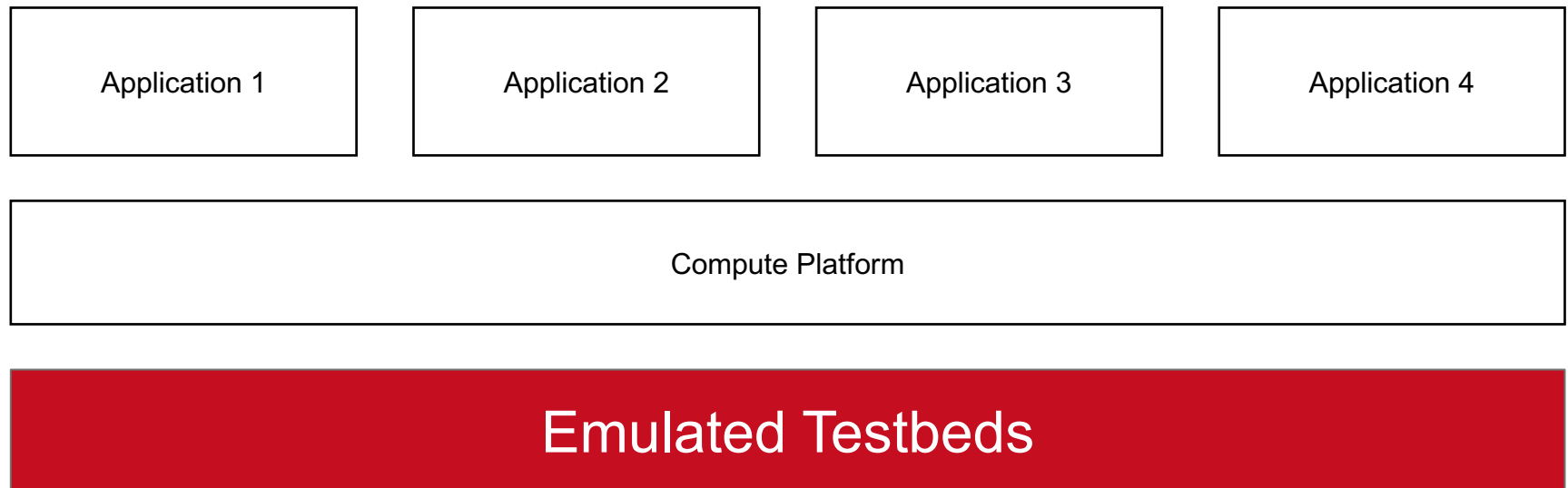
Easy Enough?



Platforms to the Rescue!



Platforms to the Rescue!



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

[4] T. Pfandzelter, and D. Bermbach, “Celestial: Virtual Software System Testbeds for the LEO Edge” in *Proceedings of the 23rd ACM/IFIP International Middleware Conference (Middleware ‘22)*, Nov. 2022.

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

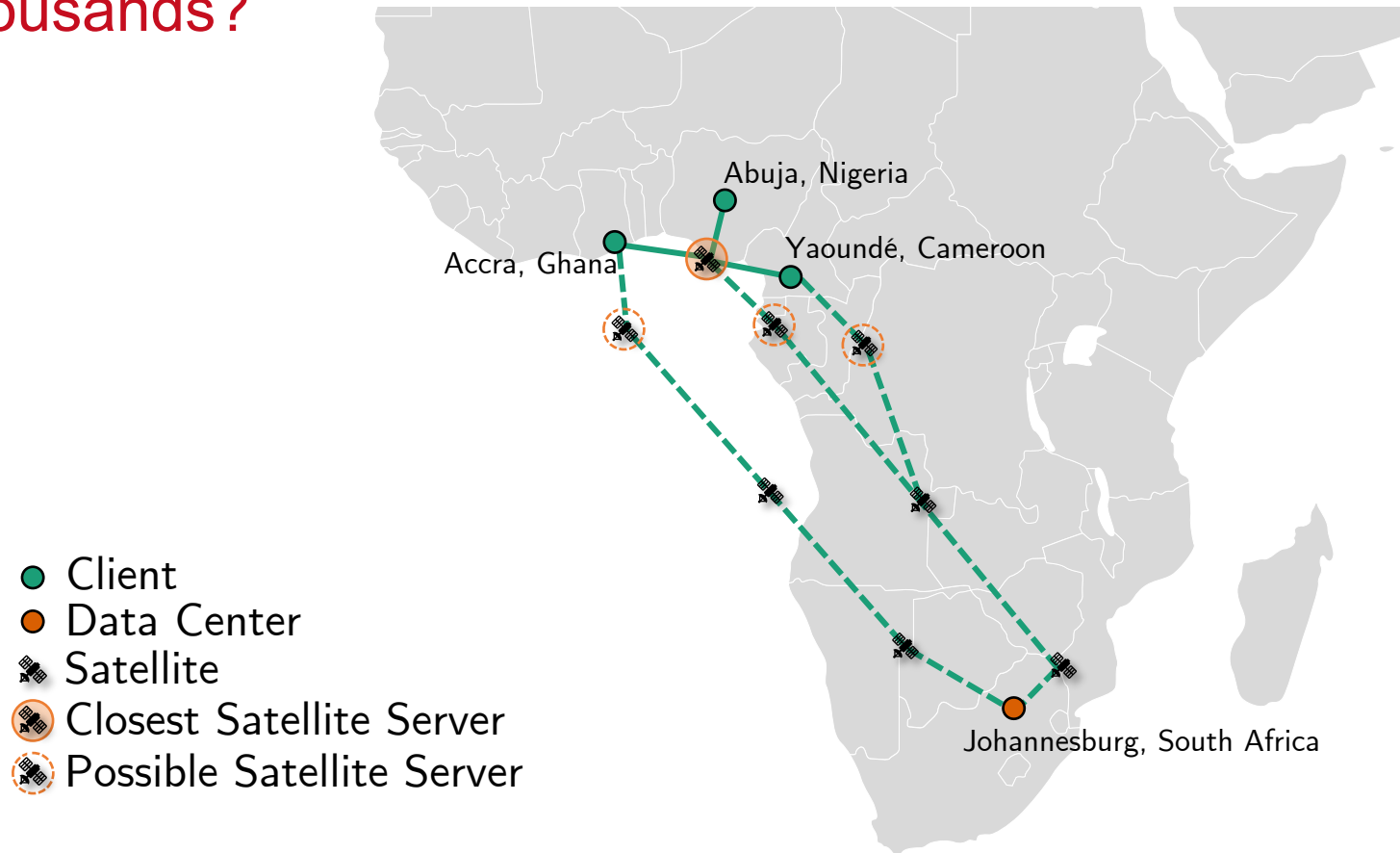
	VMs		Containers
Cost	High		Low
Isolation	High		Low
Software Support	High		Medium
Overhead	High		Low

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

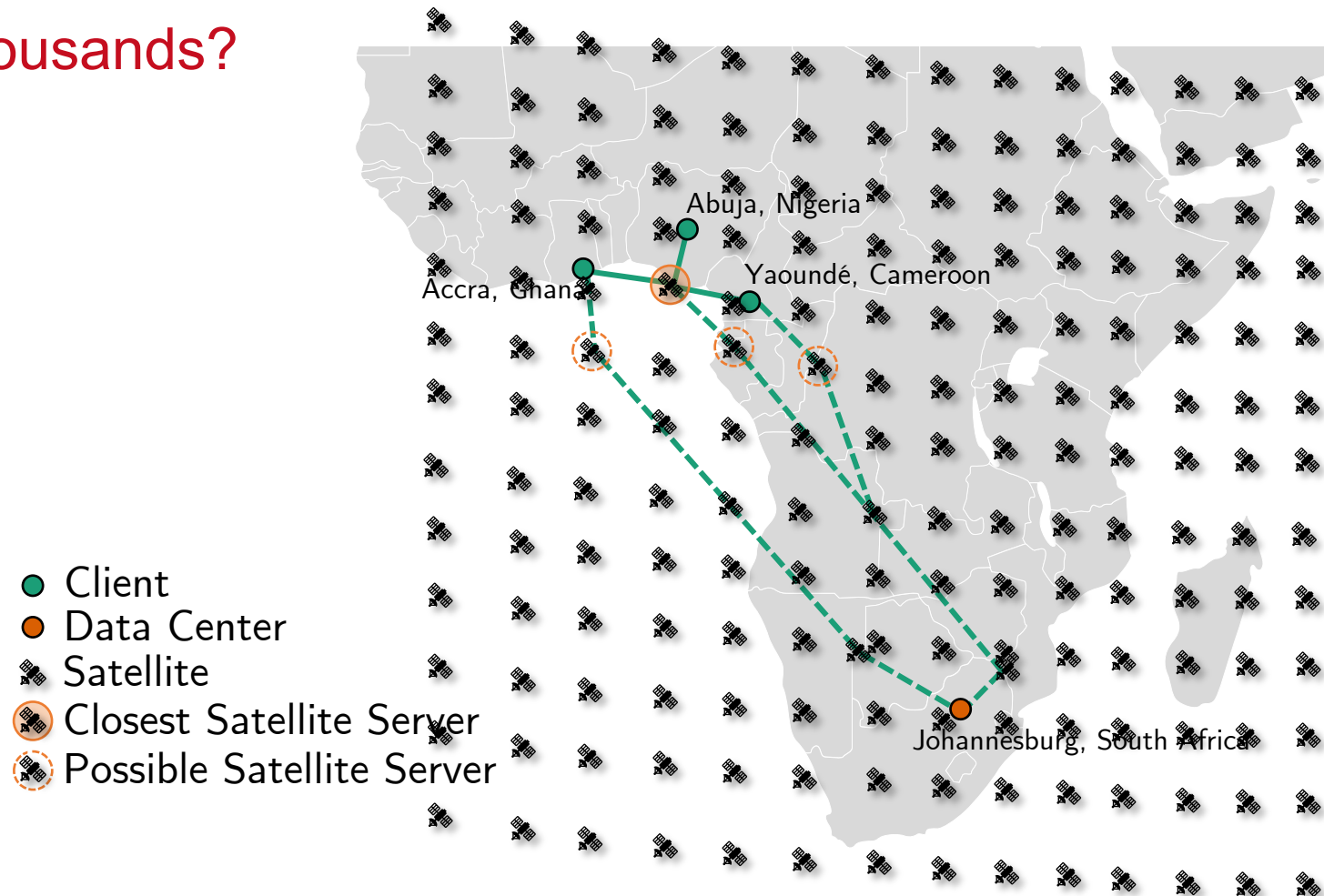
[5] A. Agache, M. Brooker, A. Iordache, A. Liguori, R. Neugebauer, P. Piwonka, and D.-M. Popa, “Firecracker: Lightweight Virtualization for Serverless Applications” in *Proceedings of the 17th USENIX Symposium on Networked Systems Design and Implementation (NSDI ’20)*, Feb. 2022, pp. 419–434.

Thousands?

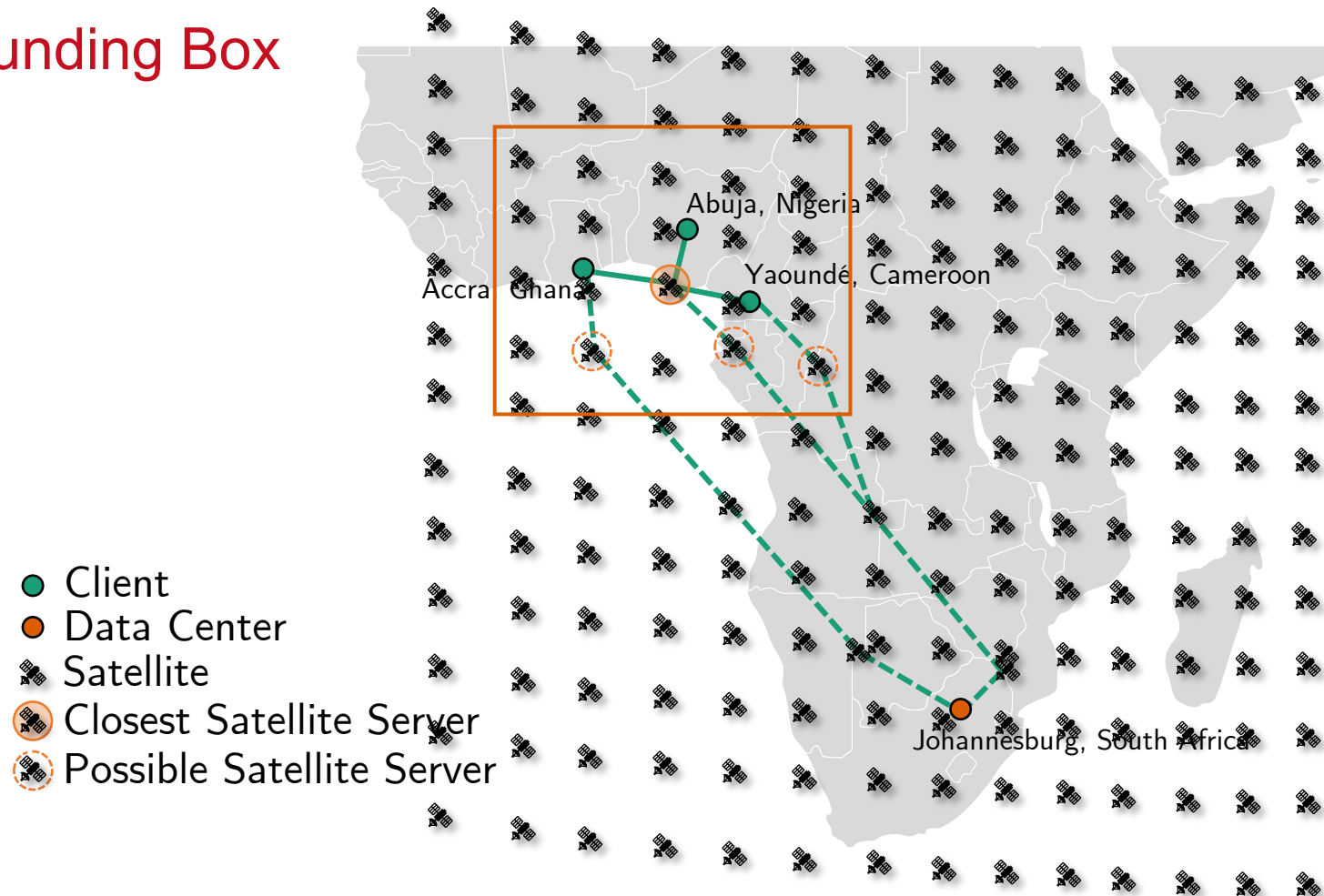


[2] D. Bhattacharjee, S. Kassing, M. Licciardello, and A. Singla, “In-orbit computing: An outlandish thought experiment?” in *Proceedings of the 19th ACM Workshop on Hot Topics in Networks (HotNets 2019)*, Nov. 2020, pp. 197–204.

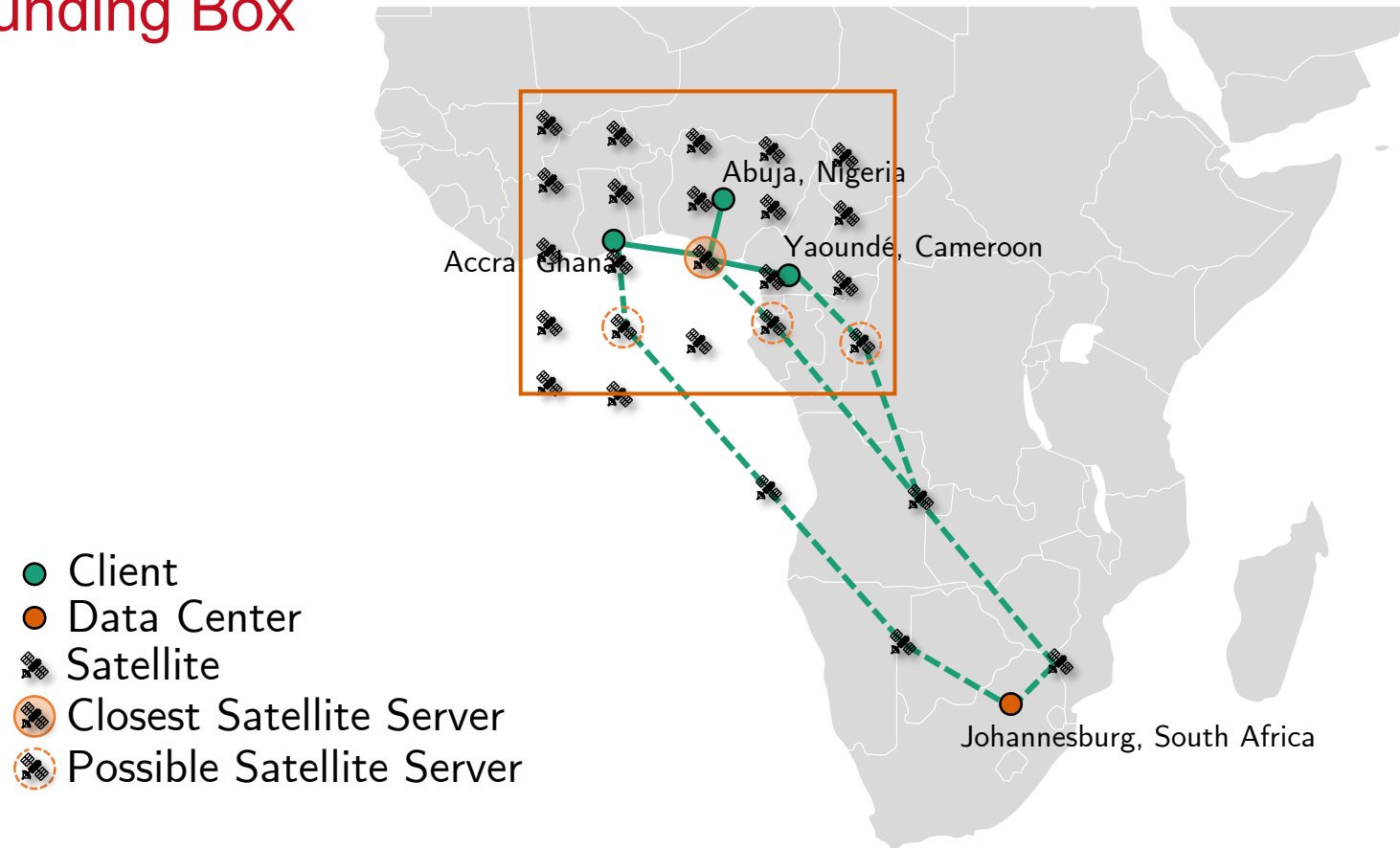
Thousands?



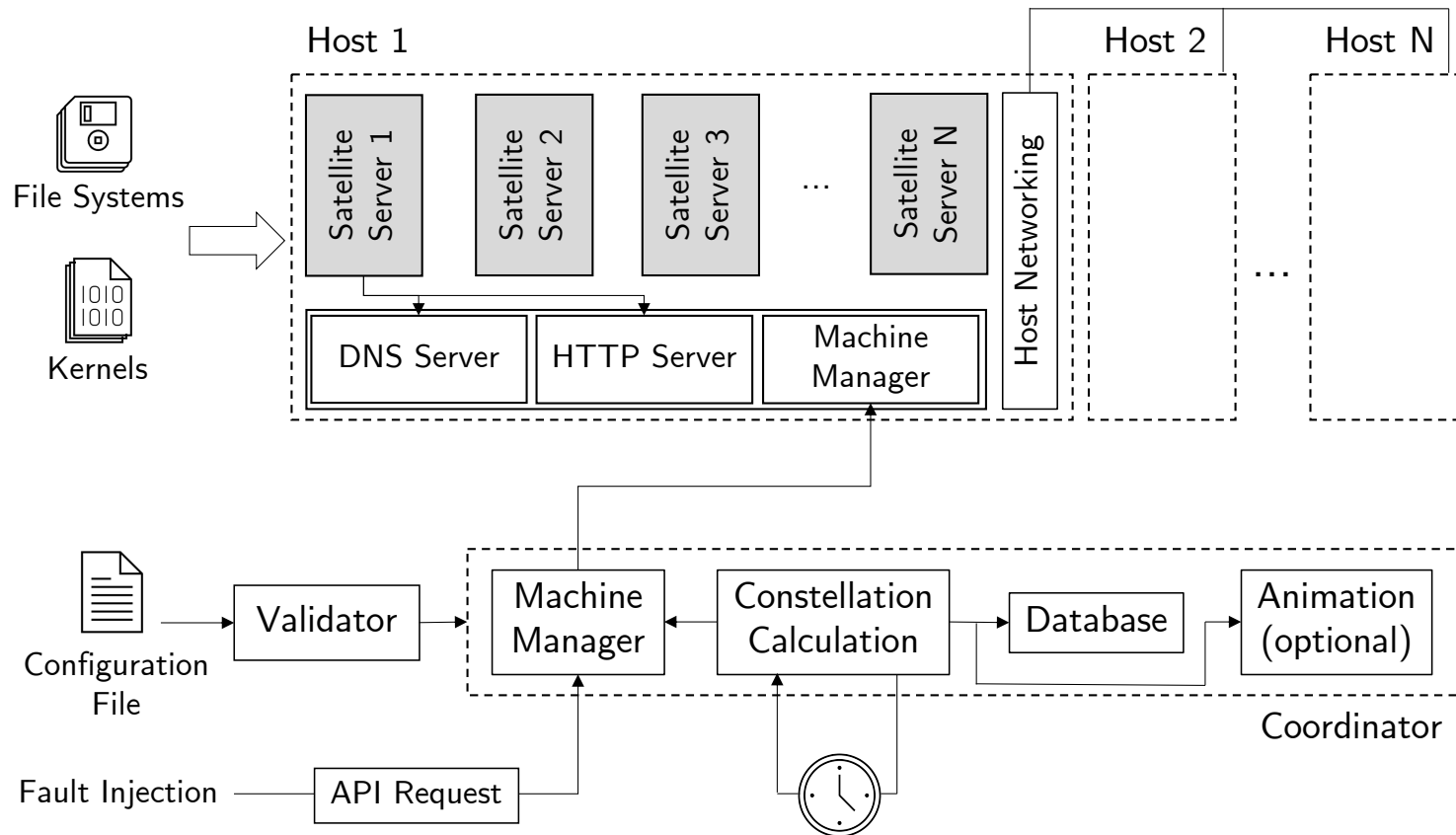
Bounding Box



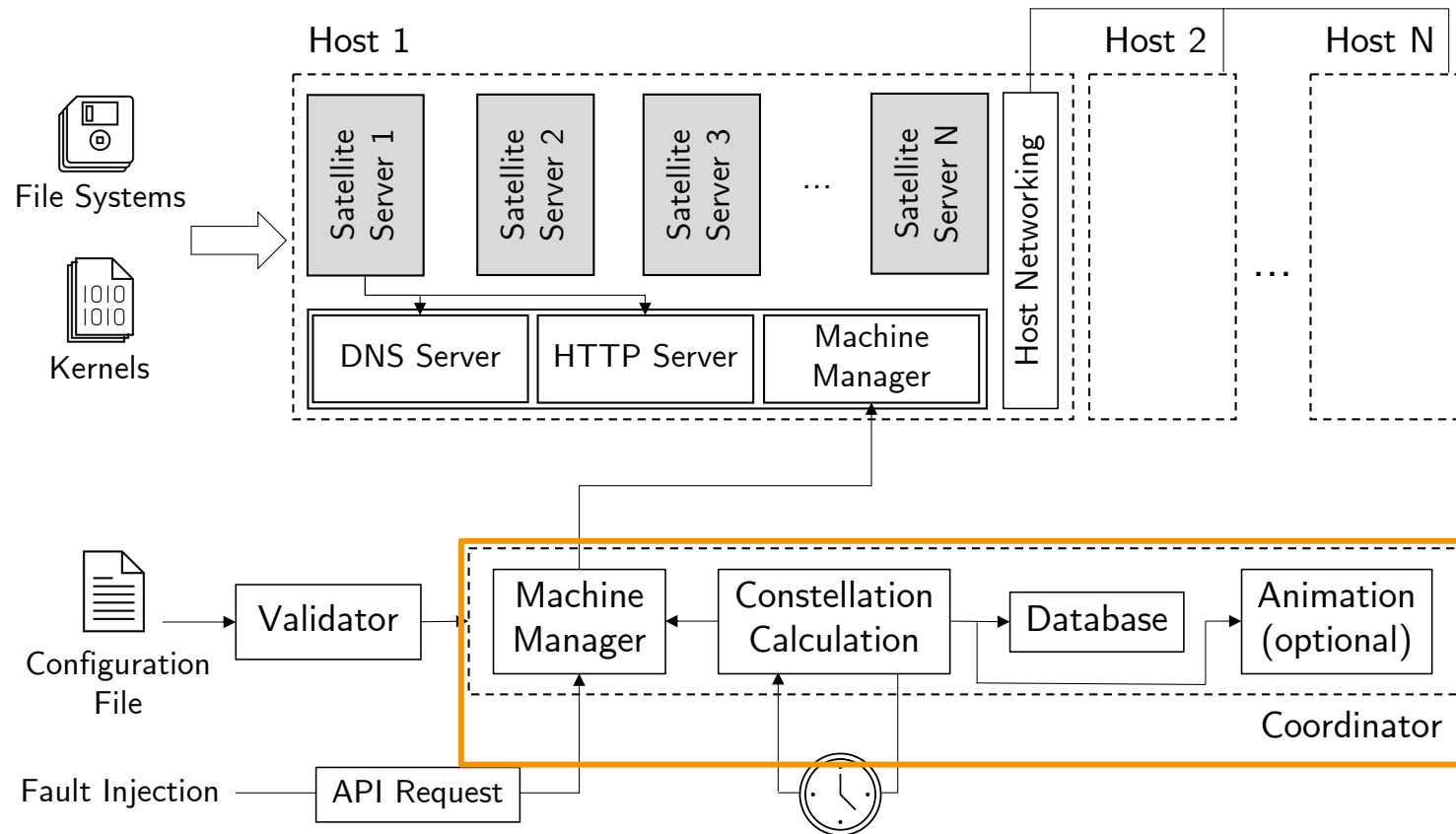
Bounding Box



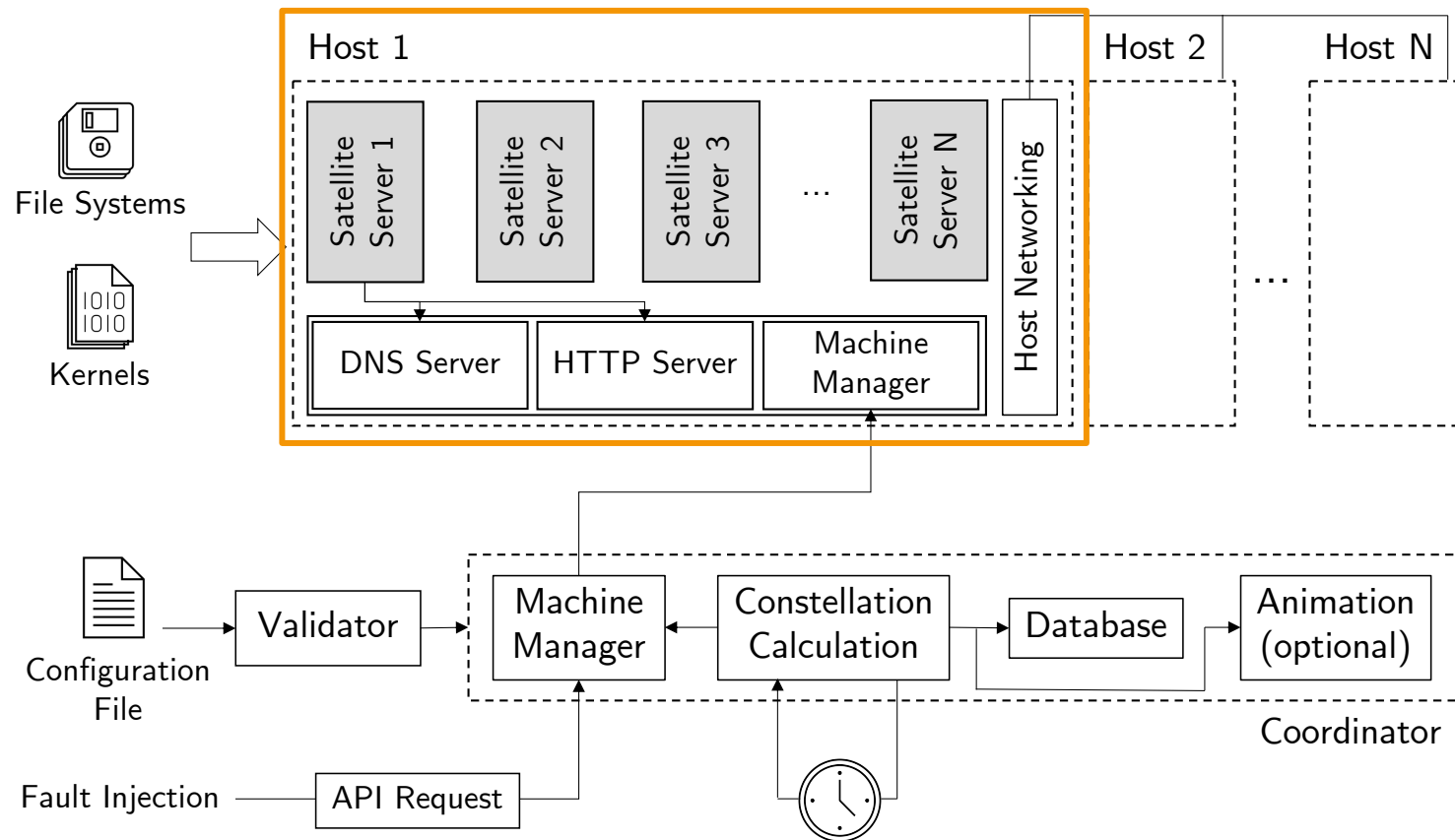
Celestial: Overview



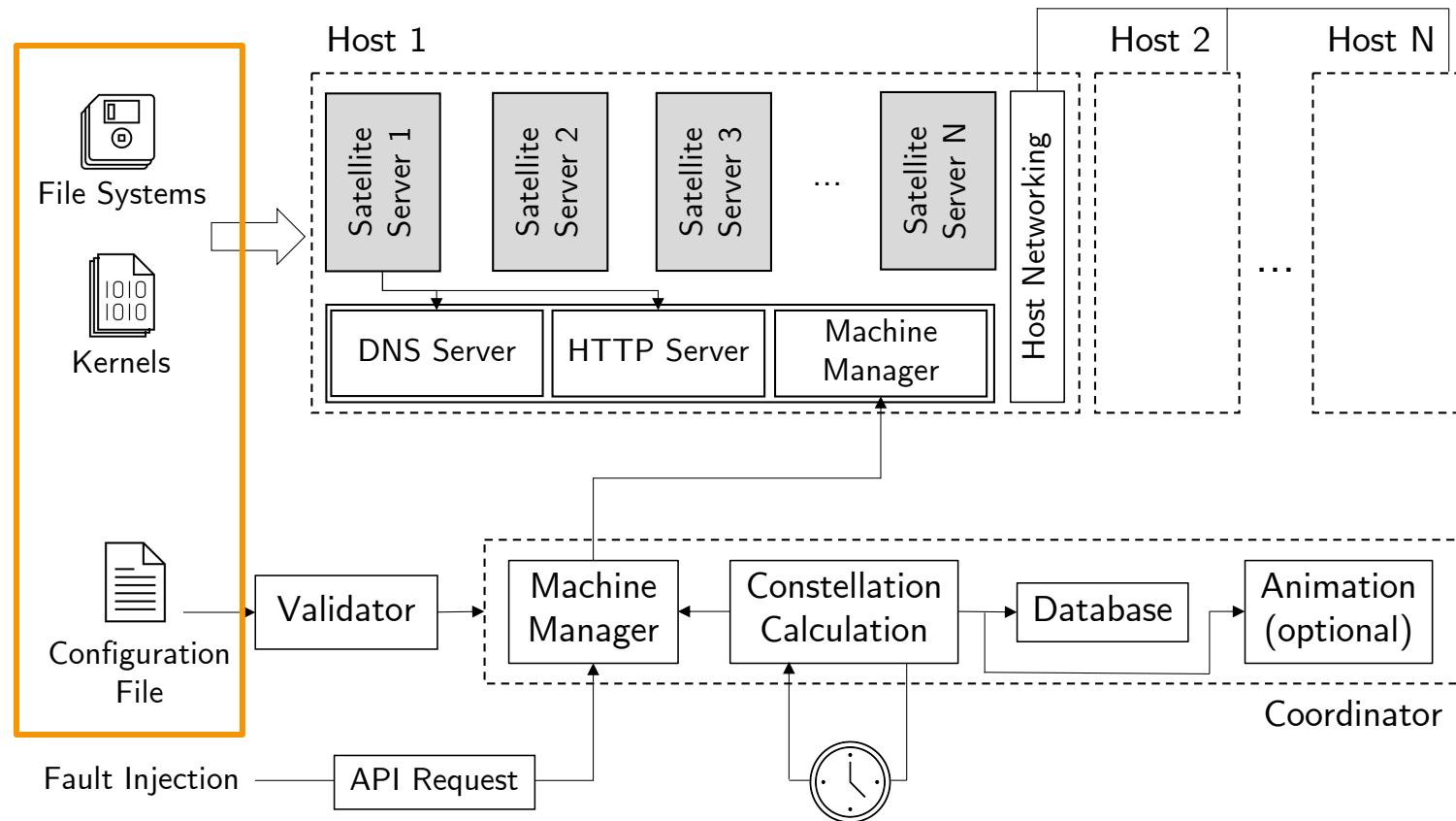
Celestial: Overview



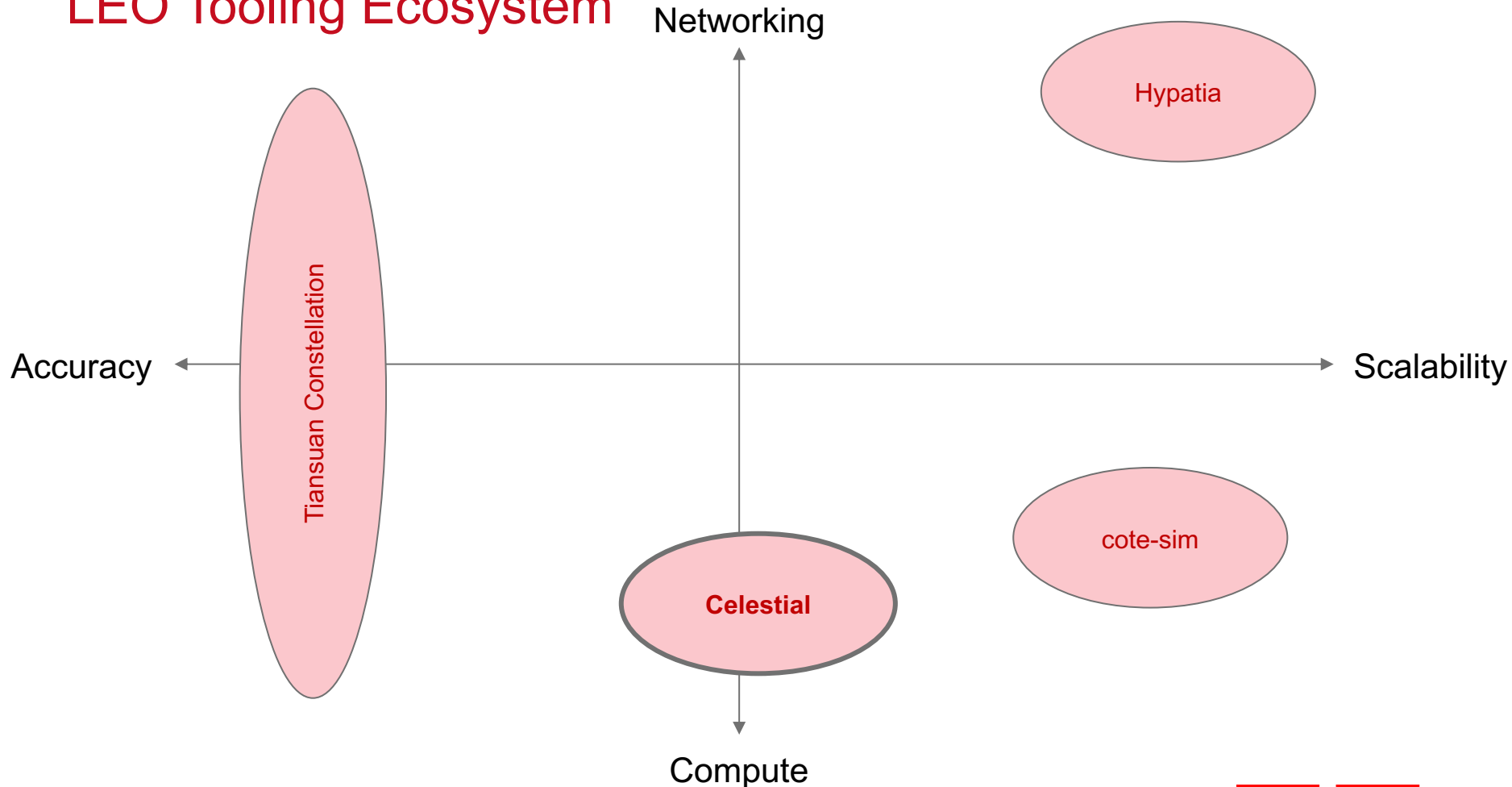
Celestial: Overview



Celestial: Overview



LEO Tooling Ecosystem



Further Information

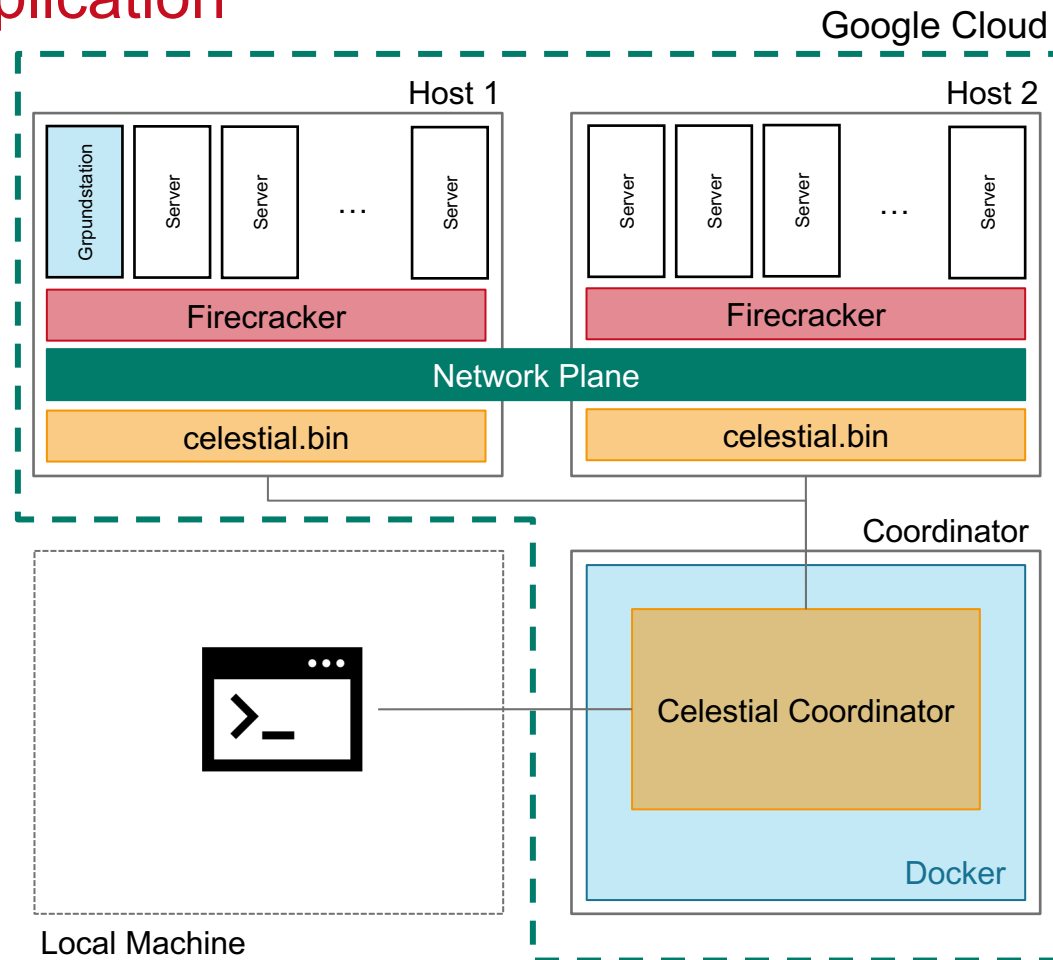
- T. Pfandzelter, and D. Bermbach, “Celestial: Virtual Software System Testbeds for the LEO Edge” in Proceedings of the 23rd ACM/IFIP International Middleware Conference (Middleware ‘22) , Nov. 2022. **arXiv:2204.06282**
- Code: <https://github.com/OpenFogStack/celestial>
- Docs: <https://openfogstack.github.io/celestial/>
- Tutorial: now! (and on YouTube later)

Example Application

- Ground station running in Berlin, “pinging” satellites
- 72x22 satellite constellation, 550km altitude, 53.0° inclination, +*GRID* topology



Example Application



Questions?



References

- [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. Bhattacharjee, 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.
- [3] T. Pfandzelter, J. Hasenburg, and D. Bermbach, “Towards a Computing Platform for the LEO Edge” in *Proceedings of the 4th International Workshop on Edge Systems, Analytics and Networking (EdgeSys '21)*, Apr. 2021, pp. 43–48.
- [4] T. Pfandzelter, and D. Bermbach, “Celestial: Virtual Software System Testbeds for the LEO Edge” in *Proceedings of the 23rd ACM/IFIP International Middleware Conference (Middleware '22)*, Nov. 2022.
- [5] A. Agache, M. Brooker, A. Iordache, A. Liguori, R. Neugebauer, P. Piwonka, and D.-M. Popa, “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.