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Developing a simulation framework and efficient data transport for LEO satellite constellations*

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*supported by GÉANT Innovation programme

Introduction

- *Internet from space* is becoming a viable reality
- SpaceX, Amazon, Telesat are/will be deploying low earth orbit (LEO) satellite constellations
  - … competing with/complementing terrestrial networks
- 1000s of satellites in multiple orbital shells and planes per shell
- Inter-satellite and ground station to satellite links

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LEO Satellite Deployments

	shell	*h (km)*	*Orbits*	*Sats/orbit*	*i*
Starlink	S1	550	72	22	53°
	S2	1,110	32	50	53.8°
	S3	1,130	8	50	74°
	S4	1,275	5	75	81°
	S5	1,325	6	75	70°
Kuiper	K1	630	34	34	51.9°
	K2	610	36	36	42°
	K3	590	28	28	33°
Telesat	T1	1,015	27	13	98.98°
	T2	1,325	40	33	50.88°

from S. Kassing, et al., Exploring the "Internet from space" with Hypatia, in Proc of IMC '20

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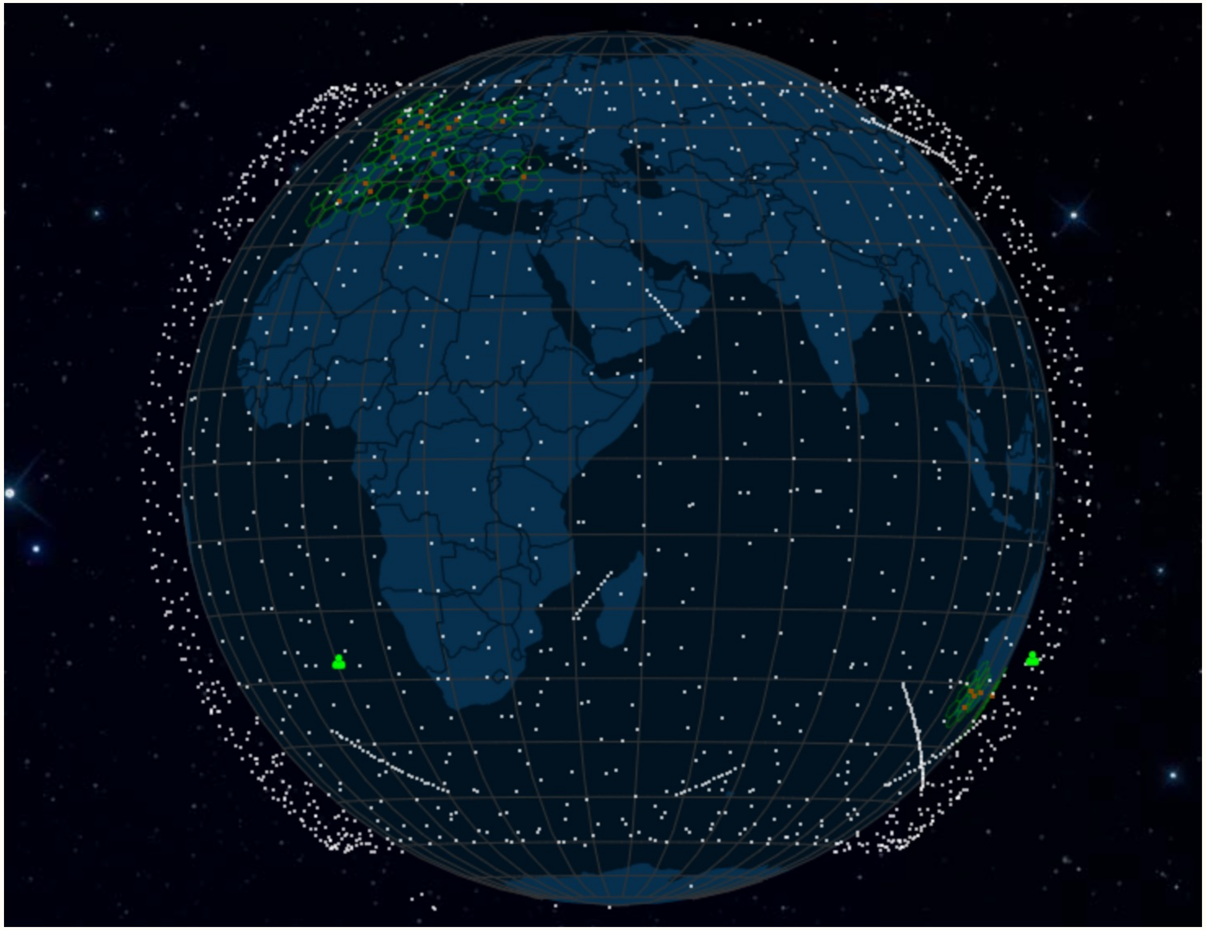
Starlink Deployment

https://satellitemap.space



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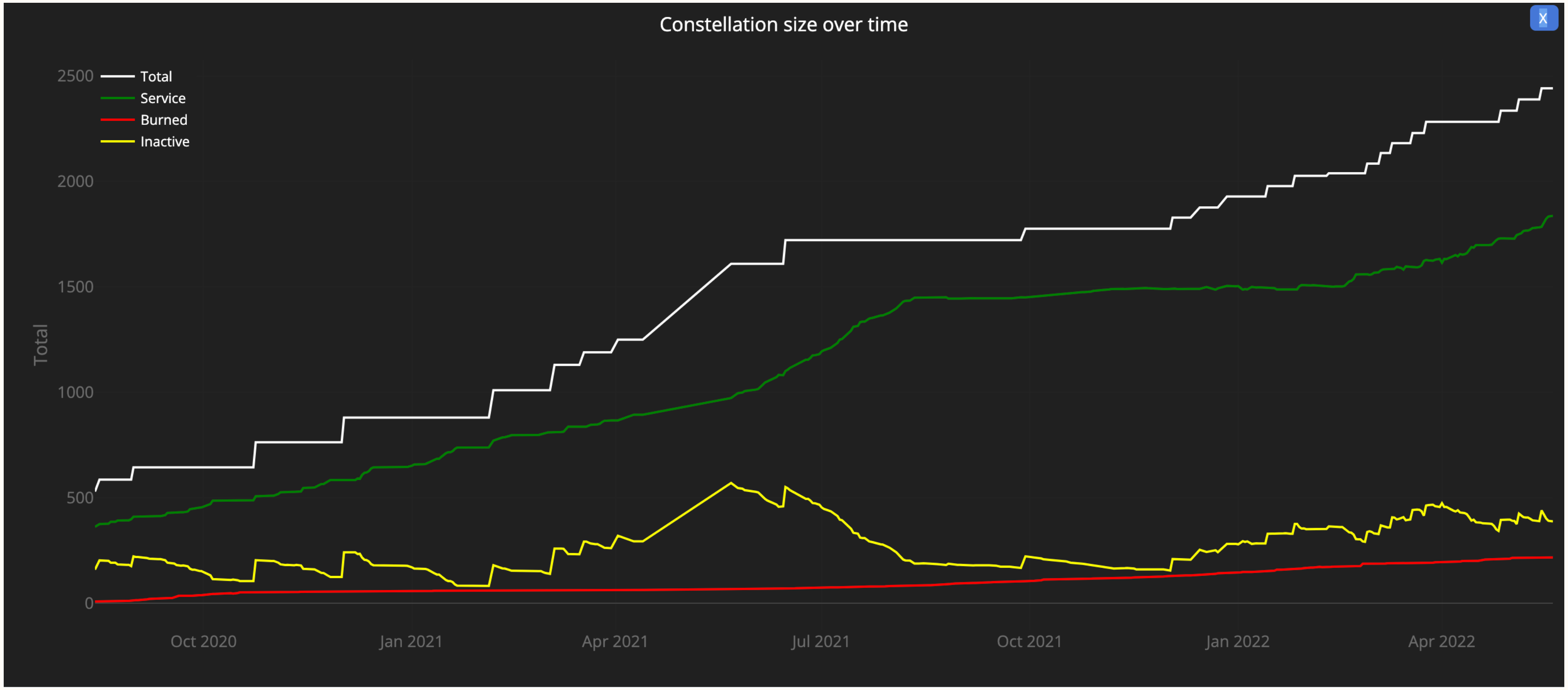
Starlink Deployment



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LEO Satellite Network Characteristics

- Aggregate bandwidth in the order of hundreds of Tbps
  - comparable to today's aggregate fibre capacity
- Path multiplicity
- Sub-10ms round-trip time between Earth and first-hop satellite
- Low end-to-end latency - can be smaller than best theoretical fibre path can support

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Network Dynamics

- Large mesh-networks - deterministic mobility
- One orbit per ~100 minutes
- GS-satellite links change
- Shortest paths (latency-wise) change constantly even when core is ISL only

Network Dynamics

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Challenges in Data Transport

- Non-congestive latency variation
- Multiple paths that change over time – packet reordering
- Hotspots (shortest-path routing on mesh networks)
- Fluctuating bandwidth

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Simulation Framework

A. Valentine and G. Parisis, Developing and experimenting with LEO satellite constellations in OMNeT++, In Proc. of the 8th OMNeT++ Community Summit Conference, 2021

- OMNeT++/INET – widely used packet-level simulator
- Open Source Satellite Simulator - OS^3 – accurate satellite mobility
- Models for satellite network nodes, ISL connectivity
- Routing
  - extended the IP layer model to use IP addresses as satellite identifiers
  - shortest-path calculation using Dijkstra's algorithm
- 2D and 3D visualisations (using OpenSceneGraph and osgEarth)

source code: https://github.com/Avian688/leosatellites

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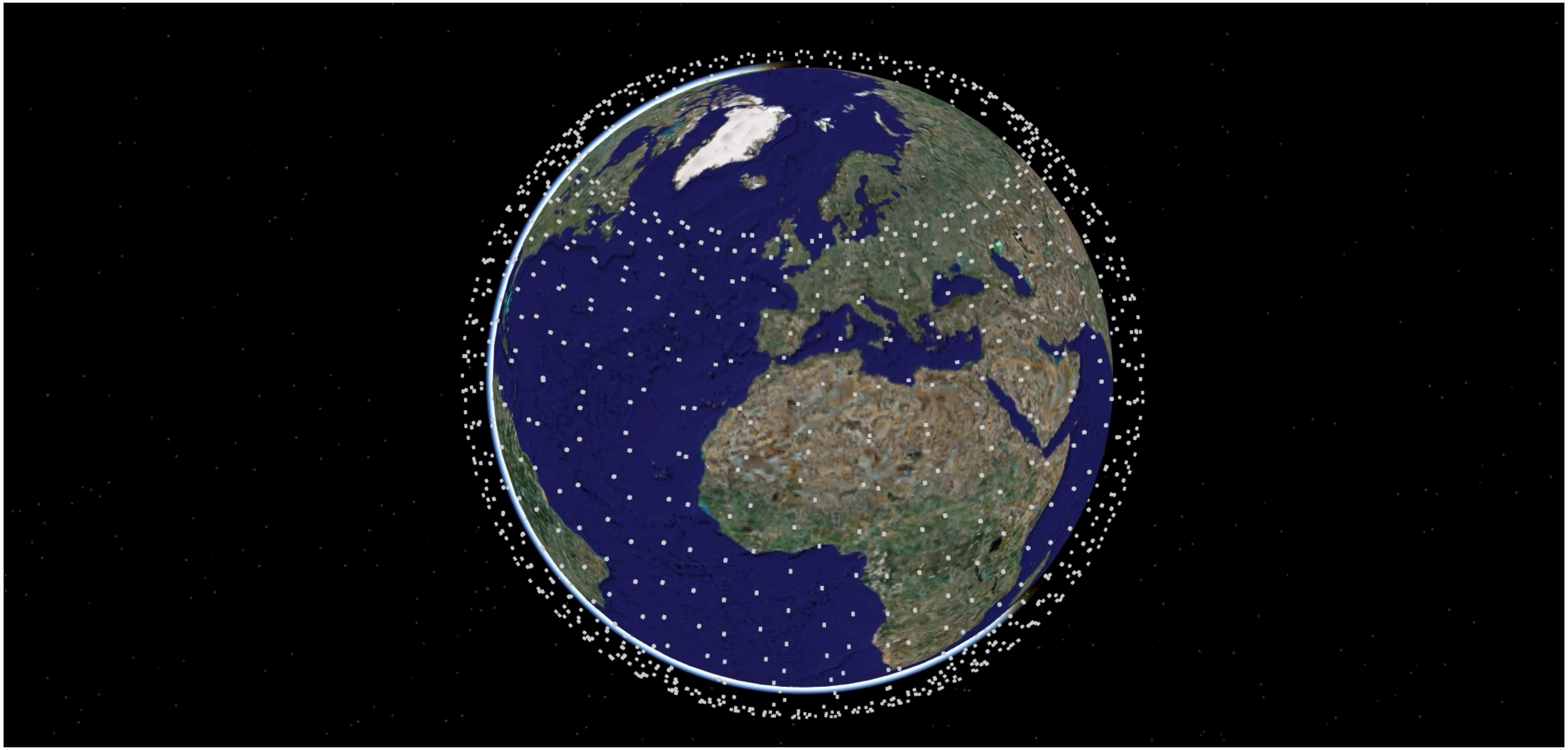

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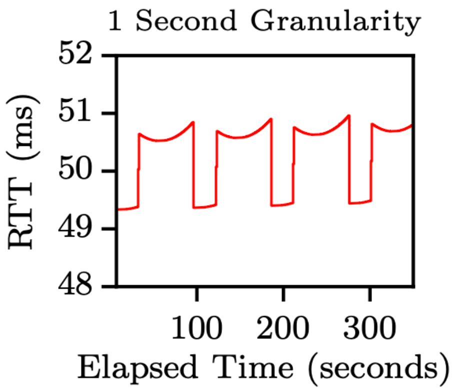
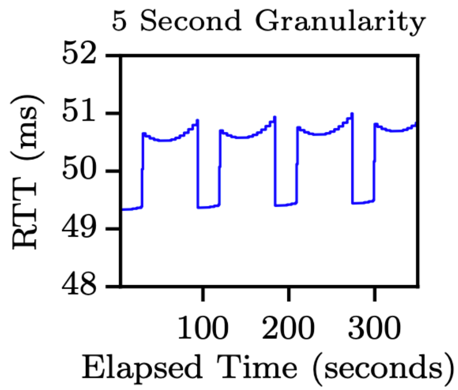
Accuracy and Scalability

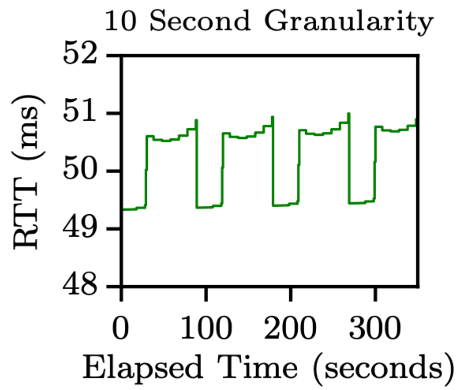
Round Trip Times for different frequencies of mobility and SP calculation



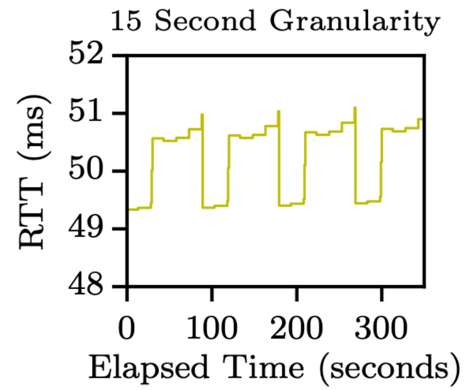
(a) 1 Second Granularity - (Elapsed Real Time: 15m 55s)



(b) 5 Second Granularity - (Elapsed Real Time: 6m 26s)



(c) 10 Second Granularity - (Elapsed Real Time: 4m 18s)



(d) 15 Second Granularity (Elapsed Real Time: 3m 55s)

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Accuracy and Scalability

Execution time for different topology sizes and IP routing configurators

TODO

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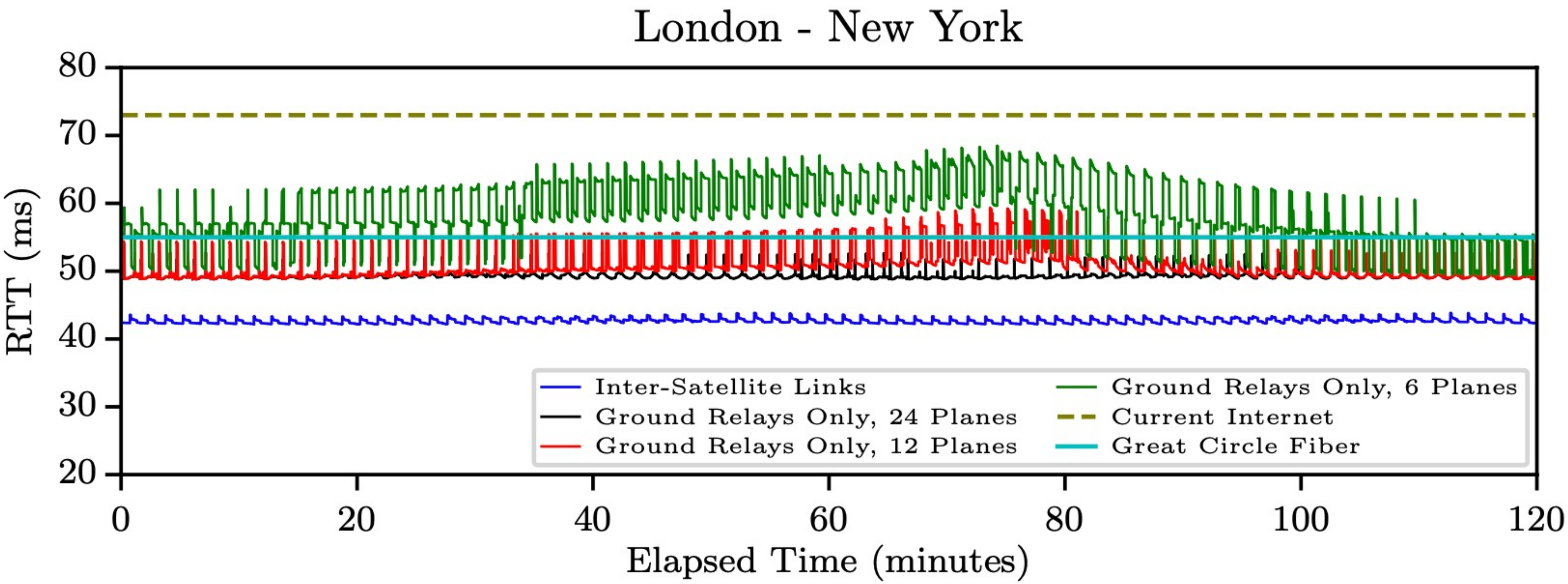
Non-Congestive Latency Variation



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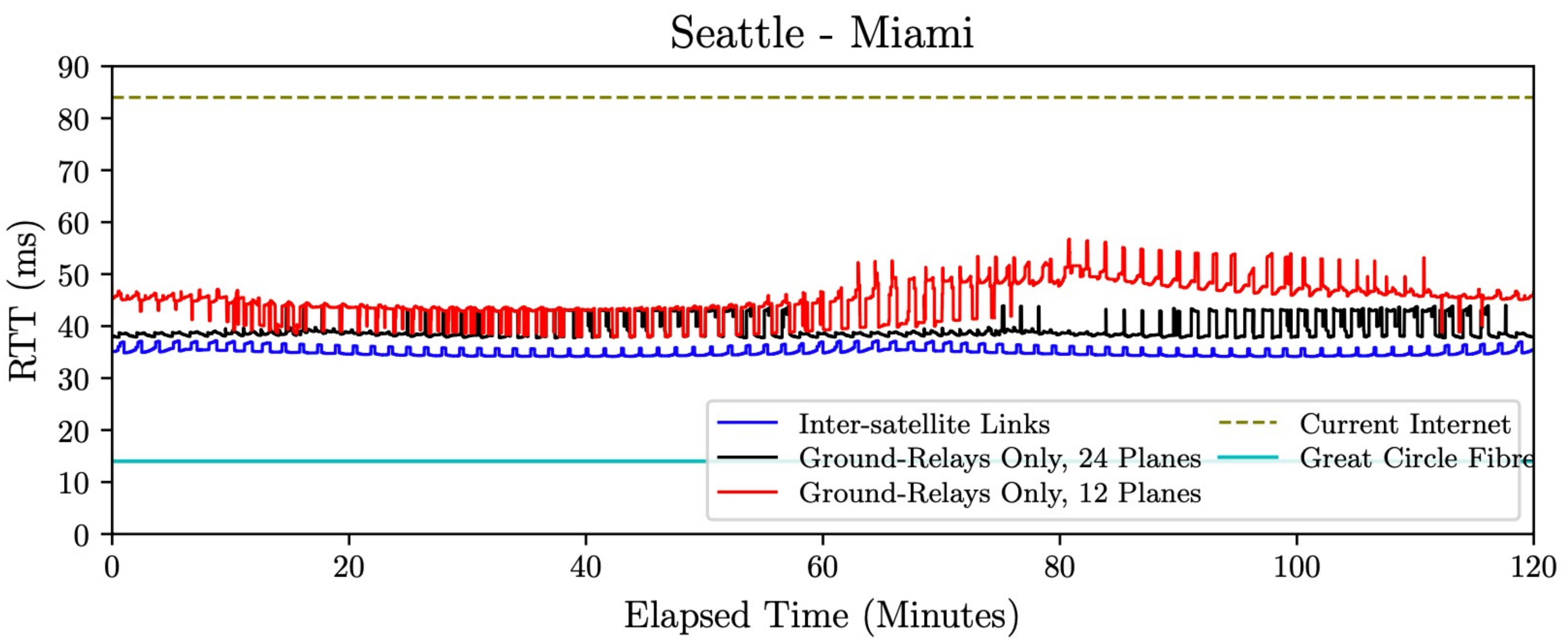
Non-Congestive Latency Variation



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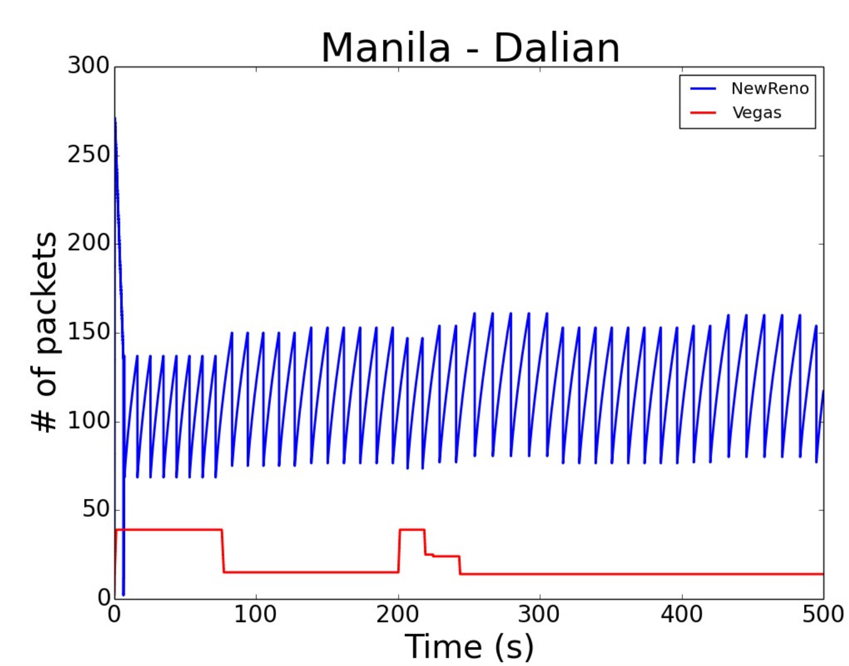
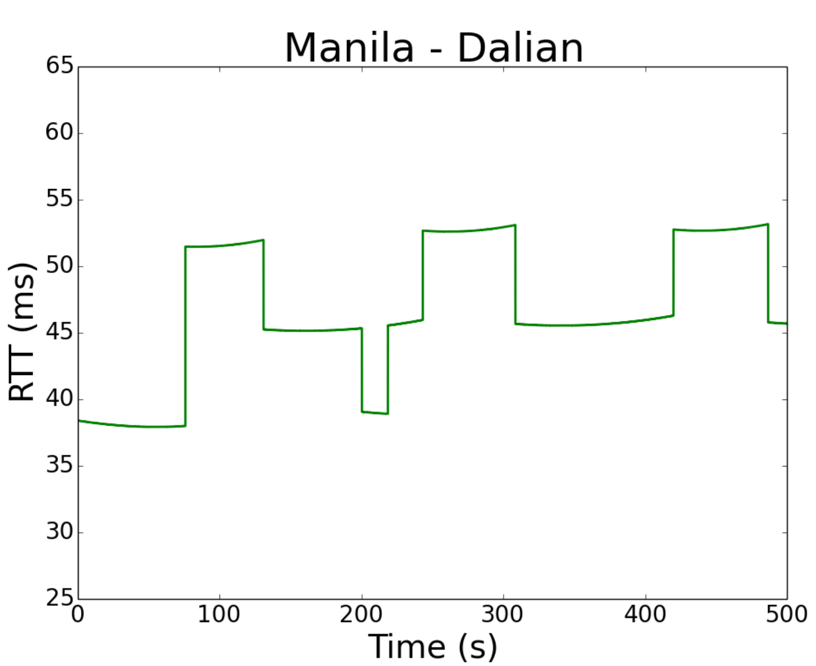
Loss- and Delay-based Data Transport

congestion window size



round trip time



Kuiper constellation - shell K1, 1156 satellites, 630km altitude, 34 orbital planes, 34 satellites per plane, 51.9º inclination, 10Mbps link speed, 100 packet buffers

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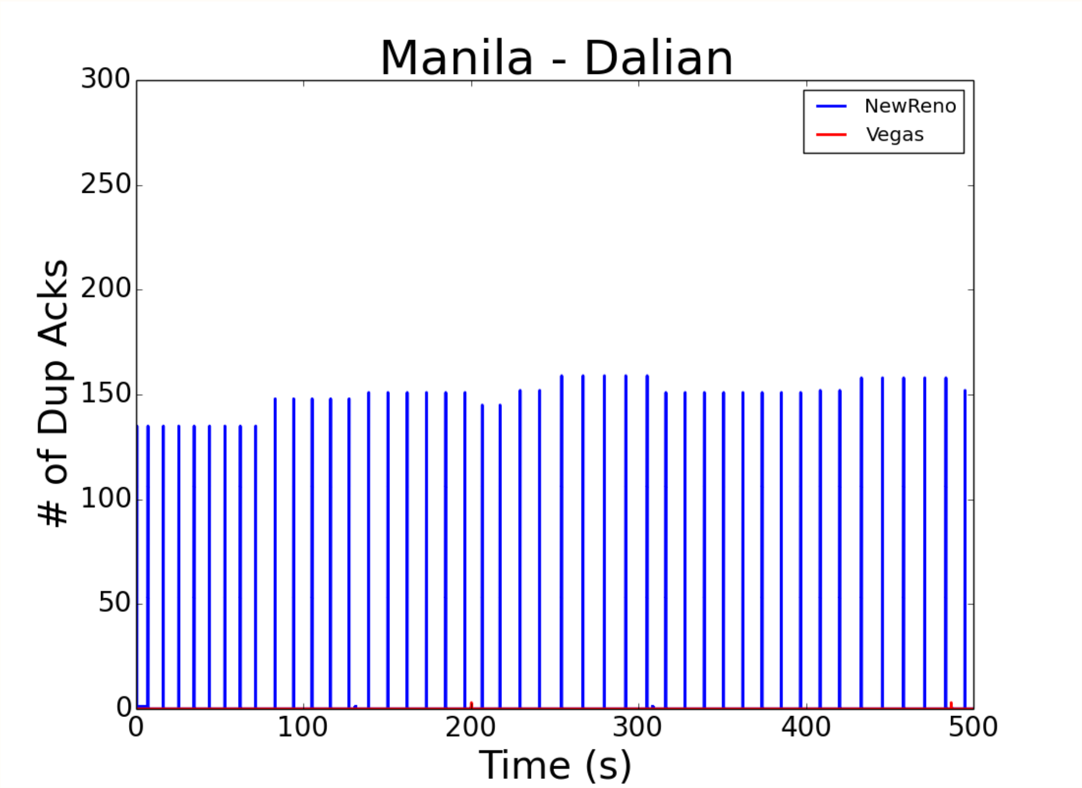
Loss- and Delay-based Data Transport

Duplicate acknowledgements



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Receiver-Driven Data Transport

- Inspired by data centre network research (NDP, SCDP)
- Sender pushes initial window of packets --> receiver pulls packets upon receiving initial window
- Pull requests are paced
- Packets are sprayed over k-edge-disjoint paths

Receiver-Driven Data Transport

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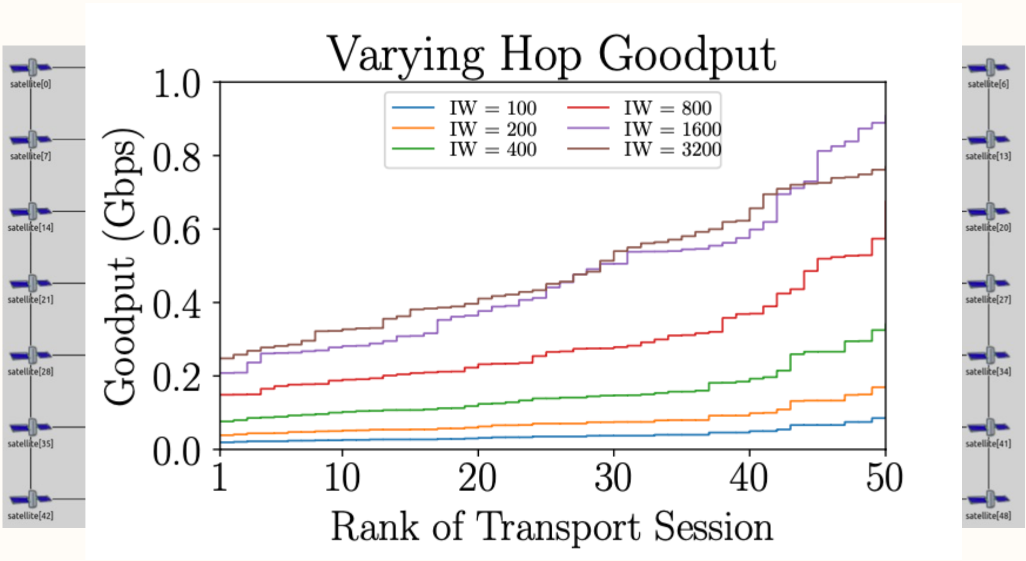
Congestion Control

- DC approaches do not need/support congestion control
- assume specific topology/pace based on incoming link capacity)
- not appropriate for a LEO satellite network



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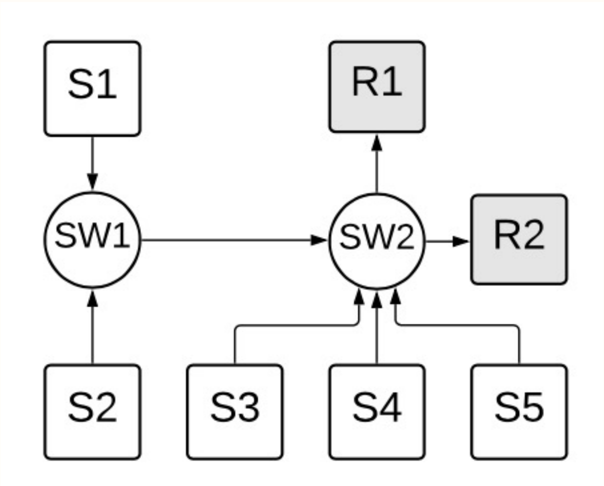
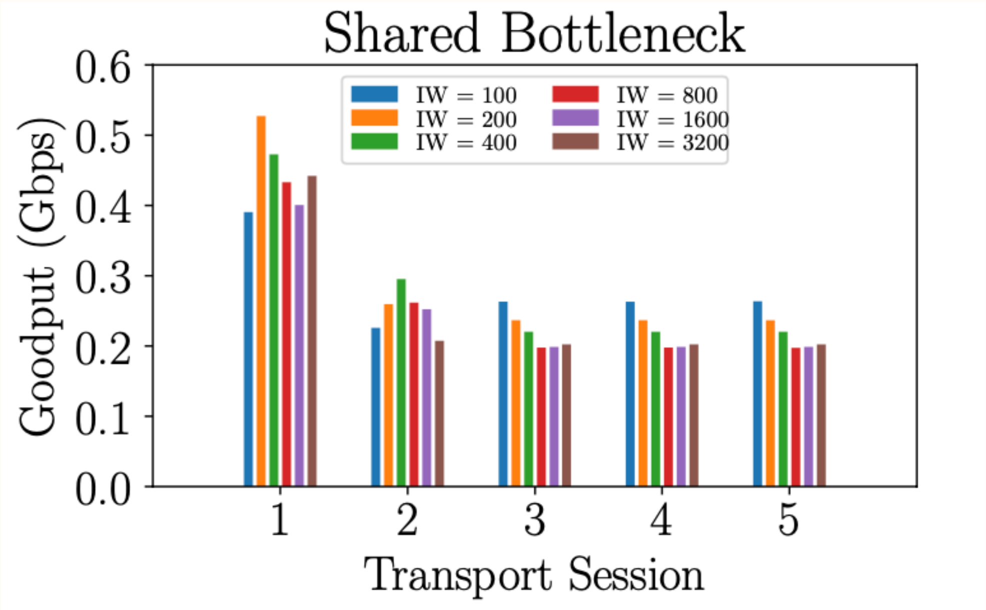
Congestion Control





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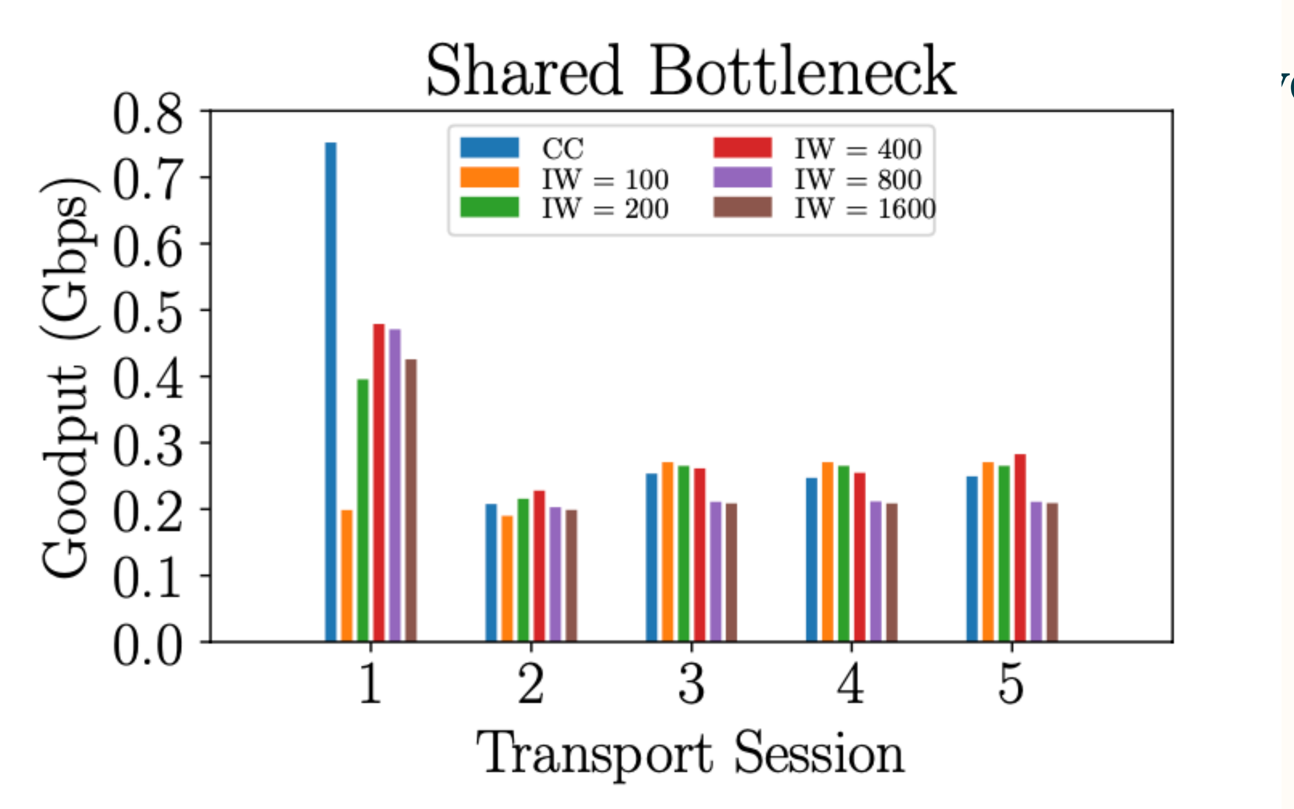
Congestion Control

- Addit   ver side
- Initia



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Current Work

- In-network signals for efficient delay-based congestion control
- RaptorQ codes for multicast and multisource communication
- Reinforcement Learning for congestion control in receiver-driven data transport

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