Starlink Protocol Performance

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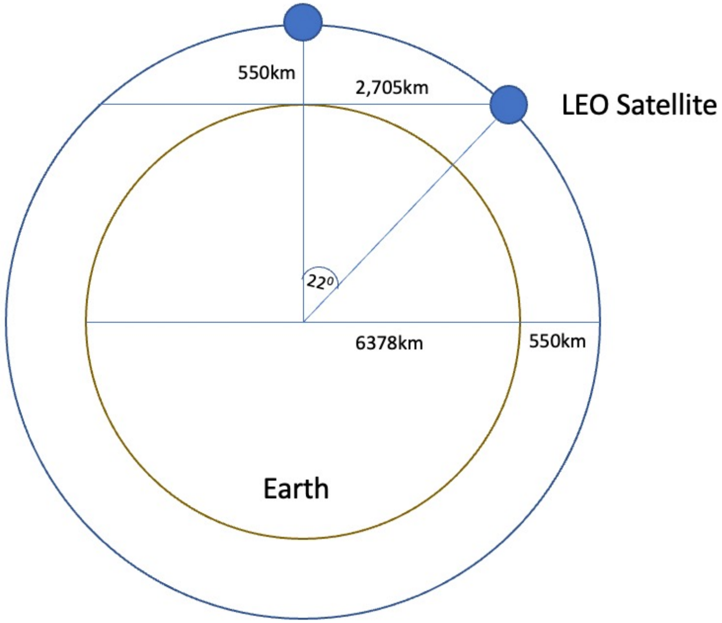
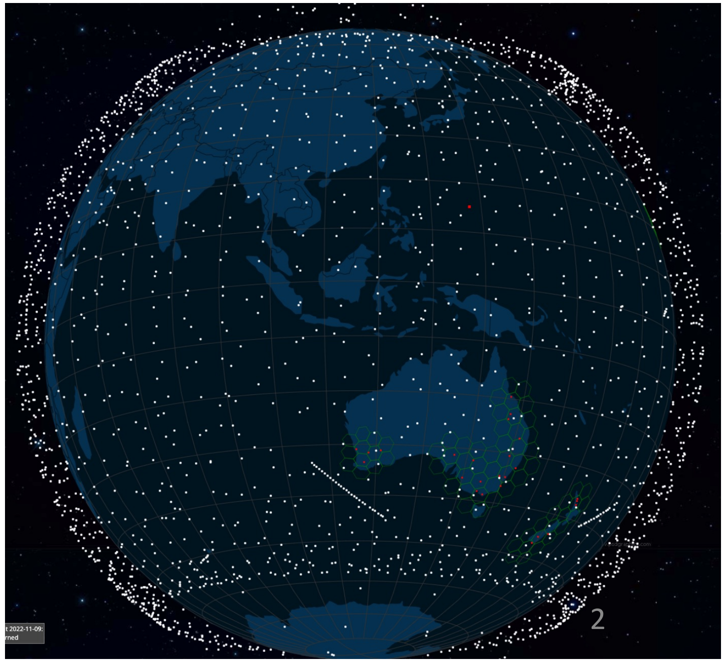
Low Earth Orbit

- LEO satellites are stationed between 160km and 2,000km in altitude
- High enough to stop them slowing down by "grazing" the denser parts of the earth's ionosphere
- Not so high that they lose 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, and at the horizon its 18ms

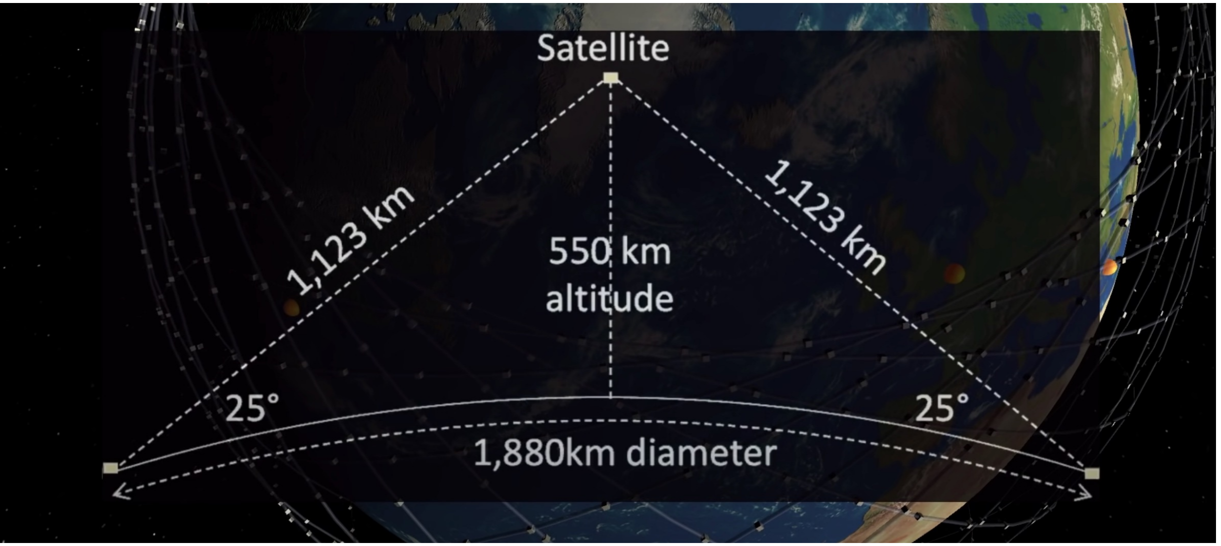
Image - spacex





screenshot from starwatch app

Starlink Constellation



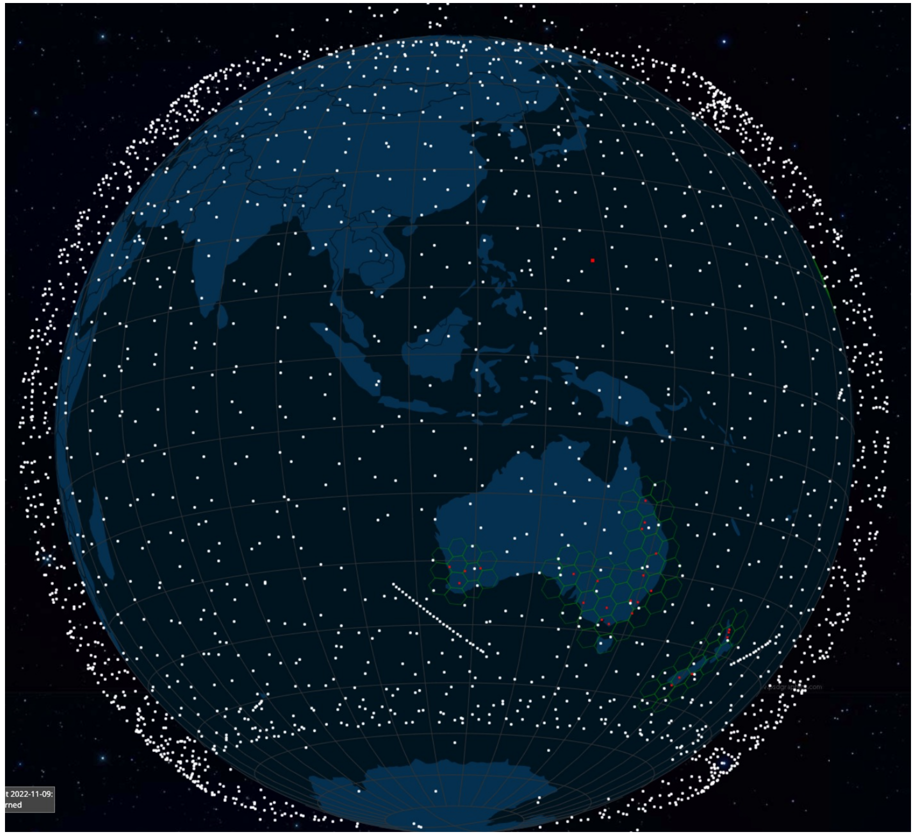
If you use a minimum angle of elevation of 25^o then at an altitude of 550km each satellite spans a terrestrial footprint of no more than ~900Km radius, or 2M K^2

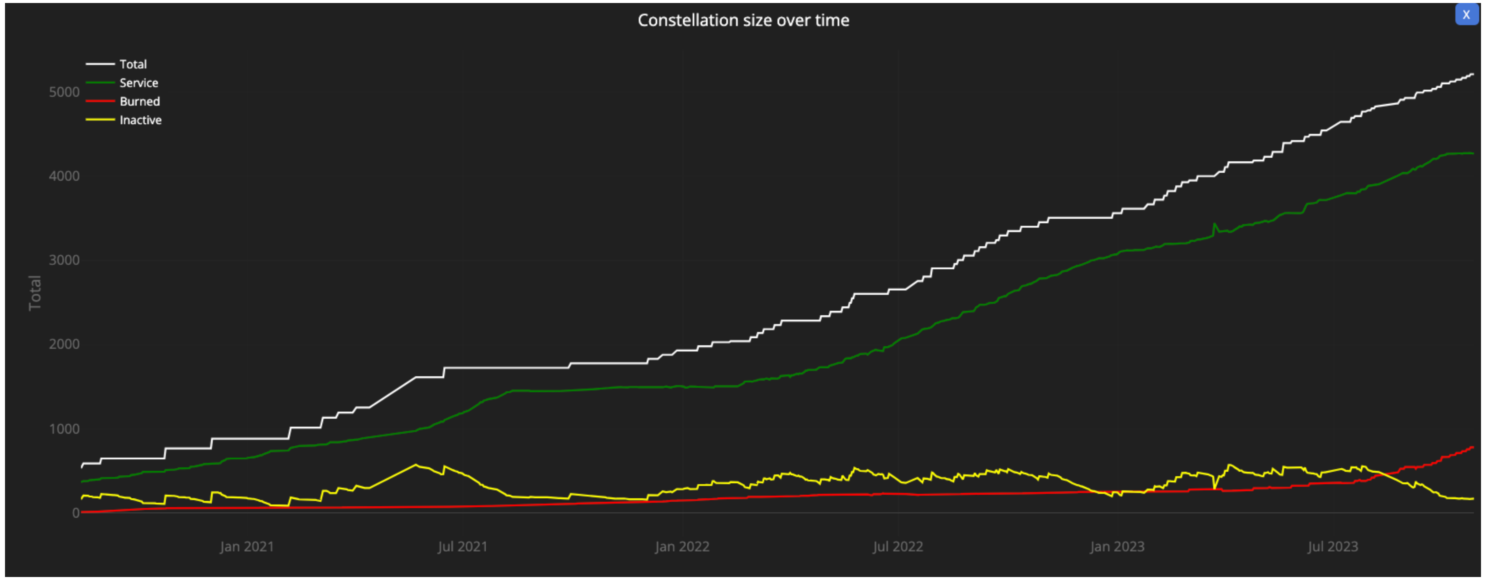
At a minimum, a LEO satellite constellation needs 500 satellites to provide coverage of all parts of the earth’s surface

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

Starlink Constellation

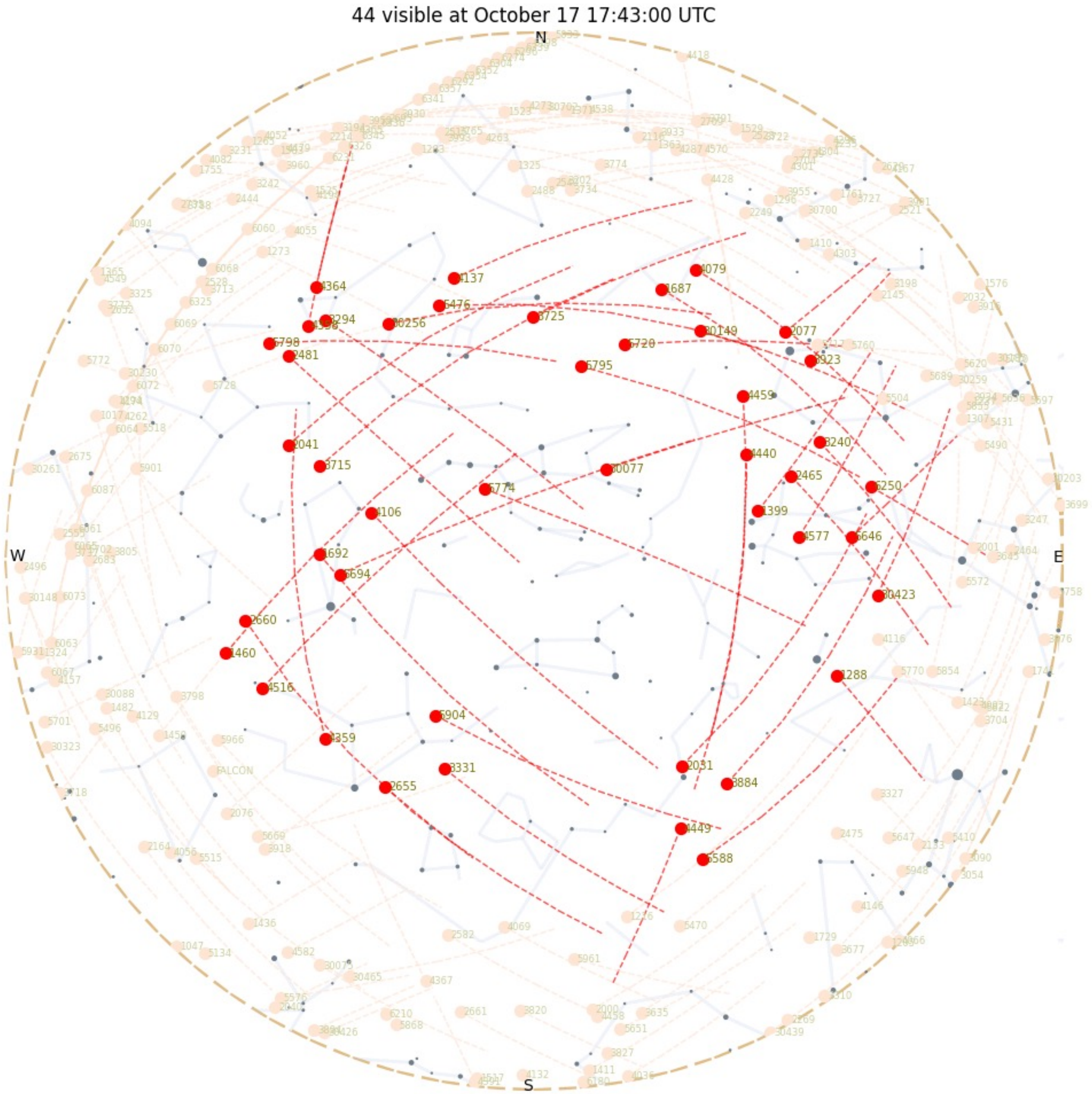
- 4,276 in-service operational spacecraft, operating at an altitude of 550km





https://satellitemap.space/

Looking Up



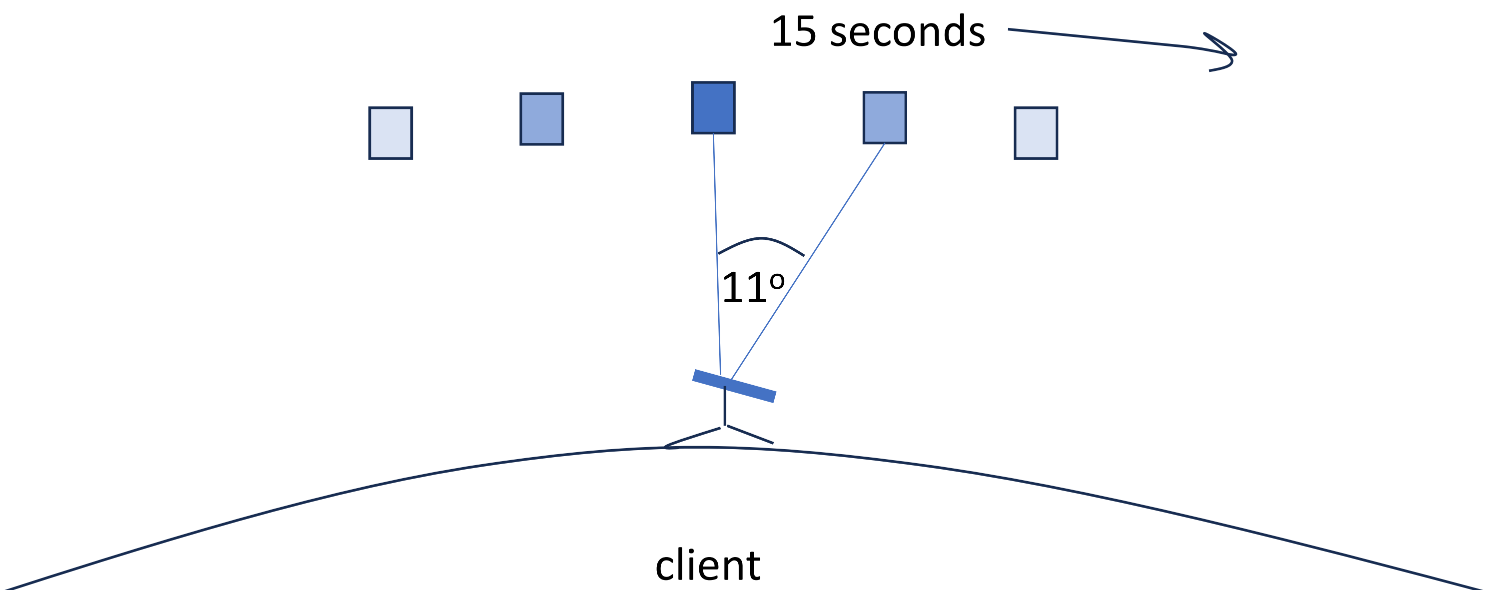
Starlink tracks satellites with a minimum elevation of 25°.

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

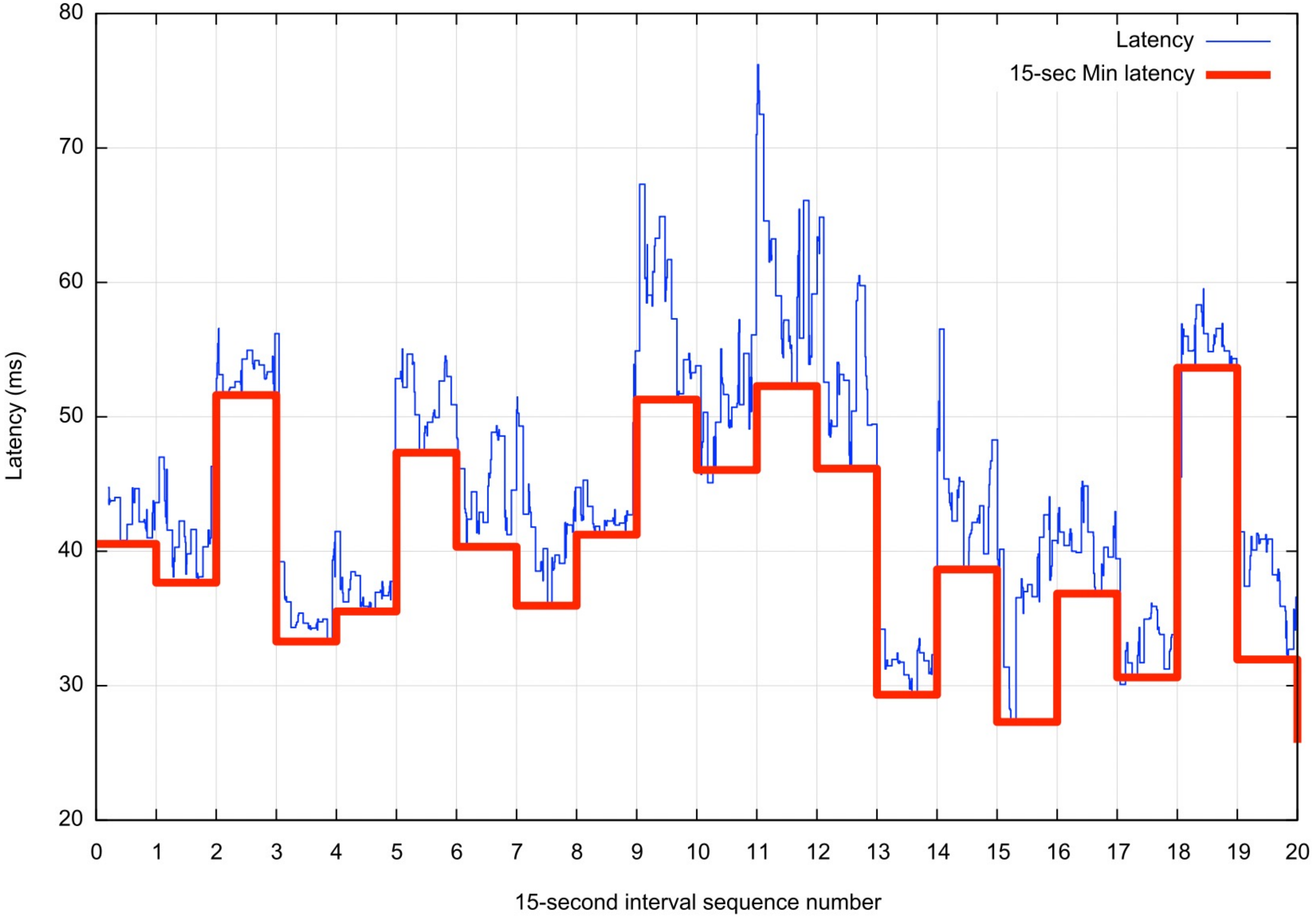
Starlink Scheduling

- 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



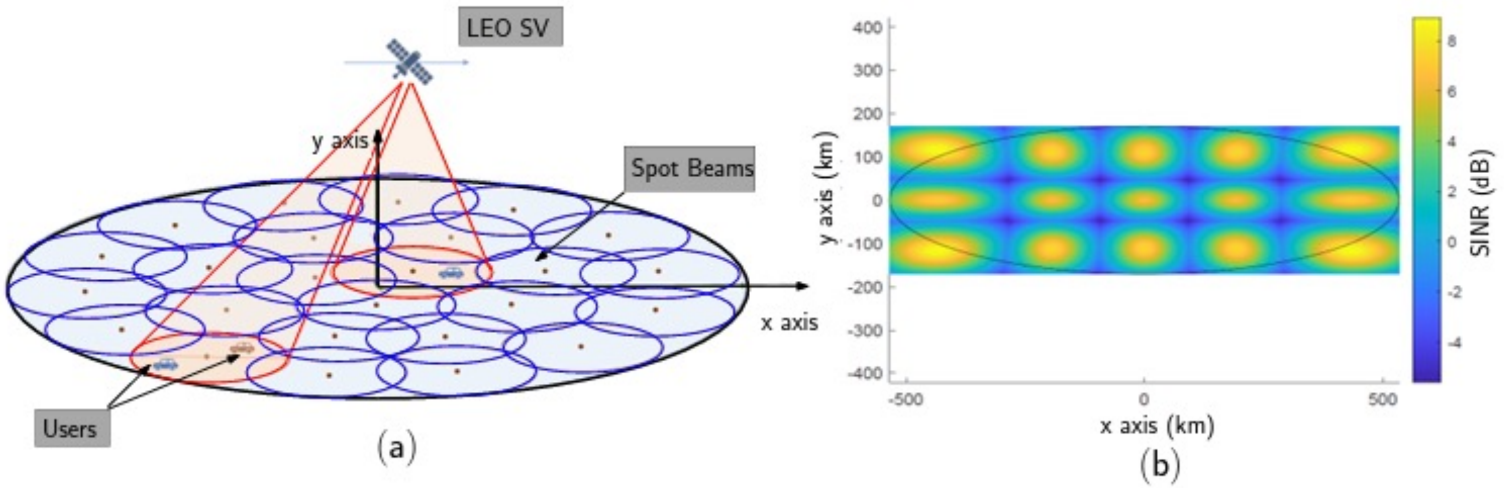
Starlink Scheduling

- 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.

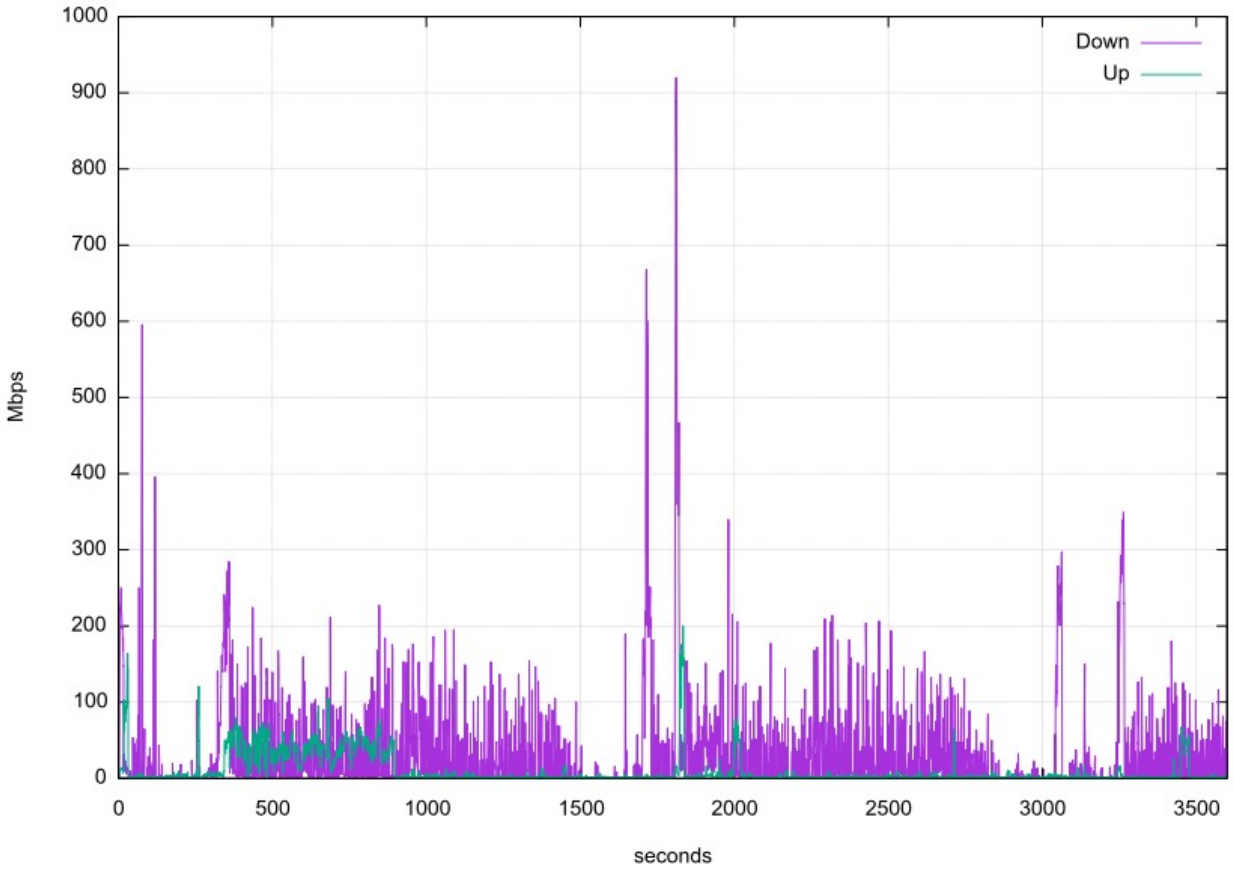


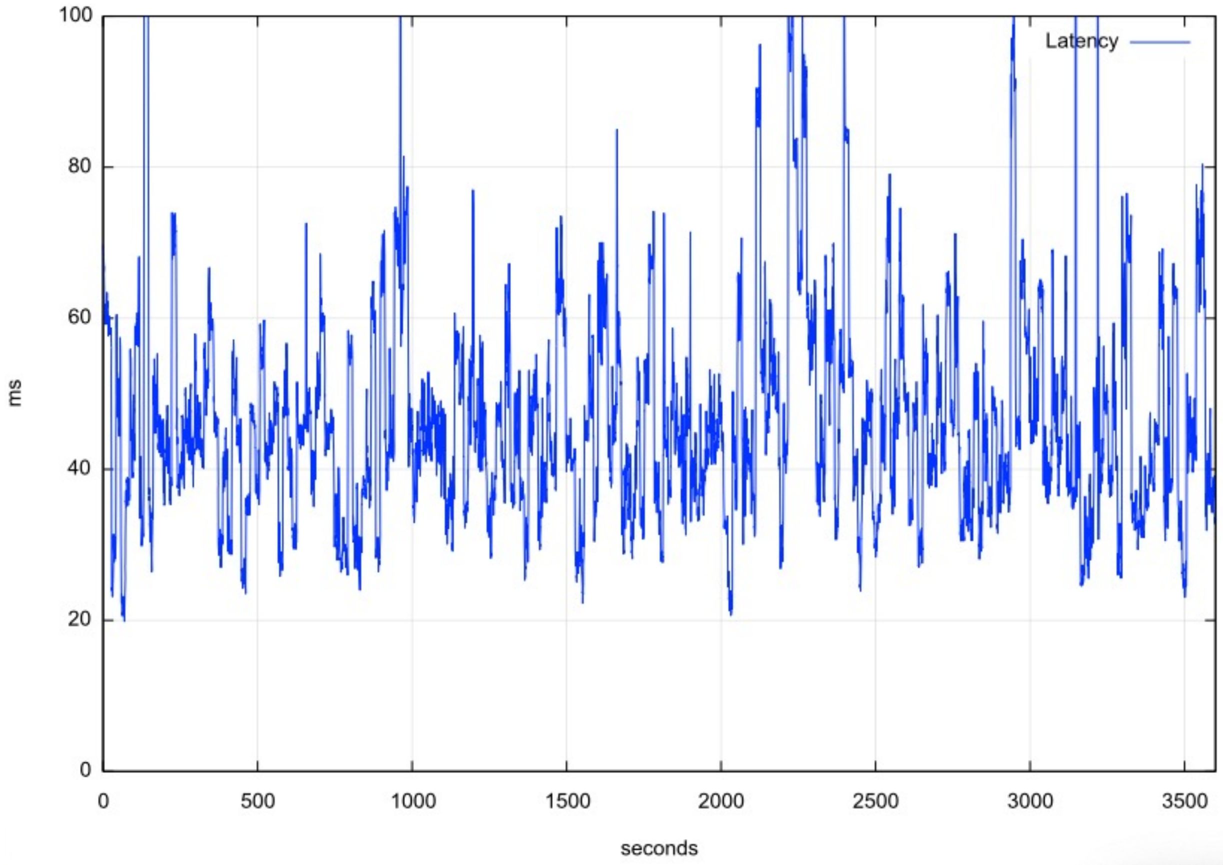
“Unveiling Beamforming Strategies of Starlink LEO Satellites”
https://people.engineering.osu.edu/sites/default/files/2022-10/Kassas_Unveiling_Beamforming_Strategies_of_Starlink_LEO_Satellites.pdf

Starlink's reports

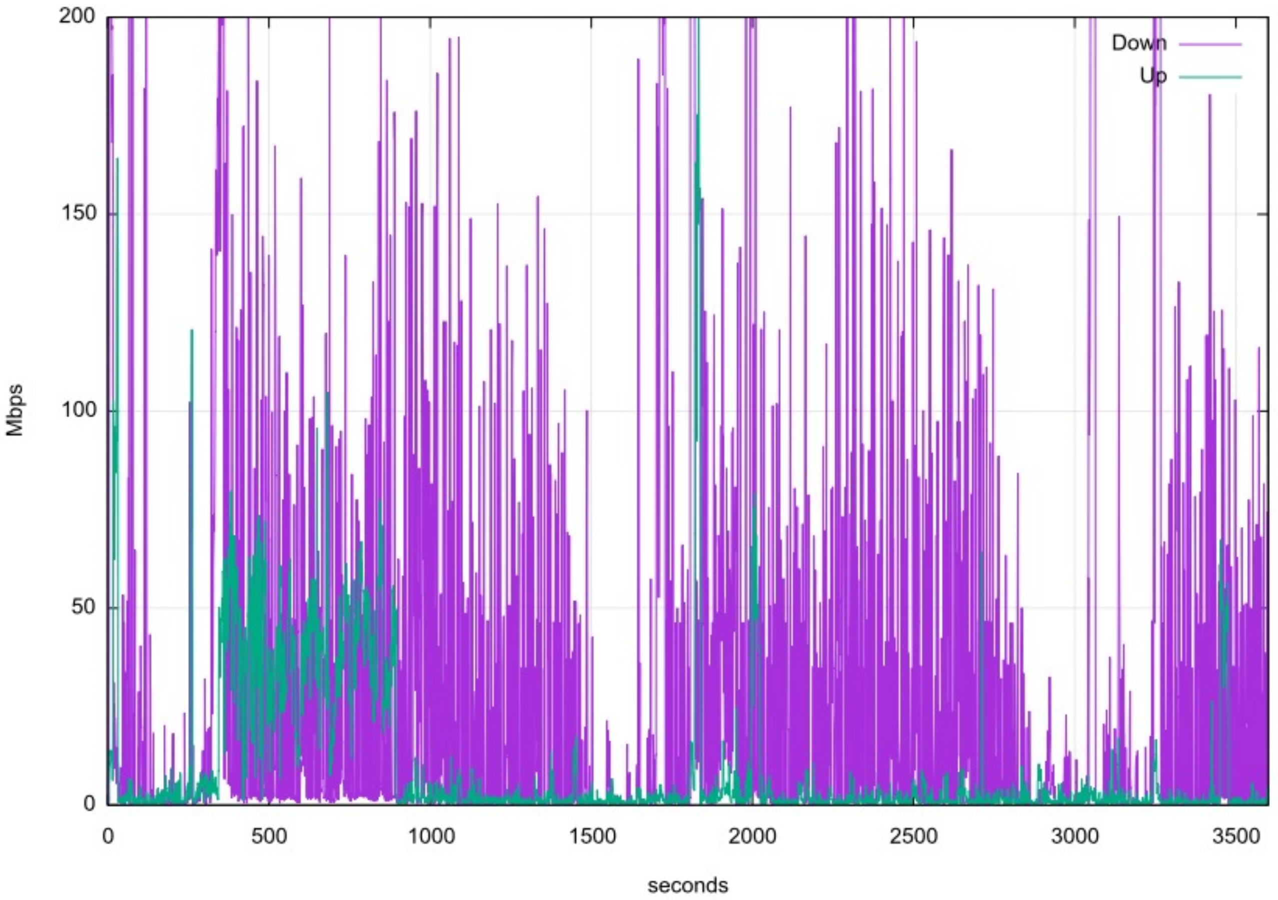
```
$ starlink-grpc-tools/dish_grpc_text.py -v  status
id:                     ut01000000-00000000-005dd555
hardware_version:       rev3_proto2
software_version:       5a923943-5acb-4d05-ac58-dd93e72b7862.uterm.release
state:                  CONNECTED
uptime:                 481674
snr:
seconds_to_first_nonempty_slot: 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
```

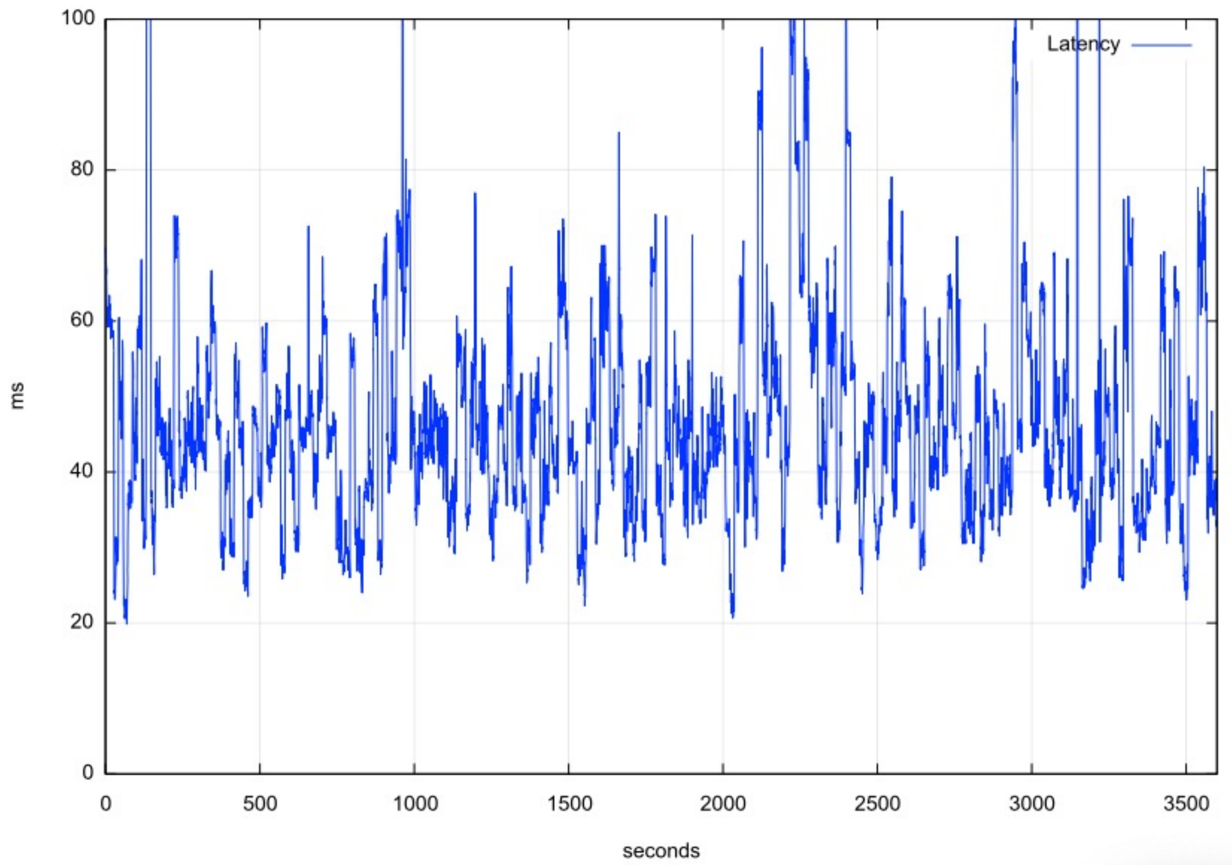
Reported Capacity & Latency





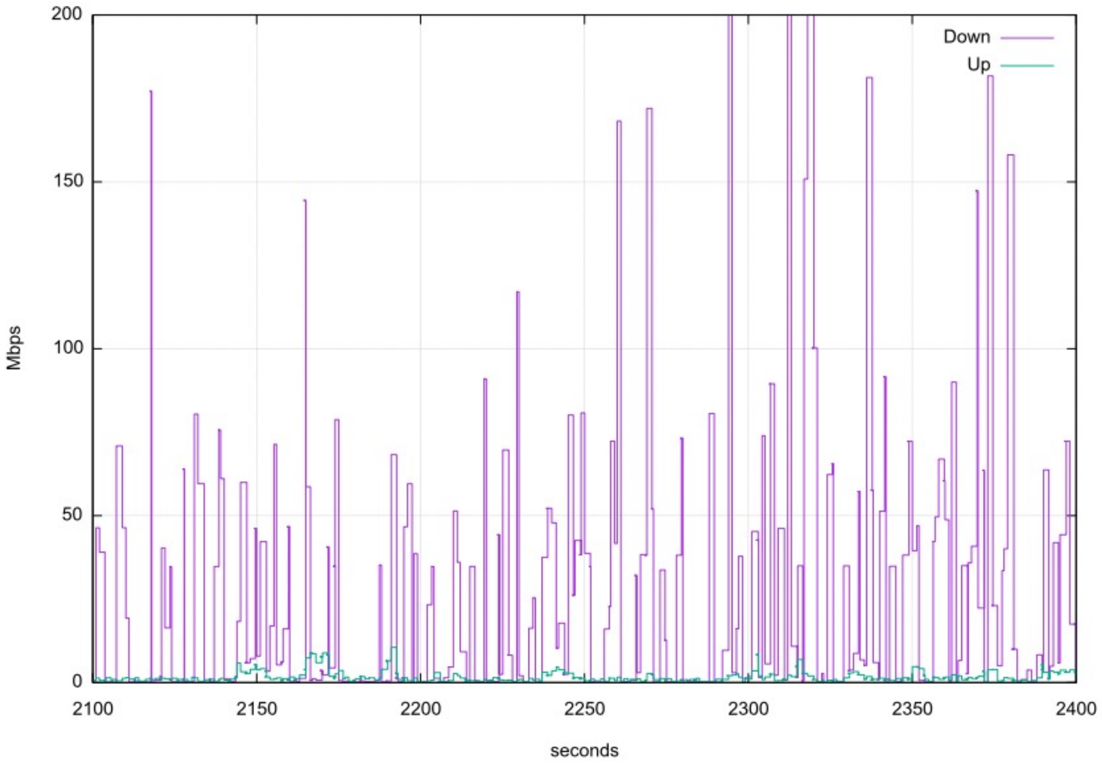
Reported Capacity & Latency

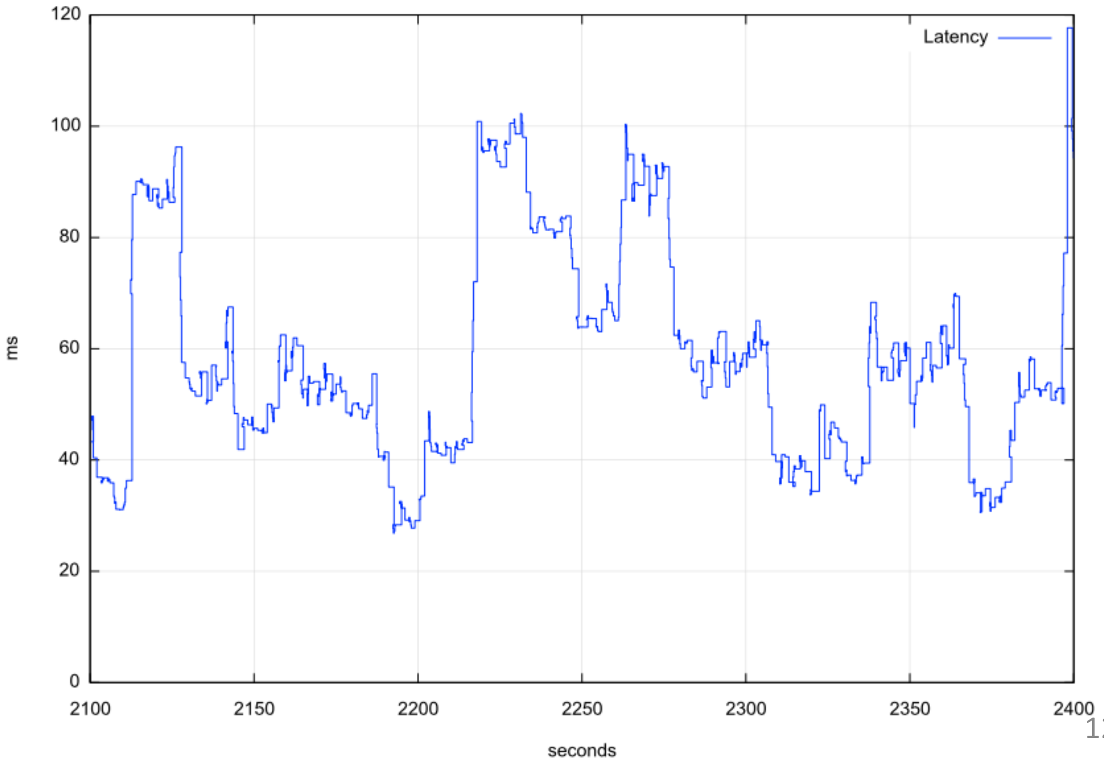




Reported Capacity & Latency

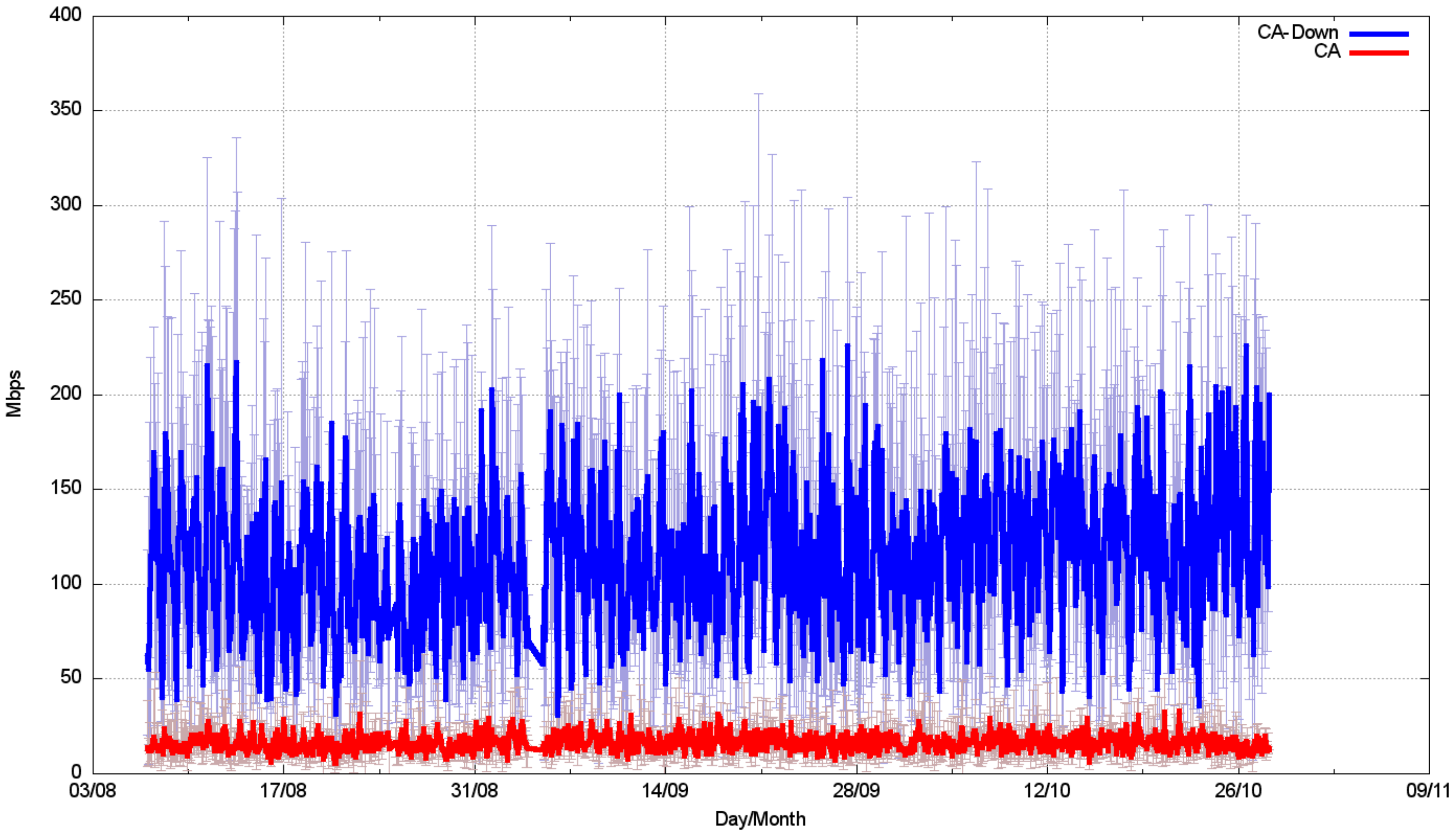
- This is going to present some interesting issues for conventional TCP
- TCP uses ACK pacing which means it attempts to optimize its sending rate over multiple RTT intervals
- The variation in latency and capacity occurs at high frequency, which means that TCP control is going to struggle to optimise





How well does all this work?

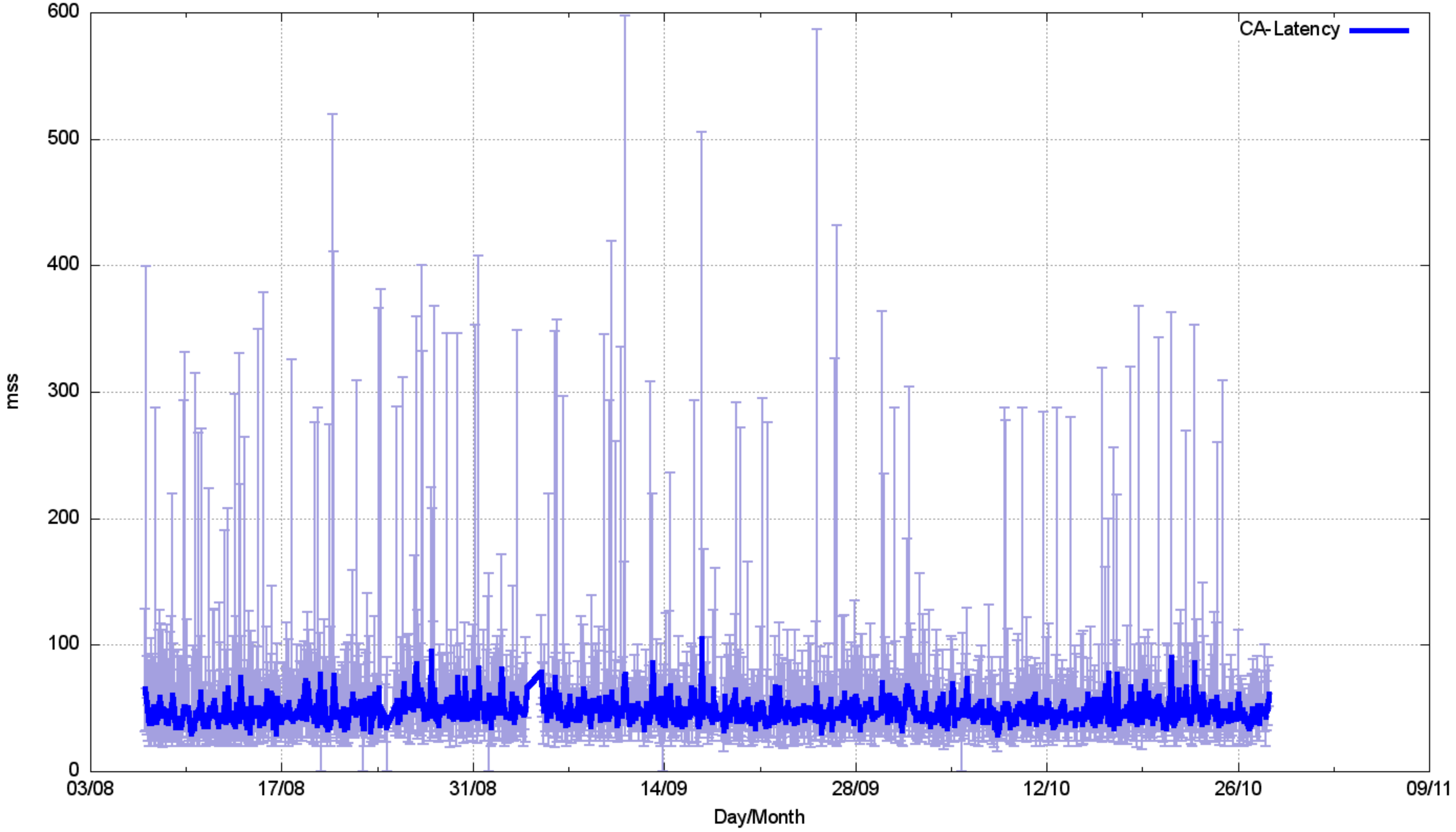
Speedtest measurements:



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

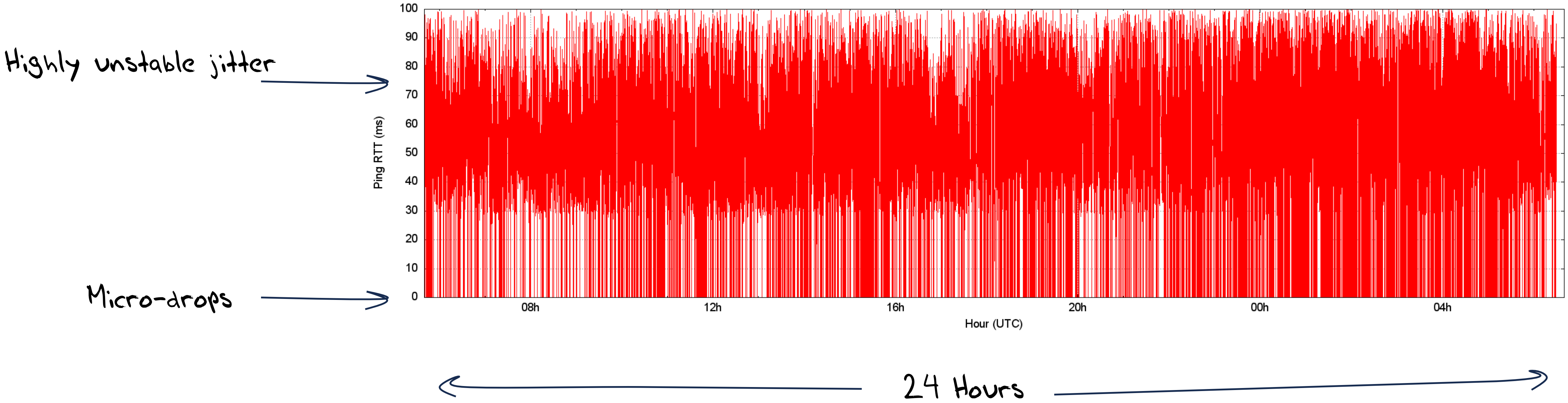
Link Characteristics

Speedtest Latency:

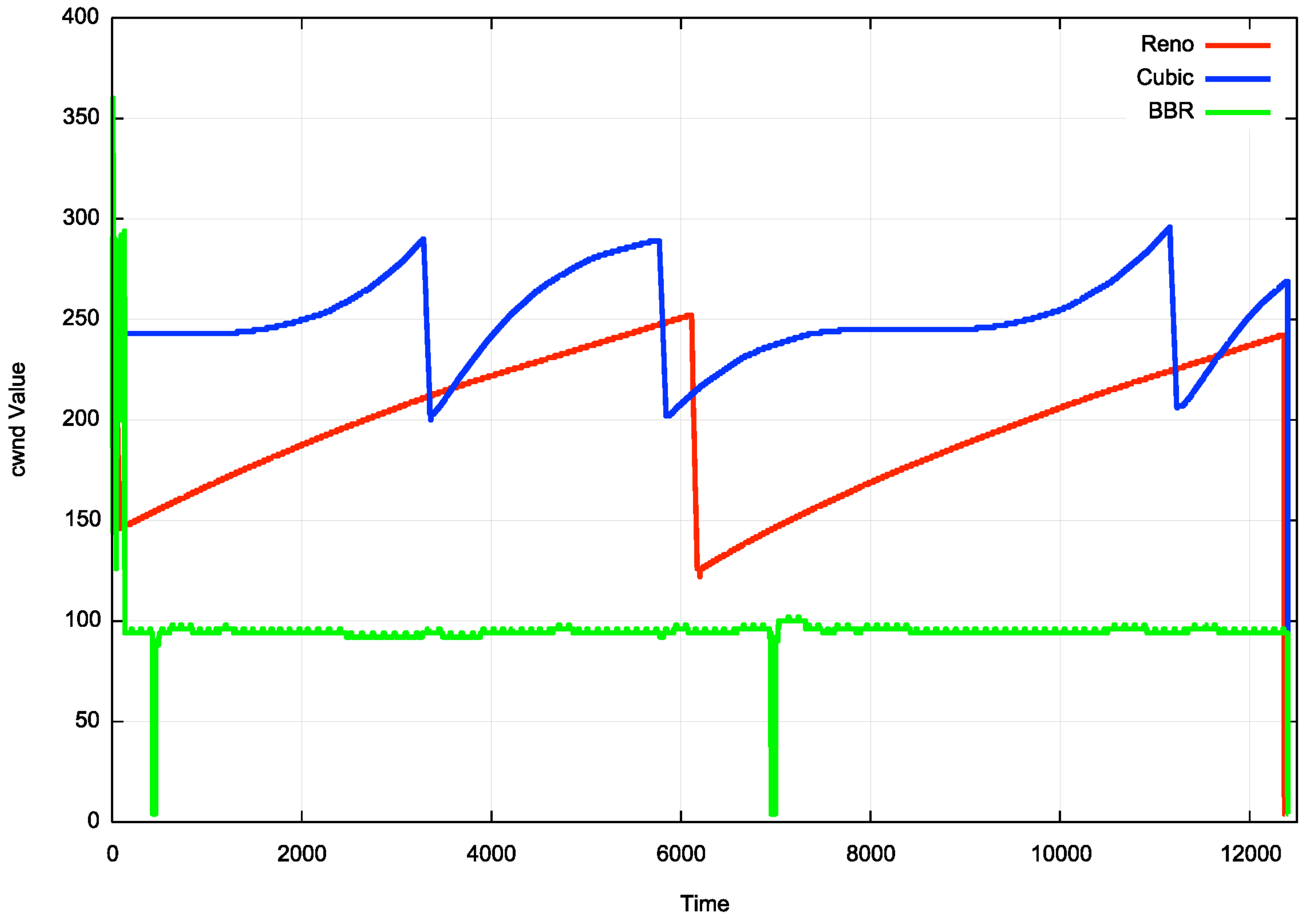


Link Characteristics

1-second ping

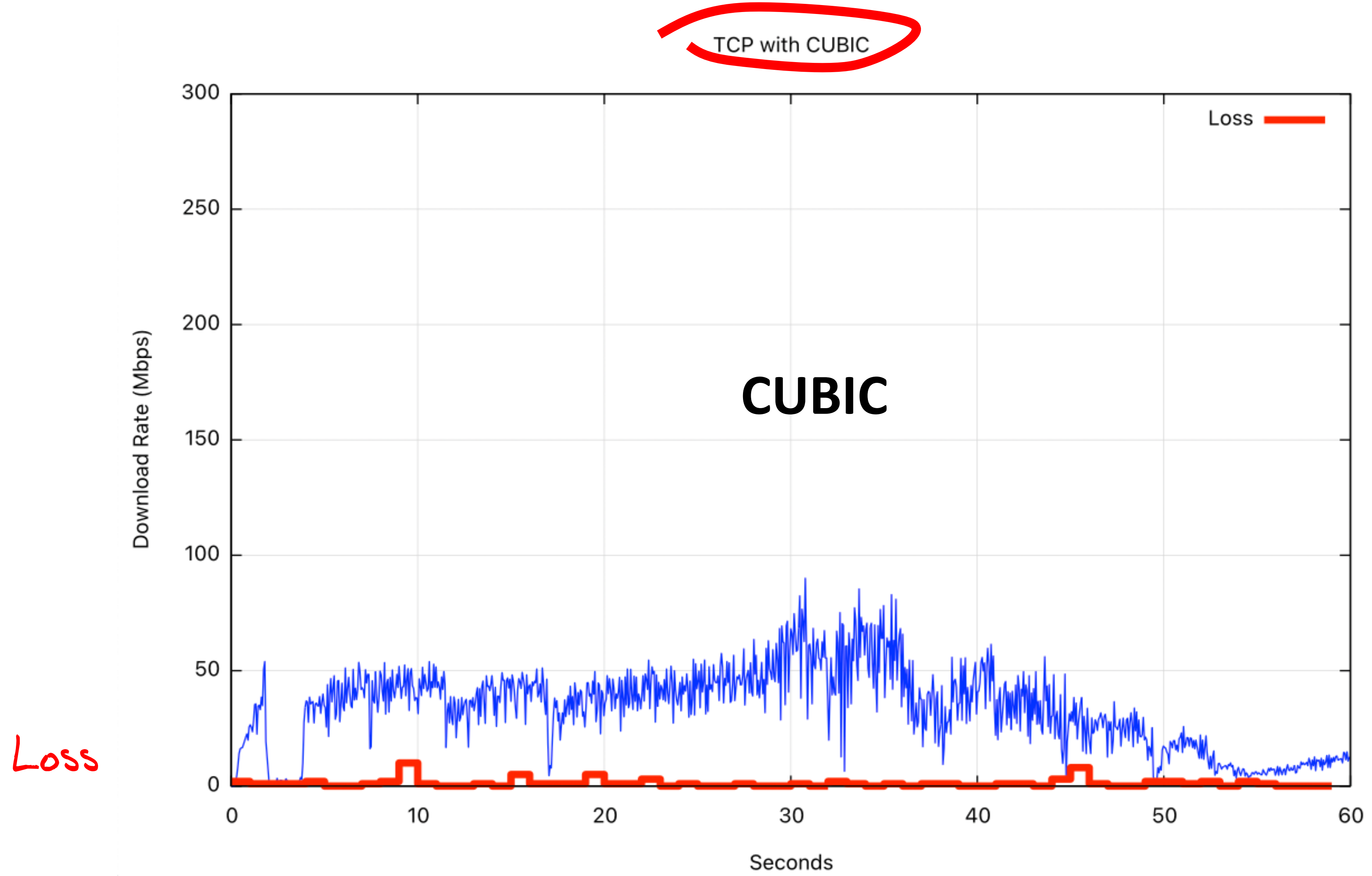


TCP Flow Control Algorithms

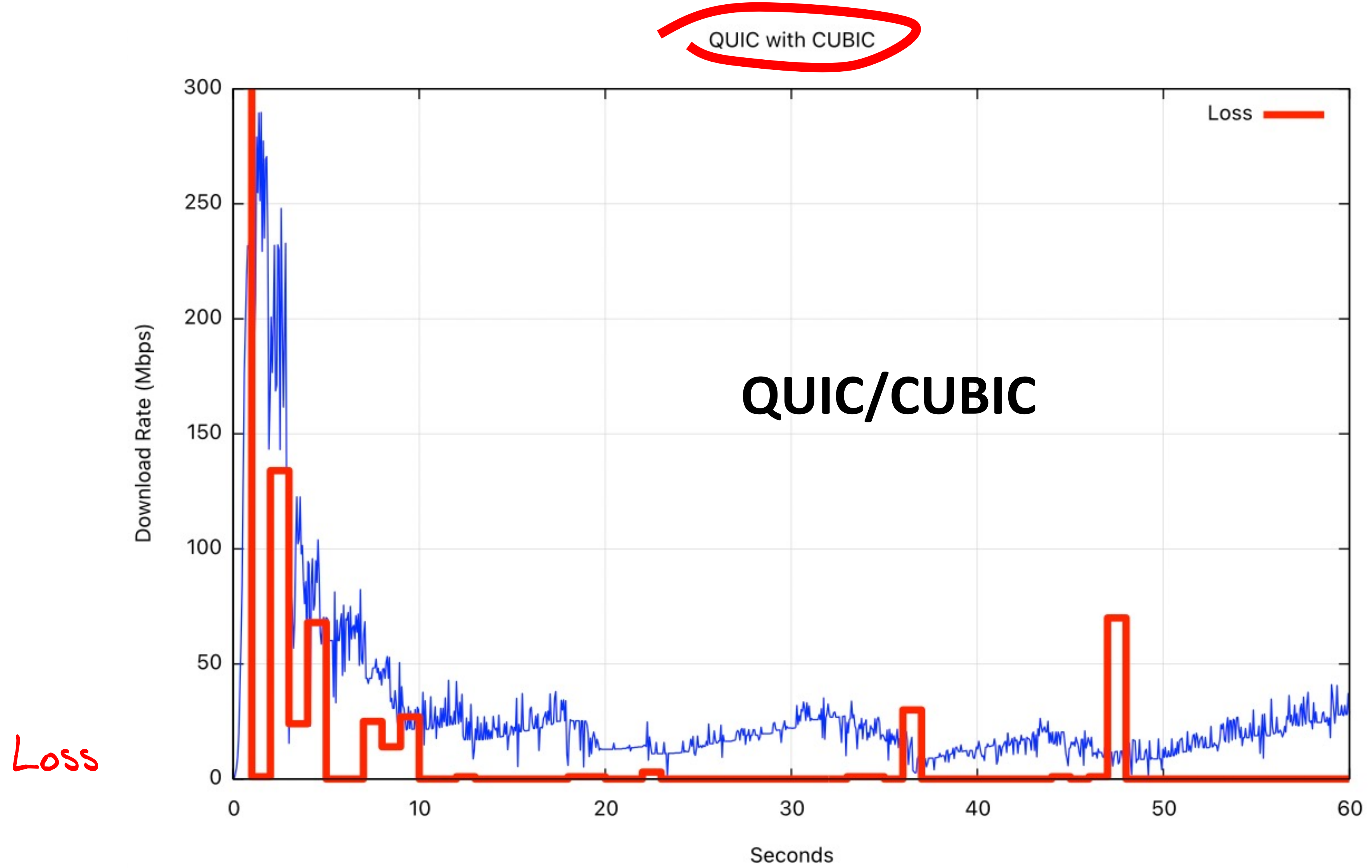


"Ideal" Flow behaviour for each protocol

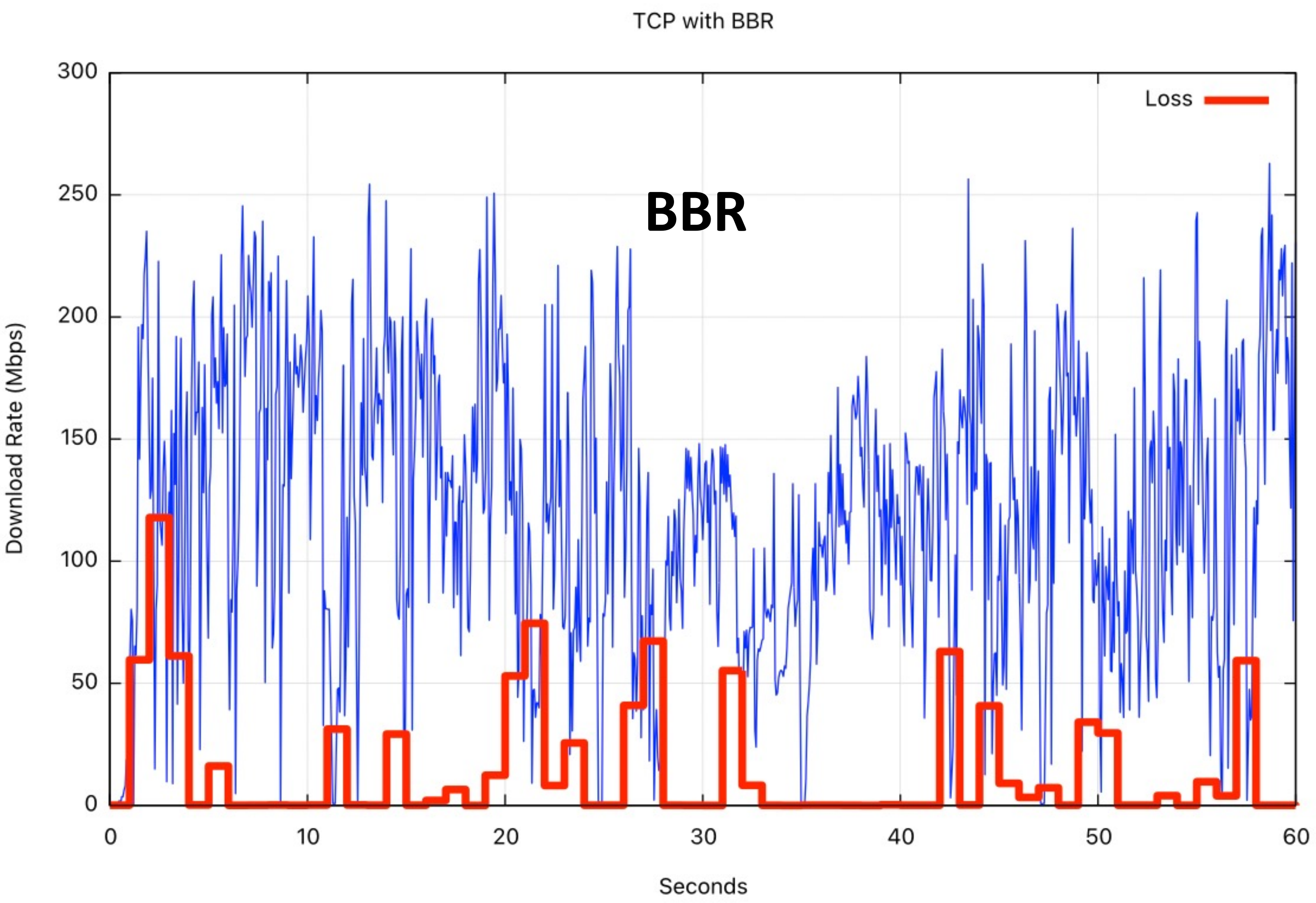
iperf3 - cubic, 60 seconds



Qperf - quic (with cubic)

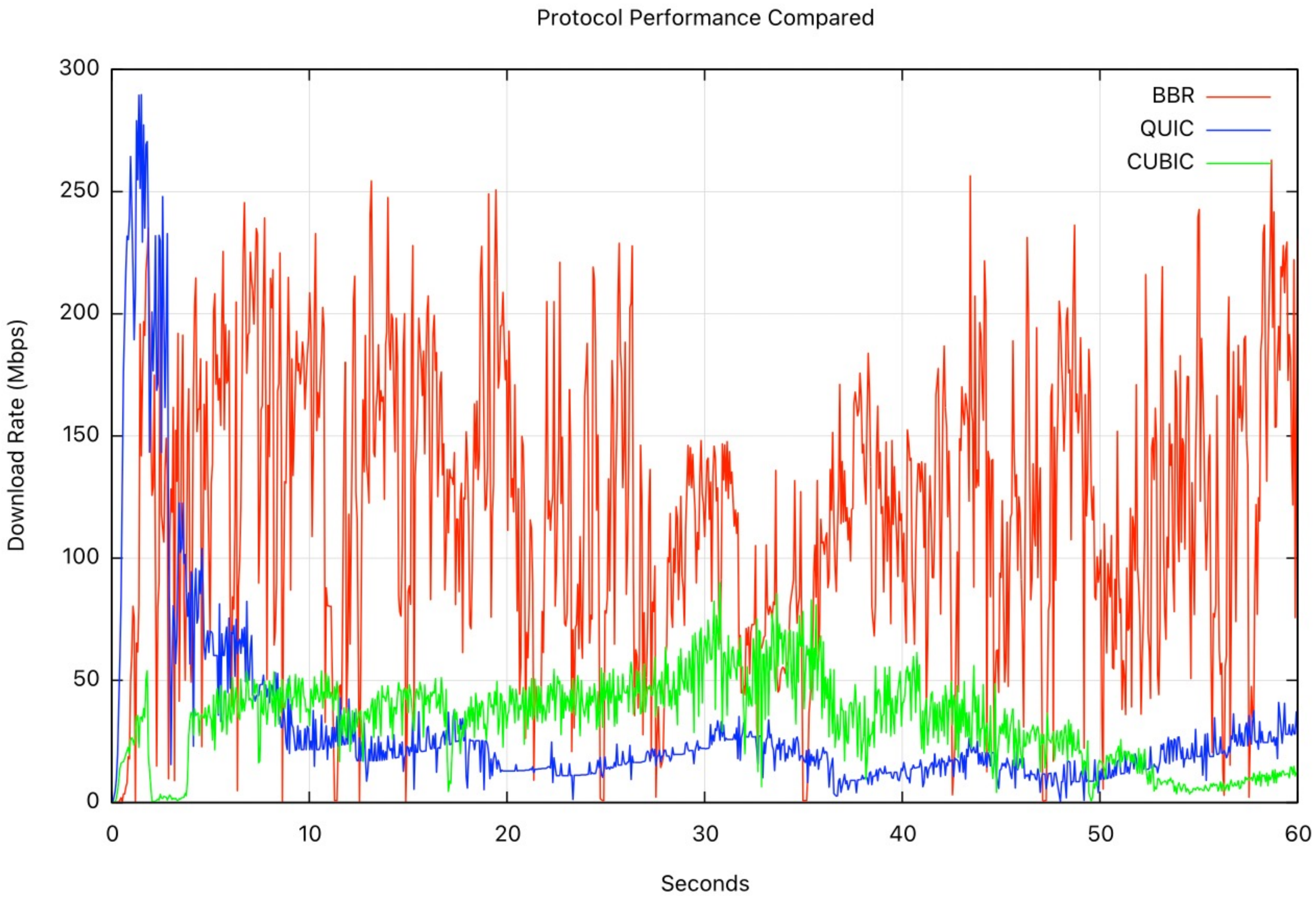


iperf3 - bbr



Loss

Cubic, Quic/Cubic, BBR



Protocol Considerations

- Starlink services have two issues for transport protocols:
  - Very high jitter rates
  - High levels of micro-loss
- Loss-based flow control algorithms will over-react and pull back the sending rate
  - Short transactions work well
  - Paced connections (voice, zoom) tend to work well most of the time
  - Bulk data transfer not so much
- It's better to use a conventional TCP control with a large SACK window or use loss-insensitive flow control algorithms, such as BBR, to get high transfer rate performance out of this service

Questions?