



Optical Link Scheduling

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About me

- PhD Candidate @ Concordia University
 - Interplanetary networking
 - Scheduling free-space lasers
- Engineer @ Amazon Kuiper
 - Optical inter-satellite links
 - Embedded systems

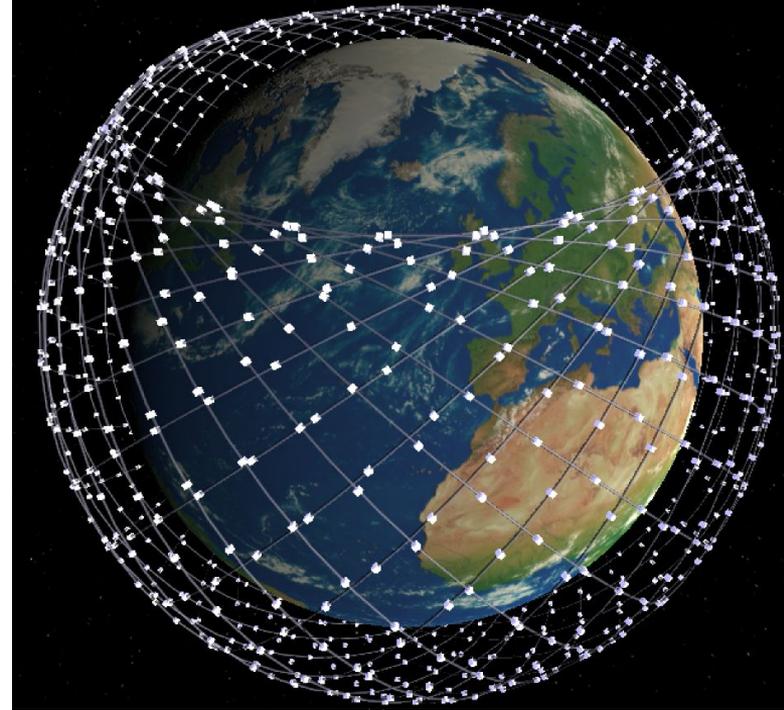
Disclaimer

All opinions are my own and are not opinions of Amazon.

The contents of this presentation are NOT specific to Kuiper and do NOT represent any non-public technological or business aspects of Kuiper.

Intuitive understanding

- Internet backbone... in space
- Each satellite is a router that can forward traffic to another satellite or down to the terrestrial network



M. Handley, "Delay is Not an Option: Low Latency Routing in Space," in Proceedings of the 17th ACM Workshop on Hot Topics in Networks, in HotNets '18. New York, NY, USA: Association for Computing Machinery, Nov. 2018, pp. 85–91. doi: 10.1145/3286062.3286075.

What is an Optical Mesh?

Access Network

- Black box that connects different access networks

SDN (control plane)

- Mesh or grid of optical fiber links

Hardware team (data plane)

- Physical layer considerations such that the optical links perform like fiber connections

Space internet

(Request/response architecture)

1. A request comes from a customer terminal up to a satellite
2. The satellite routes the request through multiple satellites until it is geographically close to the destination
3. The satellite downlinks the request to a ground station
4. The request joins the terrestrial internet core at an internet point of presence (PoP)



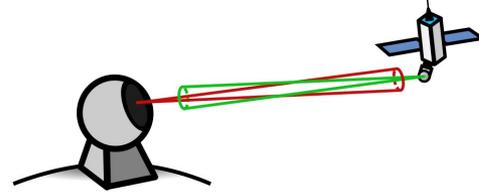
Laser Communications

- Lasercom can achieve higher data rates than RF due to narrow beam
- Subsystem to mechanically point the TX beam
- Pointing, acquisition, and tracking (PAT) is pretty slow

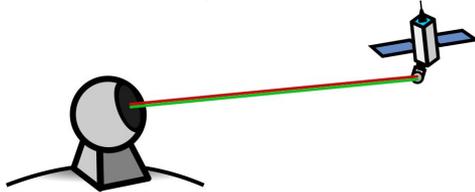
t=1) Terminate existing links.



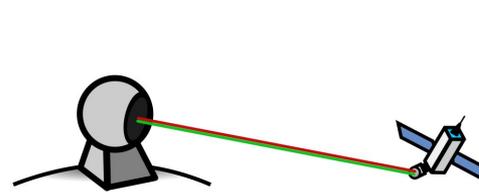
t=2) Open loop pointing.



t=3) Link acquisition.



t>3) Closed loop tracking.



How Slow is PAT?

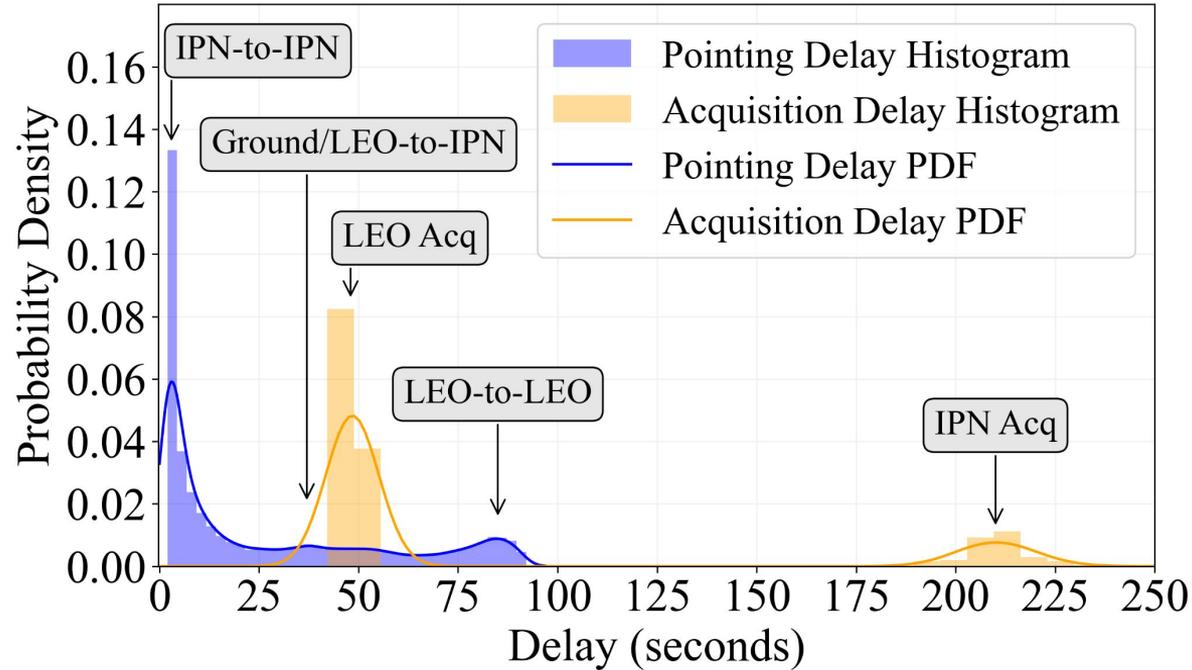
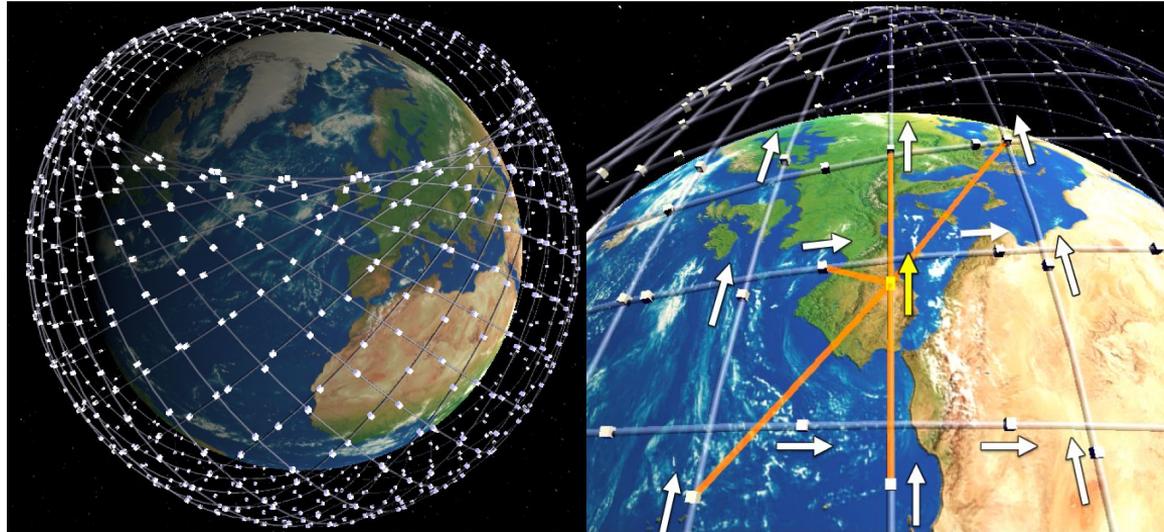


Fig. Link characterization across contact plans of various link types, planets, and constellations

Types of Optical Links

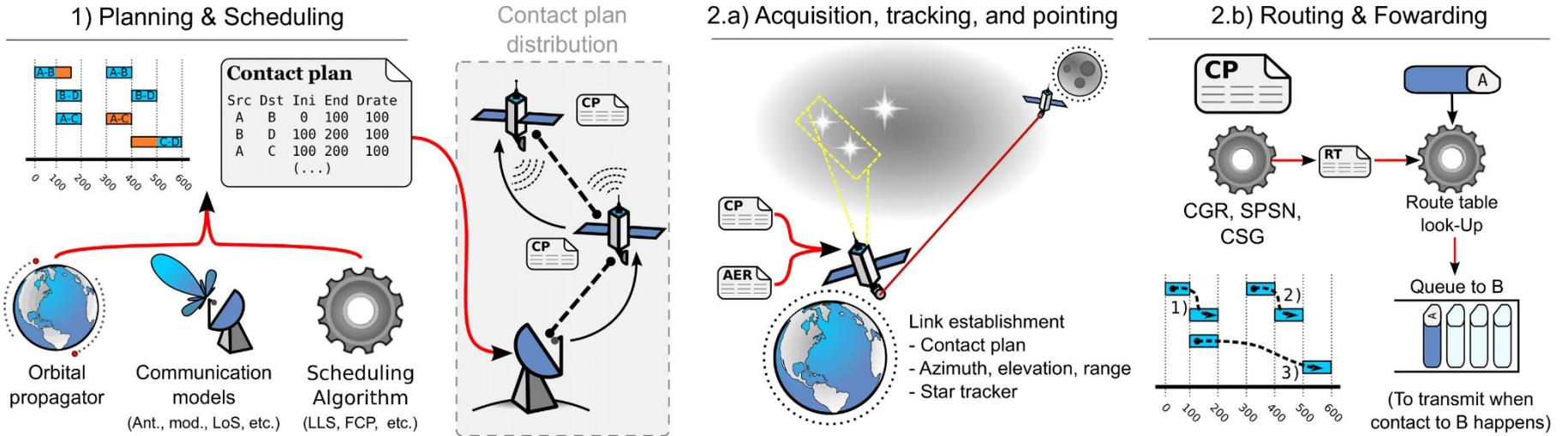
- In-plane
- Cross-plane
- Crosscending
- Inter-shell
- Space-to-ground



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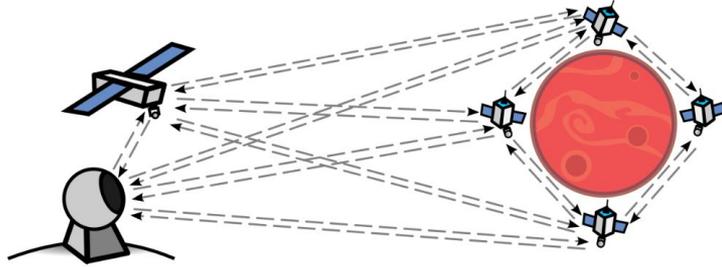
Routing vs Scheduling

- Congestion control
- Load balancing
- Optical head retargeting

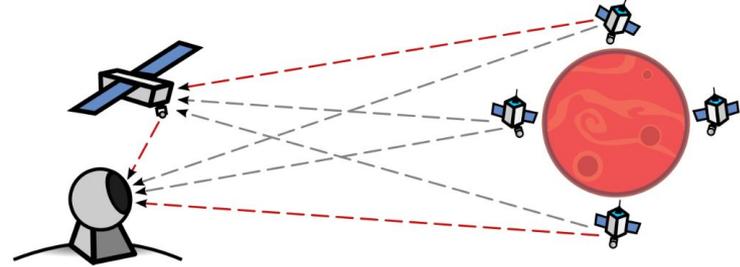


Optical Contact Plan Design Problem

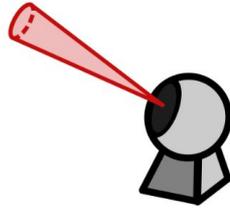
1) Topology Creation
(Bidirectional graph with cycles)



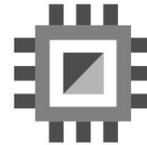
2) Link Scheduling
(Directed acyclic graph)



Orbital propagator



Communication models
(LoS, FoR, FoV, etc.)



Temporal capacity model
Laser Link Scheduler
DAG reduction algorithm



Ephemeris & cueing data
(Attitude, pose, velocity,
azimuth, elevation, range)

Issues with Integrating New Links

How / when to schedule links outside of the standard in-plane and cross-plane mesh links

- Resource constraints (limited number of optical terminals)
- Network segmentation
- Short vs long contact windows

How to Make New Links

Mostly physical layer

- ARQ (requires a buffer)
- Digital beam combining (multi aperture, spatial diversity)
- Adaptive optics (expensive, complex, and heavy)

How to Schedule Links

Minimizing the retargeting delay

- Intelligent scheduling algorithm
- Minimizing the physical delay through new coarse and fine pointing assemblies
- Reducing initial pointing uncertainty through improved ephemeris prediction

Delay and disruption tolerant networking

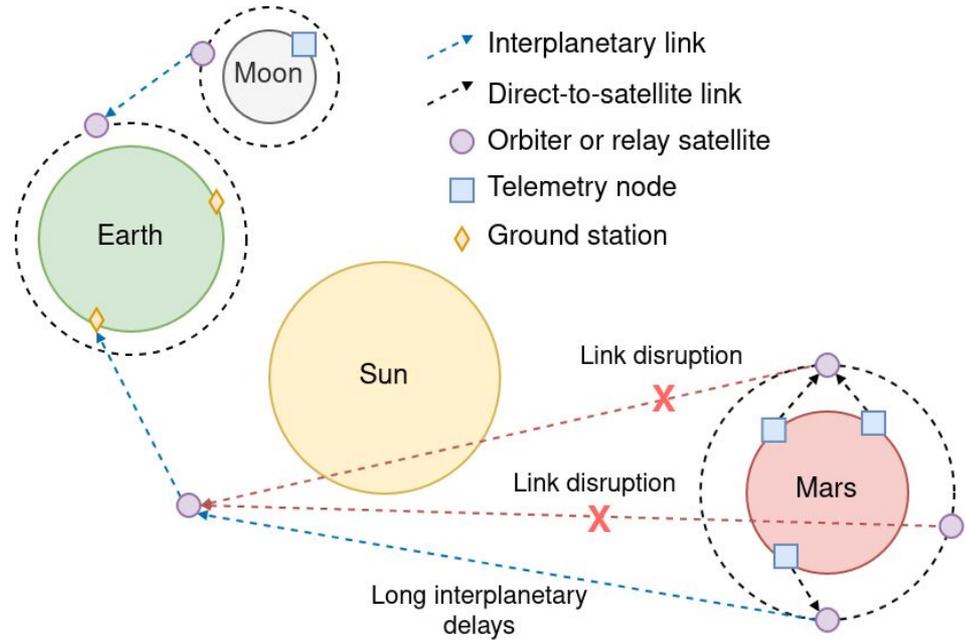
- Data aggregation / buffering
- Store-carry-and-forward

Types of networks

LEO mega constellations

Interplanetary networks

- LunaNet
- Voyager spacecraft
- Psyche spacecraft



Network Disruptions

LEO OISL mesh networks

- No end-to-end connectivity disruptions
- Propagation delay is possibly even shorter than terrestrial fiber.

IPN networks

- Anything past the moon will be substantial and will require thinking differently about networking protocols.

IPN Lasercom

- No stable mesh
- Requires constantly picking which links to make from a limited resource pool (minimal DTE links, few relay satellites)
- Sequencing, directionality, and contact window maximization

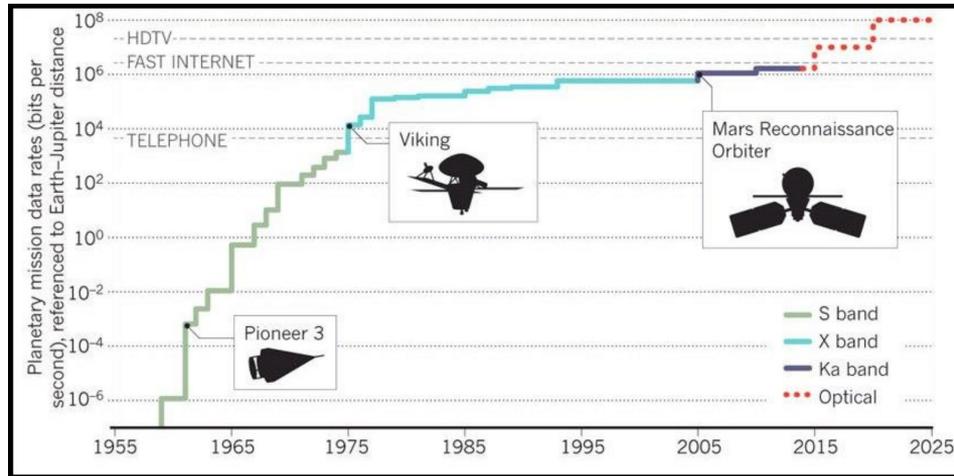


Fig. https://spaceodyssey.dmns.org/media/53989/deep_space_network.ppt

