On LEOs and Starlink

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APNIC

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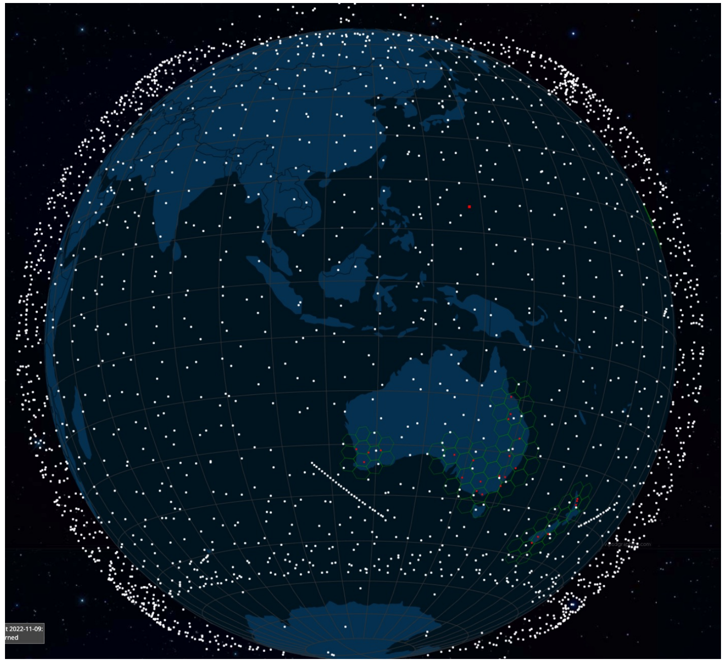
LEOs in the News



screenshot from starwatch app

Together Optus and SpaceX Plan to Cover 100% of Australia

12 July 2023, 04:00 PM

- Optus' collaboration with SpaceX aims to provide regional Australia with a new way to connect starting in late 2024.
- Optus plans to roll out SMS from late 2024, with voice and data also on the horizon from late 2025.

TECH / MOBILE / T-MOBILE

T-Mobile and SpaceX Starlink say your 5G phone will connect to satellites next year

Screenshot - https://www.theverge.com/2022/8/25/23320722/spacex-

NIKKEI Asia

TELECOMMUNICATION

Elon Musk's Starlink launches satellite internet service in Japan

Company offers high-speed access to remote areas

Screenshot: https://asia.nikkei.com/Business/Telecommunication/Elon-Musk-s-Starlink-launches-satellite-internet-service-in-Japan

Media & Telecom

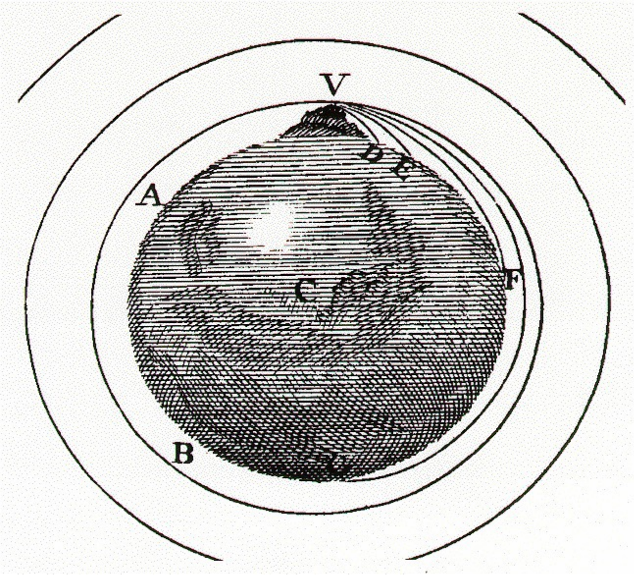
Telstra partners with Elon Musk's Starlink for internet in remote Australia

Reuters

July 2, 2023 7:35 PM PDT · Updated 22 days ago

Newtonian Physics

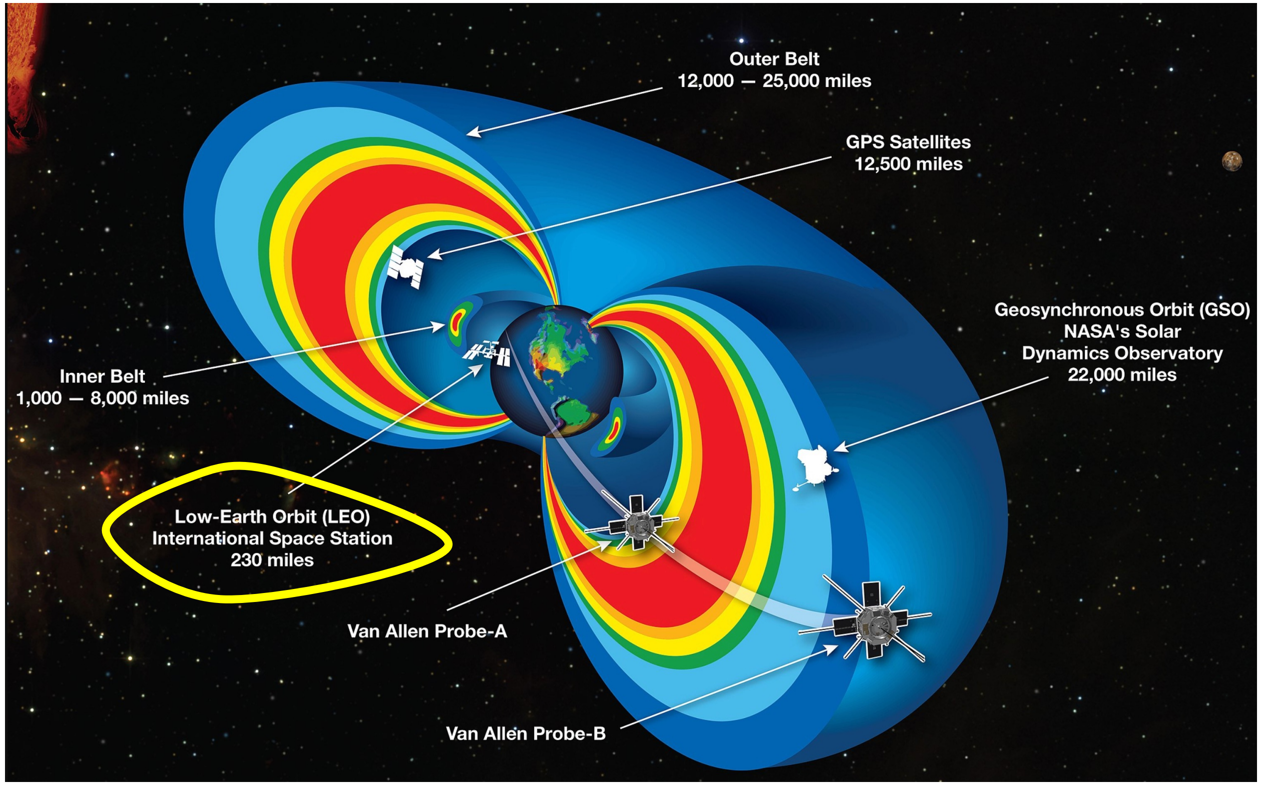
- If you fire a projectile with a speed greater than 11.2Km/sec it will not fall back to earth, and instead head away from earth never to return
- On the other hand, if you incline the aiming trajectory and fire it at a critical speed it will settle into an orbit around the earth
- The higher the altitude, the lower the orbital speed required to maintain orbit



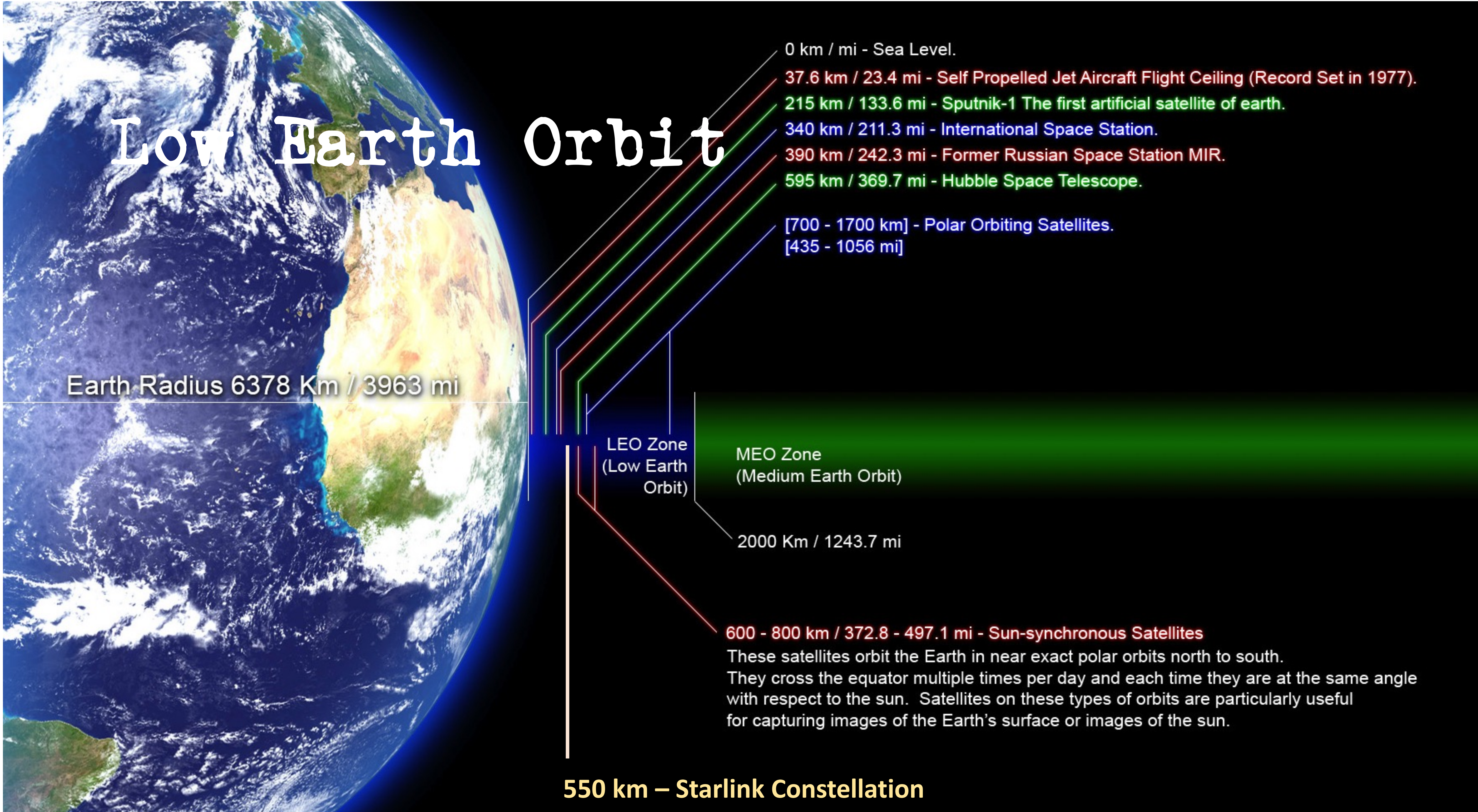
The effects of centripetal forces.

THAT by means of centripetal forces, the Planets may be retained in certain orbits, we may eaſily underſtand, if we conſider the motions of projectiles. For a ſtone projected is by the preſſure of its own weight forced out of the rectilinear path, which by the projection alone it ſhould have purſued, and made to deſcribe a curve line in the air; and through that crooked way is at laſt brought down to the ground. And the greater the velocity is with which it is projected, the farther it goes before it falls to the Earth. We may therefore ſuppoſe the velocity to be ſo encreaſed, that it would deſcribe an arc of 1, 2, 5, 10, 100,

Solar Radiation Physics



- The rotating iron core of the Earth produces a strong magnetic field
- This magnetic deflects solar radiation – the Van Allen Belt
- Sheltering below the Van Allen Belt protects the spacecraft from the worst effects of solar radiation, allowing advanced electronics to be used in the spacecraft

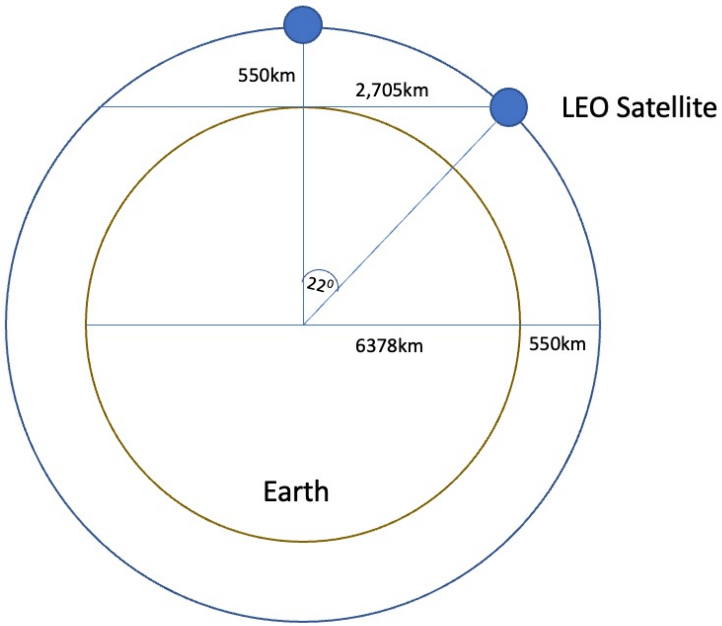


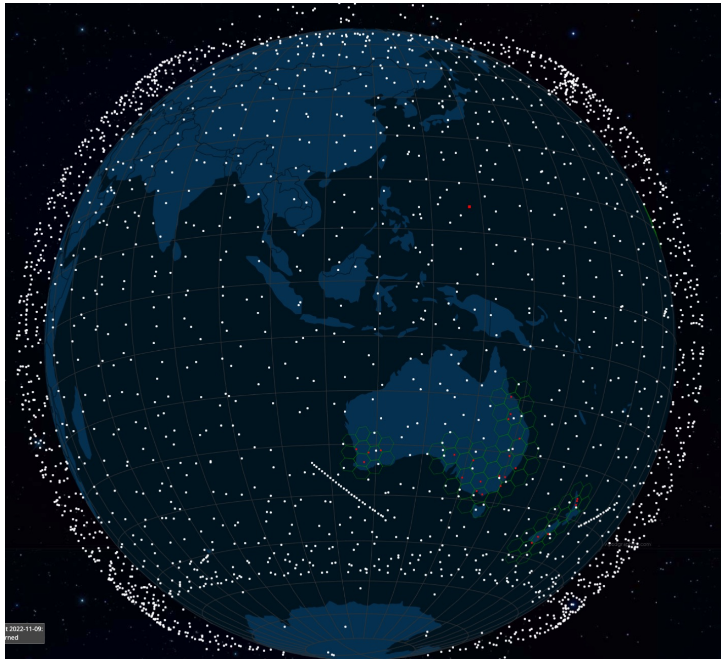
Low Earth Orbit
0 km / mi - Sea Level.
37.6 km / 23.4 mi - Self Propelled Jet Aircraft Flight Ceiling (Record Set in 1977).
215 km / 133.6 mi - Sputnik-1 The first artificial satellite of earth.
340 km / 211.3 mi - International Space Station.
390 km / 242.3 mi - Former Russian Space Station MIR.
595 km / 369.7 mi - Hubble Space Telescope.
[700 - 1700 km] - Polar Orbiting Satellites.
[435 - 1056 mi]
Earth Radius 6378 Km / 3963 mi
LEO Zone (Low Earth Orbit)
MEO Zone (Medium Earth Orbit)
2000 Km / 1243.7 mi
600 - 800 km / 372.8 - 497.1 mi - Sun-synchronous Satellites
These satellites orbit the Earth in near exact polar orbits north to south.
They cross the equator multiple times per day and each time they are at the same angle with respect to the sun. Satellites on these types of orbits are particularly useful for capturing images of the Earth's surface or images of the sun.
550 km – Starlink Constellation

Low Earth Orbit

- LEO satellites are stations between 160km and 2,000km in altitude.
- High enough to stop it slowing down by “grazing” the denser parts of the earth’s ionosphere
- Not so high that it loses the radiation protection afforded by the Inner Van Allen belt.
- At a height of 550km, the minimum signal propagation delay to reach the satellite and back is 3.7ms, at 25^{o} it’s 7.5ms.

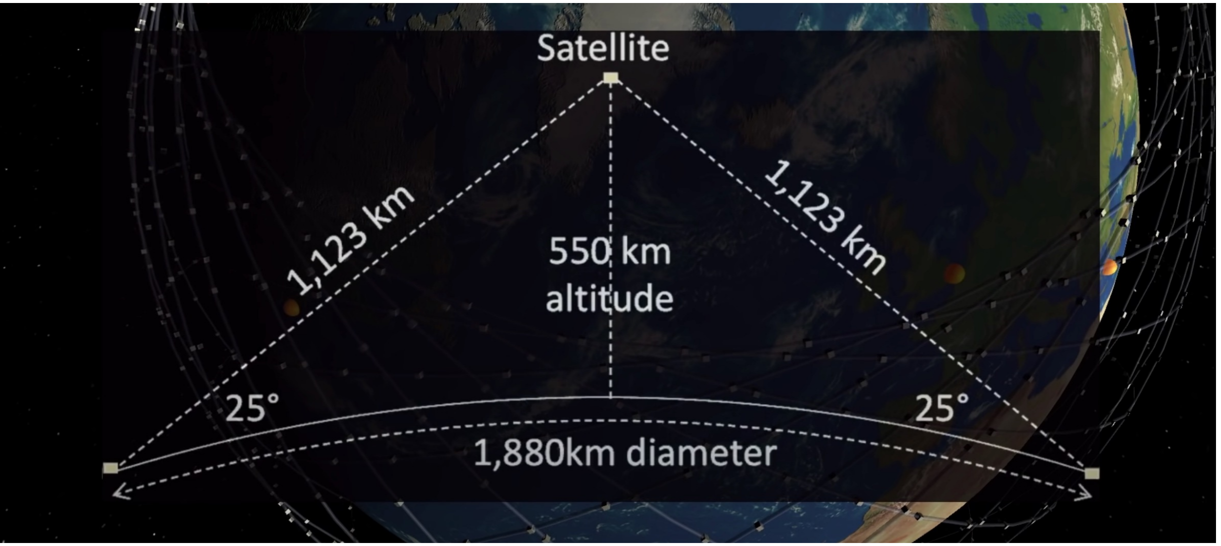
Image - spacex





screenshot from starwatch app

Starlink Constellation



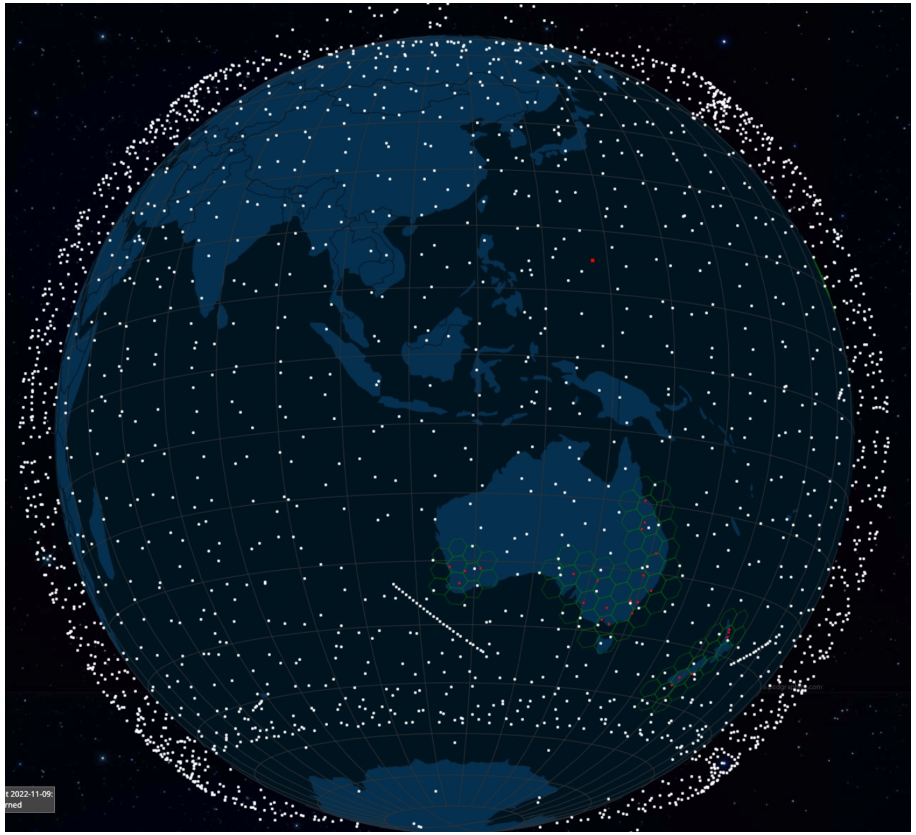
If you use a minimum angle of elevation of 25^o then at an altitude of 550km each satellite spans a terrestrial footprint of no more than ~900Km radius, or 2M K^2

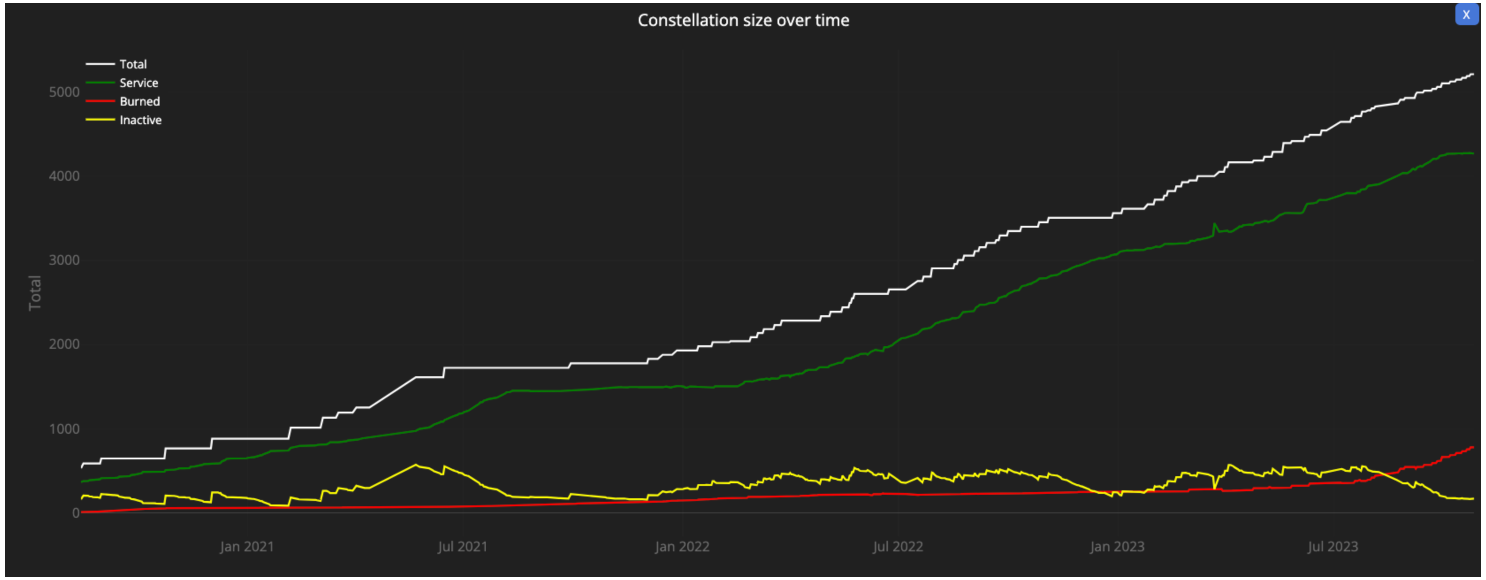
At a minimum, a LEO satellite constellation needs 500 satellites to provide coverage of all parts of the earth's surface

For high quality coverage the constellation will need 6x-20x that number (or more!)

Starlink Constellation

- 4,276 in-service operational spacecraft, operating at an altitude of 550km





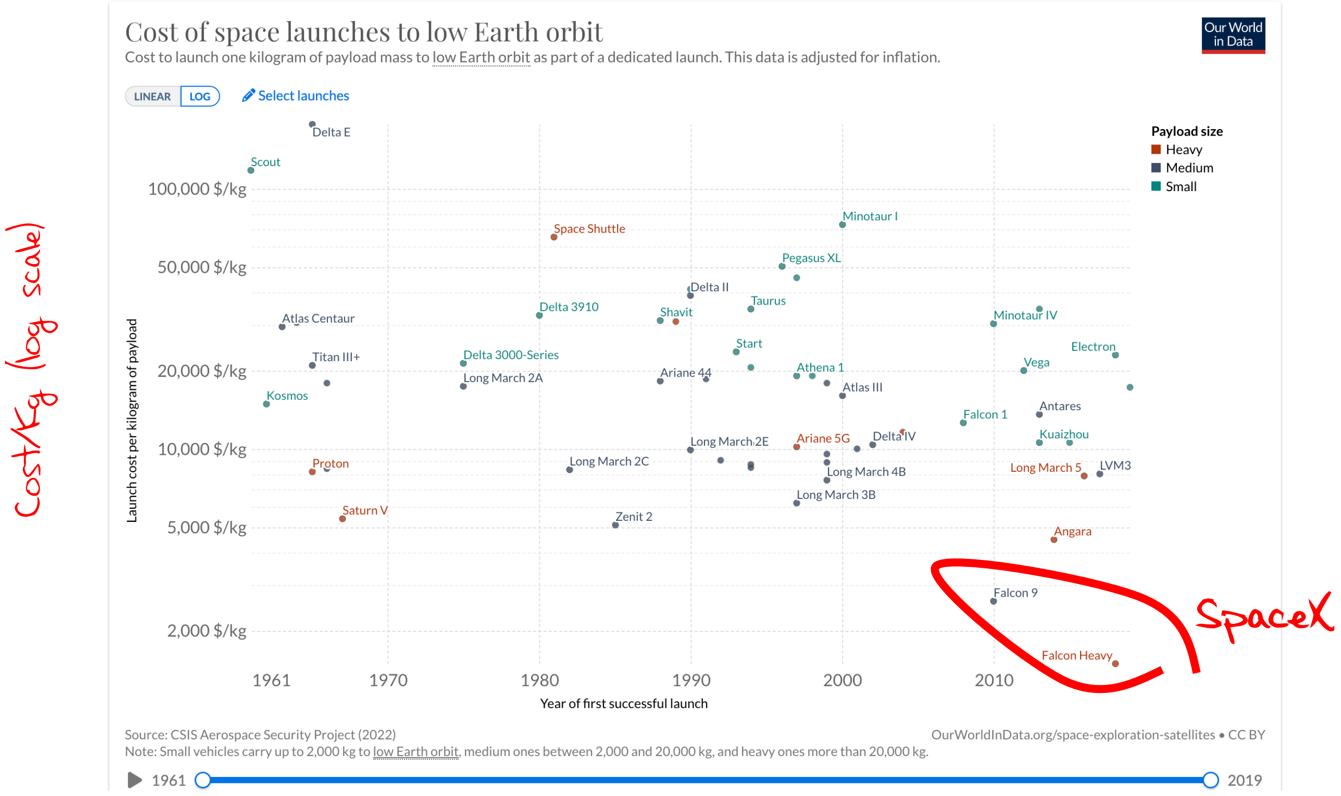
https://satellitemap.space/

So LEOs are "interesting"!

- They are very close to the Earth – which means:
  - They don't need specialised high-power equipment to send and receive signals
    - Even hand-held mobile devices can send and receive signals with a LEO!
  - They can achieve very high signal speeds
    - It's a highly focussed signal beam
  - They are harder to disrupt by external interference
- But you need a large number of them to provide a continuous service
- The extremely host cost of launching a large constellation of LEO spacecraft has been the major problem with LEO service until recently
  - Which is why Motorola's Iridium service went bankrupt soon after launch

What's changed recently?

- SpaceX's reusable rocket technology has slashed the cost of lifting spacecraft into low earth orbit



Time

https://ourworldindata.org/grapher/cost-space-launches-low-earth-orbit

So Many LEO Satellites!

SpaceX Starlink Gen 1	4,408
SpaceX Starlink Gen 2	29,988
OneWeb, Phase 1	718
OneWeb, Phase 2	6,372
Amazon Project Kuiper	7,774
China Guowang	12,992
Astra	13,620
Boeing	5,842
Globalstar	3,080
Lynk	2,000
Telesat Lightspeed	1,969
Spin Launch	1,190
TOTAL	**89,953**
E-Space	337,323

Current and Planned satellite constellations

What about Starlink Gen2?

- These satellites are larger, heavier and operate at a higher power level
- More bandwidth available, and high achievable data speeds
- Multiple orbital plans at a collection of discrete altitudes
- Incorporates 5G cellular services
- Will use inter-satellite laser connectors to support packet routing across satellites – details sparse so far, and it’s not clear how flexible this will be in terms of routing in the mesh

ISL in action

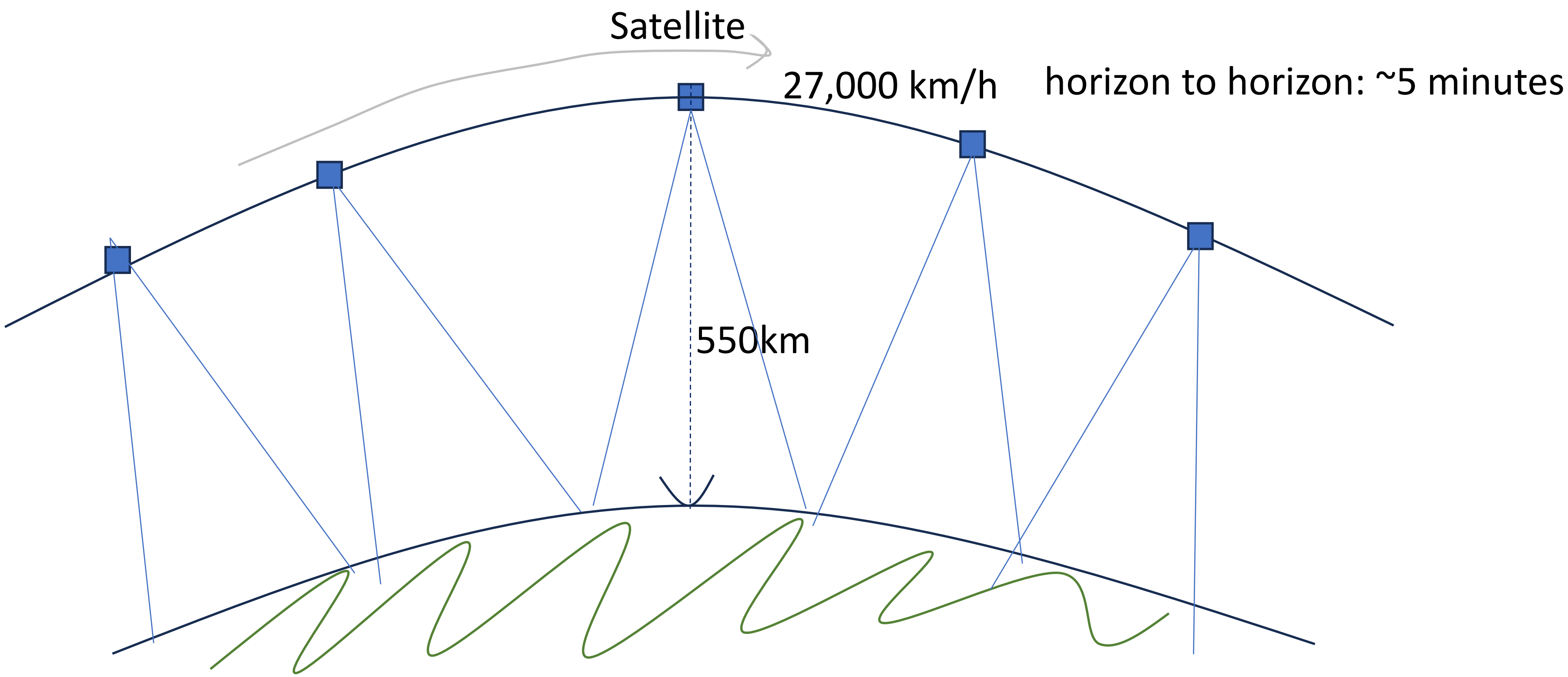
The introduction of ISL has allowed Starlink to extend its coverage area to the entirety of the Australian continent, and it manages this by relaying the signal between spacecraft to one that is within range of an earth station

ISL in Mongolia

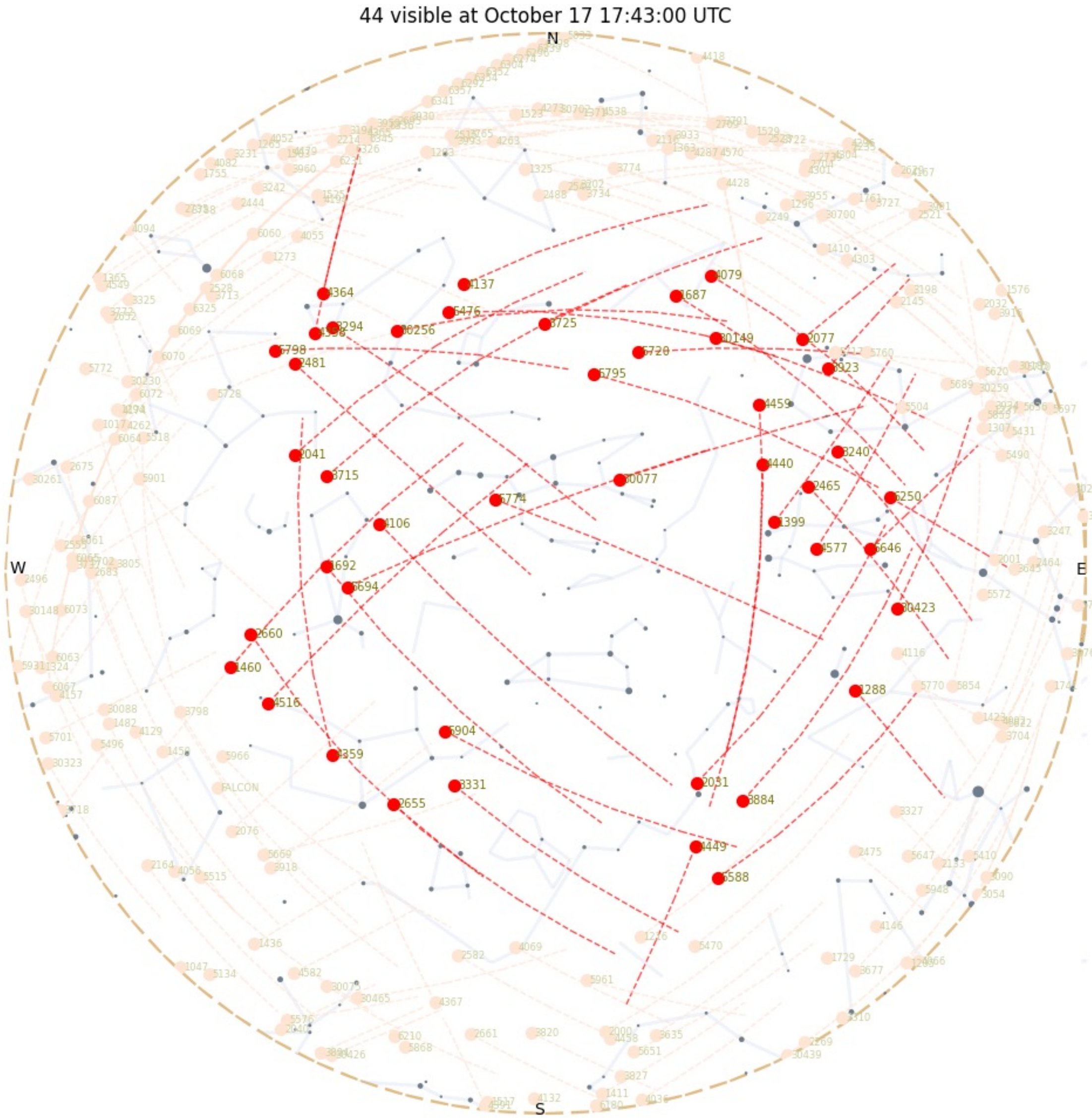

```
Tracing route to e-mongolia.mn [104.22.23.221]
over a maximum of 30 hops:

  1    <1 ms    <1 ms     1 ms  192.168.1.1
  2   149 ms   202 ms   202 ms  100.64.0.1
  3    77 ms    74 ms    82 ms  172.16.249.16
  4    87 ms    82 ms    82 ms  149.19.109.20
  5    80 ms    78 ms    91 ms  210.171.224.134
  6    86 ms    82 ms    83 ms  172.70.220.2
  7    80 ms    78 ms    74 ms  104.22.23.221
```

Use of ISL appears to add no more than ~20ms to the RTT in this case

Tracking a LEO satellite



Looking Up



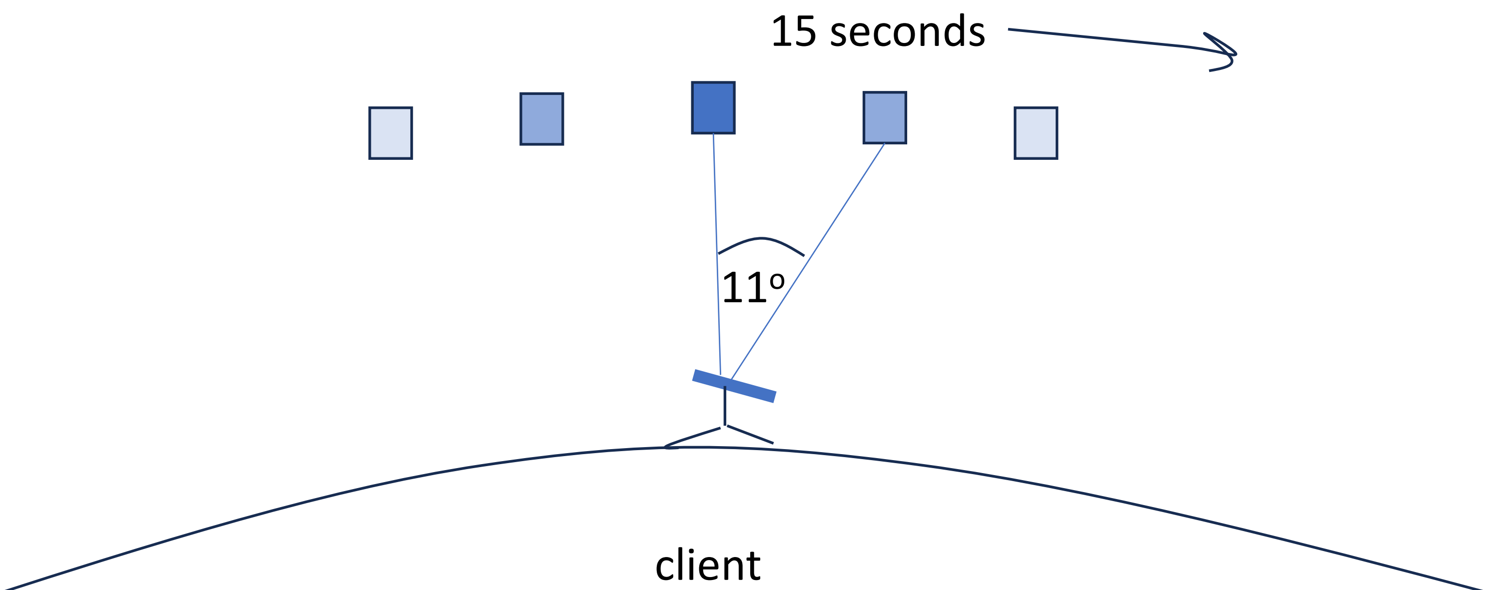
Starlink tracks satellites with a minimum elevation of 25°.

There are between 30 – 50 visible Starlink satellites at any point on the surface between latitudes 56° North and South

Each satellite traverses the visible aperture for a maximum of ~3 minutes

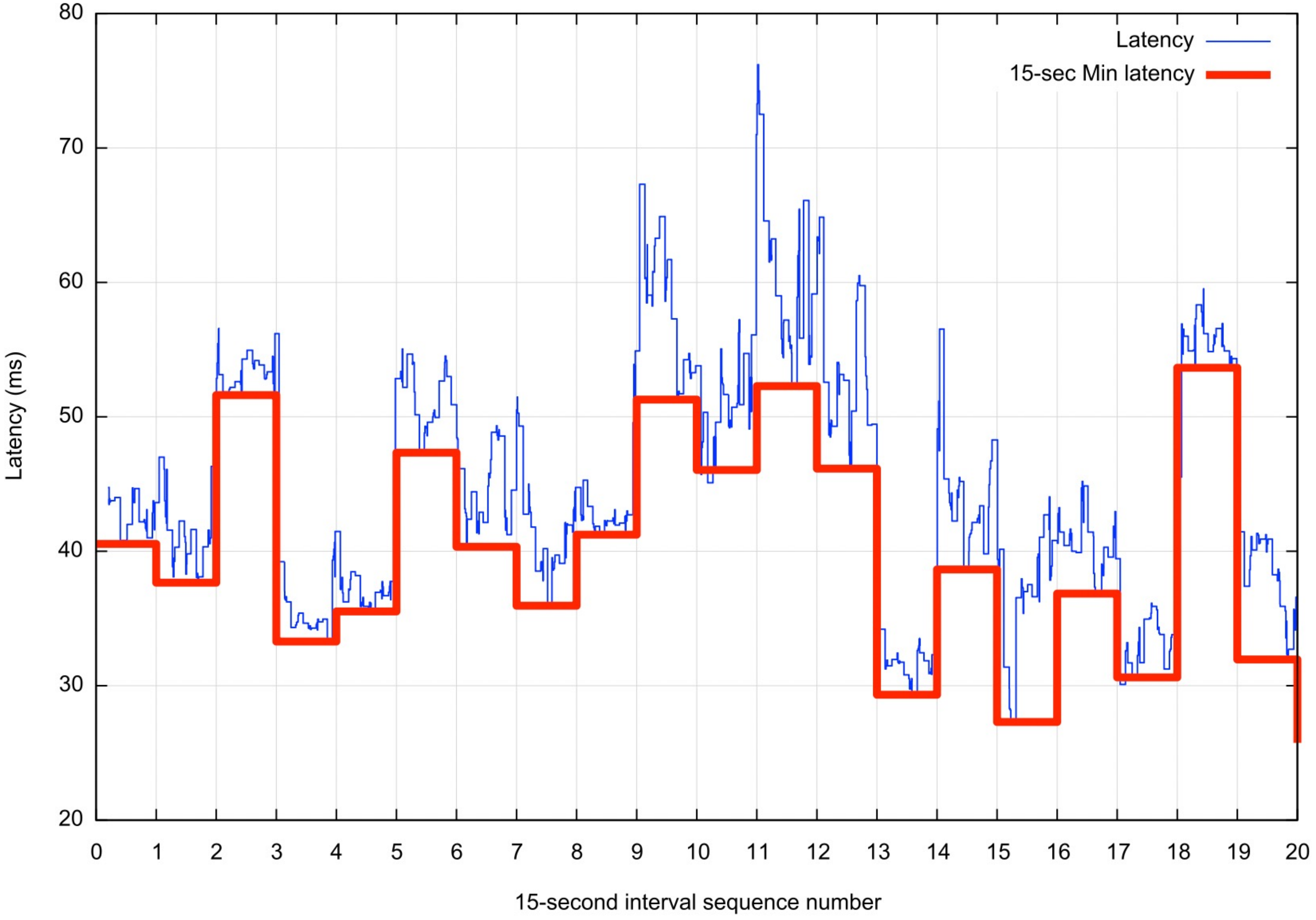
Starlink Scheduling

- A satellite is assigned to a user terminal in 15 second time slots
- Tracking of a satellite (by phased array focussing) works across 11 degrees of arc per satellite in each 15 second slot



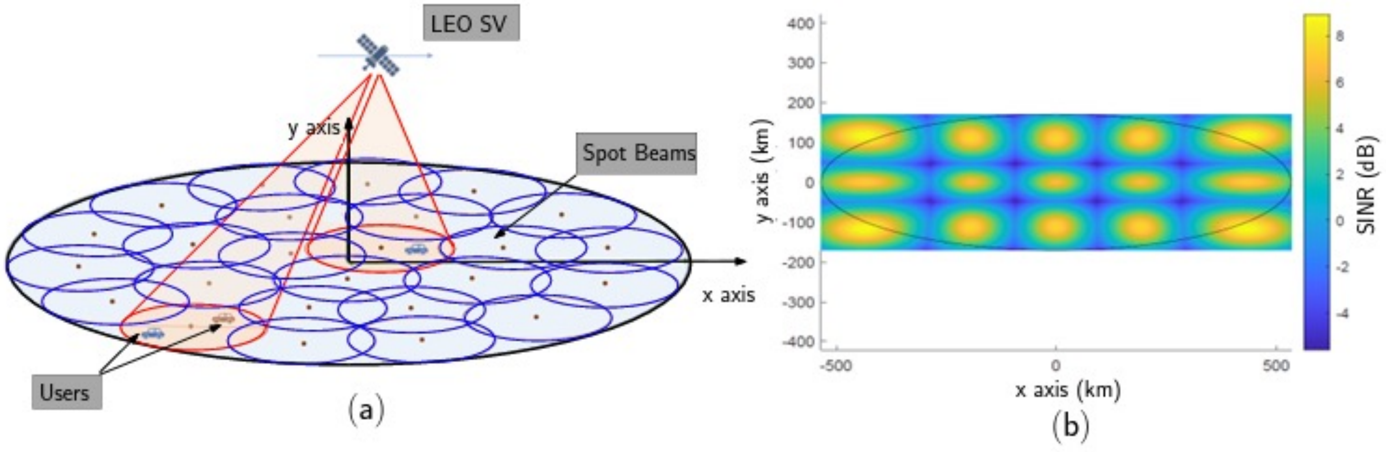
Starlink Scheduling

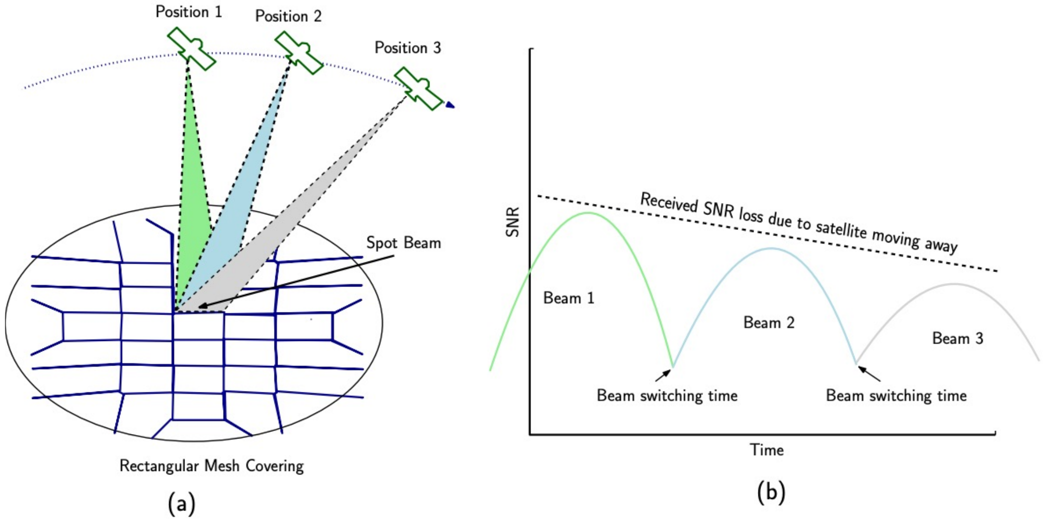
- Latency changes on each satellite switch
- If we take the minimum latency on each 15 second scheduling interval, we can expose the effects of the switching interval on latency
- Across the 15 second interval there will be a drift in latency according to the satellite's track and the distance relative to the two earth points
- Other user traffic will also impact on latency, and also the effects of a large buffer in the user modem



Starlink Spot Beams

- Each spacecraft 2,000 MHz of spectrum for user downlink and splits it into 8x channels of 250 MHz each
- Each satellite has 3 downlink antennas and 1 uplink antennas, and each can do 8 beams x 2 polarizations, for a total of 48 beams down and 16 up.





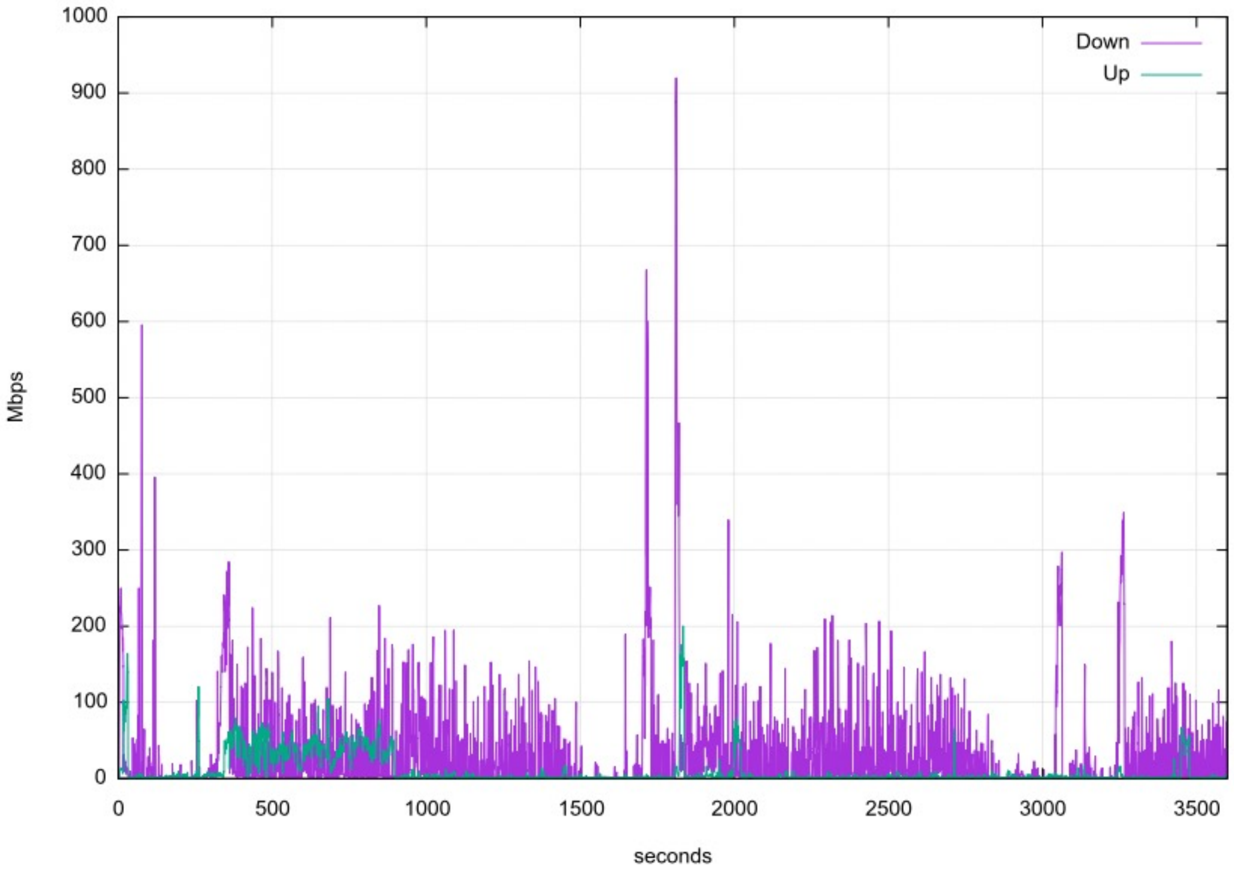
"Unveiling Beamforming Strategies of Starlink LEO Satellites"

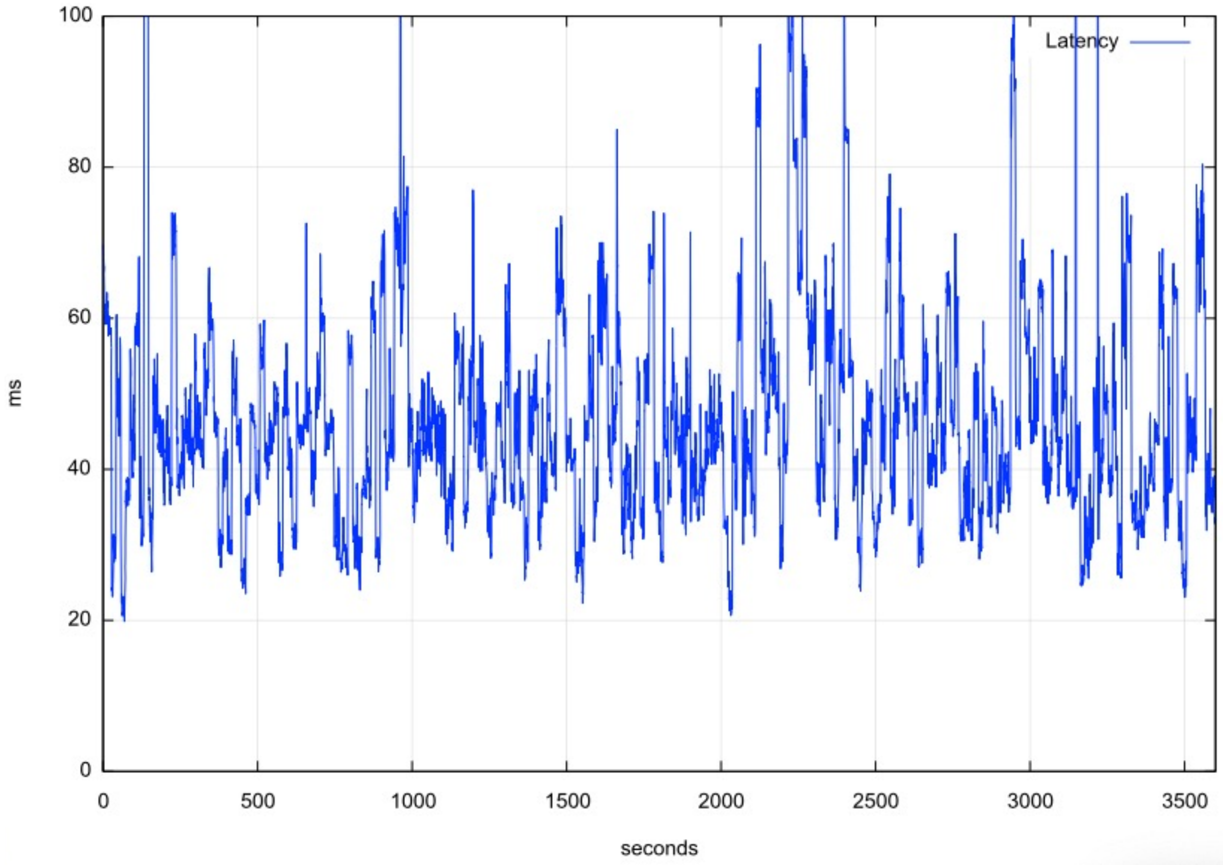
https://people.engineering.osu.edu/sites/default/files/2022-10/Kassas_Unveiling_Beamforming_Strategies_of_Starlink_LEO_Satellites.pdf

Starlink's reports

```
$ starlink-grpc-tools/dish_grpc_text.py -v  status
id:                     ut01000000-00000000-005dd555
hardware_version:       rev3_proto2
software_version:       5a923943-5acb-4d05-ac58-dd93e72b7862.uterm.release
state:                  CONNECTED
uptime:                 481674
snr:
seconds_to_first_nonempty_slot: 0.0
pop_ping_drop_rate:     0.0
downlink_throughput_bps: 16693.330078125
uplink_throughput_bps:  109127.3984375
pop_ping_latency_ms:    49.5
Alerts bit field:       0
fraction_obstructed:    0.04149007424712181
currently_obstructed:   False
seconds_obstructed:
obstruction_duration:   1.9579976797103882
obstruction_interval:   540.0
direction_azimuth:      -42.67951583862305
direction_elevation:    64.61225128173828
is_snr_above_noise_floor: True
```

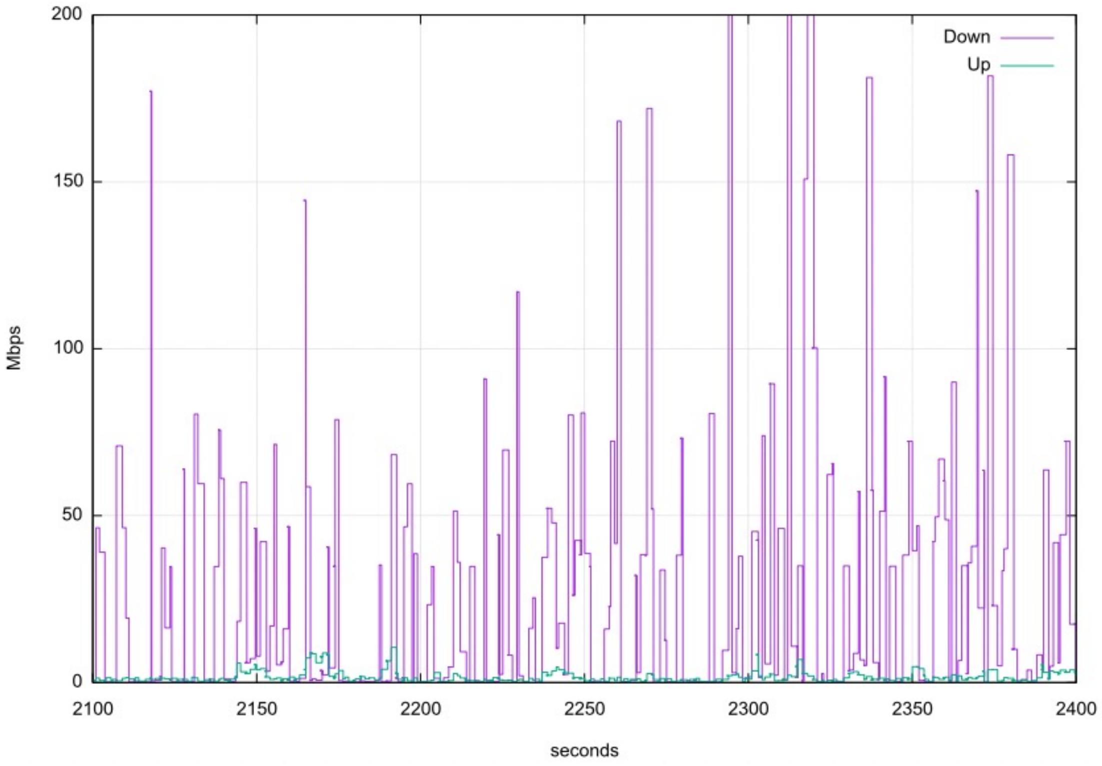
Reported Capacity & Latency

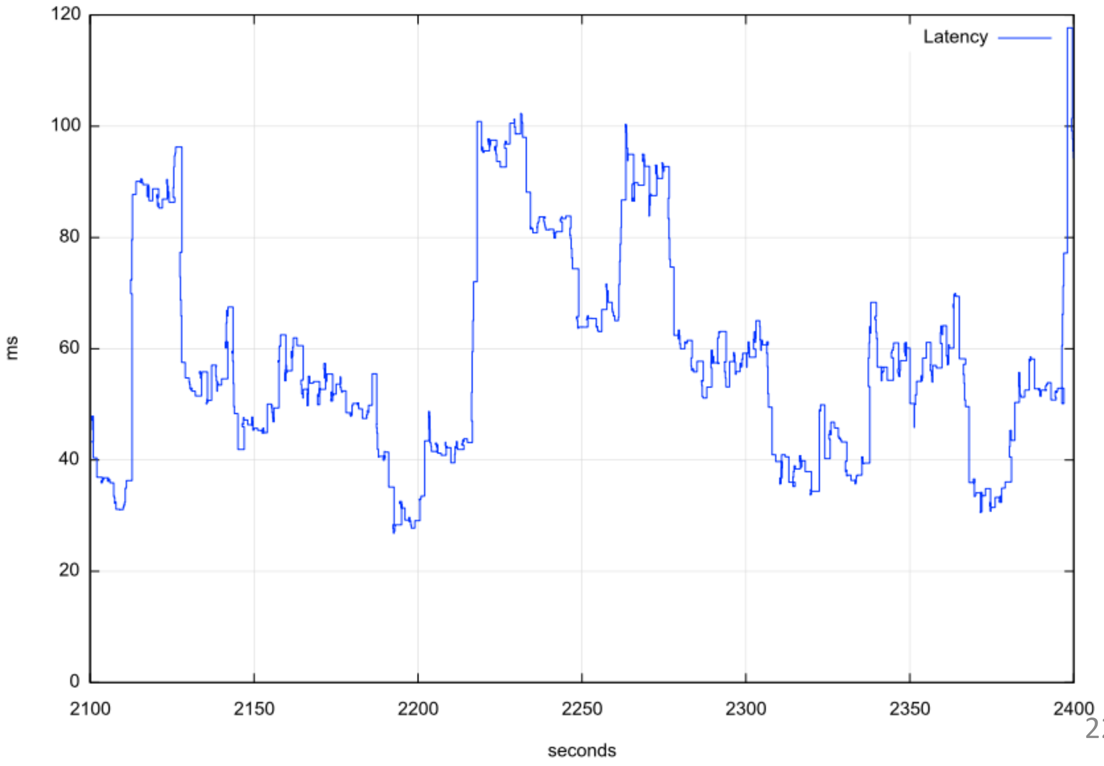




Reported Capacity & Latency

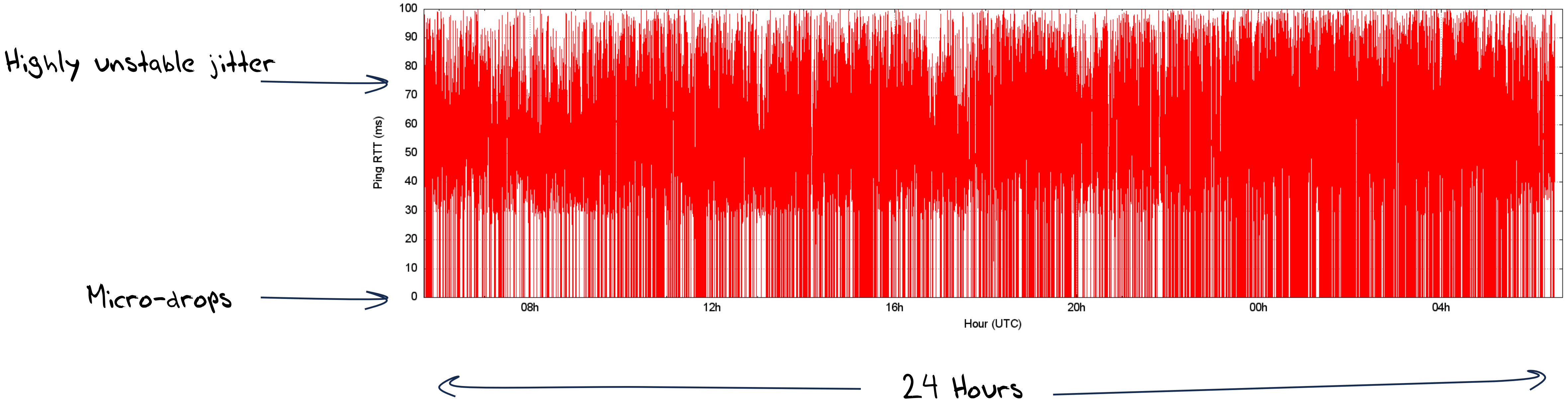
- This is going to present some interesting issues for conventional TCP
- TCP uses ACK pacing which means it attempts to optimize its sending rate over multiple RTT intervals
- The variation in latency and capacity occurs at high frequency, which means that TCP control is going to struggle to optimize itself against a shifting target





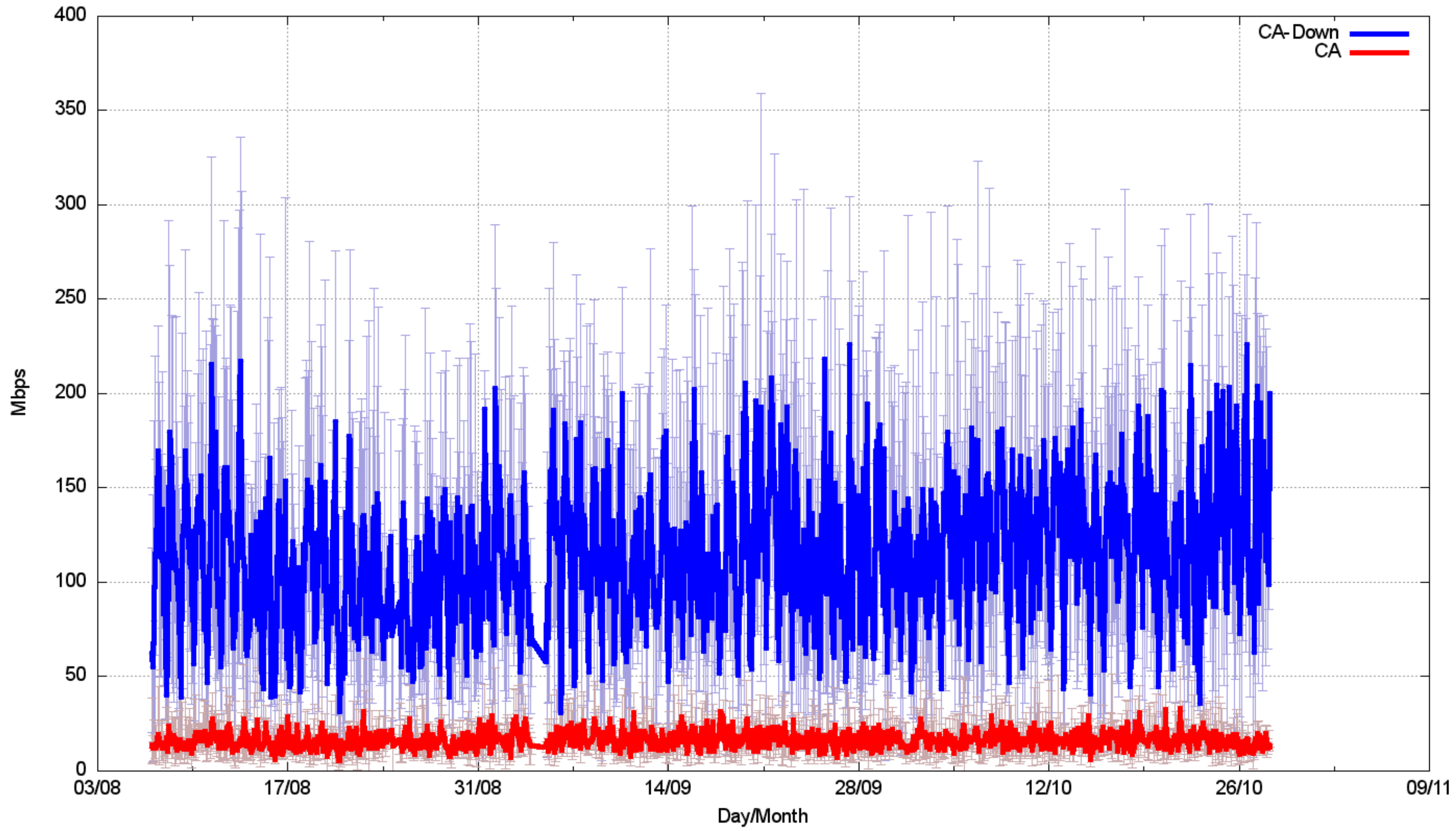
Link Characteristics

1-second ping



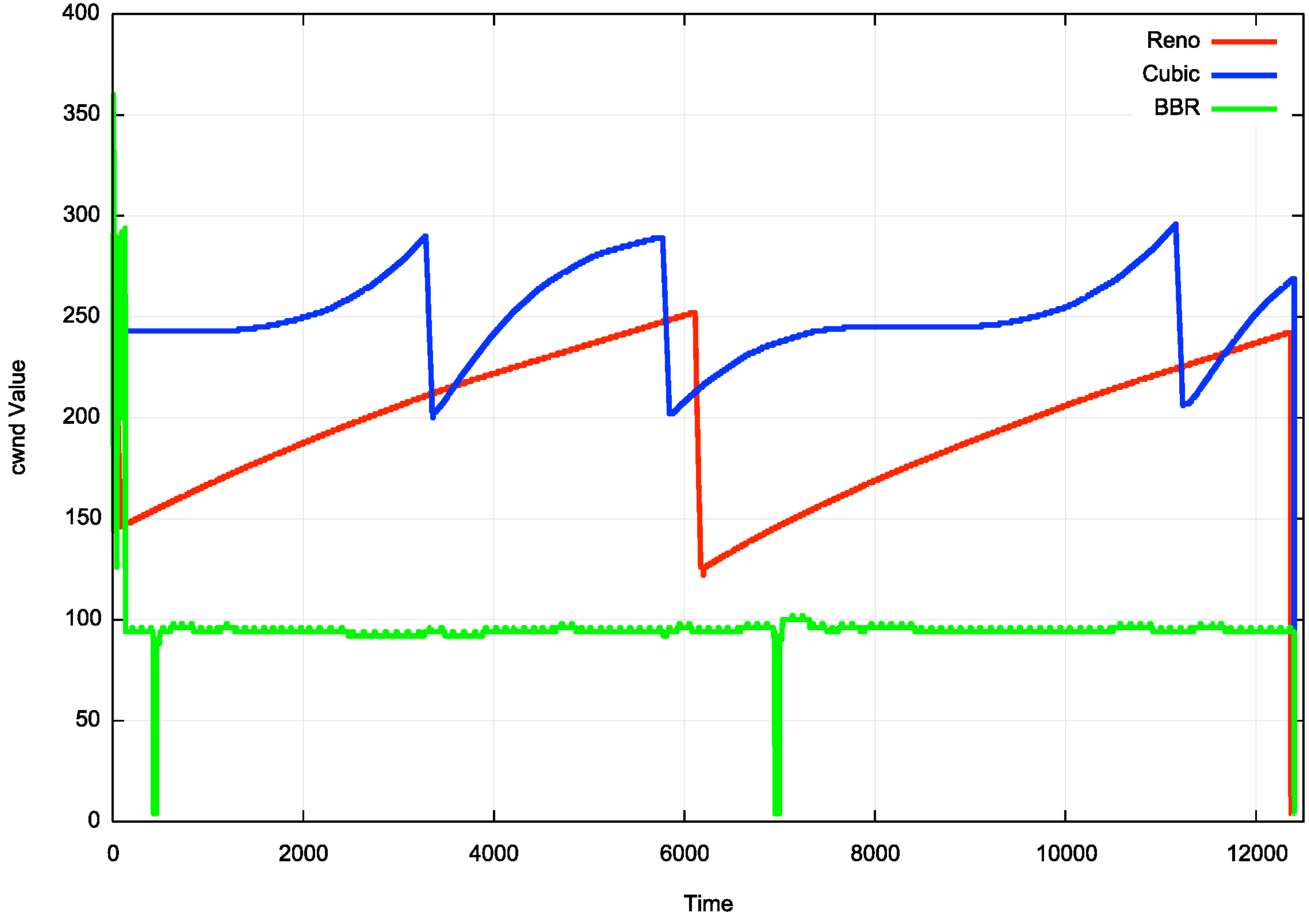
How well does all this work?

Speedtest measurements:



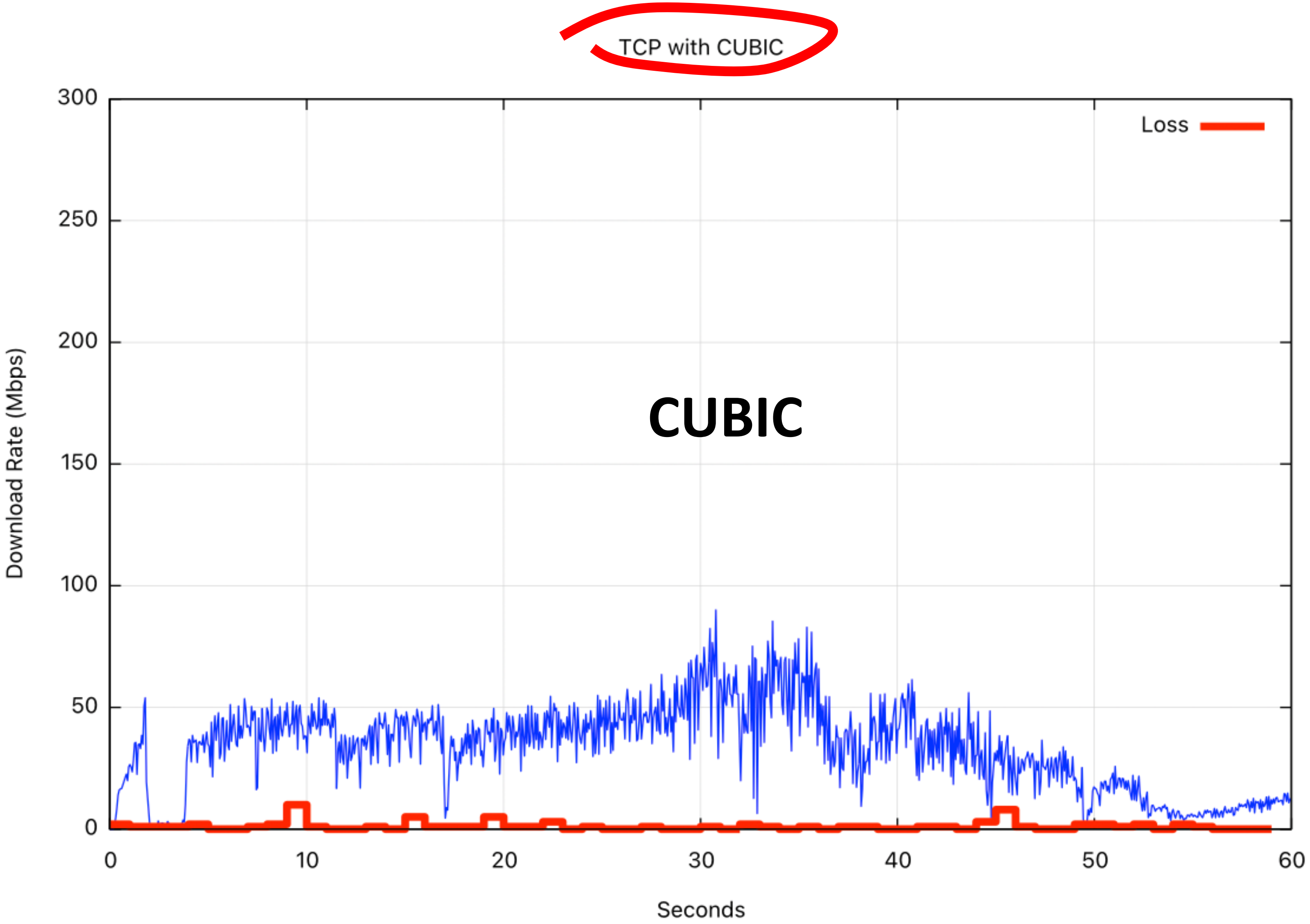
We should be able to get ~120Mbps out of a starlink connection. Right?

TCP Flow Control Algorithms



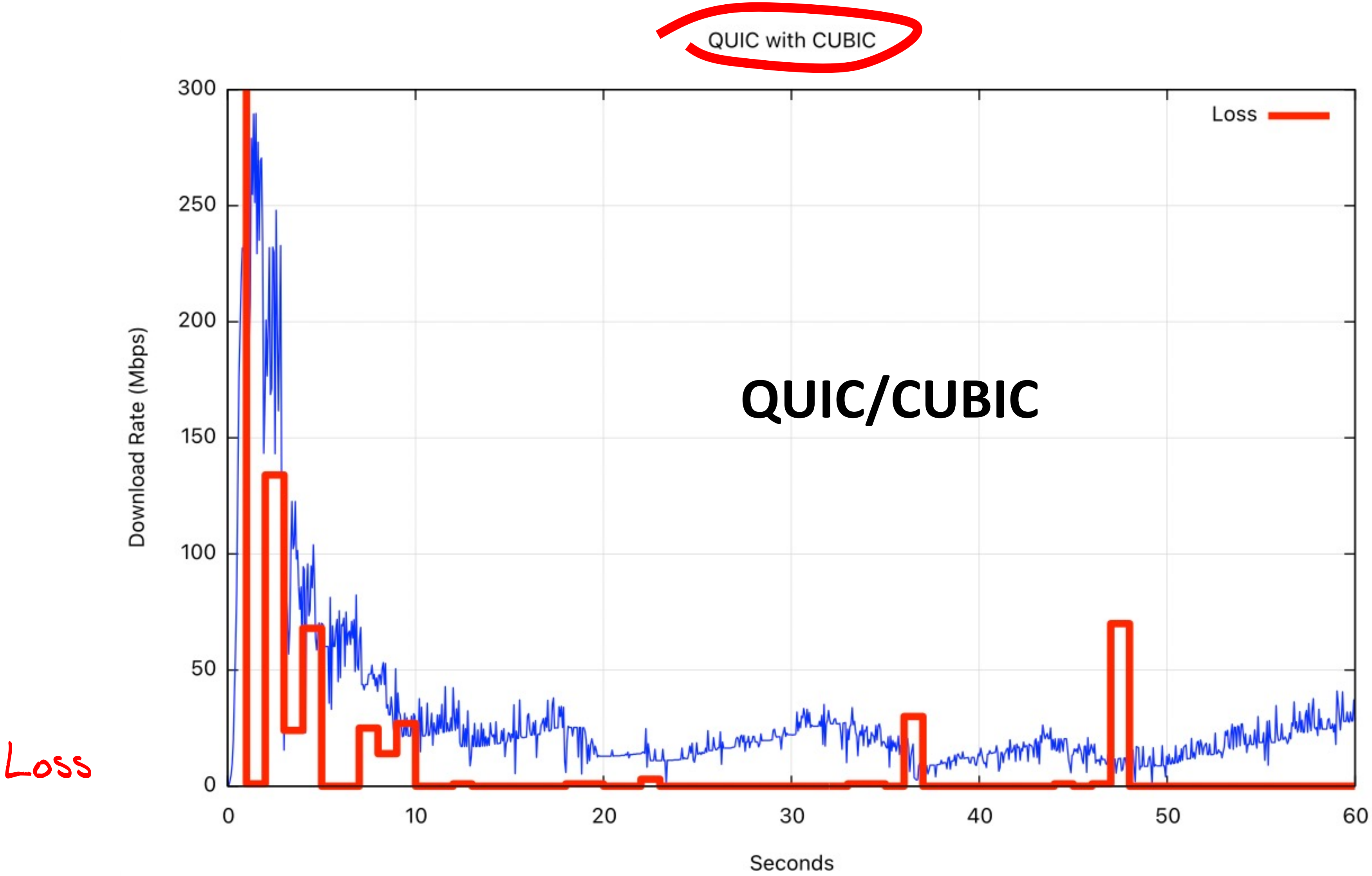
"Ideal" Flow behaviour for each protocol

iperf3 - cubic, 60 seconds

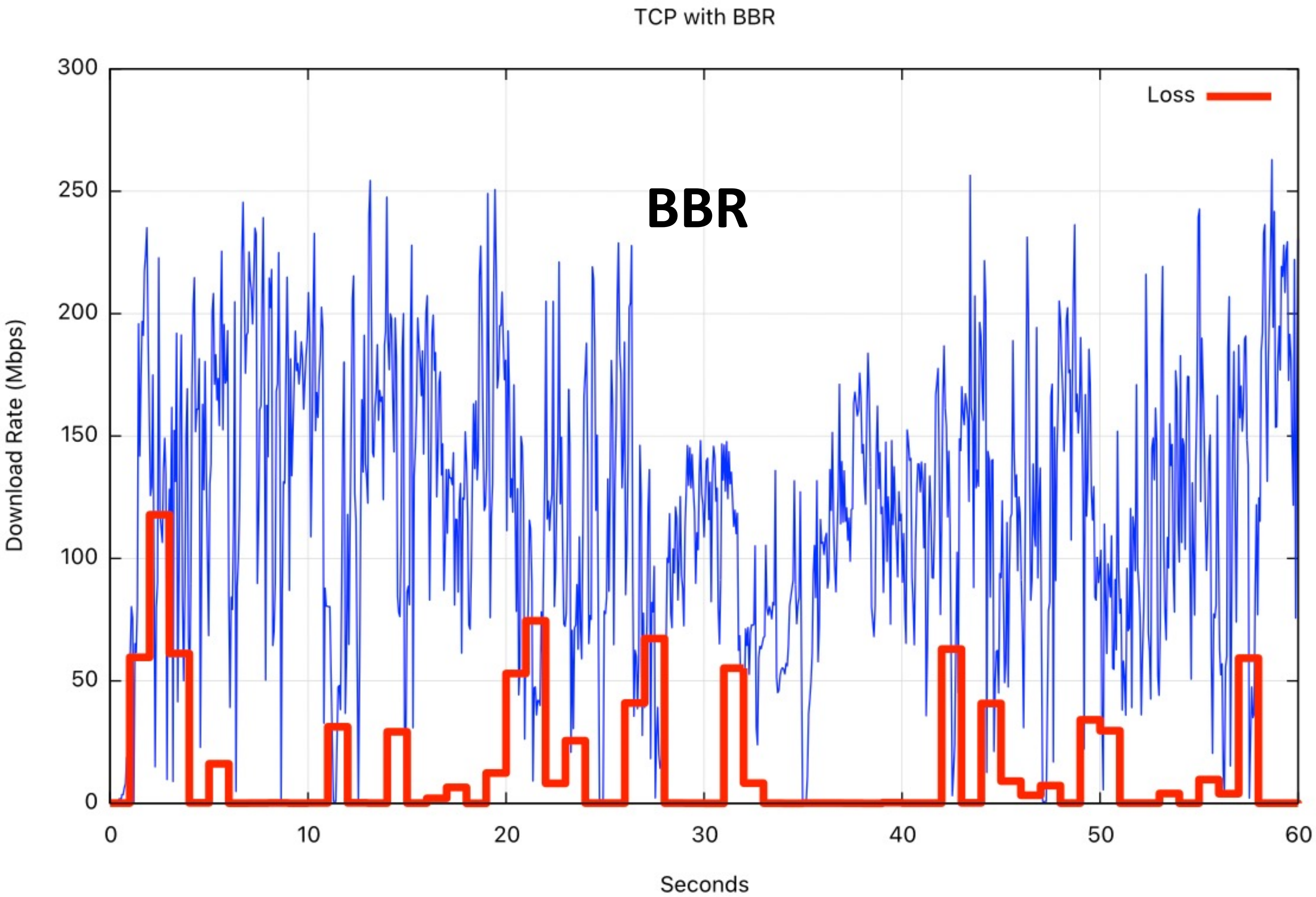


Loss

Qperf - quic (with cubic)

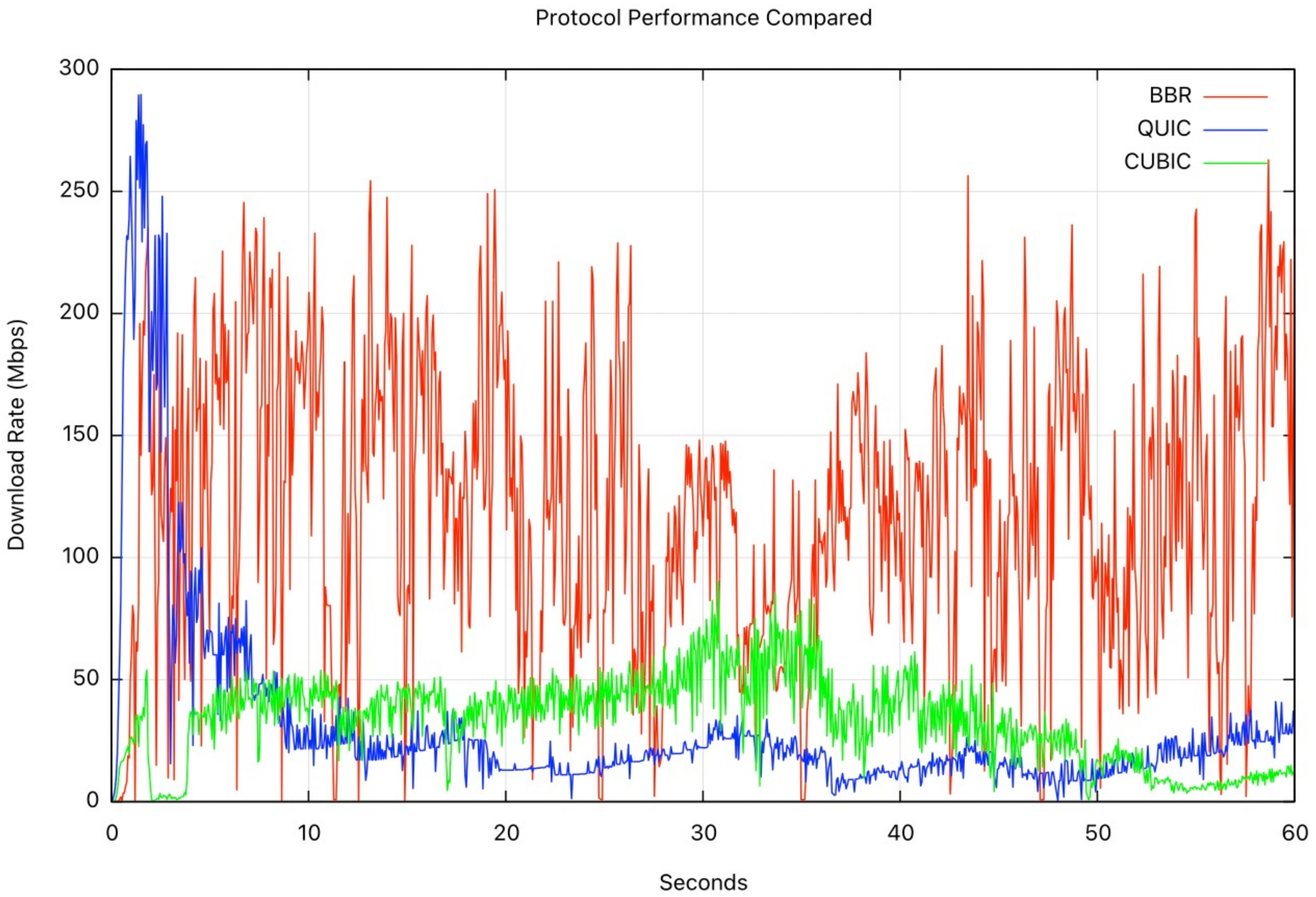


iperf3 - bbr



Loss

Cubic, Quic/Cubic, BBR



Protocol Considerations

- Starlink services have two issues:
  - Very high jitter rates
  - High levels of micro-loss
- Loss-based flow control algorithms will over-react and pull back the sending rate over time
  - Short transactions work very well
  - Paced connections (voice, zoom, video streaming) tend to work well most of the time
  - Bulk data transfer, not so much
- You need to move to less loss-sensitive flow control algorithms, such as BBR to get good performance out of these services

I don't want to leave you with the wrong impression of Starlink

Starlink is perfectly acceptable for:

- short transactions
- video streaming
- conferencing

- The service can sustain 10 – 20Mbps delivery for long-held sessions
  - The isolated drop events generally do not intrude into the session state
- And it can be used in all kinds of places where existing wire and mobile radio systems either under-perform or aren’t there at all!
- Its probably not the best trunk infrastructure service medium, but it’s a really good high speed last mile direct retail access service, particularly for remote locations!
- Its also very challenging to jam!


Questions?