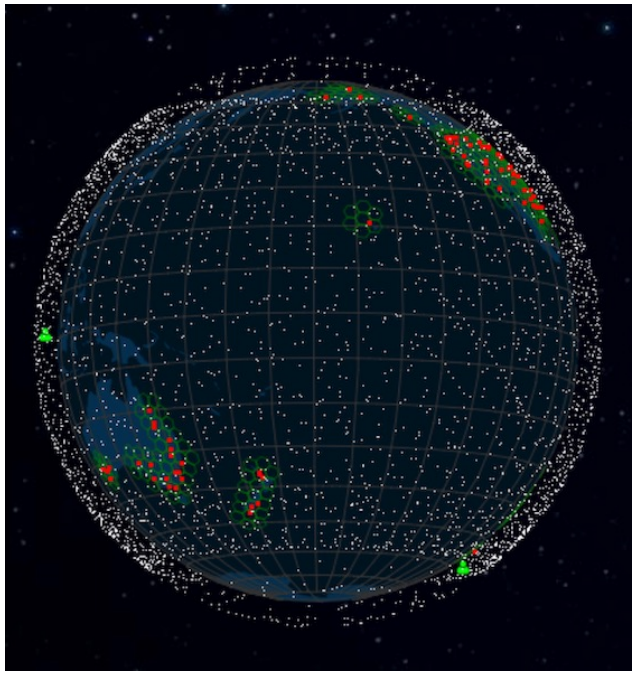
Measuring Starlink

Geoff Huston AM
APNIC

AUSNOG 2024

LEOs in the News



screenshot from starwatch app

Together Optus and SpaceX Plan to Cover 100% of Australia

12 July 2023, 04:00 PM

Science / Entertainment / More +

- 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.

NIKKEI Asia

World Trending Business Markets Tech Politics Economy Featur

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

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-starlink-t-mobile-satellite-internet-mobile-messaging

Home › News › Technology › Telco/ISP

Telstra goes live with Starlink for homes

By Richard Chirgwin

Mar 26 2024 12:10PM

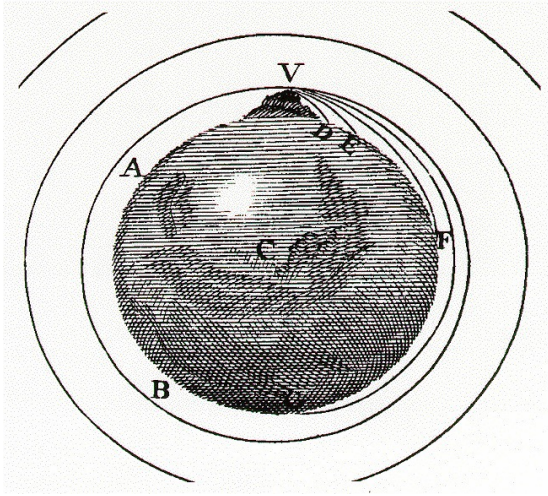
10

Lower cost, marginally lower performance than buying direct.

https://www.itnews.com.au/news/telstra-goes-live-with-starlink-for-homes-606423#:~:text=Telstra%20has%20kicked%20off%20its,the%20end%20of%20the%20ye

Newtonian Physics

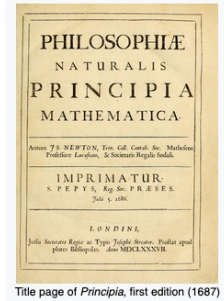
- If you fire a projectile with a speed greater than 11.2Km/sec it will not fall back to earth, and instead head away from earth never to return
- On the other hand, if you incline the aiming trajectory and fire it at a critical speed it will settle into an orbit around the earth
- The higher the altitude,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



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

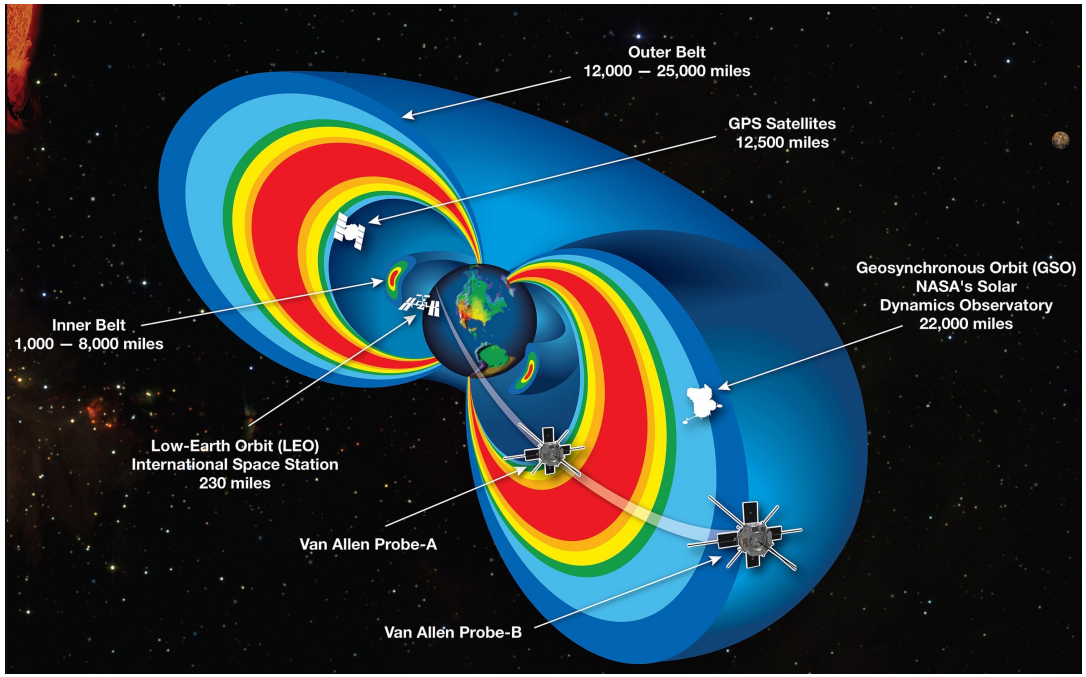
The effects of centripetal forces.

1, 2, 5, 10, 100,


PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA

Title page of *Principia*, first edition (1687)

Solar Radiation Physics

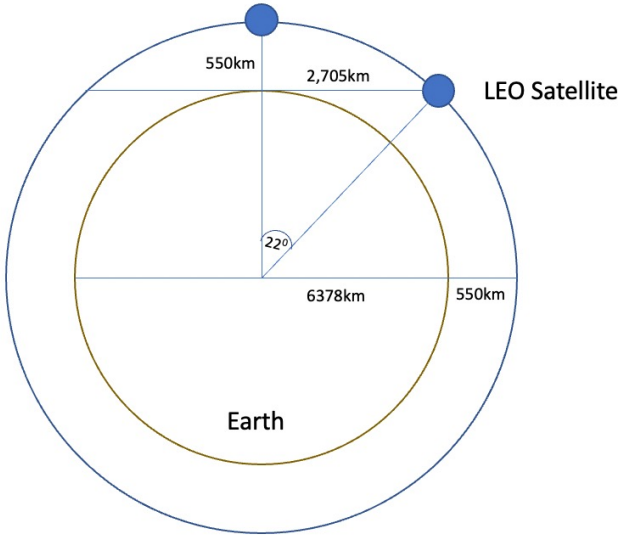


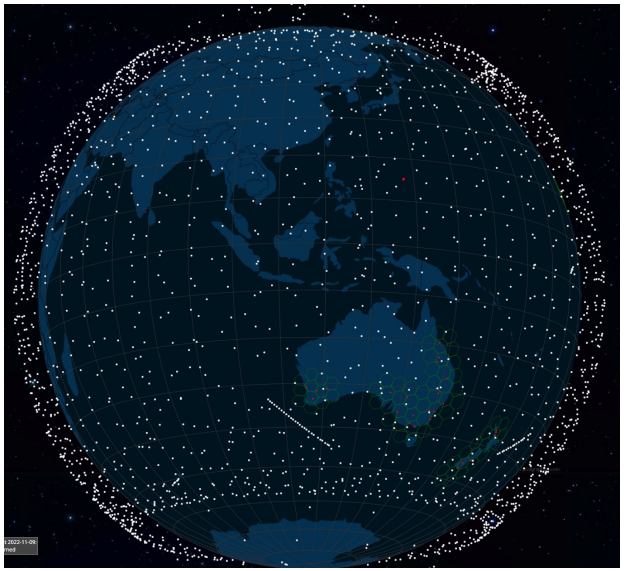
- The rotating iron core of the Earth produces a strong magnetic field
- This magnetic field deflects solar radiation – the Van Allen Belt
- Sheltering below the Van Allen Belt protects the spacecraft from the worst effects of solar radiation, allowing advanced electronics to be used in the spacecraft

Low Earth Orbit

- 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° it’s 7.5ms.

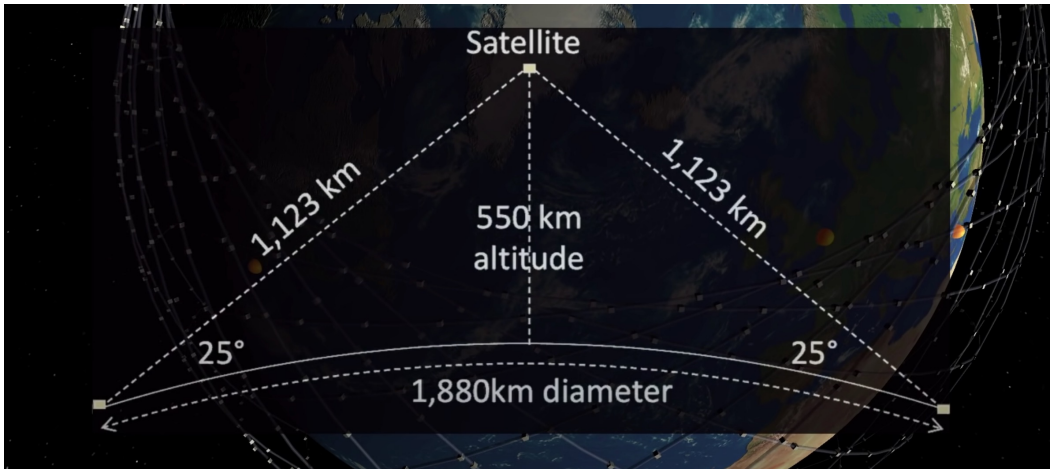
Image - spacex





screenshot from starwatch app

Starlink Constellation



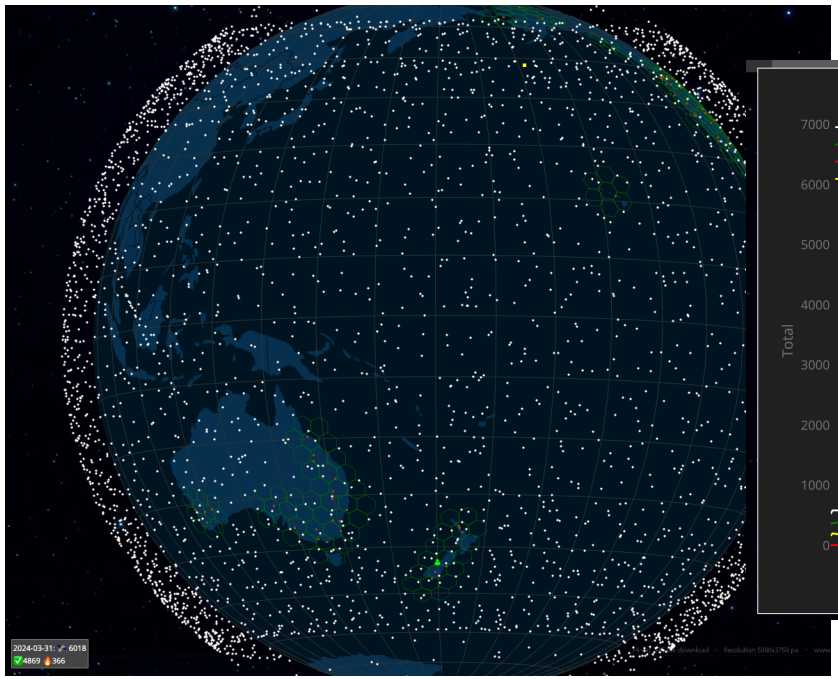
If you use a minimum angle of elevation of 25° then at an altitude of 550km each satellite spans a terrestrial footprint of no more than ~950Km radius, or 2M K^2

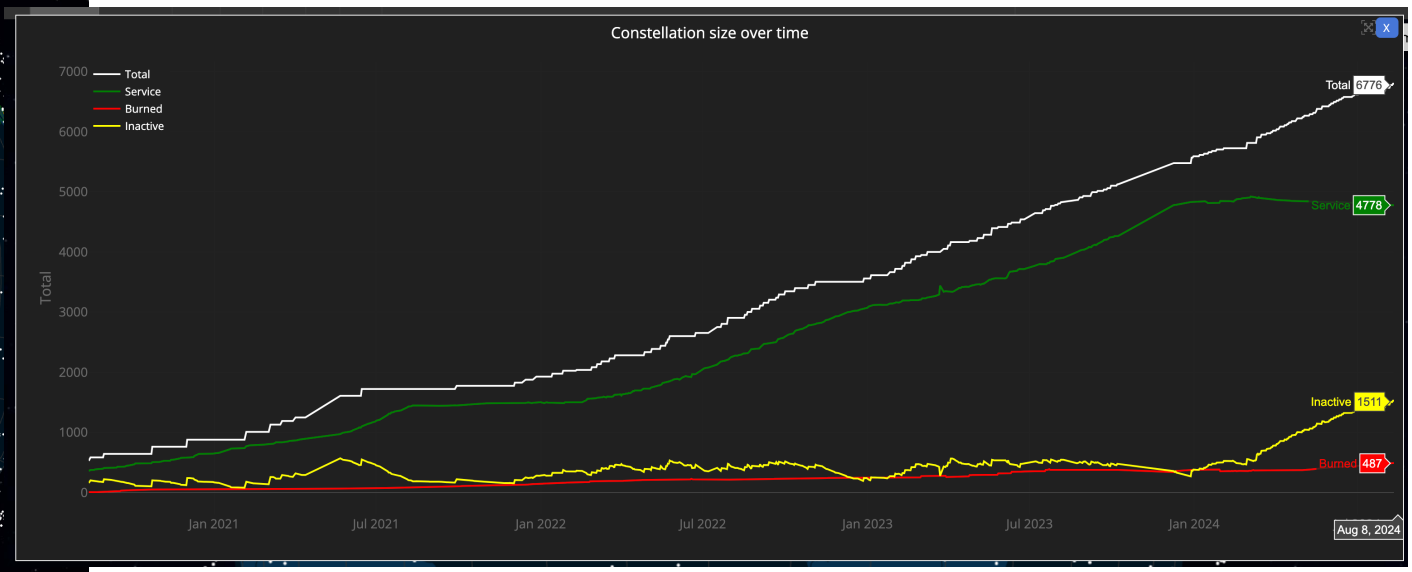
At a minimum, a LEO satellite constellation needs 500 satellites to provide coverage of all parts of the earth's surface

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

Starlink Constellation

- 4,778 in-service operational spacecraft, operating at an altitude of 550km



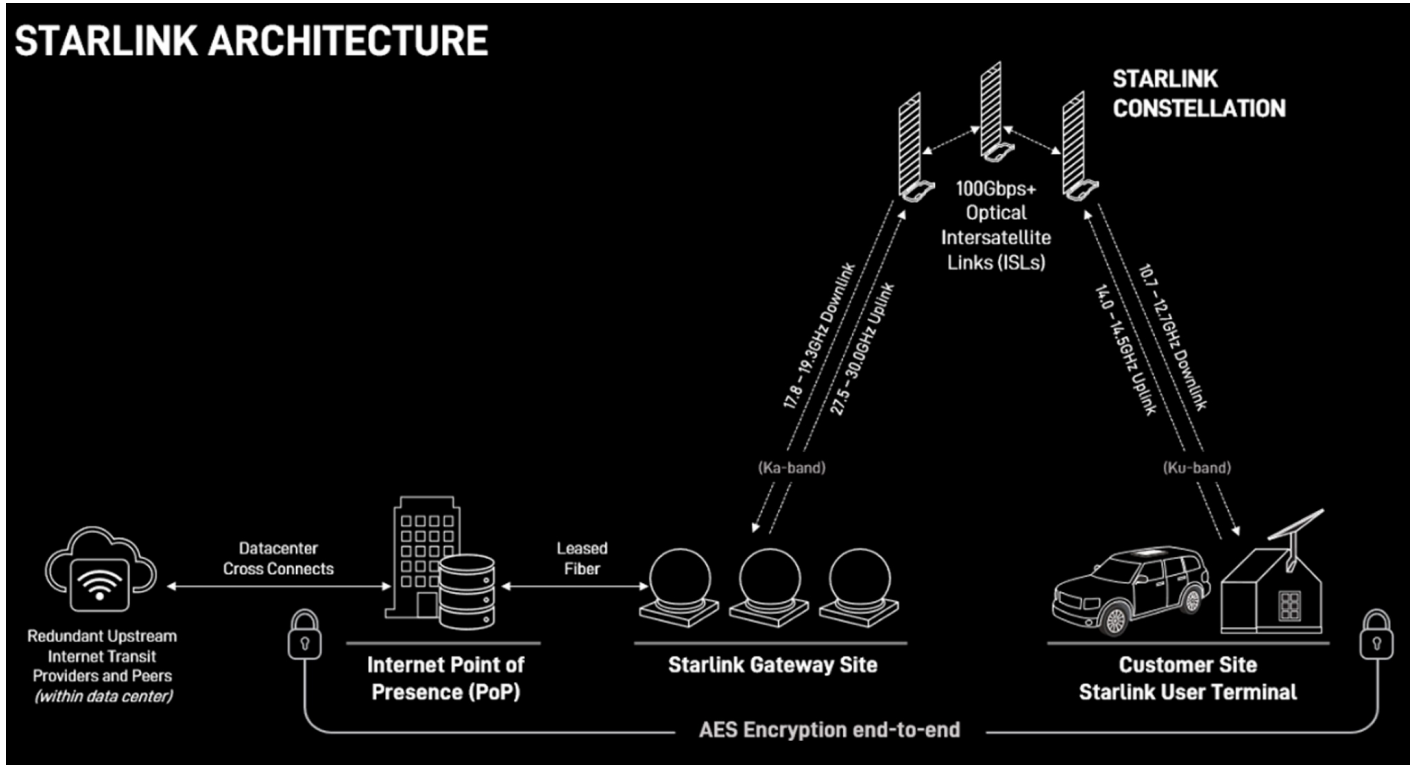


https://satellitemap.space/

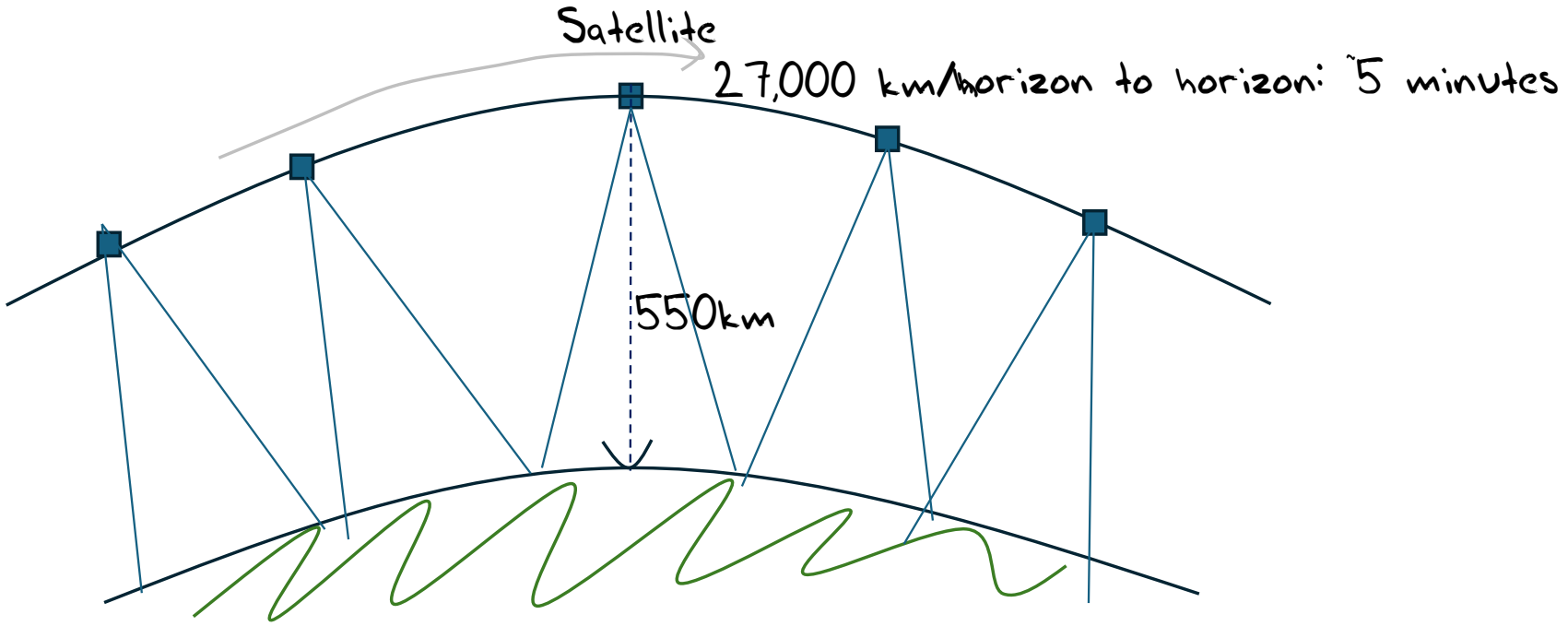
So LEOs are "interesting"!

- 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

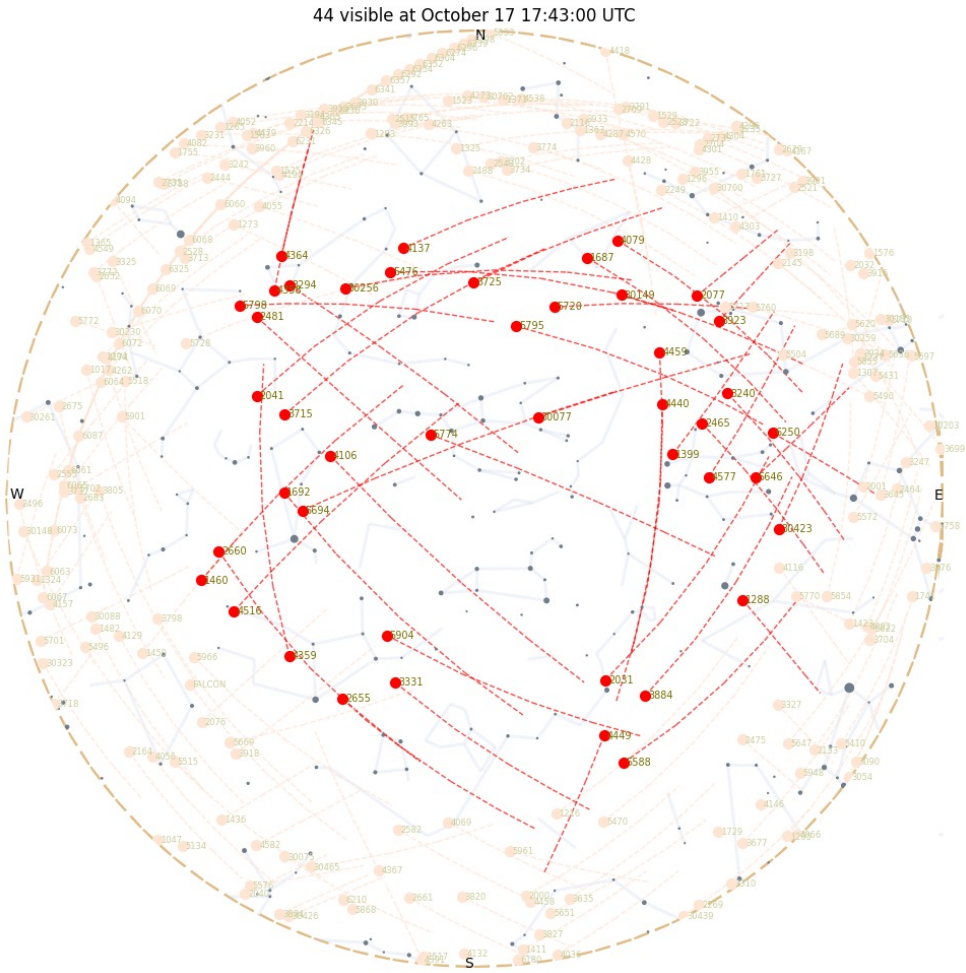
Starlink Architecture



Tracking a LEO satellite



Looking Up



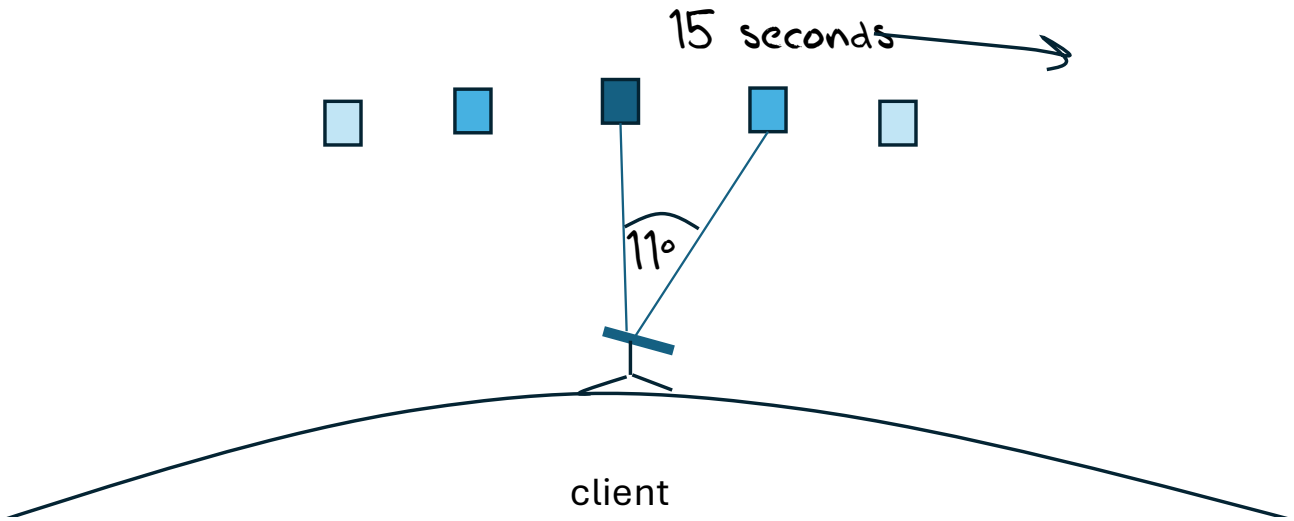
Starlink tracks satellites with a minimum elevation of 25°.

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

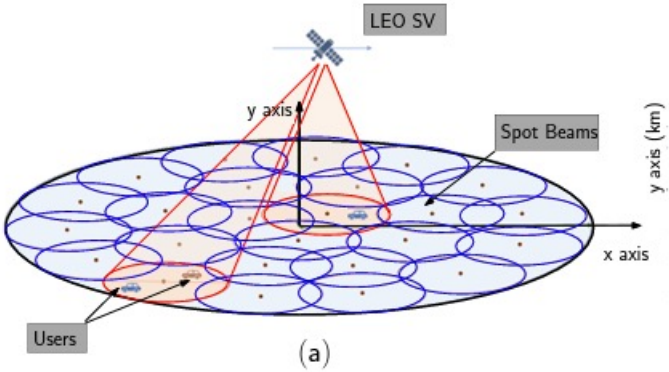
Starlink Scheduling

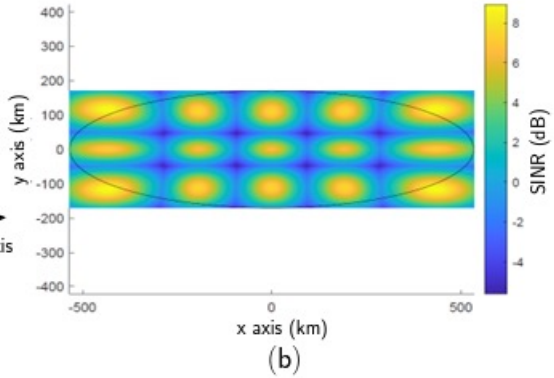
- A satellite is assigned to a user terminal in 15 second time slots
- Tracking of a satellite (by phased array focussing) works across 11 degrees of arc per satellite in each 15 second slot

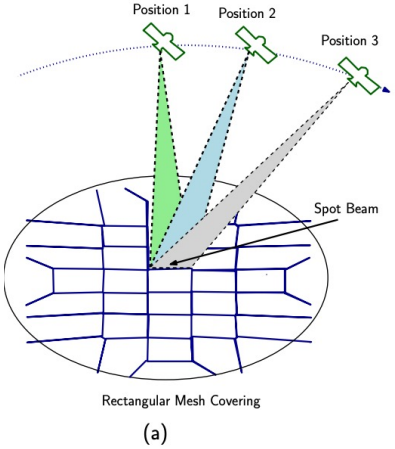


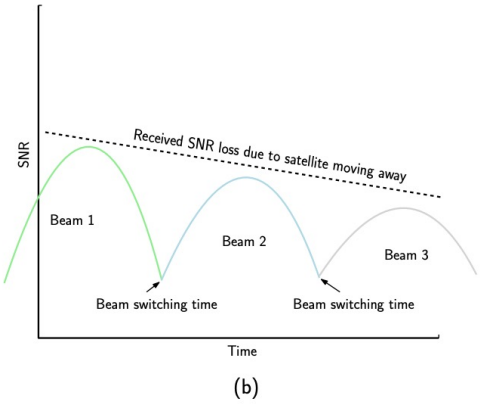
Starlink Spot Beams

- Each spacecraft uses 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.







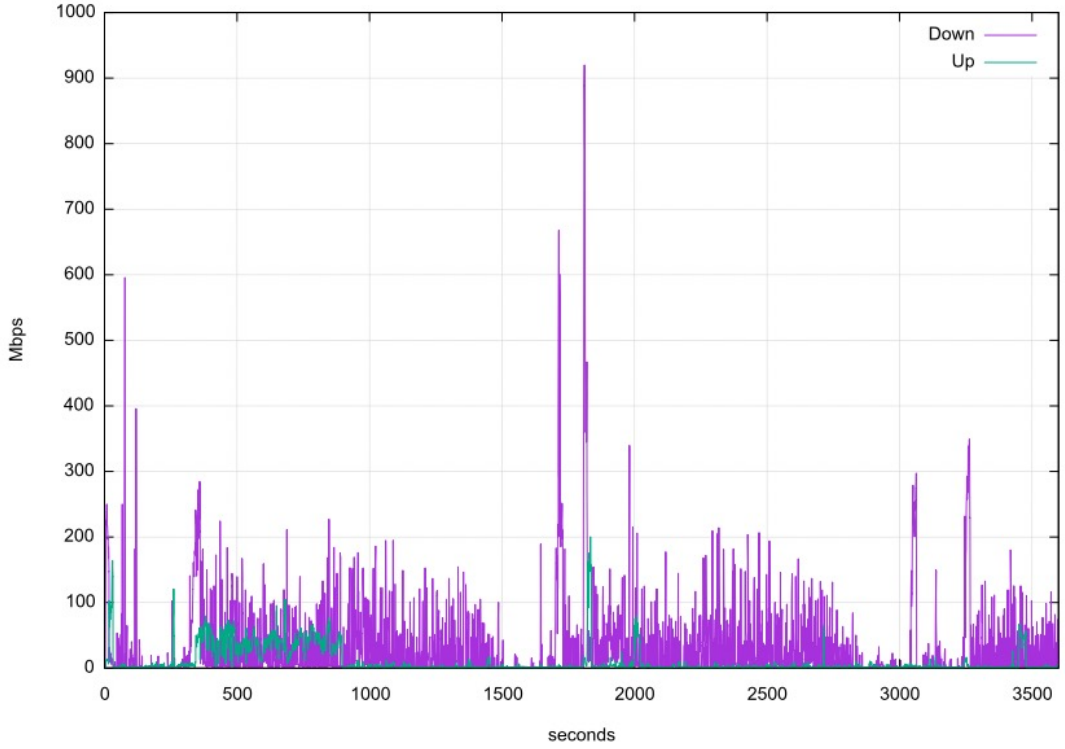


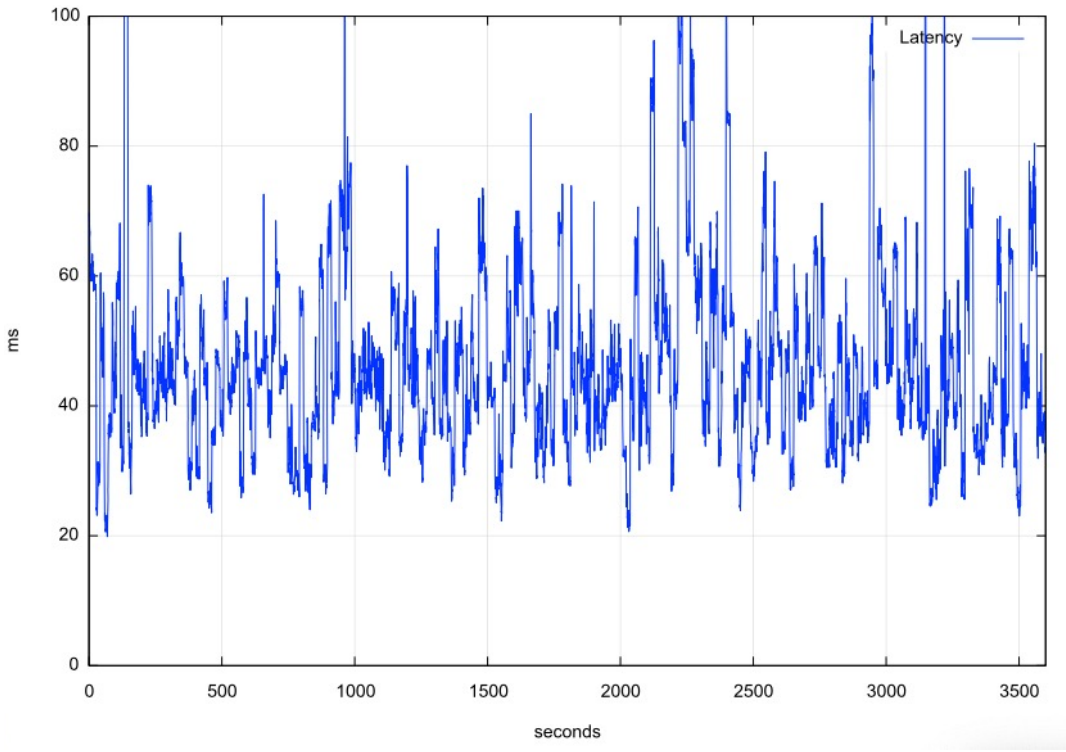
"Unveiling Beamforming Strategies of Starlink LEO Satellites"
https://people.engineering.osu.edu/sites/default/files/2022-10/Kassas_Unveiling_Beamforming_Strategies_of_Starlink_LEO_Satellites.pdf

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

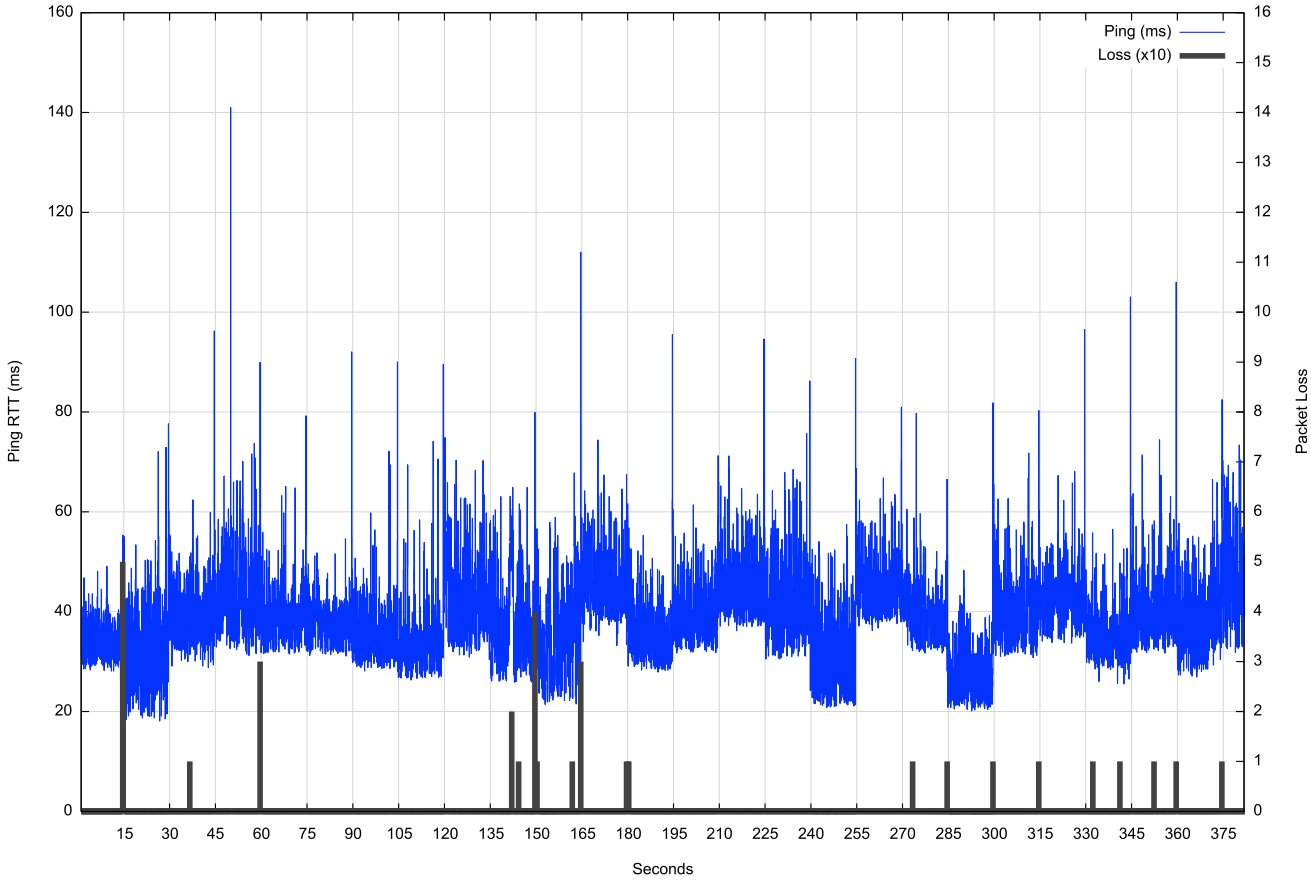




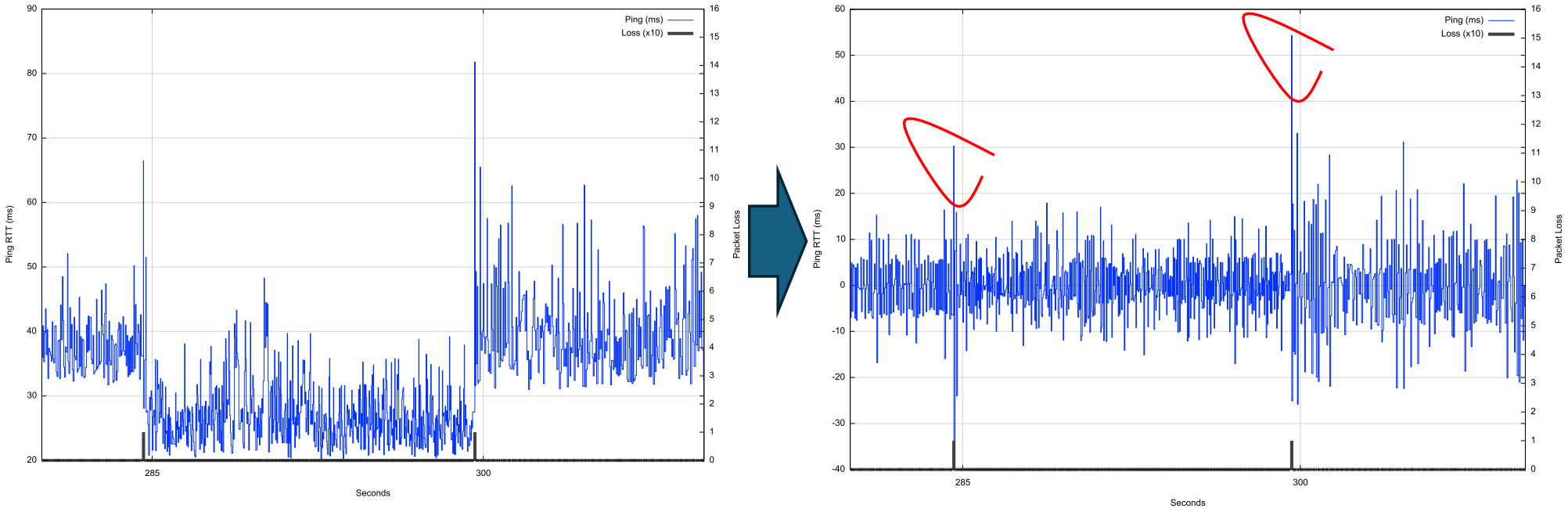
Why so "noisy"?

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

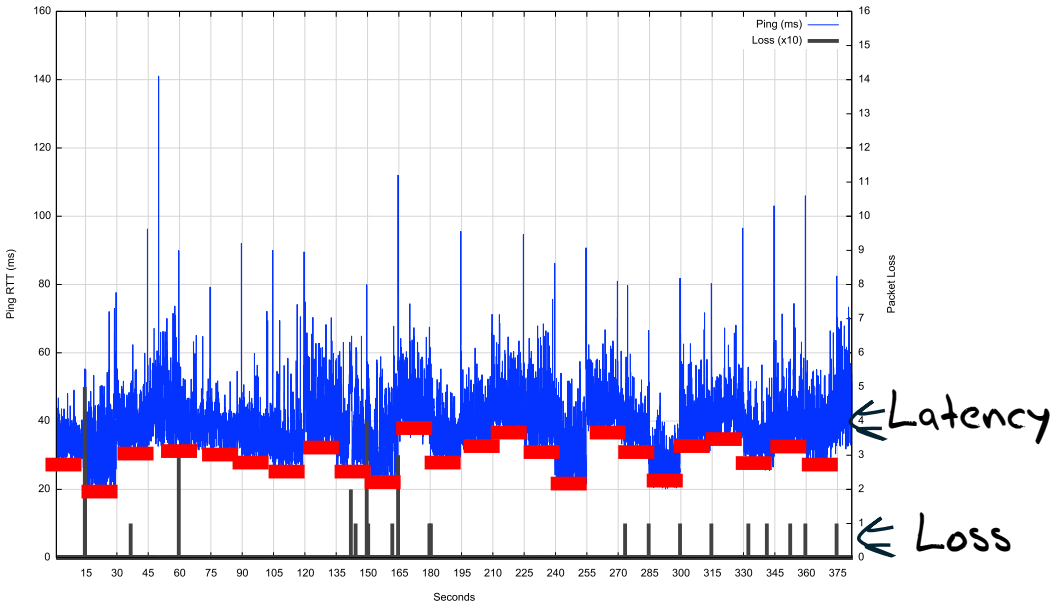


Satellite handover



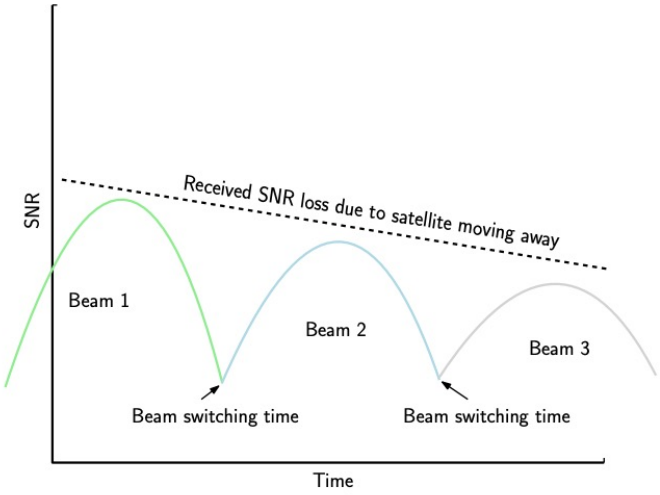
Satellite handover

- Packet loss occurs most frequently during handover events, and if confined to small set of packets
- This is NOT congestion-based tail-drop loss - so the packet loss can be generally repaired by a TCP SACK mechanism without needing a TCP session restart



Varying SNR

- Starlink likely uses IEEE 802.11ac dynamic channel rate control, adjusting the signal modulation to match the current SNR
- This continual adjustment causes continual shift in the available capacity and imposes a varying latency on the round-trip time



Why?

- 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
- TCP uses ACK pacing which means it attempts to optimize its sending rate over multiple RTT intervals

Frames

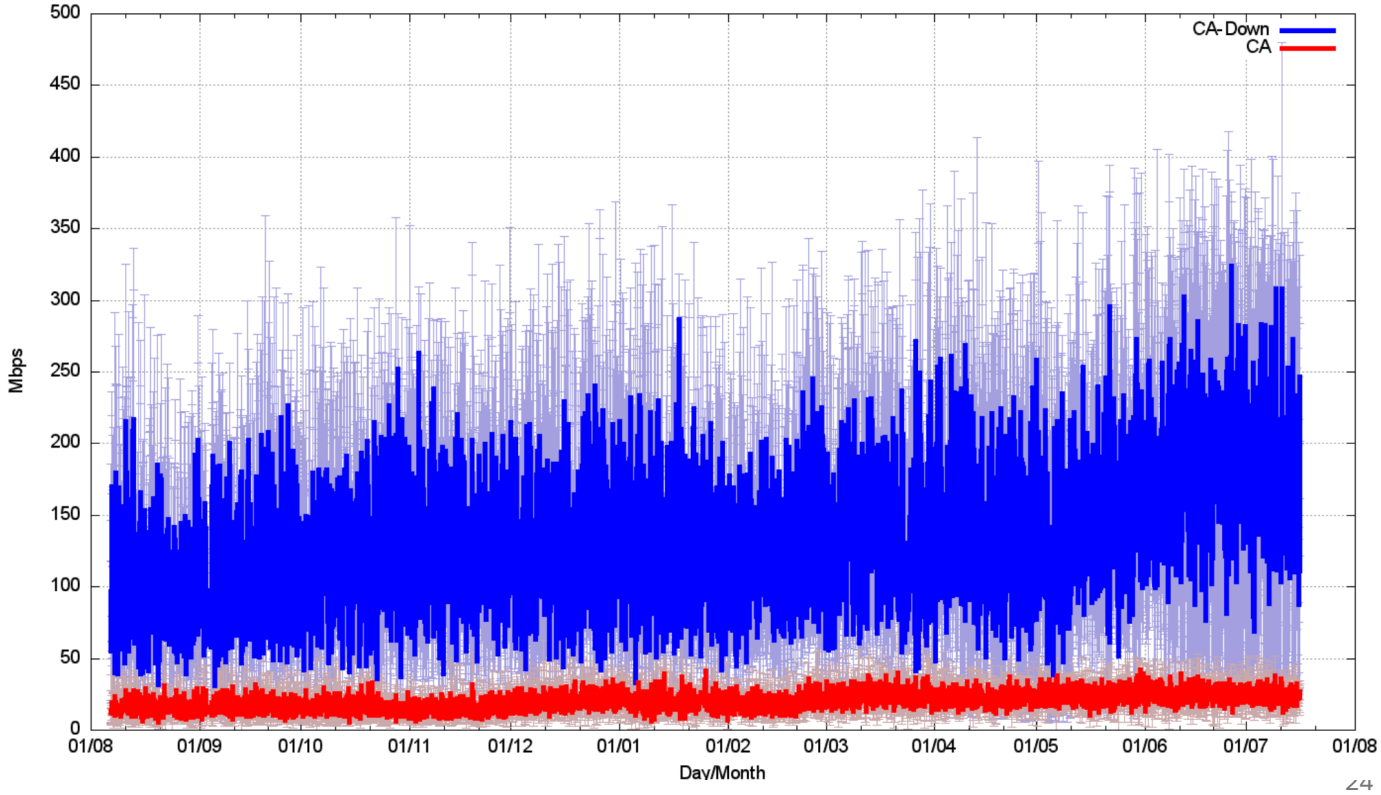
- Starlink does NOT provide each user with a dedicated frequency band
- The system uses Multiplexing to divide a channel into frames, and sends 750 frames per second. Each frame is divided into 302 intervals.
- Each frame carries a header that carrier satellite, channel and modulation information

Starlink Characteristics

- Varying SNR produces varying modulation, which is expressed as varying capacity and delay
- Relative motions of earth and spacecraft add to varying latency
- 15 second satellite handover generates regular loss and latency extension
- Contention for common transmission medium leads to queuing delays

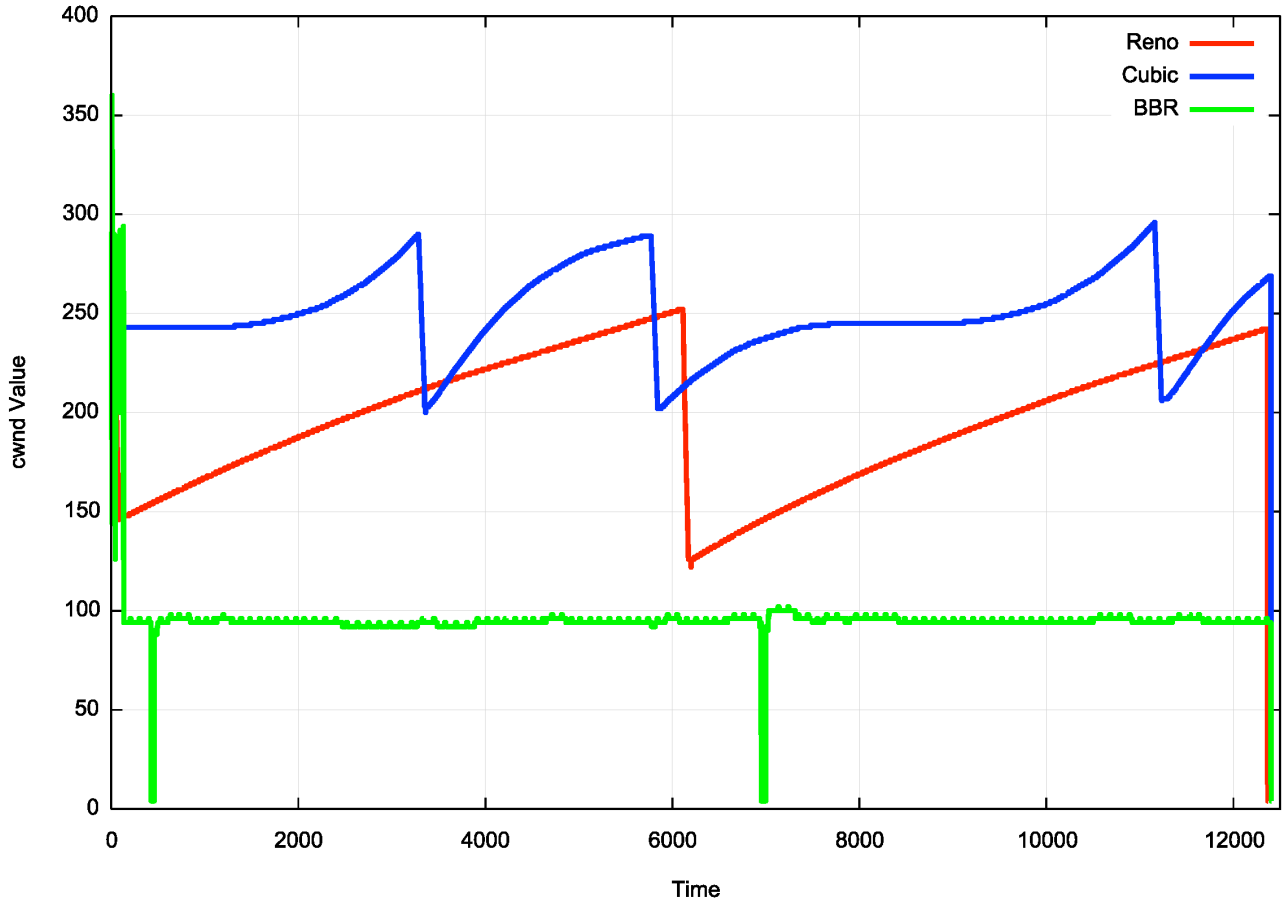
How well does all this work?

Speedtest measurements:



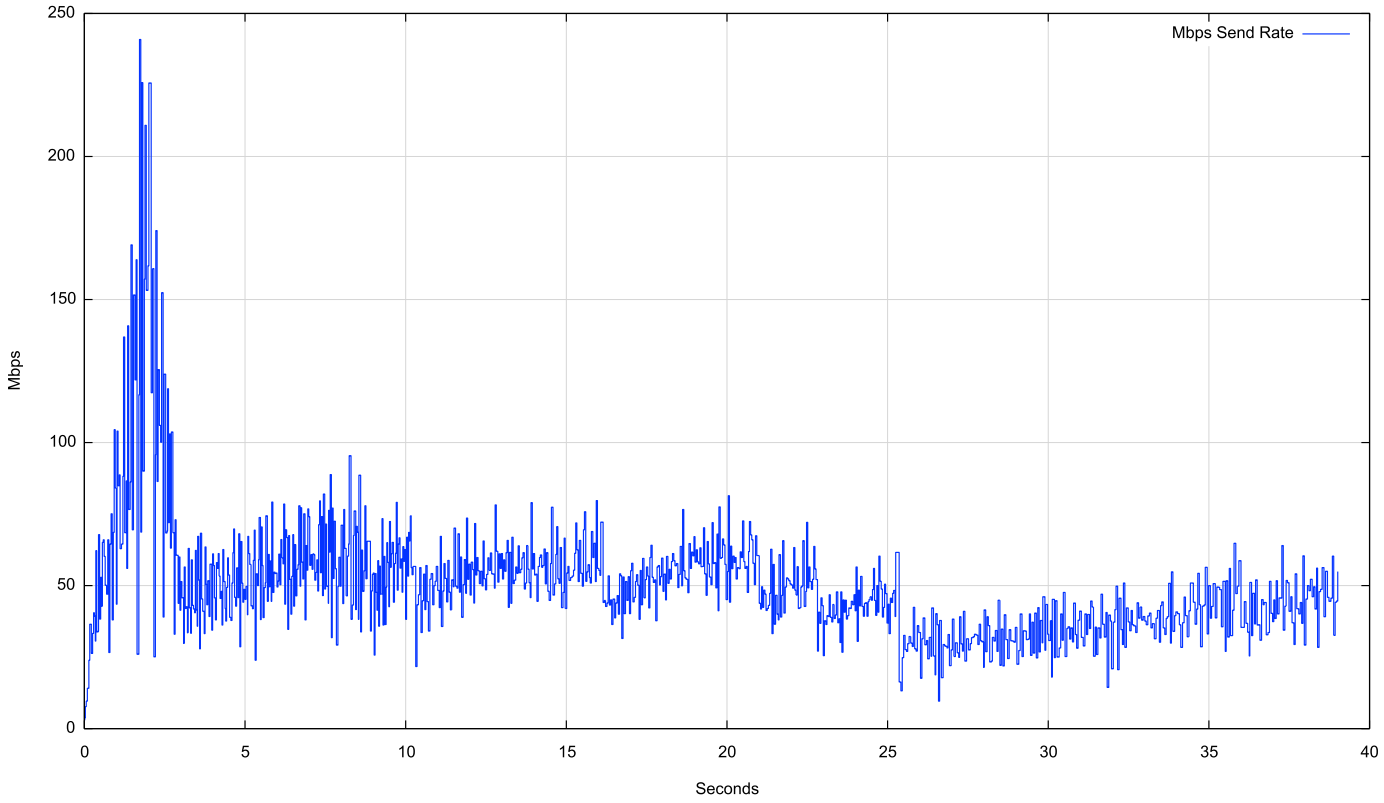
We should be able to get ~160Mbps out of a Starlink connection.

TCP Flow Control Algorithms

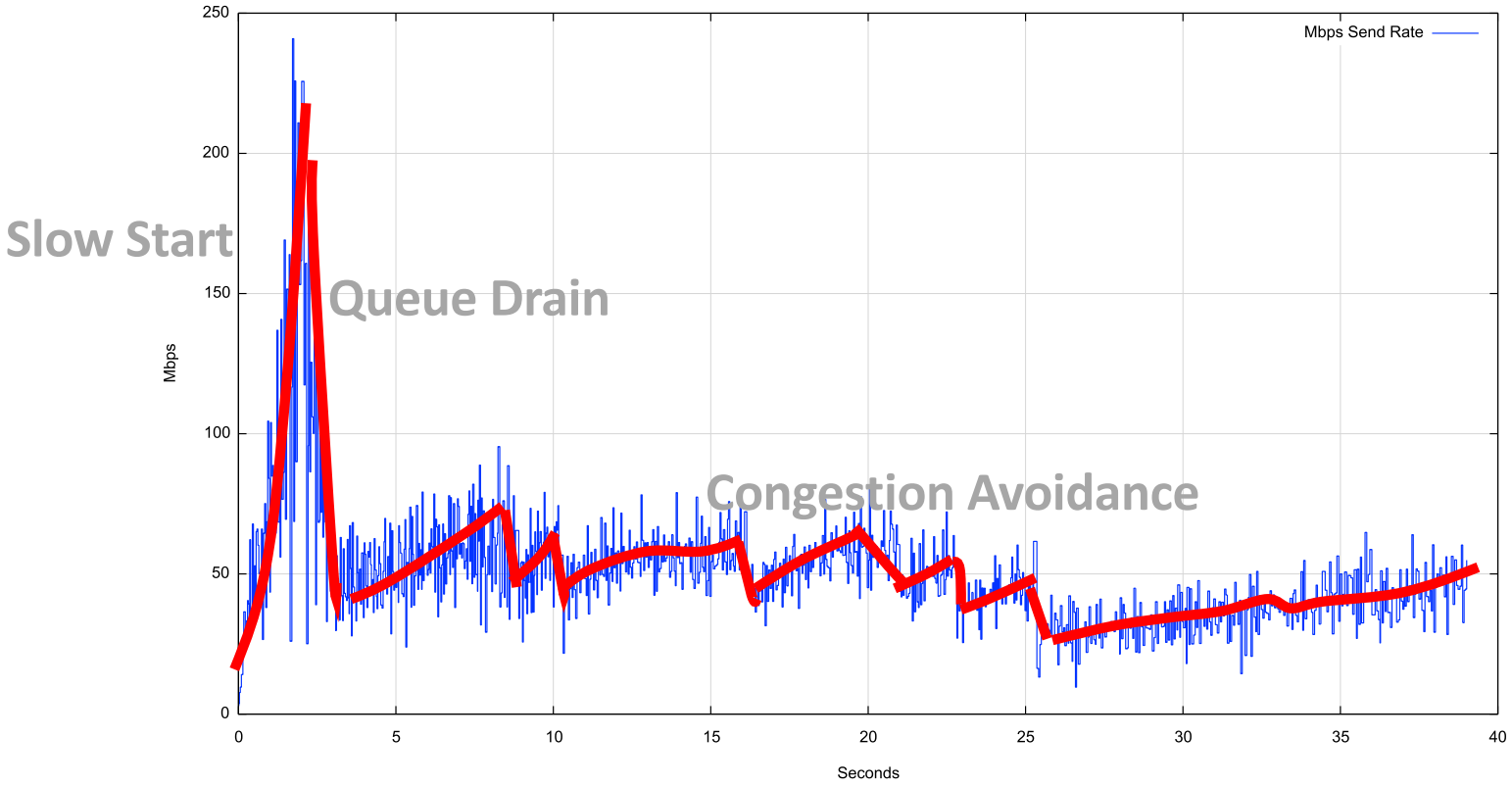


"Ideal" Flow behaviour for each protocol

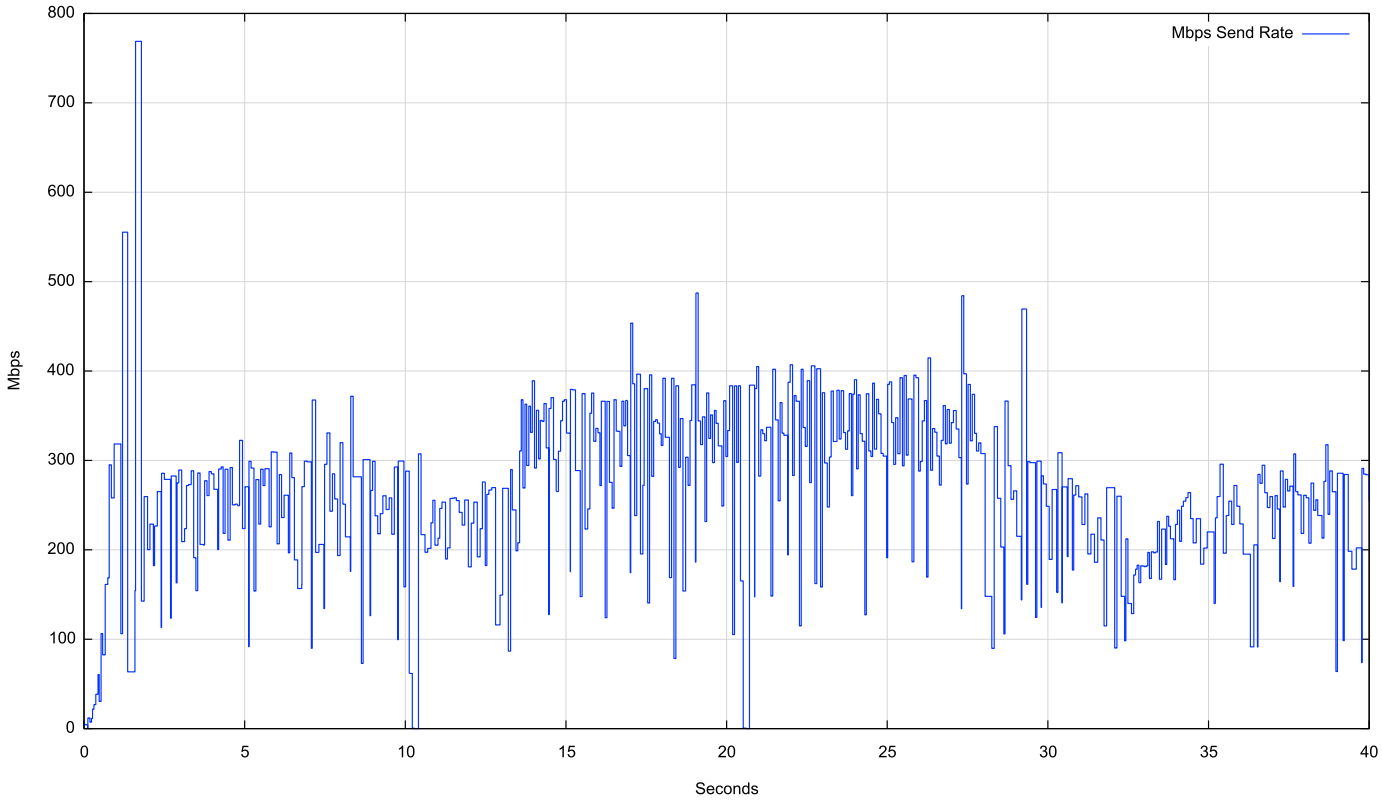
iperf3 - cubic, 40 seconds



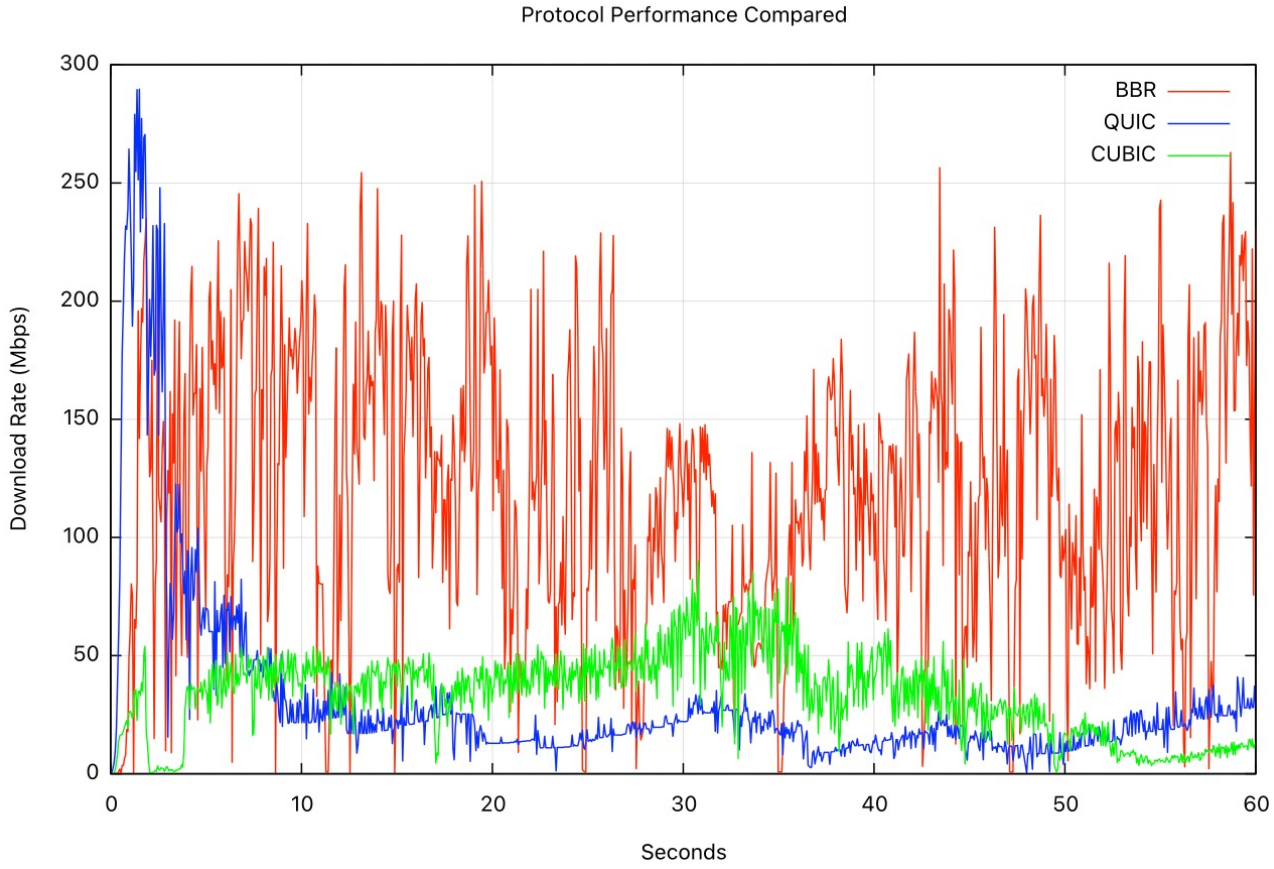
iperf3 - cubic, 40 seconds



iperf3 - bbr


Mbps Send Rate
Mbps
Seconds
0
100
200
300
400
500
600
700
800
0
5
10
15
20
25
30
35
40

Cubic, Quic/Cubic, BBR



Protocol Considerations

- Starlink services have three issues:
  - Very high jitter rates – varying signal modulation
  - High levels of micro-loss (1.4%) – largely due to loss on satellite handover events (every 15 seconds)
  - Common bearer contention between users
- 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
- To obtain better performance you need to move to flow control algorithms that are not loss-sensitive, such as BBR

Other considerations

- Senders should use **fair queuing** to pace sending rates and avoid bursting and tail drop behaviours
- **SACK** (selective acknowledgement) for TCP can help in rapid repair to multiple lost packets
- Its likely that **ECN** would also be really helpful to disambiguate latency changes due to satellite behaviours and network queue buildup

Starlink Performance

Starlink is perfectly acceptable for:

- short transactions
- video streaming
- conferencing

- The service can sustain 40 – 50Mbps delivery for long-held sessions during local peak use times in high density use scenarios
  - The isolated drop events generally do not intrude into the session state
- In off-peak and/or low-density contexts it can deliver 200-300Mbps
- Or, if the server uses BBR then higher throughput is possible!
- 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!


Questions?