Starlink Protocol Performance

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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.

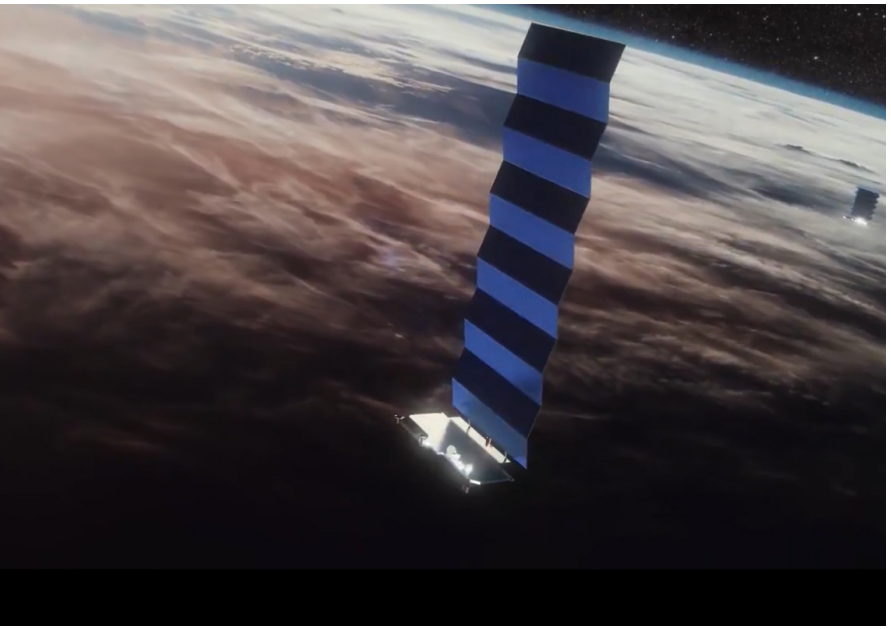
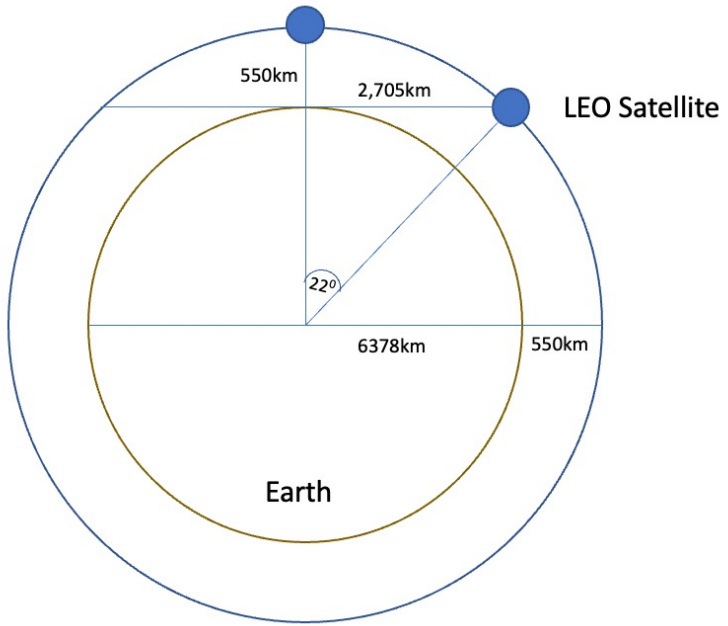
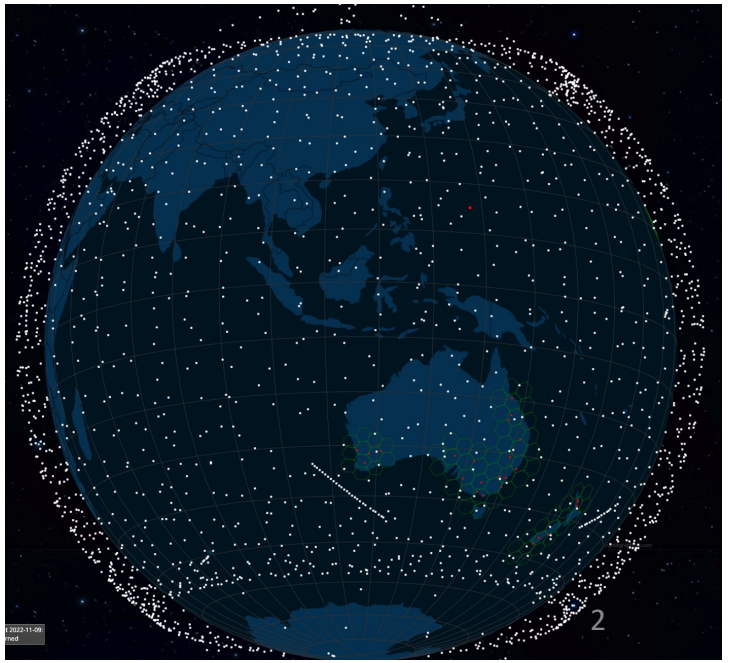


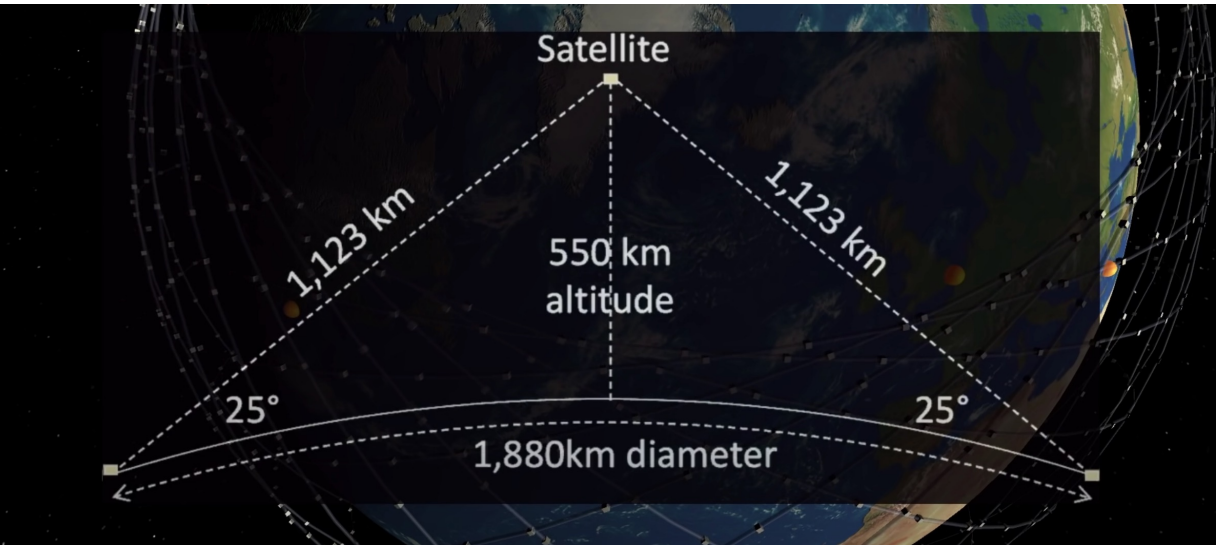
Image - spacex





screenshot from starwatch app

Starlink Constellation



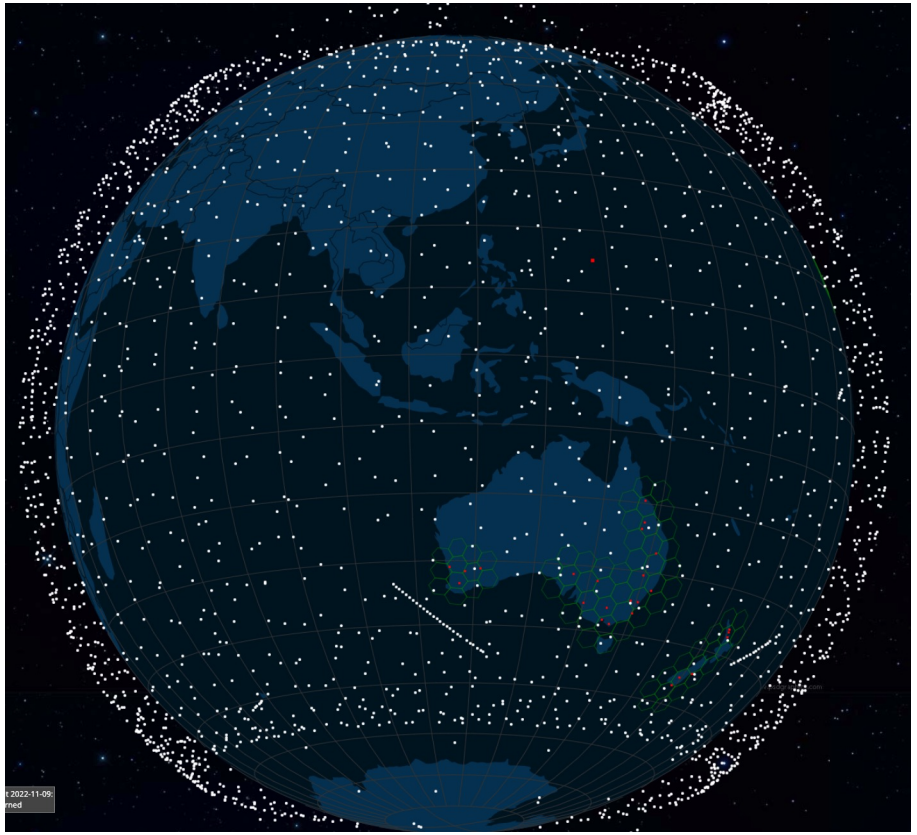
At an altitude of 550km each satellite spans a terrestrial footprint of no more than ~900Km radius, or 2M K^2

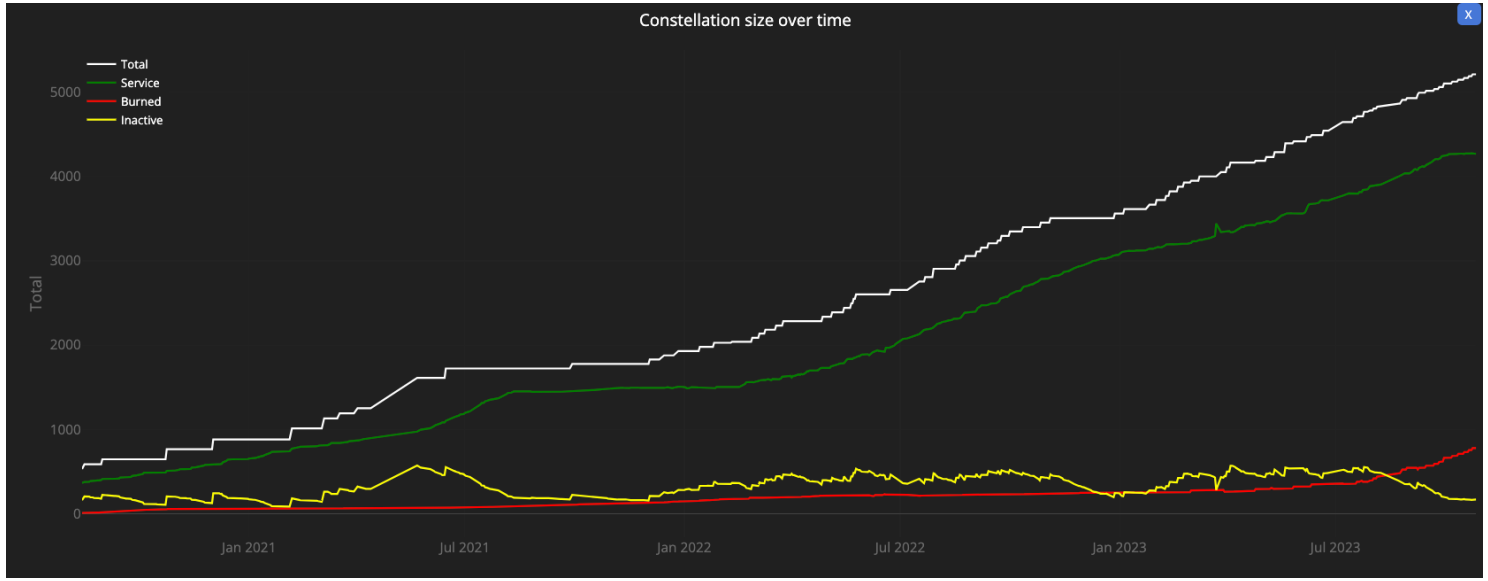
At a minimum, a satellite constellation needs 500 satellites to provide continuous coverage

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

Starlink Constellation

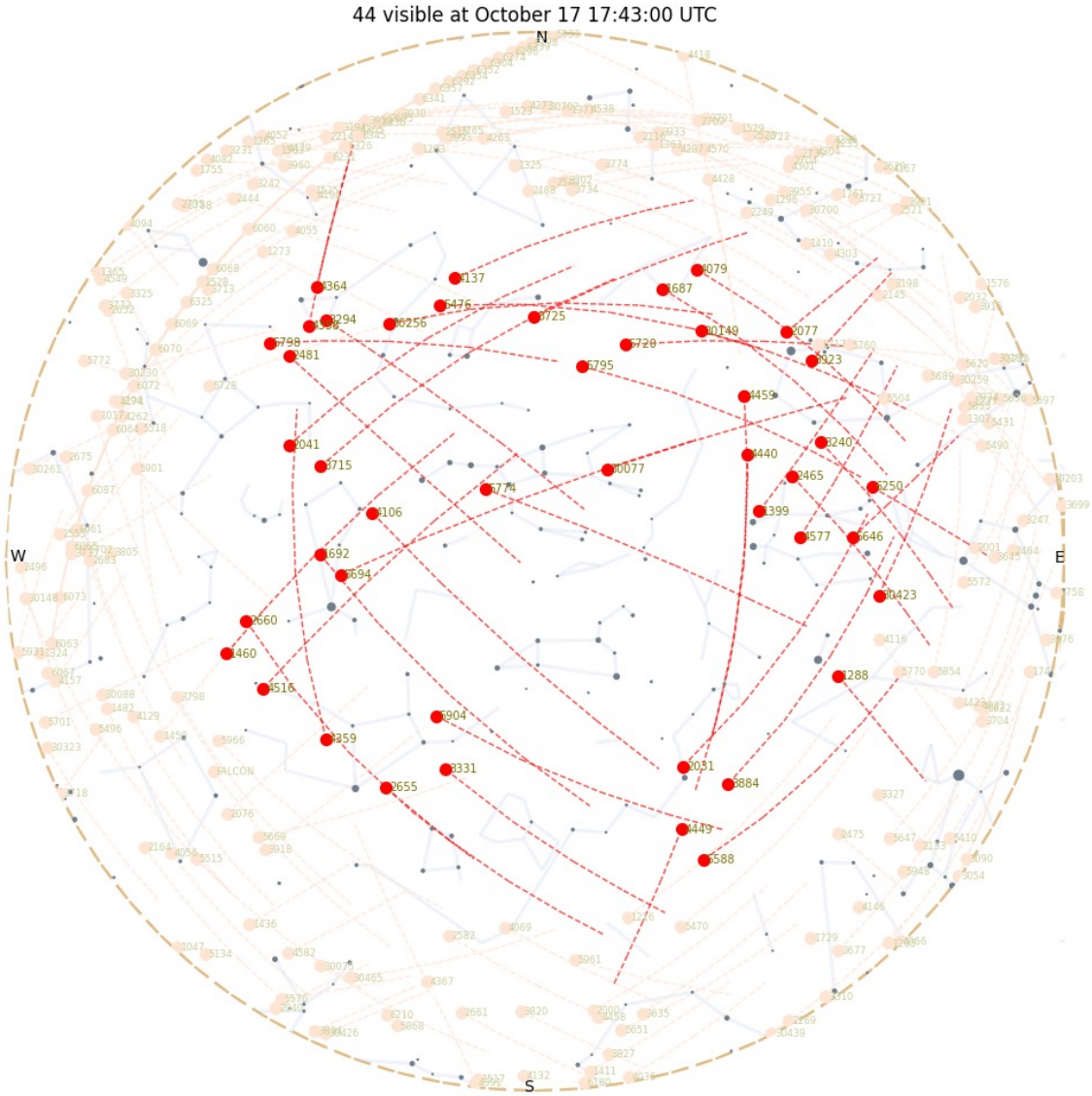
- 4,276 in-service operational spacecraft, operating at an altitude of 550km





https://satellitemap.space/

Looking Up



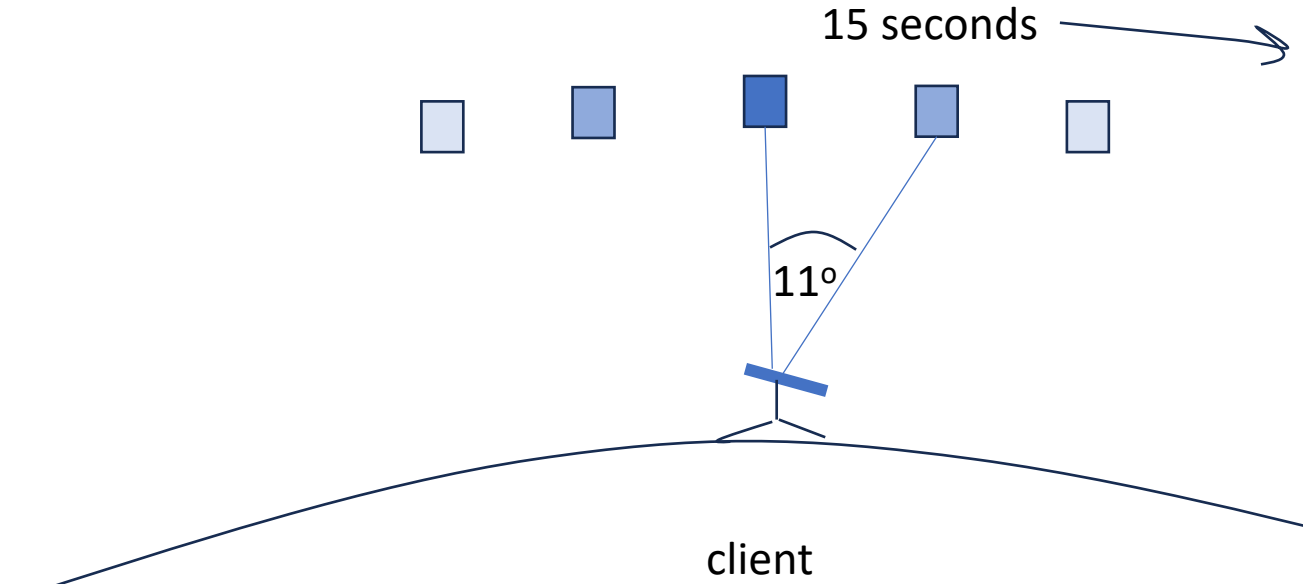
Starlink tracks satellites with a minimum elevation of 25°.

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

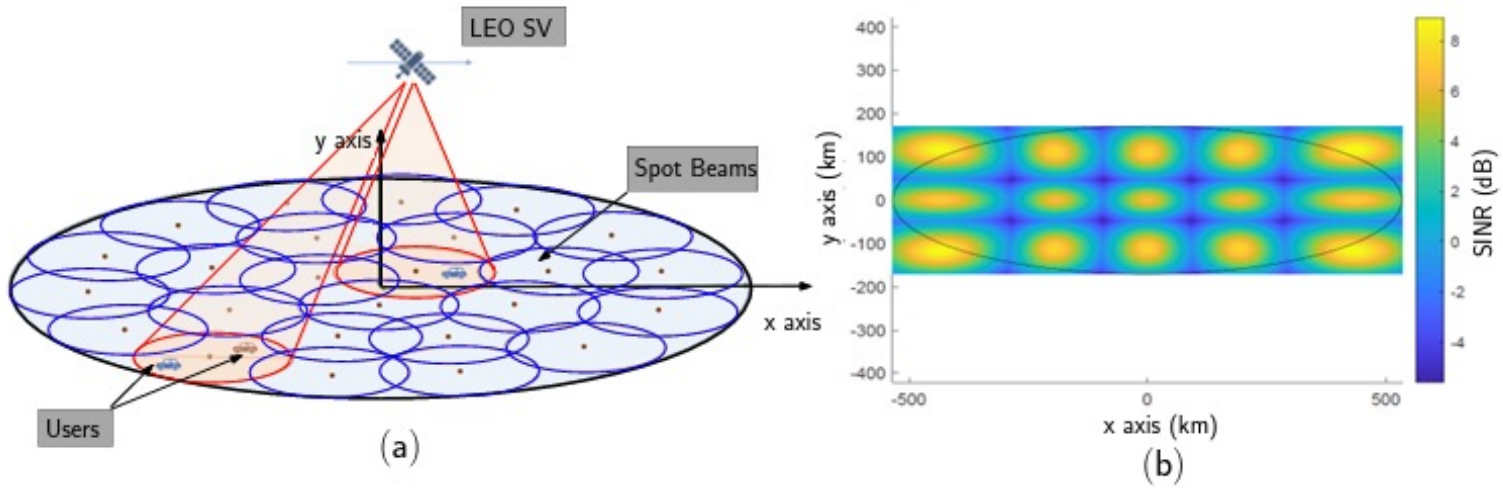
Starlink Scheduling

- 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 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"

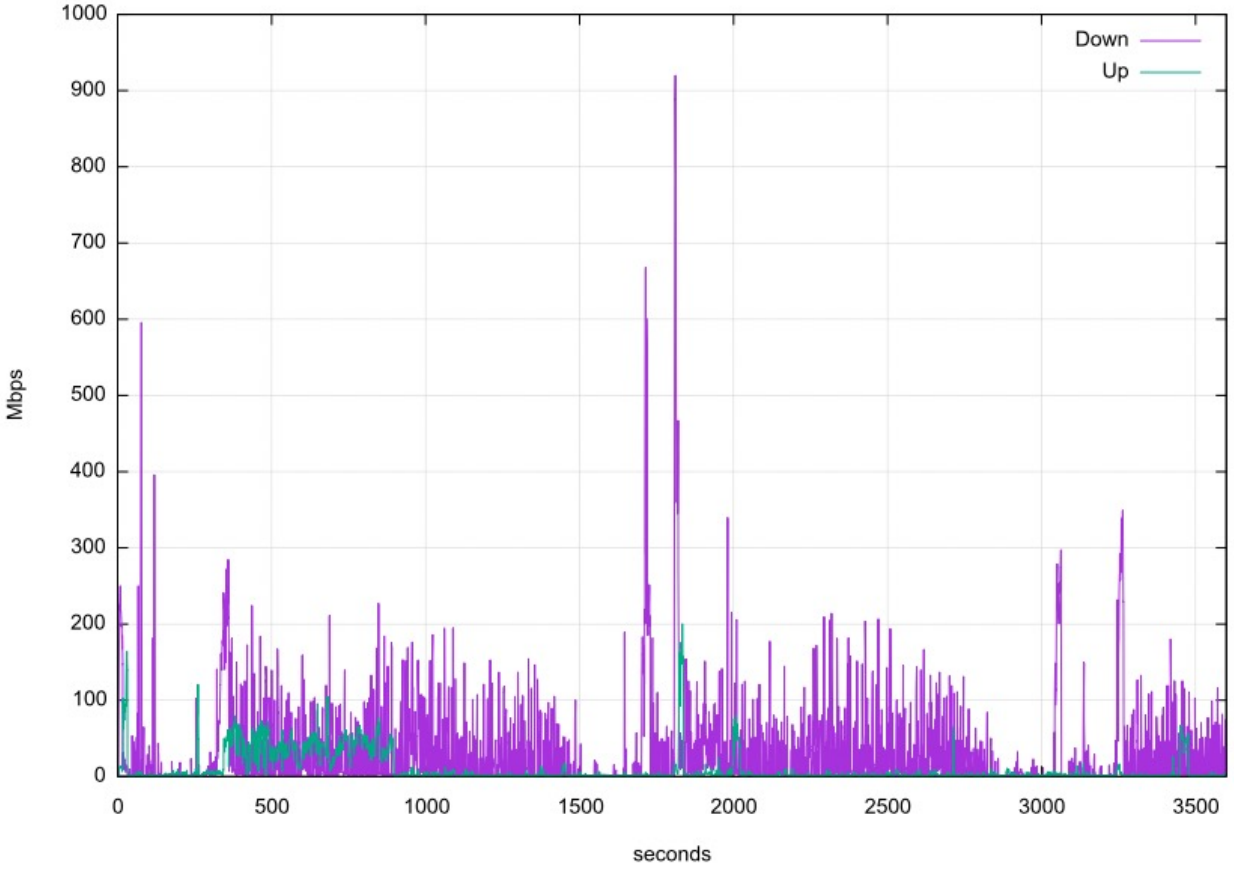
https://people.engineering.osu.edu/sites/default/files/2022-10/Kassas_Unveiling_Beamforming_Strategies_of_Starlink_LEO_Satellites.pdf

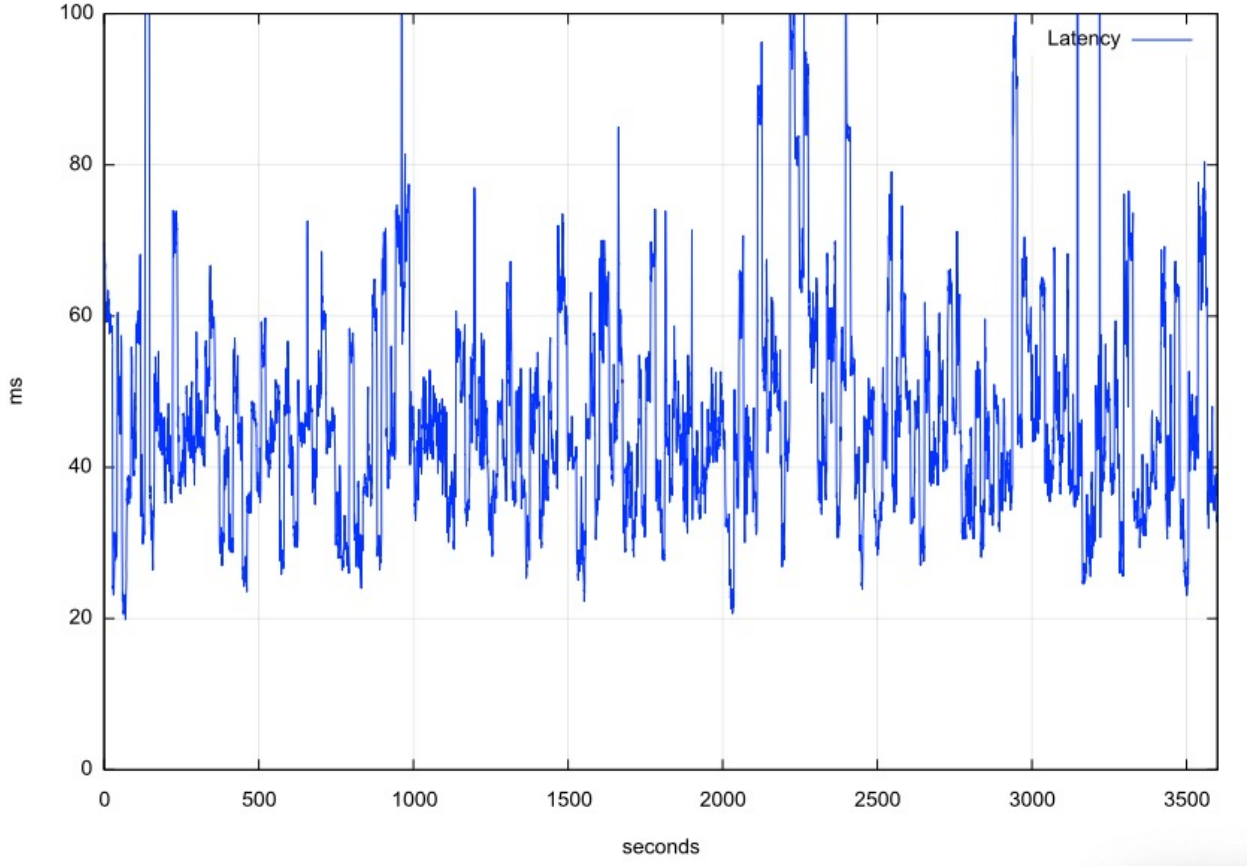
How well does all this work?

Let’s ask the Starlink modem

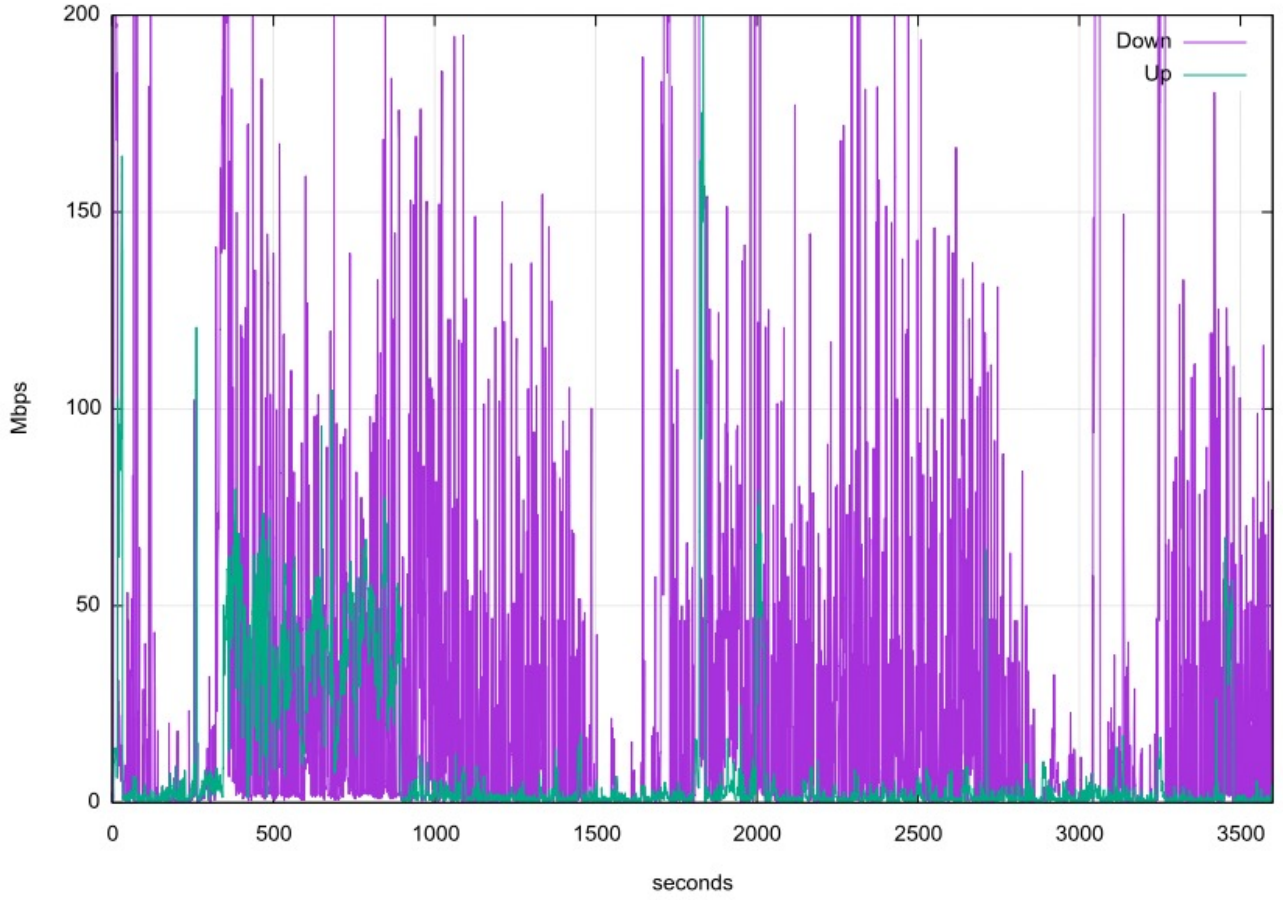
```
$ starlink-grpc-tools/dish_grpc_text.py -v  status
id:                       ut01000000-00000000-005dd555
hardware_version:         rev3_proto2
software_version:         5a923943-5acb-4d05-ac58-dd93e72b7862.uterm.release
state:                    CONNECTED
uptime:                   481674
snr:
seconds_to_first_nonempty_slot: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

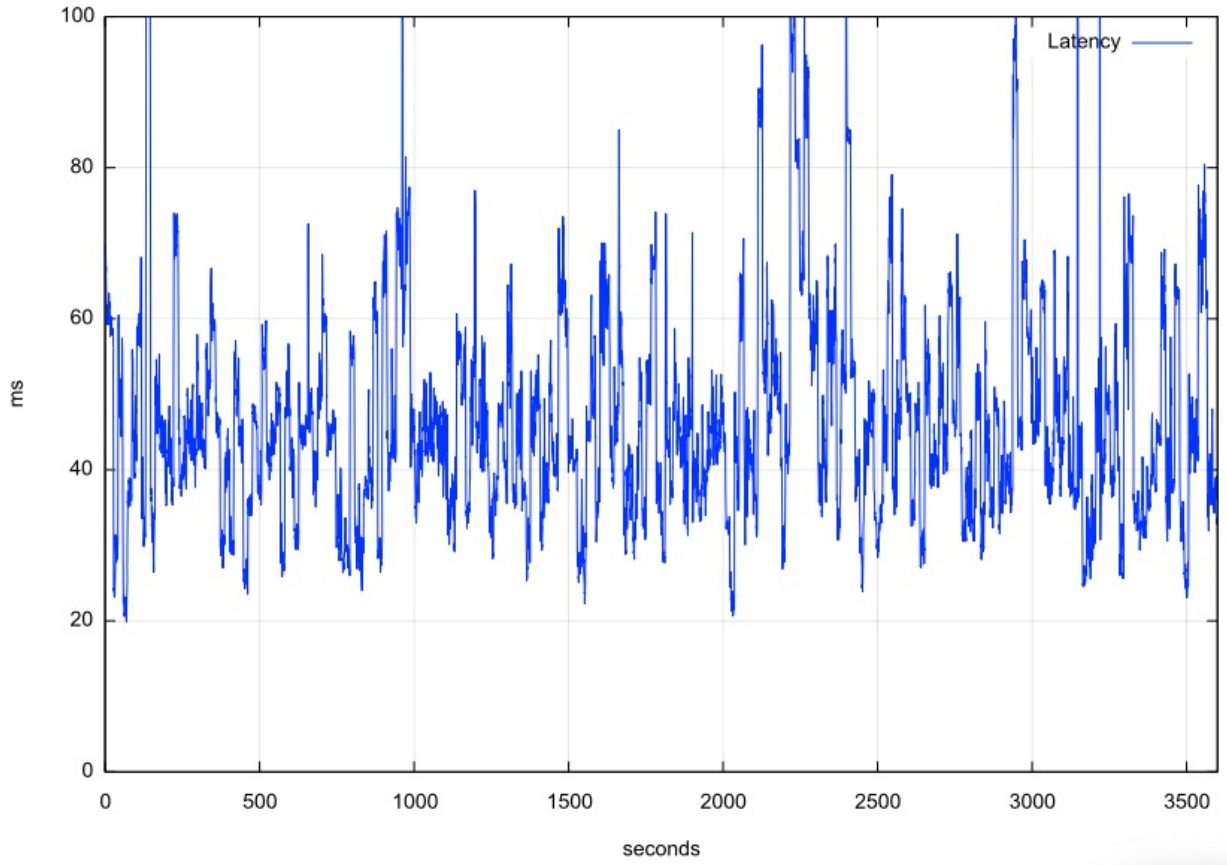
Reported Capacity & Latency





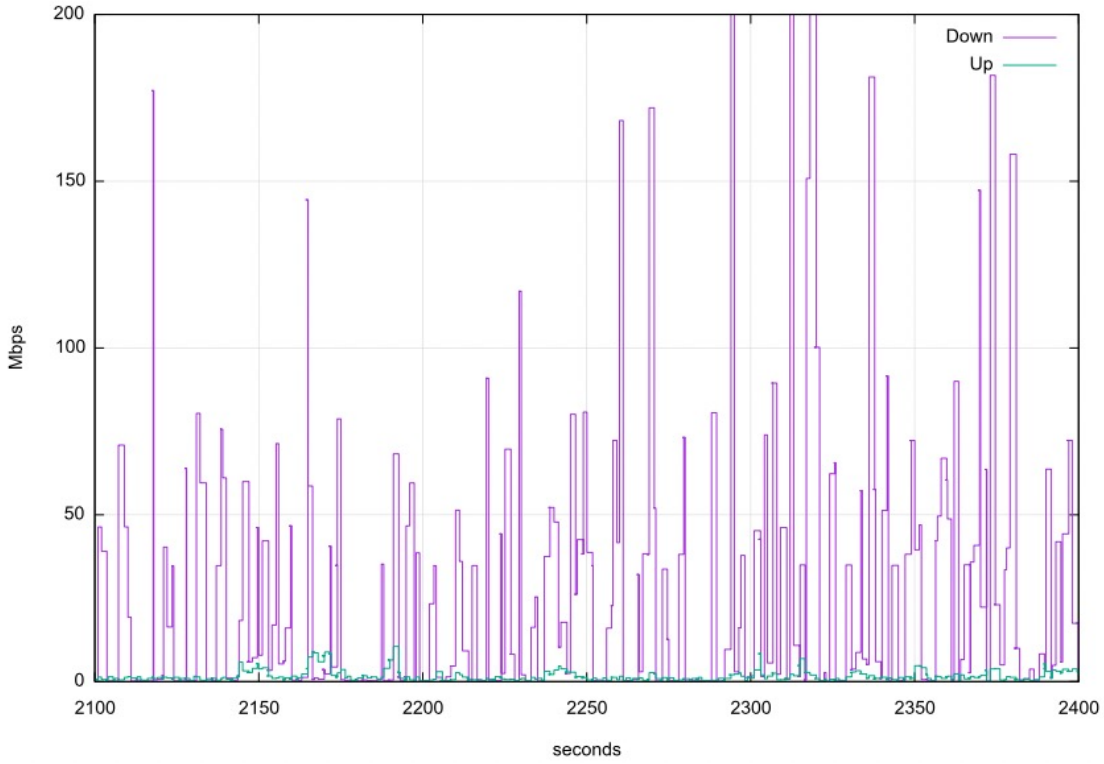
Reported Capacity & Latency

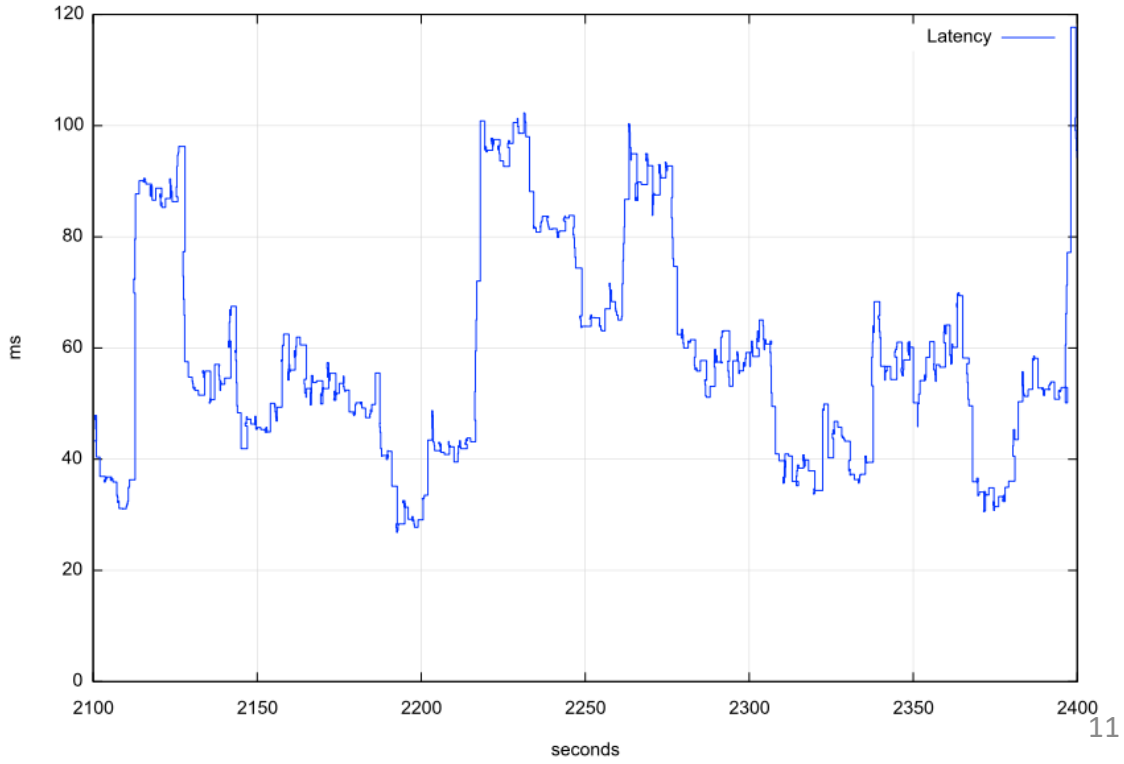




Reported Capacity & Latency

- 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

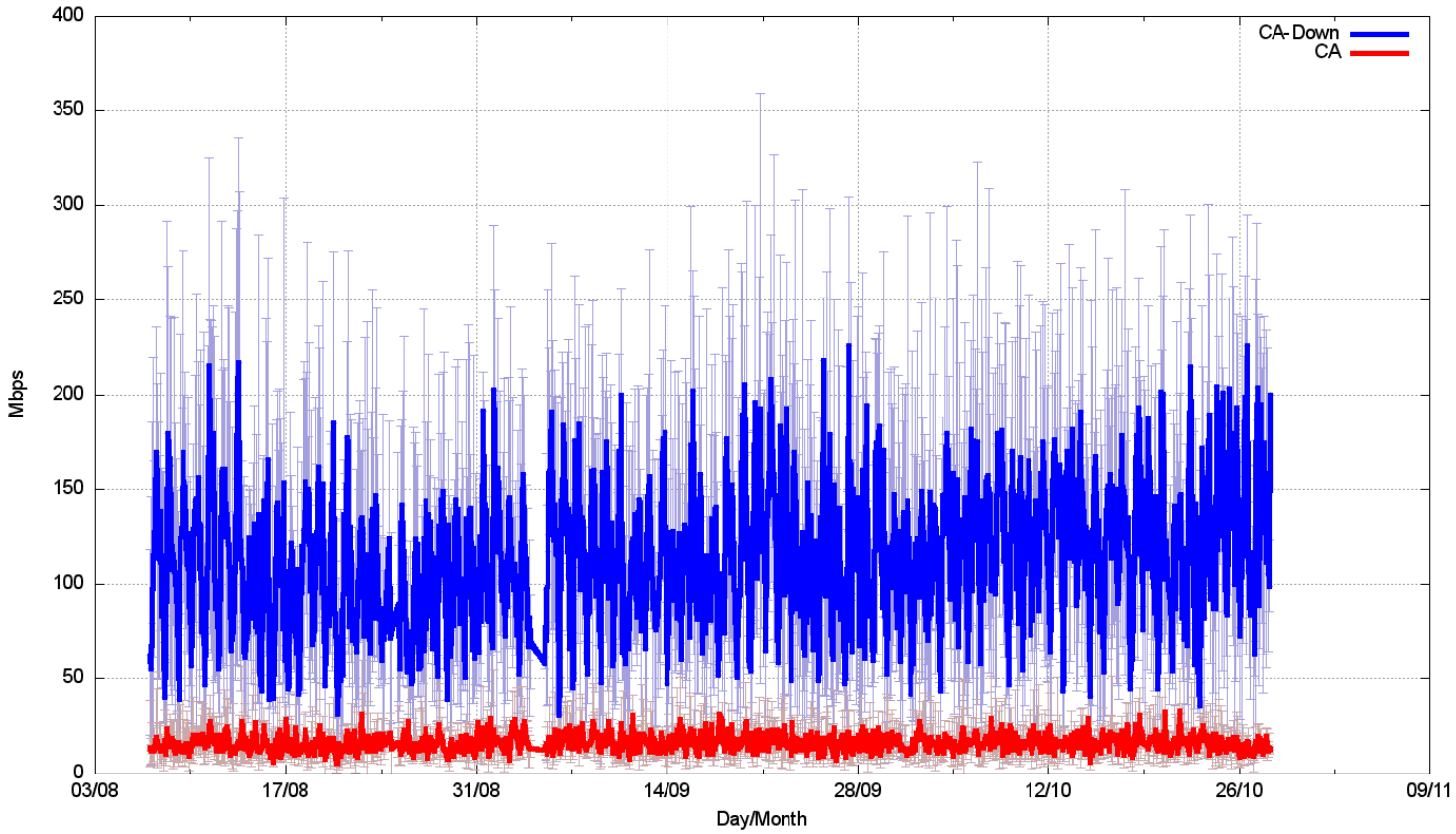




How well does all this work?

Let's measure it!

Speedtest:

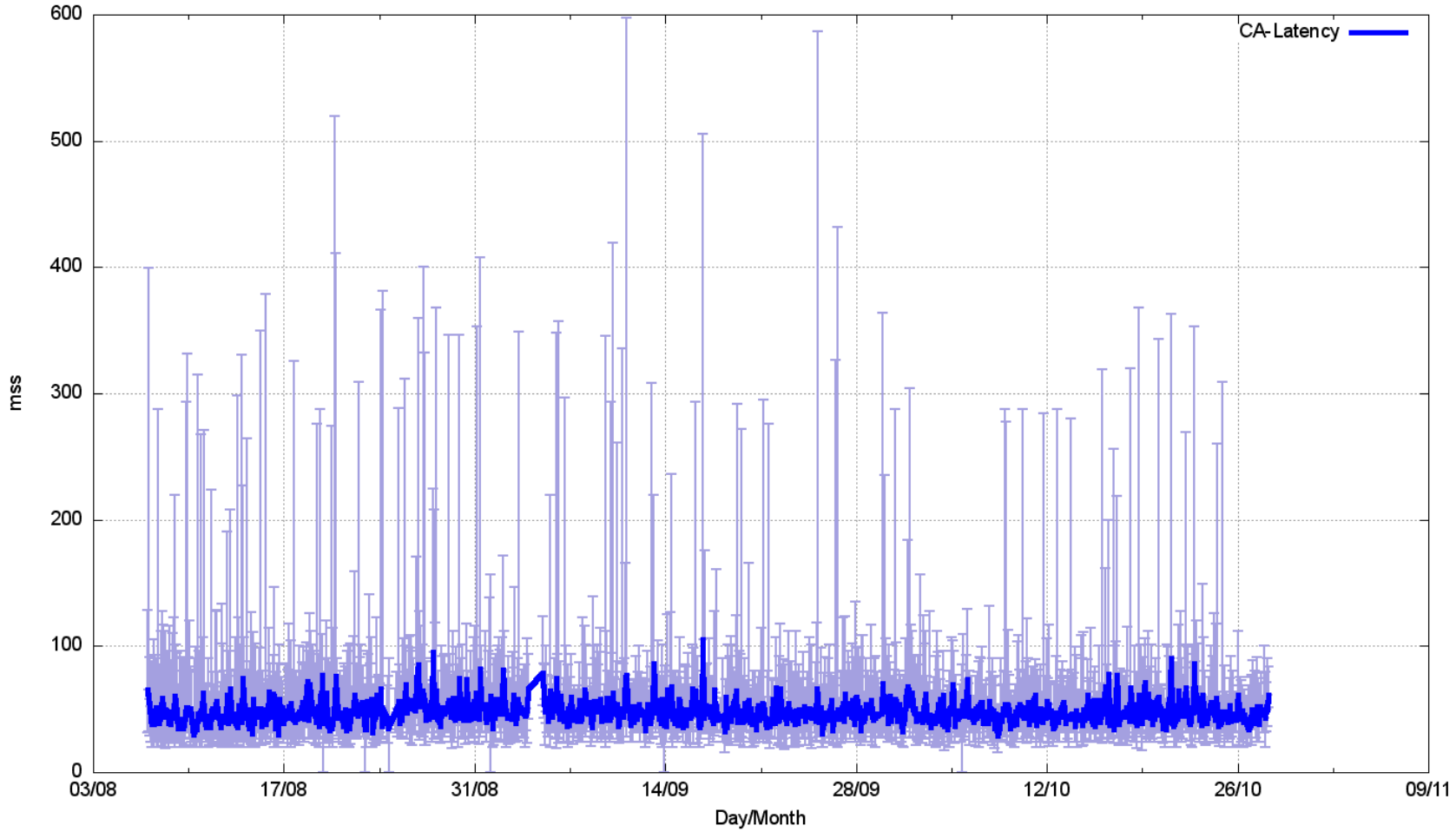


We should be able to get ~120Mbps out of a starlink connection. Right?

Link Characteristics

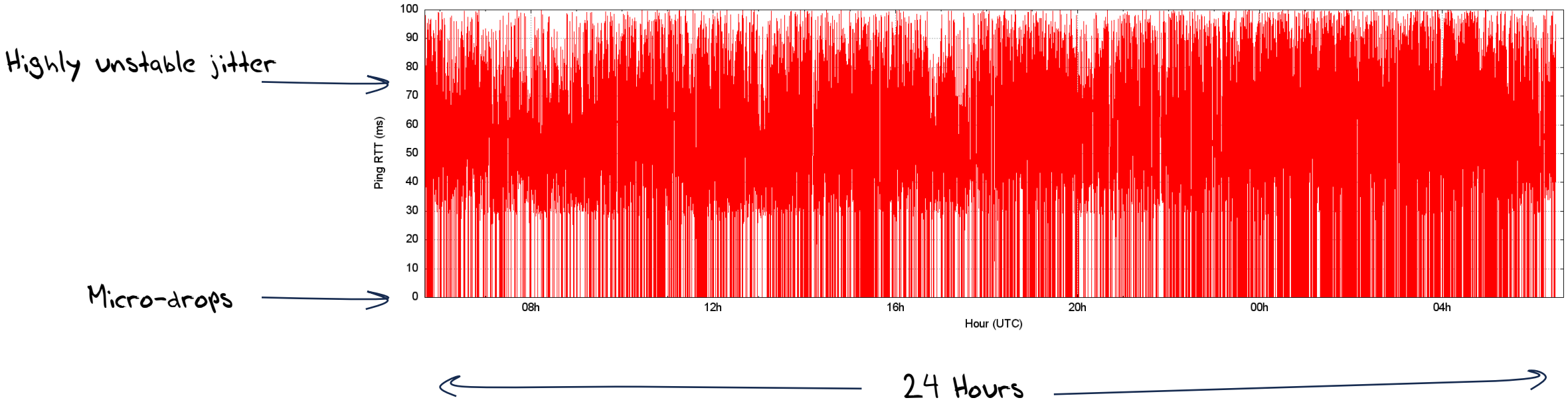
Let's measure it!

Speedtest Latency:

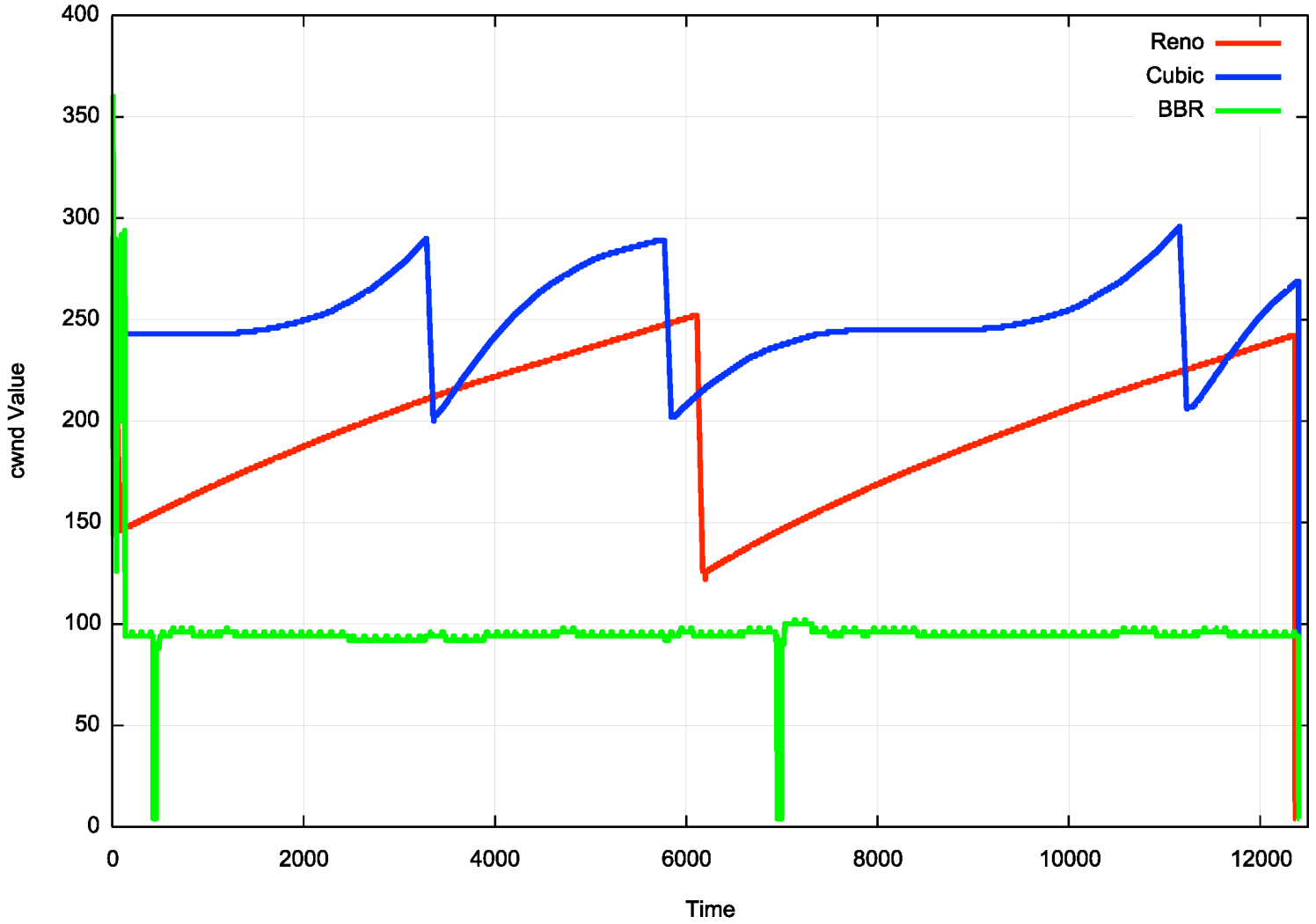


Link Characteristics

1-second ping

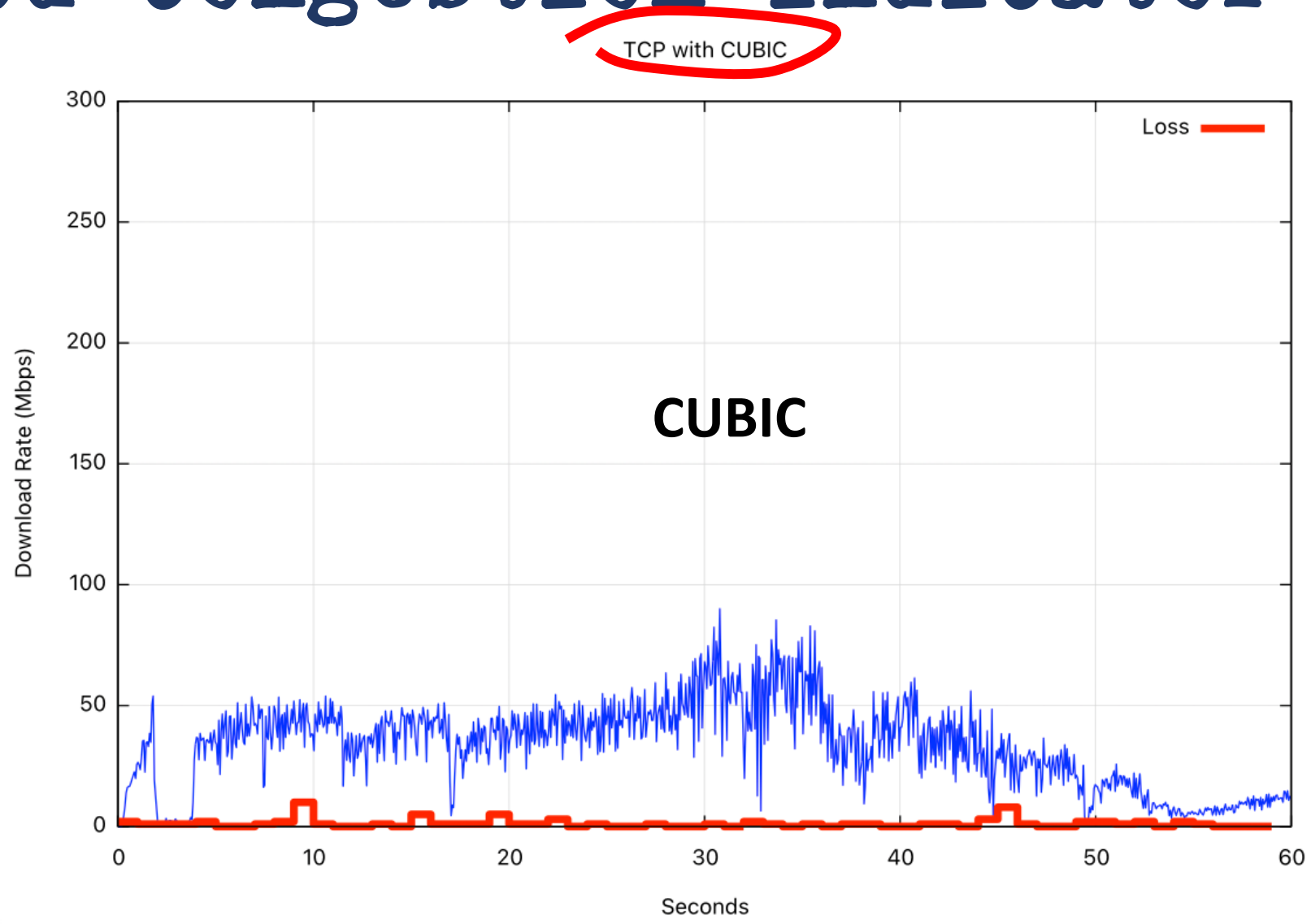


TCP Flow Control Algorithms



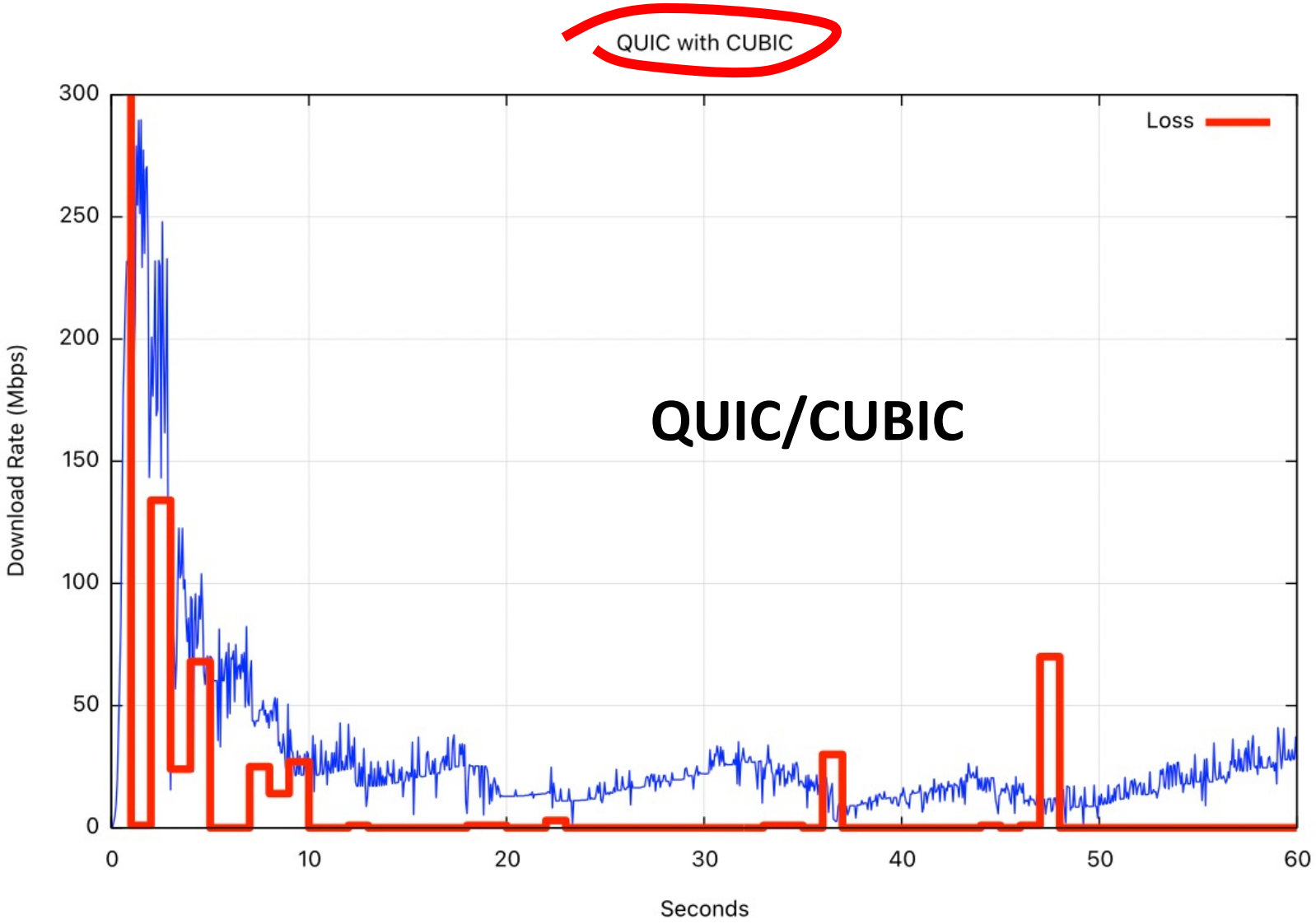
"Ideal" Flow behaviour for each protocol

Packet Loss is not always a good congestion indicator



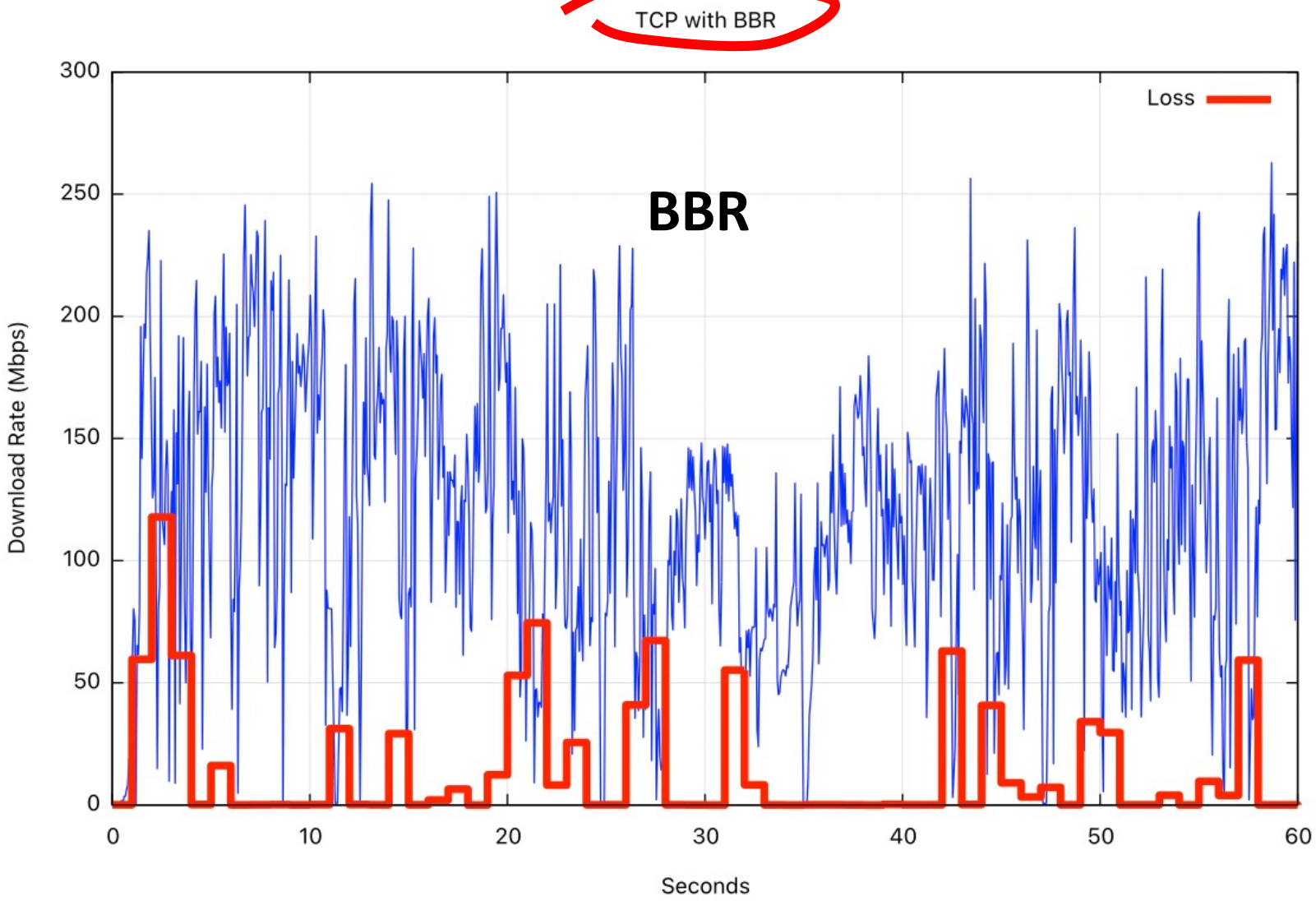
Loss

QUIC with CUBIC - much the same



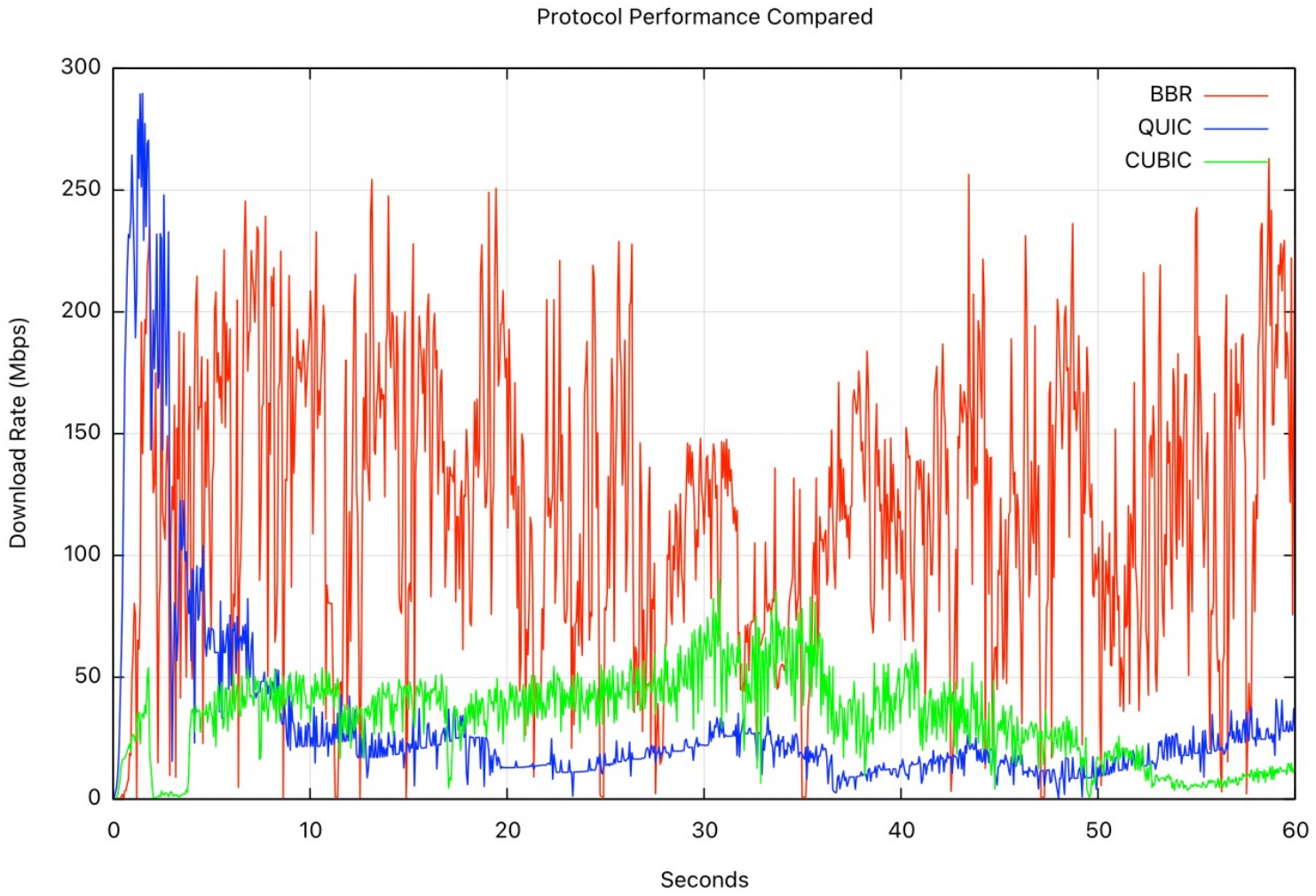
Loss

It's better to use a loss-tolerant protocol with Starlink



Loss

Protocol choice matters for performance in Starlink services



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 good performance out of these service


Questions?