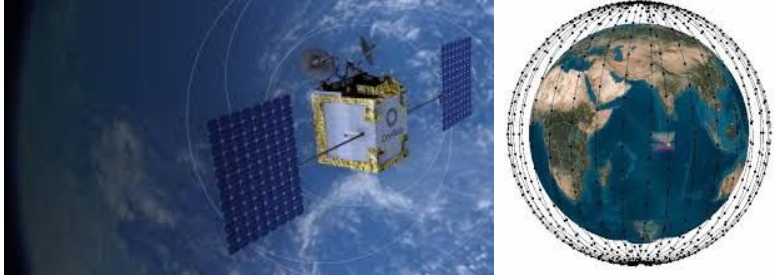
vs

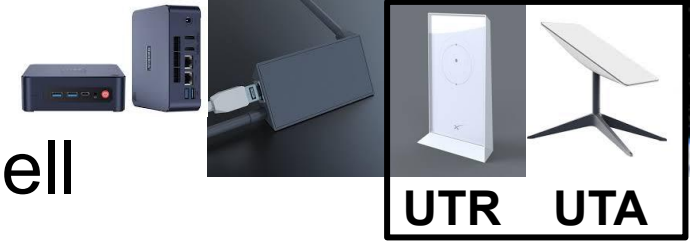


Measuring the Satellite Links of LEO Networks

Jianping Pan
University of Victoria, BC, Canada
with Jinwei Zhao and Lin Cai

PANDA
Parallel, Networking and Distributed Applications

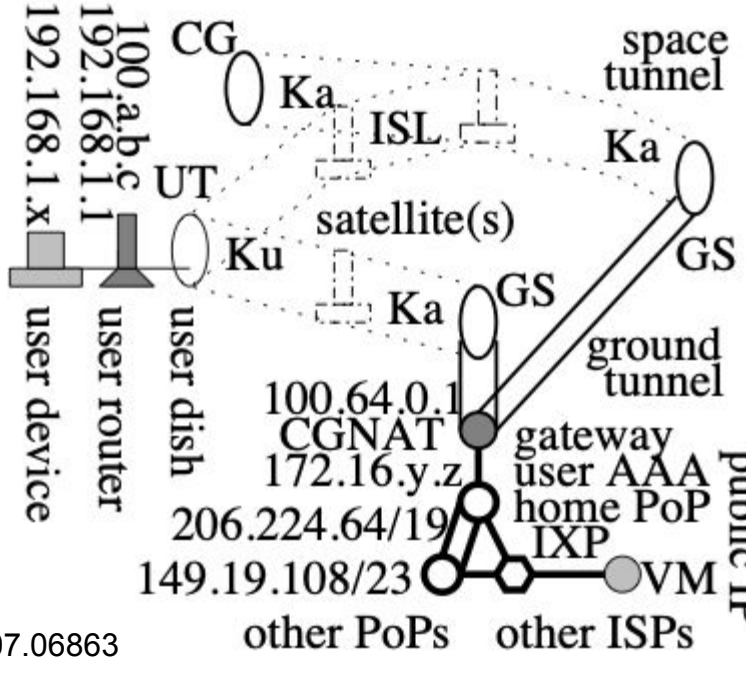
UVIC



Starlink in a nutshell

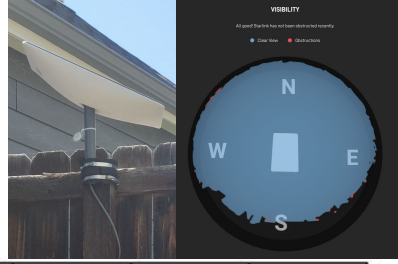
- An ***outgoing*** packet's journey to the Internet (reverse for the incoming one)
  - User devices
    - 192.168.1.*x* if the default gateway at 192.168.1.1/24
  - **User <u>router</u>** (User Terminal Router, **UTR**, provided by Starlink, can be *replaced* or *bypassed*)
    - LAN: 192.168.1.1 (by default)
    - WAN: **100.64/10** (*unique* per user dish)
  - **User dish** (Antenna, **UTA**, provided by Starlink)
    - 192.168.**100**.1 (*fixed* address as modem)
  - ***Satellite**** (inter-satellite links, **ISL**s, possible)
  - Landing ground station (**GS**, transparent to IP)
  - **<u>CGNAT</u>** (Carrier-Grade NAT) gateway (GW)
    - **100.64.0.1** (or public IP user's gateway)
  - Home **PoP** (Point-of-Presence) entry
    - 172.16/12
  - PoP, other PoPs/ISPs, ICPs, etc: the **Internet**

1 IP hop

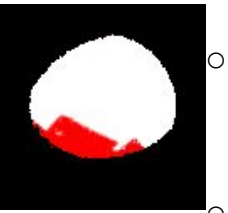


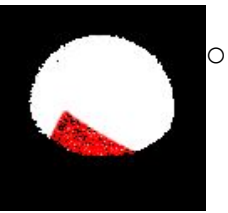
* UT-(space/ground tunnel)-GW-PoP-backbone: see https://arxiv.org/pdf/2307.06863

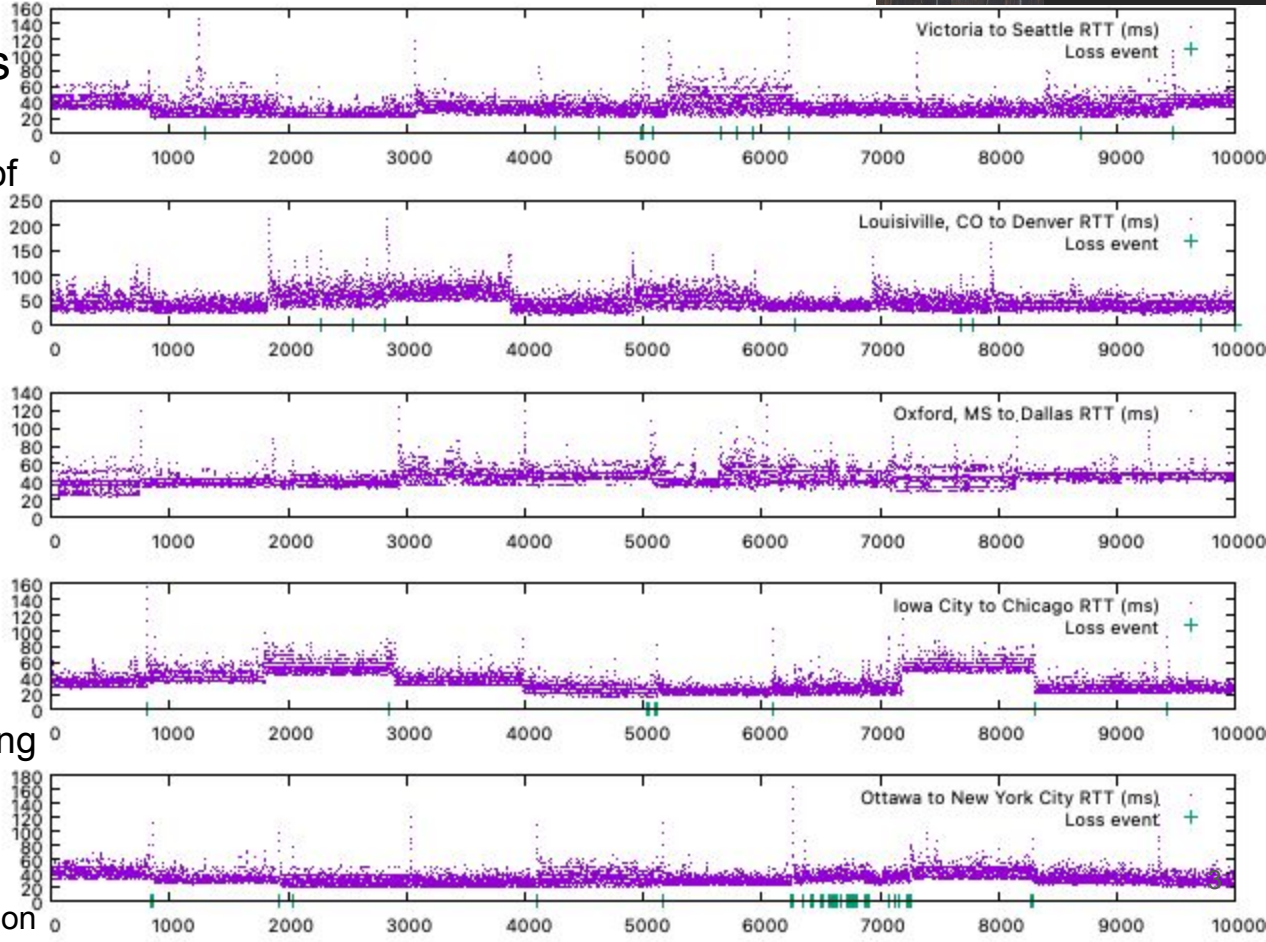
From user device to their **gateway**



- Ping in 15-ms intervals
  - Victoria to Seattle PoP
    - On UVic ECS roof
  - **Louisville**, CO^
    - Hosted by Matt
    - To **Denver** PoP
  - Oxford, MS+
    - Shared by Feng
    - To Dallas PoP
  - Iowa City, IA
    - By Hammas
    - To Chicago PoP
  - Ottawa, ON+
    - Hosted by Minming
    - To New York City

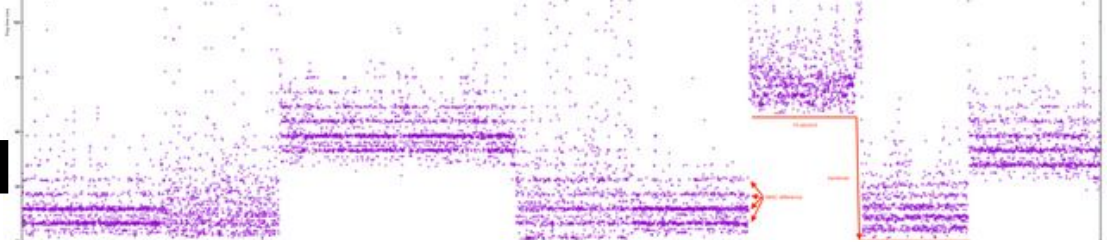




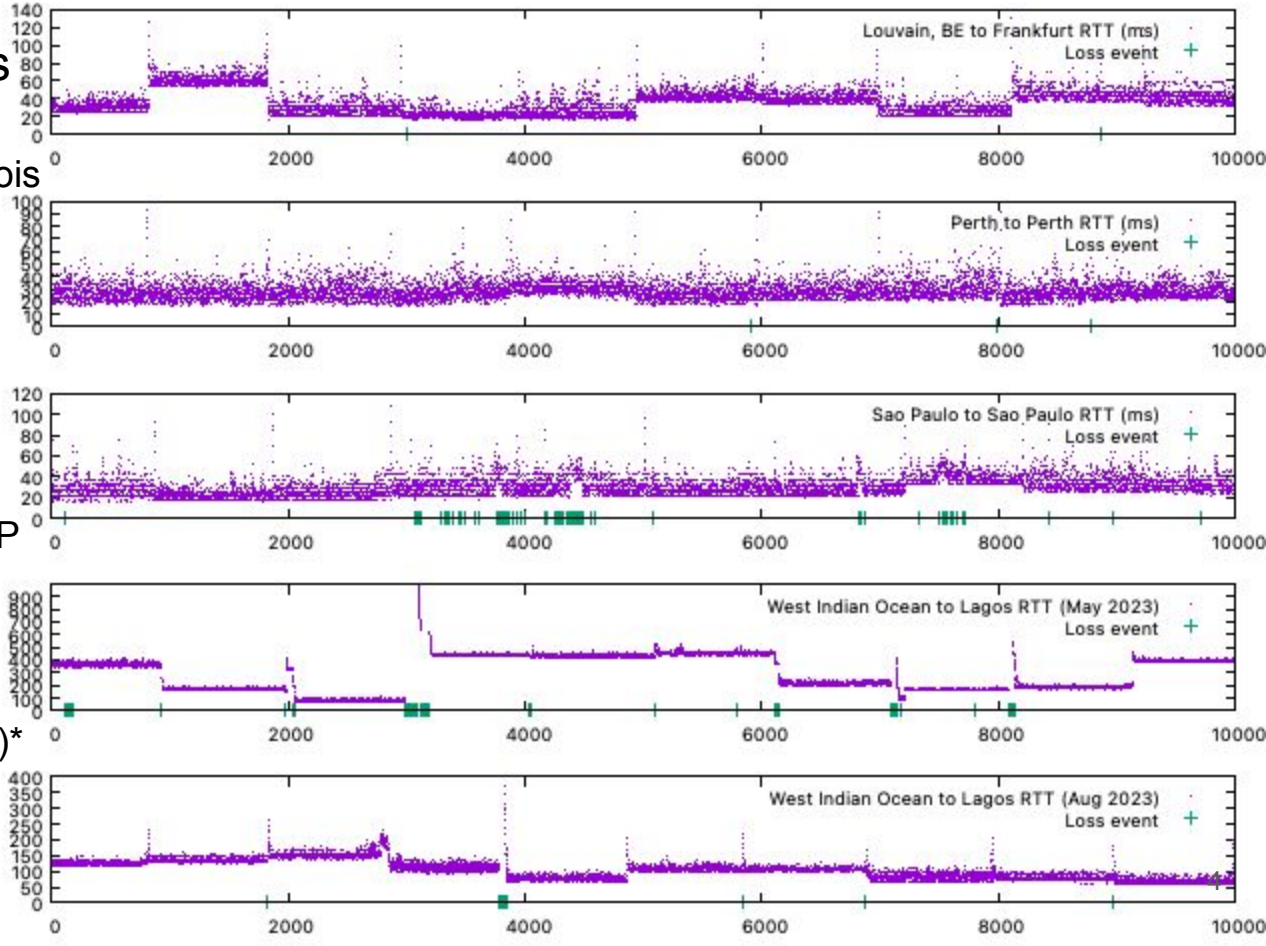


* minRTT **jumps**; ^ local WiFi; + dish obstruction

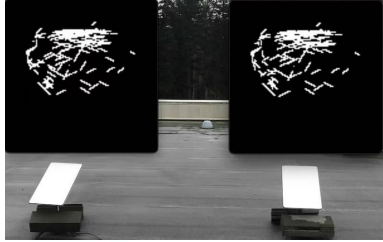
Also around the **world**



- Ping in 15-ms intervals
  - Louvain, BE
    - Shared by Francois
    - To Frankfurt PoP
  - Perth, AU^
    - By a Redditor
    - To Perth PoP
  - São Paulo, BR
    - By a Redditor
    - To São Paulo PoP
  - Seychelles (May 2023)
    - By Dominique
    - To Lagos PoP
  - **Seychelles** (Aug 2023)*
    - **ISL improved**

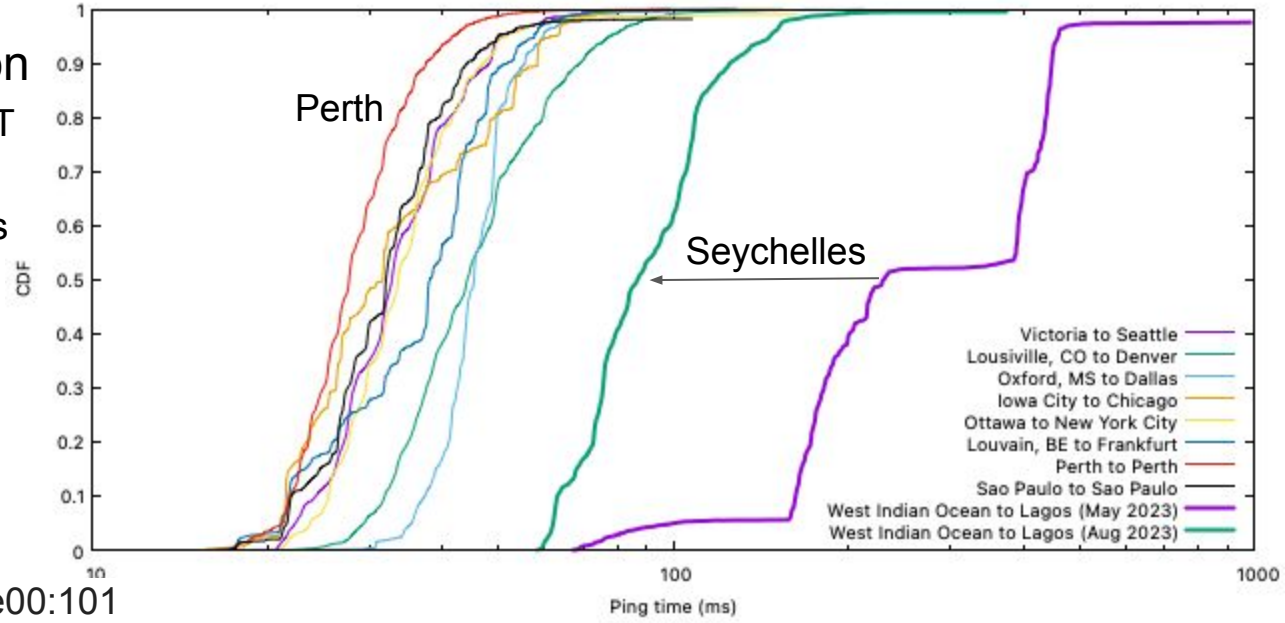


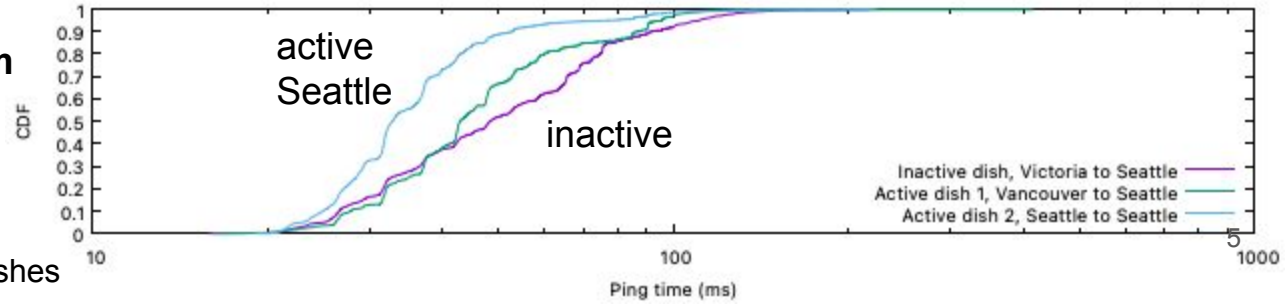
* GEO protection; ^ user population; **MAC**



From sequence to **frequency**

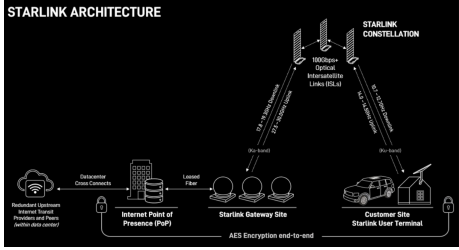
- *Cumulative* distribution
  - ISL, much **higher** RTT
  - Non-ISL
    - min RTT: ~20ms
    - Still high **jitter**
- ***Inactive*** dishes
  - IPv4 gateway
    - 100.64.0.1
    - By ARPing
  - IPv6 gateway
    - fe80::200:5eff:fe00:101
    - By Ping
  - **connect.starlink.com**
    - 34.107.166.226
    - By (HTT)Ping



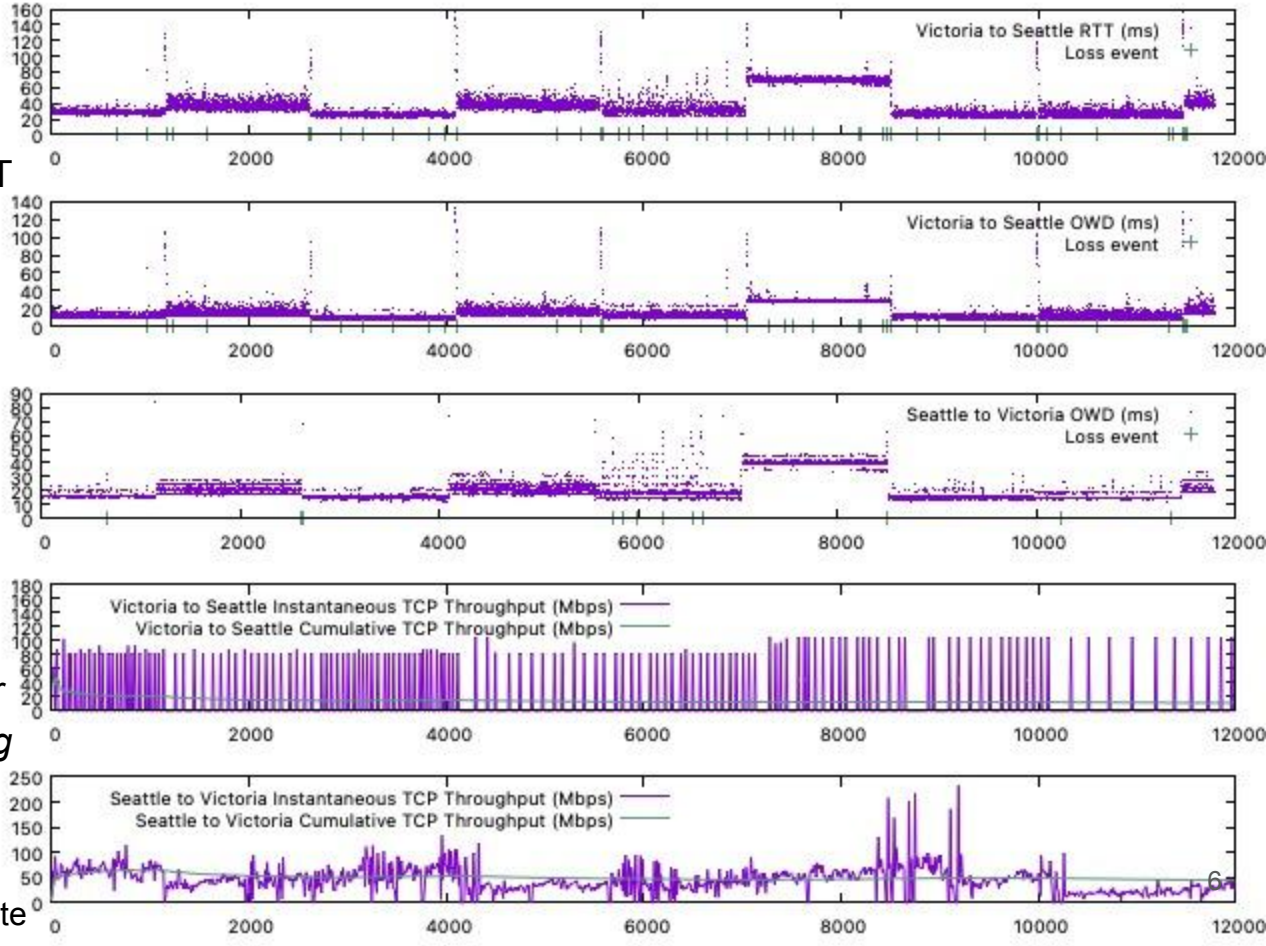


* **active** measurement on many ***inactive*** dishes

Up vs **down** link from user's viewpoint

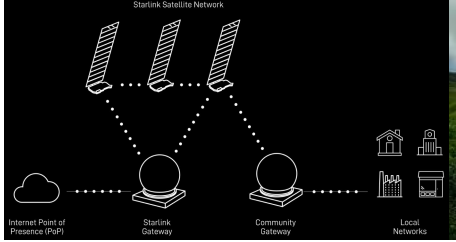


- Victoria ⇔ Seattle
  - RTT by Ping to GW
  - *One-way* delay by IRTT
    - A VM near PoP
    - Time synced
  - **Bidirectional** tunnel
    - Same satellite(s)
    - And landing GS
  - *Asymmetric* bandwidth
    - Up: contention
    - Down: allocation
  - iPerf3 TCP throughput
    - Sat-GS handover
    - Packet *reordering*
    - *Timeout*

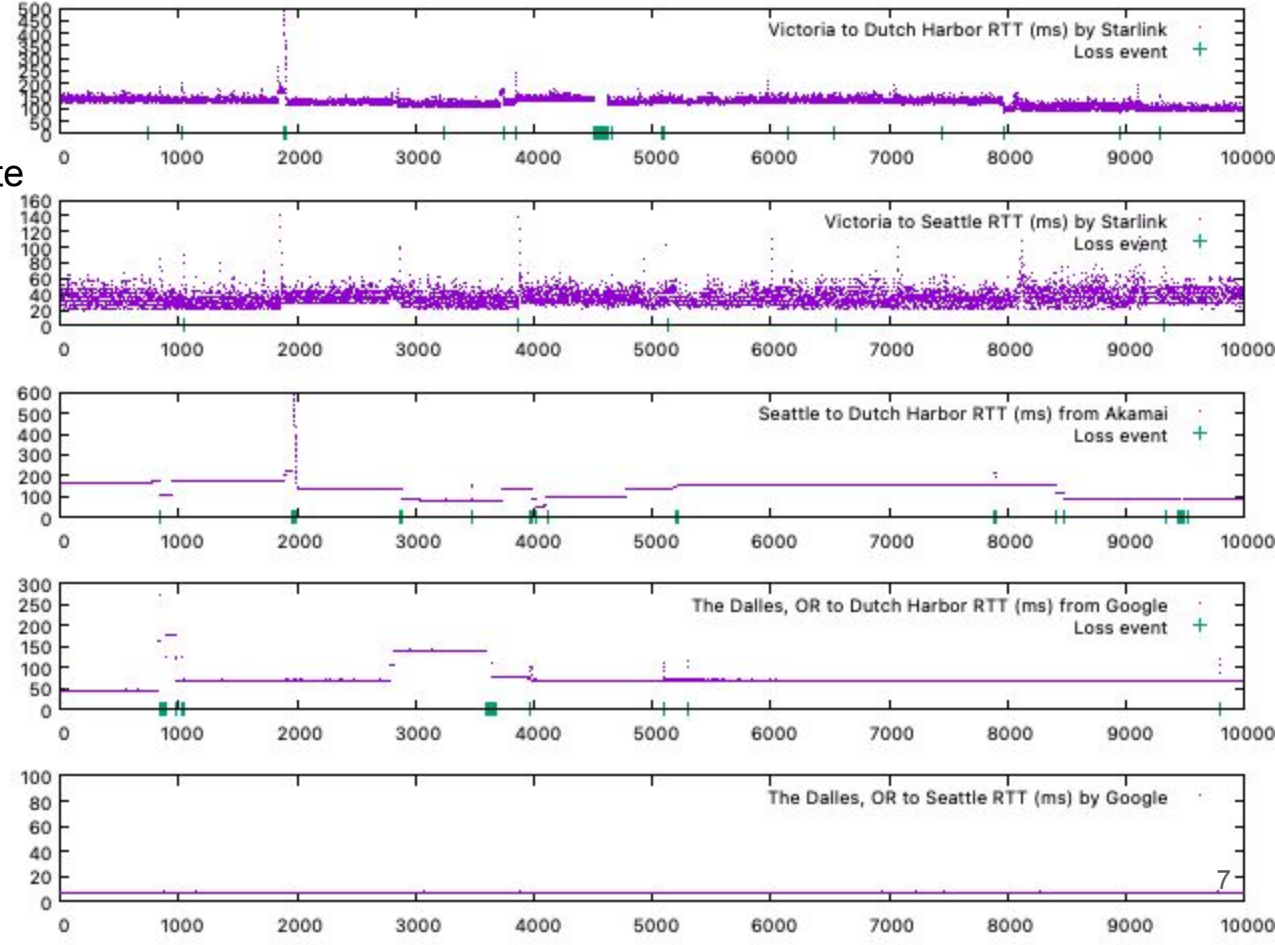


* TCP affected at 57, 12, 27 and 42 sec/minute

Community gateway



- **First** in Dutch Harbor
  - Unalaska, AK
  - A **mini** GS to aggregate
  - In **Ka** (not Ku) bands
  - 10Gbps **symmetric**
- ***Outside-in*** testing
  - From Victoria dish
    - UT-Sat-GS and
    - GS-Sat-GS
  - From Akamai VM
    - In Seattle
  - From Google VM
    - The Dalles, OR
    - Through Seattle

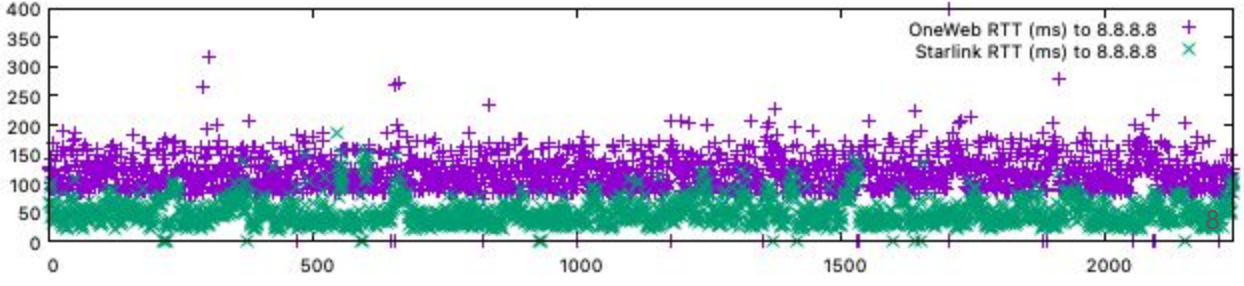


* capex: $1.25m; opex: $75k/gbps/month!

Comparing with **another** LEO network

- Starlink
  - Initially target *consumer* users
  - Mostly 53° inclination
  - Mostly 550km above the Earth
  - **Spotting** beams for individual dishes
    - Ku for UT and Ka for GS
  - Currently >6000 active satellites
    - All launched by SpaceX
  - Currently >100x ground stations
  - Many PoPs around the world
  - Lower but *relatively fluctuating* RTT
    - Due to Spotting beams
    - **UT-Sat-GS shuffling every 15 seconds**

- ***OneWeb***
  - Currently target *enterprise* users
  - Polar orbits
  - Above 1000km in altitude
  - **Sweeping** beams for community dishes
    - Similarly Ku and Ka
  - Currently ~600 active satellites
    - Limited 3rd-party launch capacity
  - Currently ~10x ground stations
  - Very few customer PoPs now
  - High but *relatively stable* RTT to PoP



* Amazon Kuiper and Telesat Lightspeed?

Low Earth Network of Satellites

- **https://github.com/clarkzjw/LENS**
  - Our ***public*** datasets updated monthly

Starlink User Terminal models and hardware revisions

January 2024

REV1 - Original Starlink "Dishy"

rev1_pre_production
rev1_production
rev_rev1_proto3

Years in production: 2020 - 2021

High Performance

rev_hp1_proto0
rev_hp1_proto1

Years in production: 2022 -

REV2 - Mass production "Dishy"

rev2_proto1
rev2_proto2
rev2_proto3
rev2_proto4

Years in production: 2021 - 2022

Flat High Performance

rev_hp1_proto0
rev_hp1_proto1

Years in production: 2022 -

REV3 - Standard Actuated

rev3_proto0
rev3_proto1
rev3_proto2

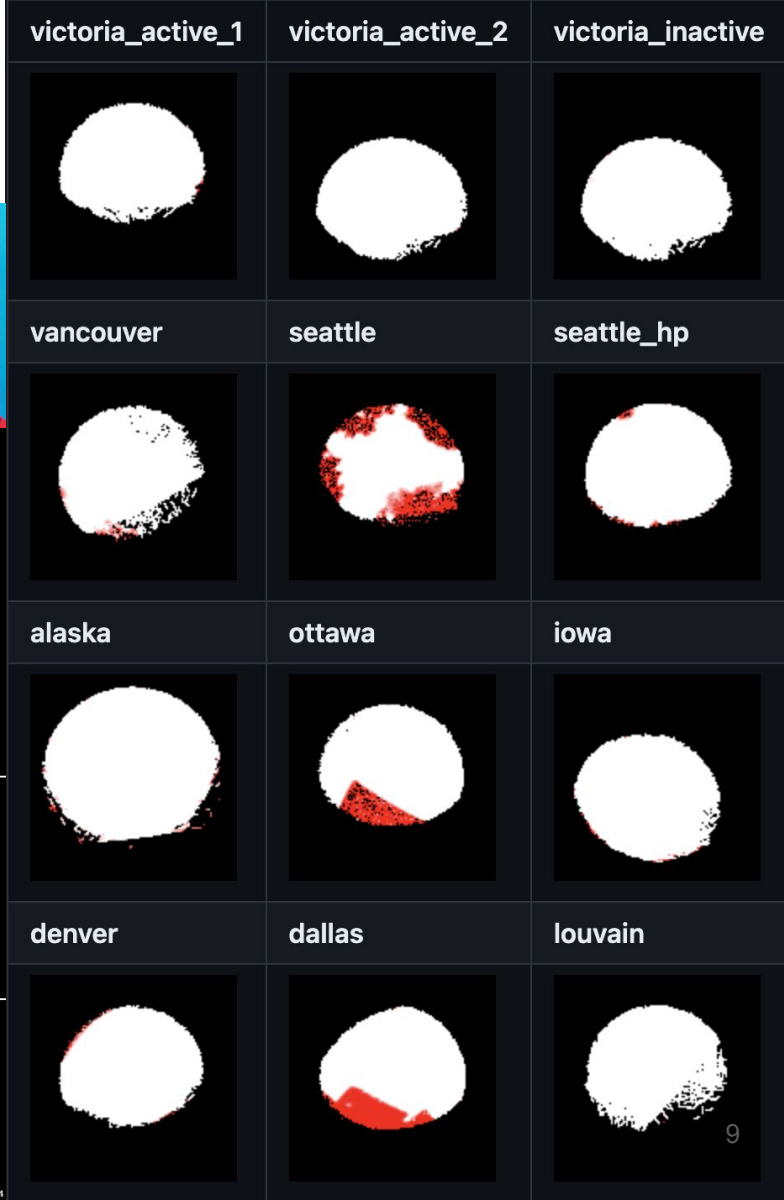
Years in production: 2022 -

REV4 - Standard

rev4_proto3
rev4_proto4
rev4_prod1

Years in production: Q4 2023 -

olegkutkov.me, 2024



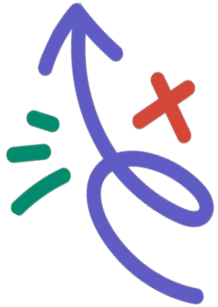
leoscope.surrey.ac.uk

LEOScope:

A GLOBAL TESTBED

for Low-Earth Orbit

Satellite Networks



Nishanth Sastry

SAEED FADAEI

MOHAMED KASSEM

Debopam Bhattacherjee

Nodes for the testbed have been donated/contributed by:

Node Contributors

University of Surrey (London, Wrexham, and Nigeria)

Edinburgh (Edinburgh Node)

Telefonica (Madrid Node)

University of Victoria

Email
s.fadaei@surrey.ac.uk

Website
leoscope.surrey.ac.uk

Thanks!

- ***Questions?***
  - Join us!

Obstruction test

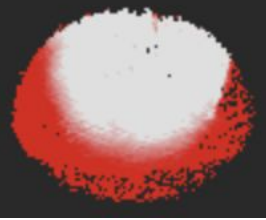
Starlink added **6** new PoPs in US in 2024

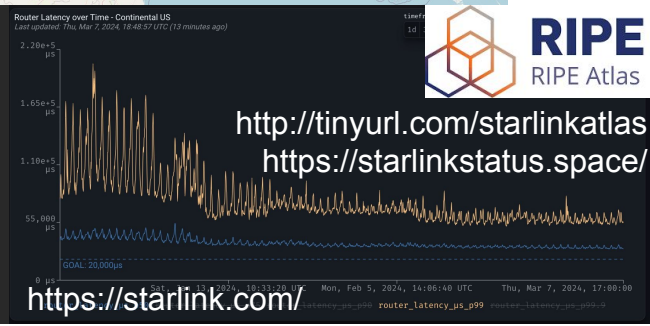
LEOScope

http://starlink.sx
http://tinyurl.com/nathanstarlink

Active vs inactive vs *obstructed* dish in a cell

flat dish





From Anchorage, AK to Seattle, WA: Starlink vs OneWeb vs Fiber (% Mark)
more at https://github.com/clarkzjw/LENS