On GEOs, LEOs and Starlink

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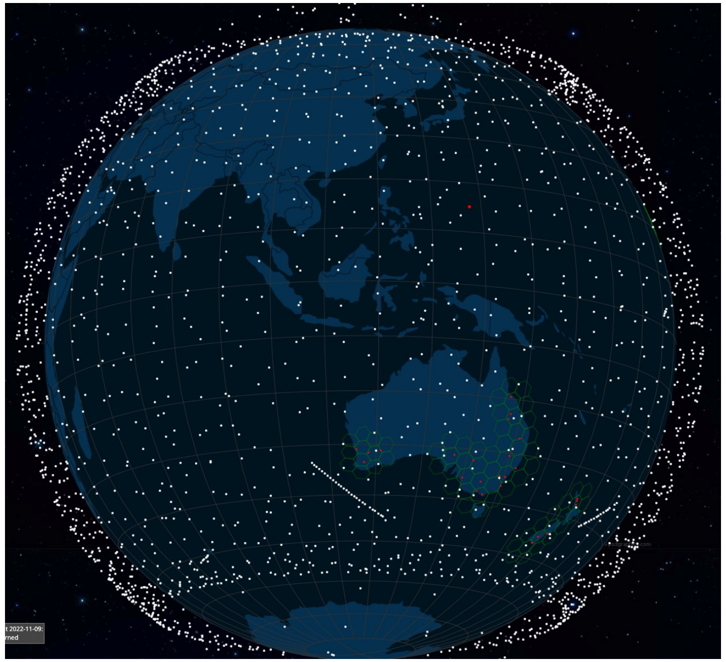
APNIC

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.

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

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

Media & Telecom

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

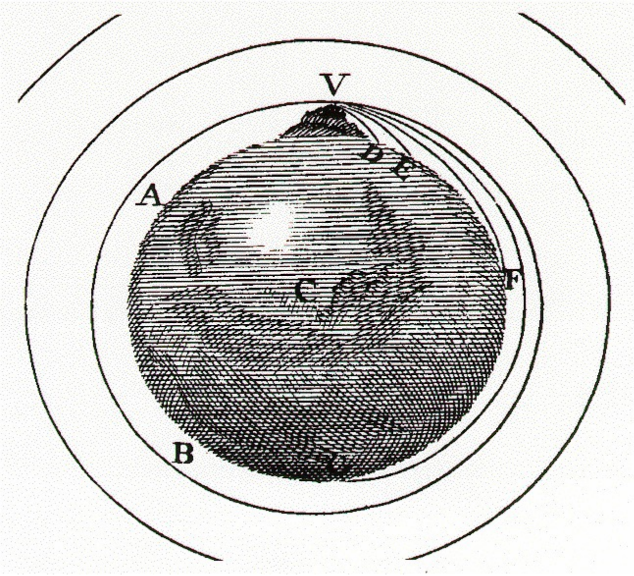
Reuters

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

Aa

Newtonian Physics

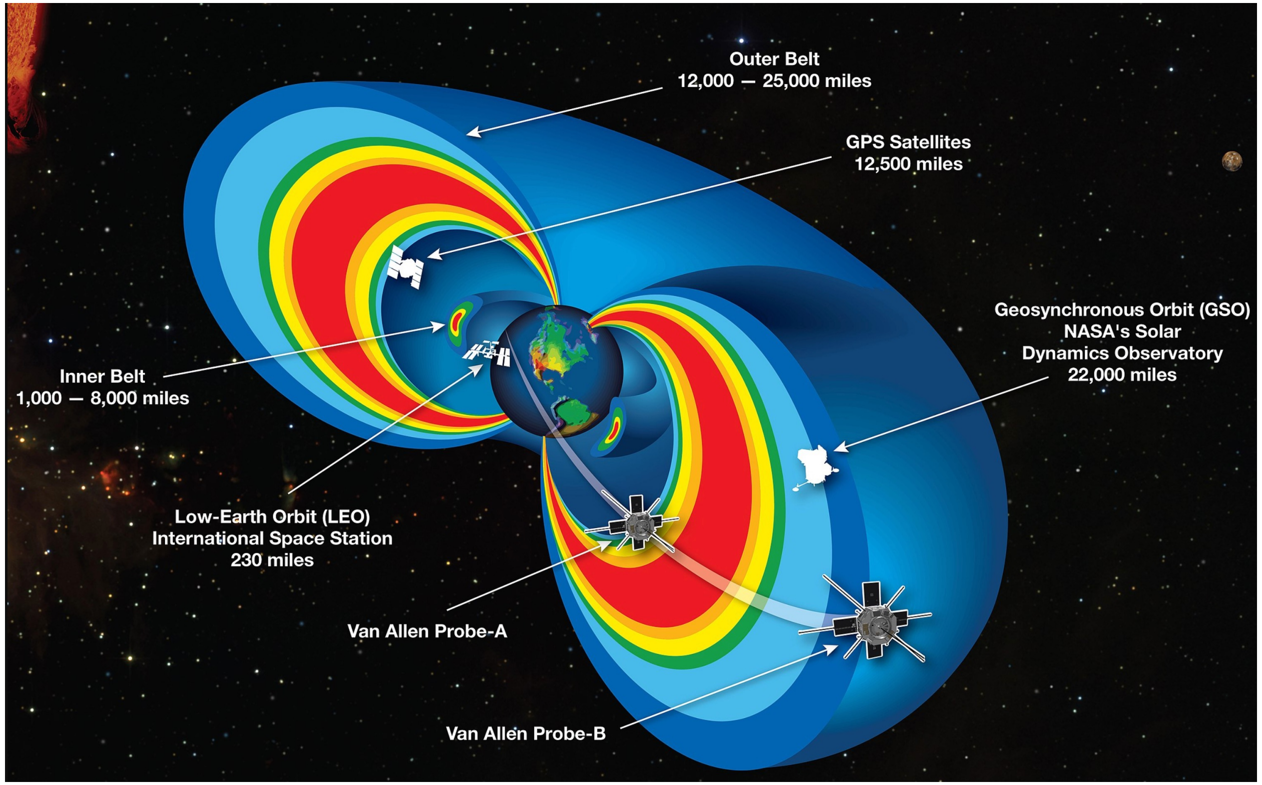
- If you fire a projectile with a speed greater than 11.2Km/sec it will not fall back to earth, and instead head away from earth never to return
- On the other hand, if you incline the aiming trajectory and fire it at a critical speed it will settle into an orbit around the earth
- The higher the altitude,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

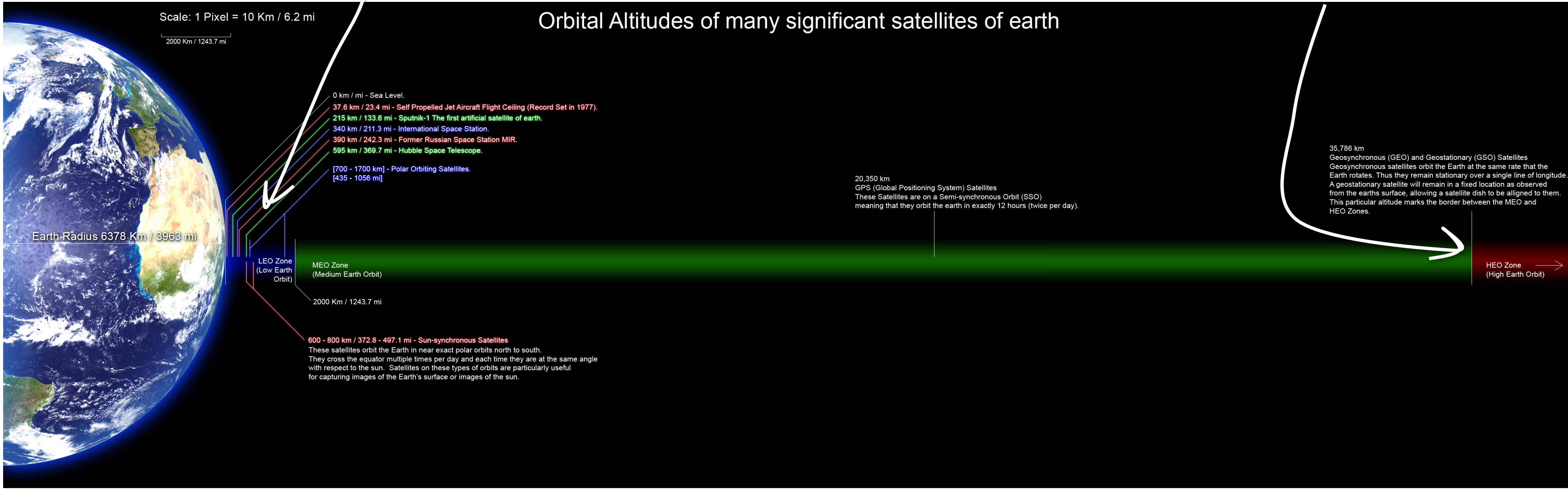
Solar Radiation Physics



- 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

Leos

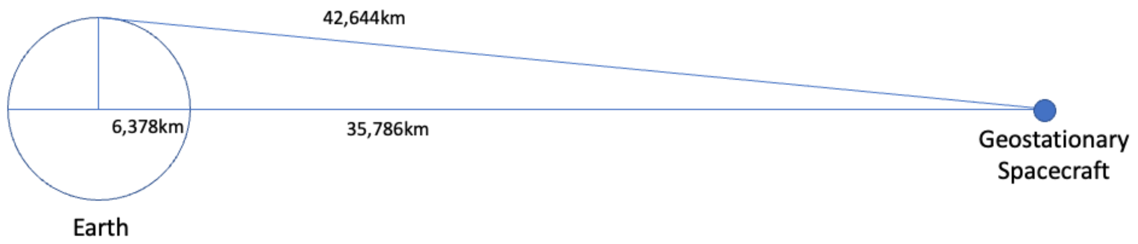
Geos



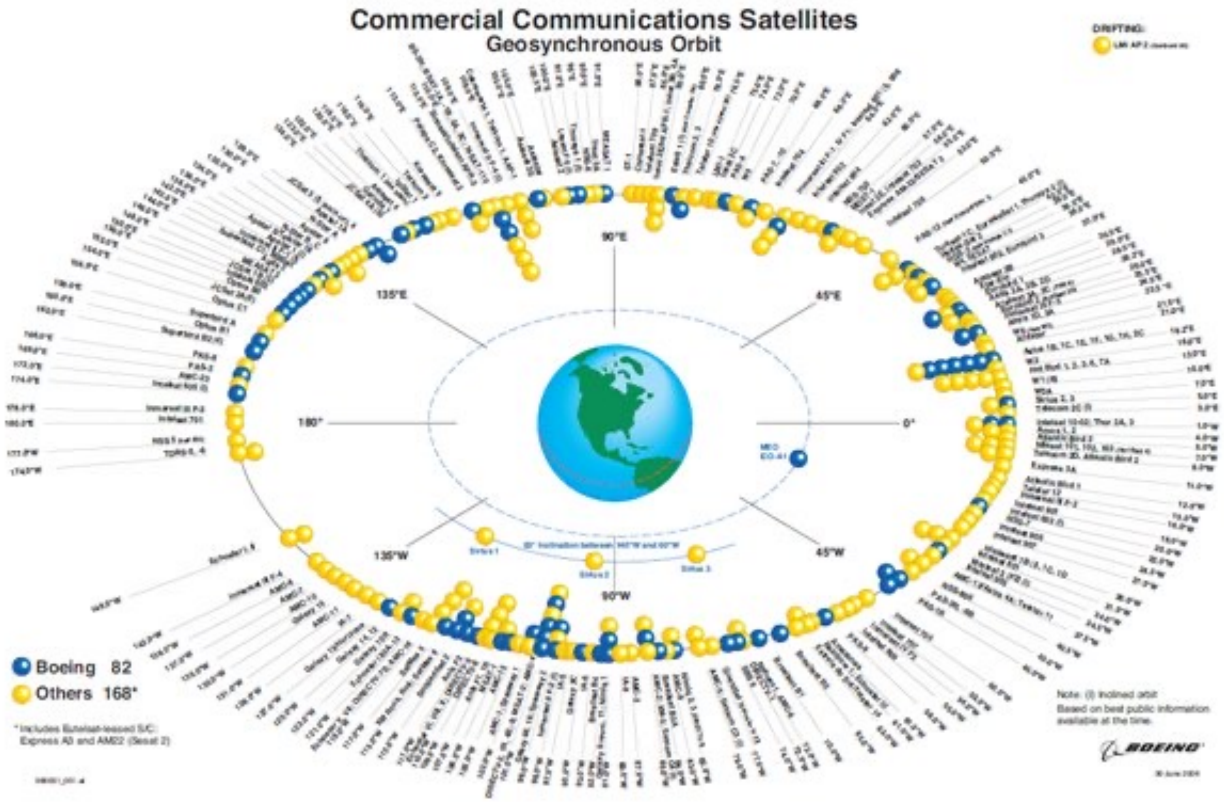
Scale: 1 Pixel = 10 Km / 6.2 mi
2000 Km / 1243.7 mi
Orbital Altitudes of many significant satellites of earth
0 km / mi - Sea Level.
37.6 km / 23.4 mi - Self Propelled Jet Aircraft Flight Ceiling (Record Set in 1977).
215 km / 133.6 mi - Sputnik-1 The first artificial satellite of earth.
340 km / 211.3 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.
20,350 km
GPS (Global Positioning System) Satellites
These Satellites are on a Semi-synchronous Orbit (SSO) meaning that they orbit the earth in exactly 12 hours (twice per day).
35,786 km
Geosynchronous (GEO) and Geostationary (GSO) Satellites
Geosynchronous satellites orbit the Earth at the same rate that the Earth rotates. Thus they remain stationary over a single line of longitude.
A geostationary satellite will remain in a fixed location as observed from the earths surface, allowing a satellite dish to be alligned to them.
This particular altitude marks the border between the MEO and HEO Zones.
HEO Zone (High Earth Orbit)

Geostationary Earth Orbit

- At an altitude of 35,786km a satellite will orbit the earth with the same period as the earth’s rotation – from the earth it will appear to be stationary in the sky

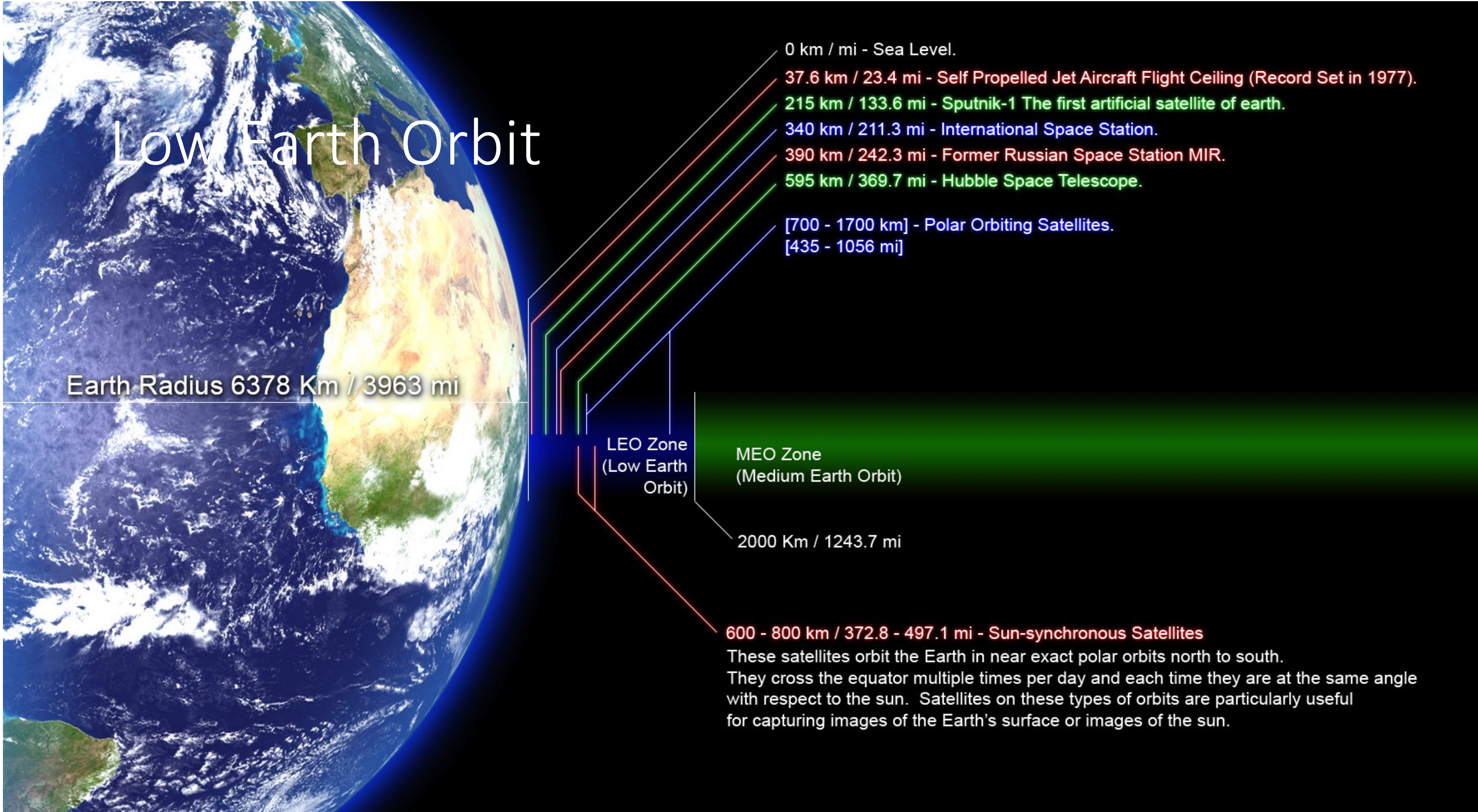


https://commons.wikimedia.org/wiki/File:Communications_satellite_with_TEMPO_spacecraft_model.png – public domain



https://secure.boeingimages.com/archive/Commercial-Communications-Satellites-Orbit-2F3XC5KQCM9.html

Low Earth Orbit



https://commons.wikimedia.org/wiki/File:Orbitalaltitudes.jpg *GNU Free Documentation*

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.

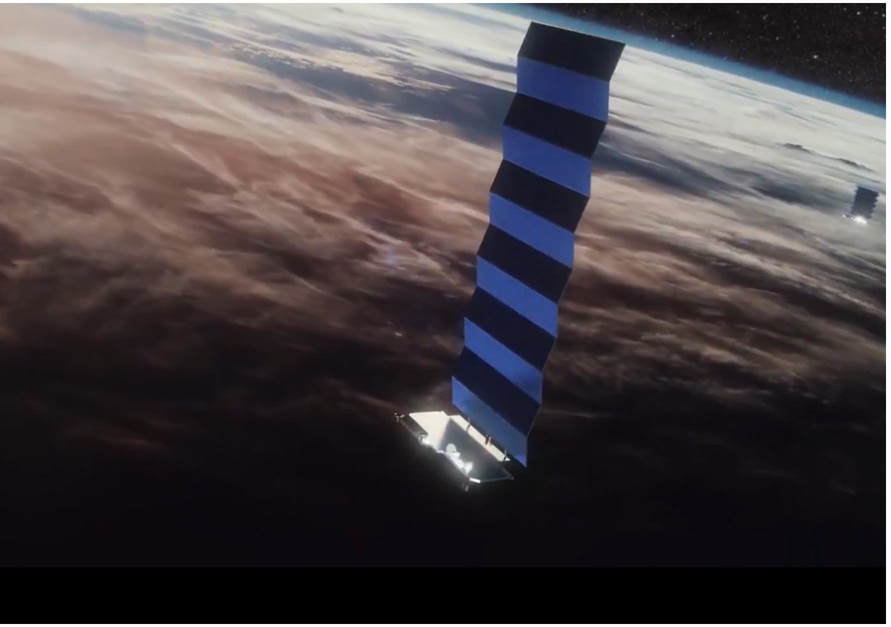
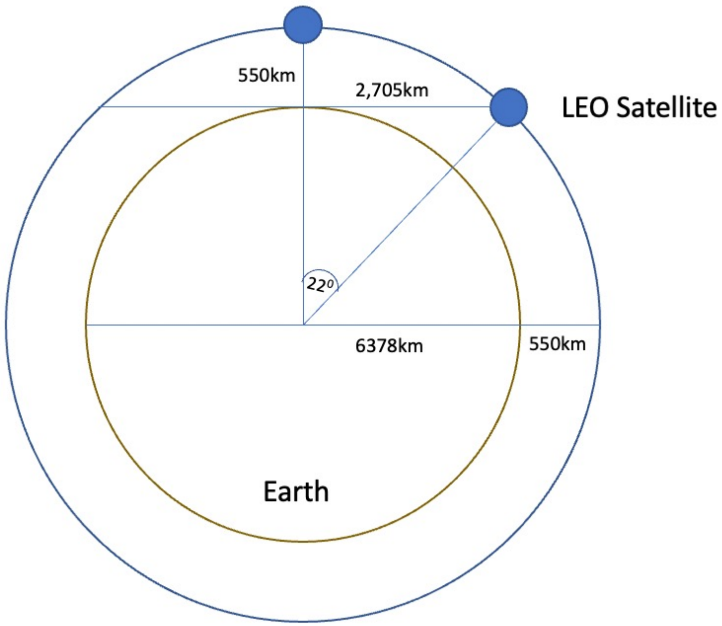
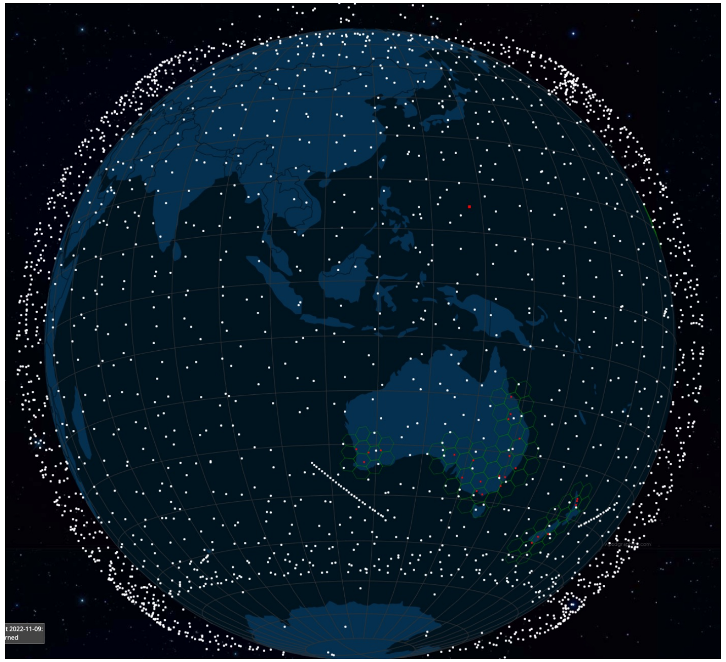


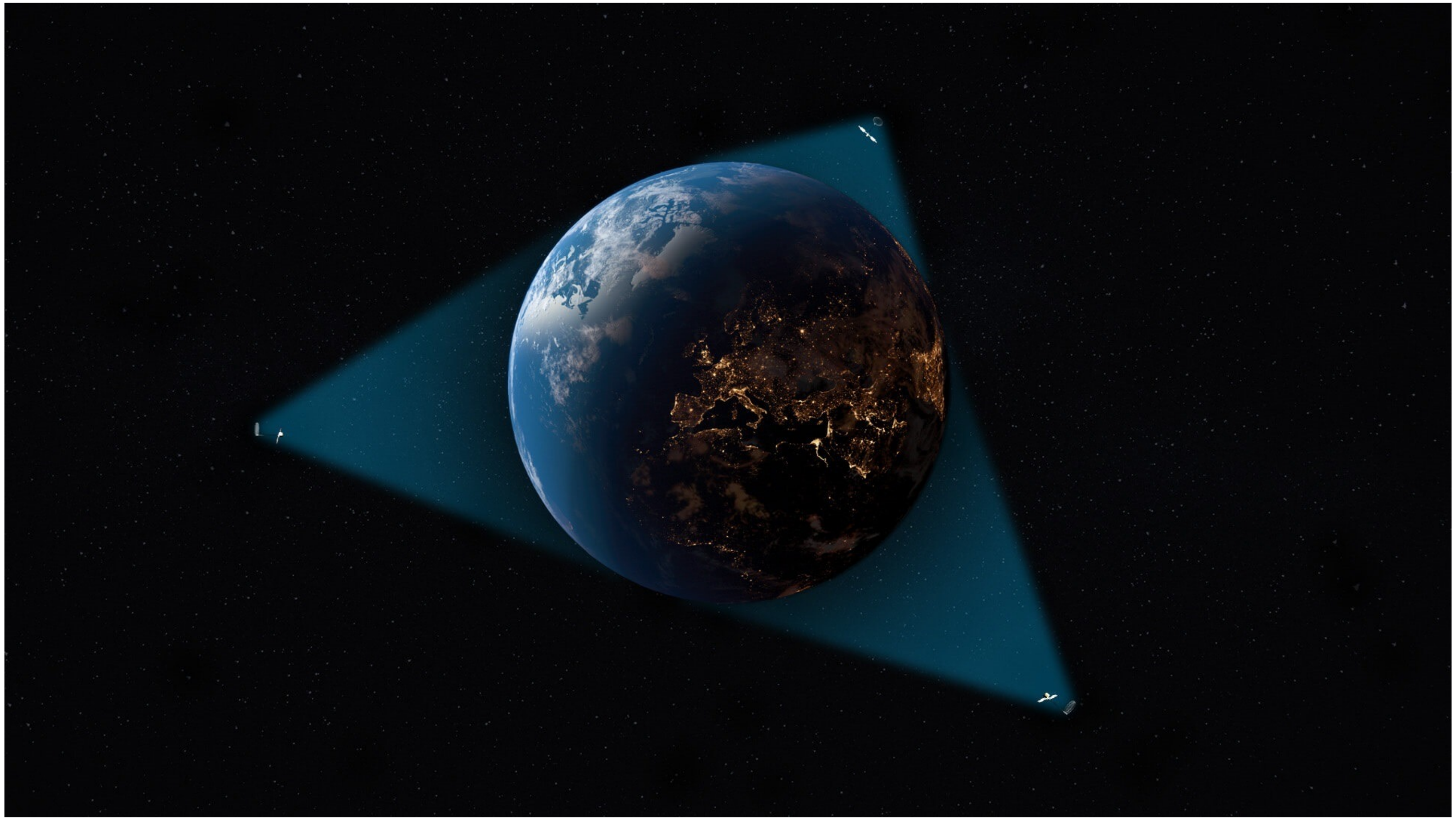
Image - spacex





screenshot from starwatch app

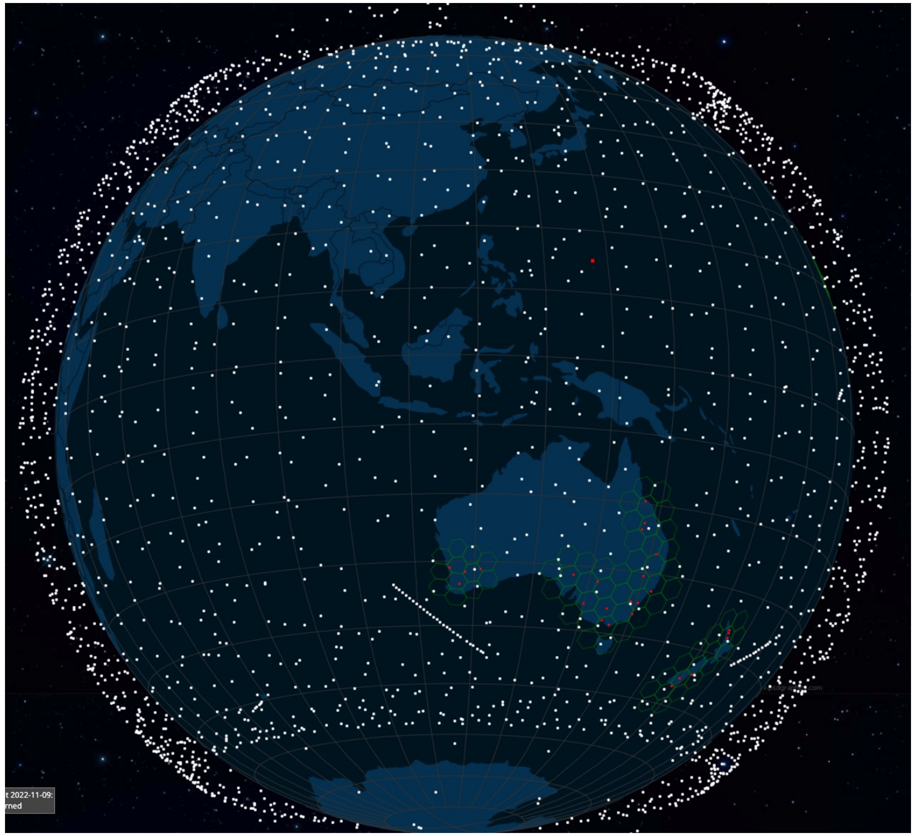
Geo Coverage



Source: Viasat

It needs just 3 GEO satellites to provide global continuous coverage everywhere (except polar)

LEO coverage



It needs a minimum of some 500 LEO satellites to provide global continuous coverage everywhere (at 550km altitude)

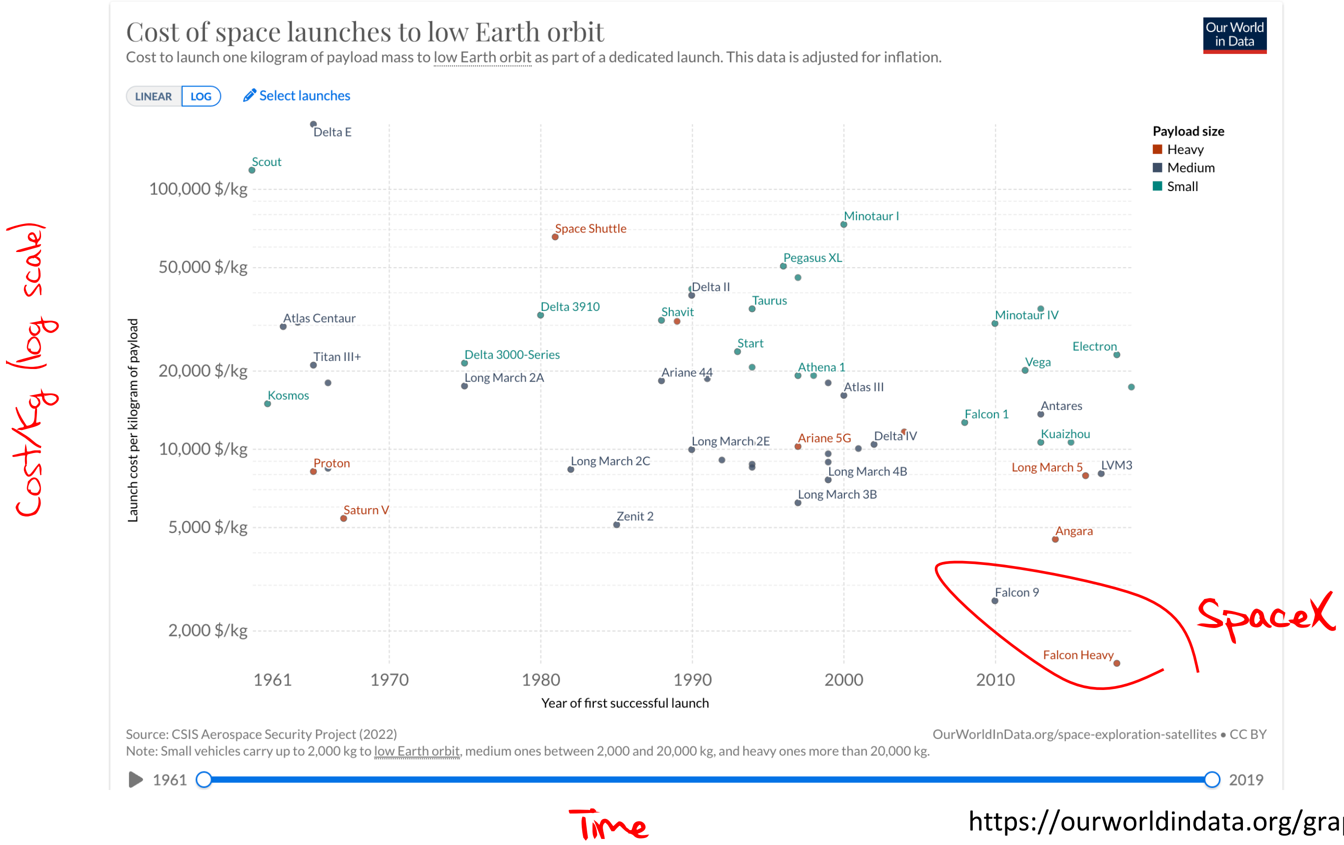
Depending on the quality of coverage you are after, you may need some thousands of LEO spacecraft!

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
- But you need a large number of them to provide a continuous service
  - Each satellite spans footprint of no more than ~900Km radius, or 2M K^2
  - At a minimum you'll need 500 satellites to provide continuous coverage
  - But if you want high quality coverage you are going to need 6x-20x that number (or more)
- The extremely host cost of launching a large constellation of LEO spacecraft has been the major problem with LEO service
  - 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



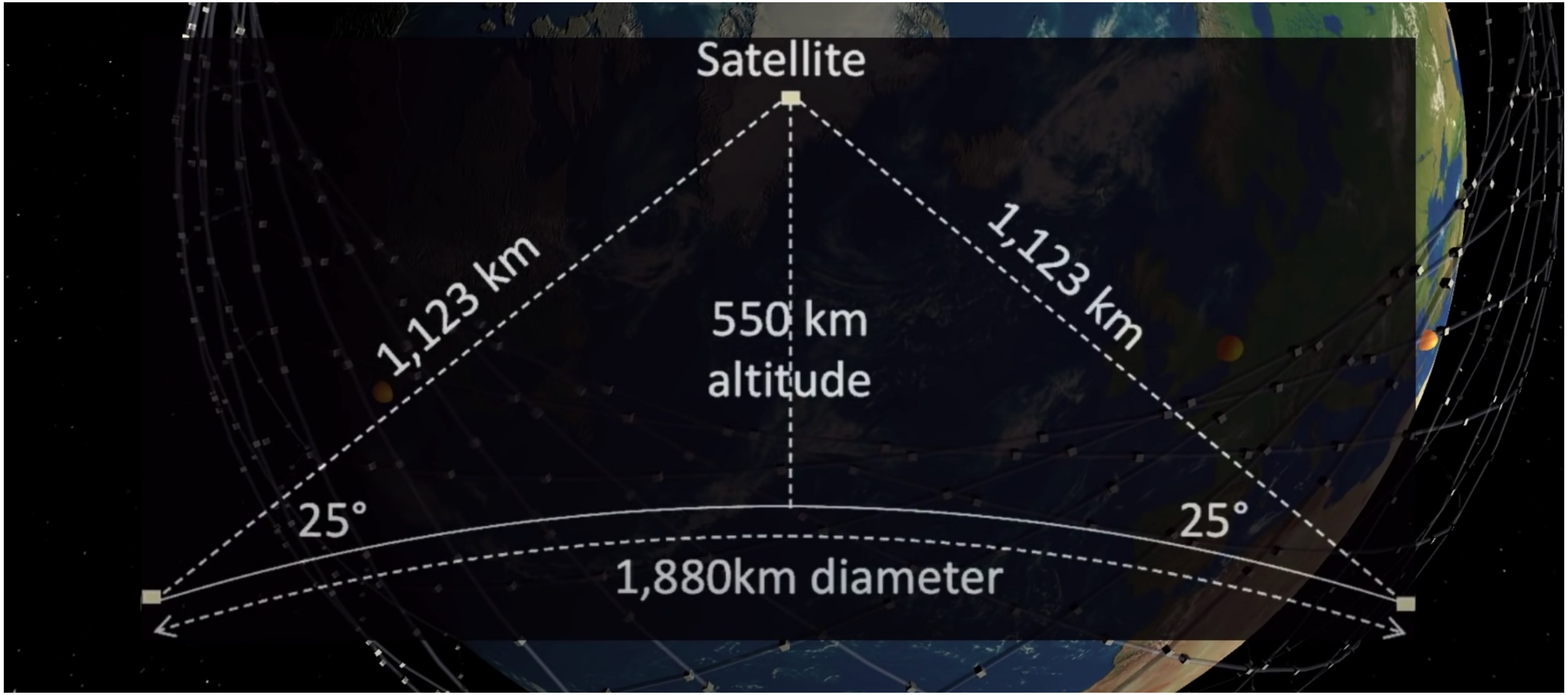
https://ourworldindata.org/grapher/cost-space-launches-low-earth-orbit

So Many LEO Satellites!

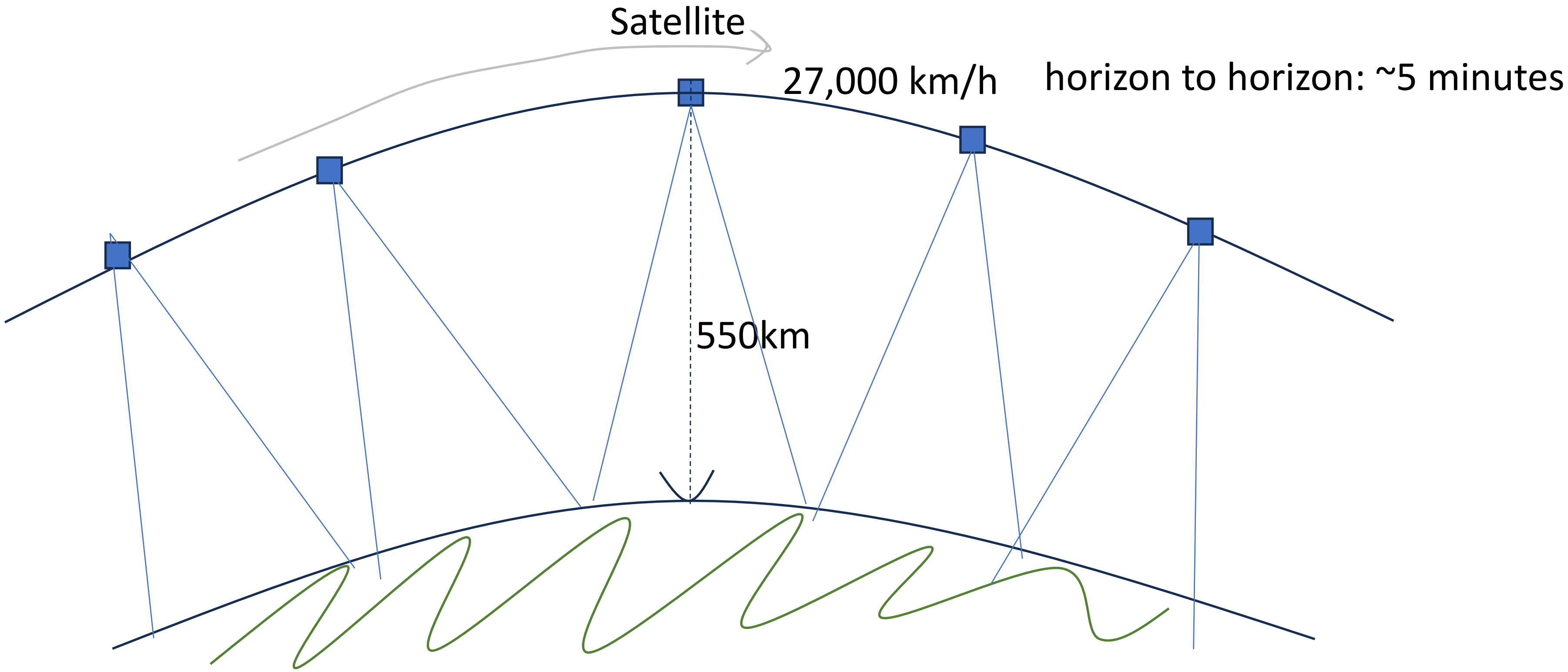
SpaceX Starlink Gen 1	4,408
SpaceX Starlink Gen 2	29,988
OneWeb, Phase 1	718
OneWeb, Phase 2	6,372
Amazon Project Kuiper	7,774
China Guowang	12,992
Astra	13,620
Boeing	5,842
Globalstar	3,080
Lynk	2,000
Telesat Lightspeed	1,969
Spin Launch	1,190
TOTAL	**89,953**
E-Space	337,323

Current and Planned satellite constellations

Low altitude: smaller footprint



Tracking a LEO satellite



Earth Dishes for LEOs

Just overkill!

(in every possible way!)

Earth Dishes for LEOs

Still too big

And it needs to be steered

Earth Dishes for LEOs

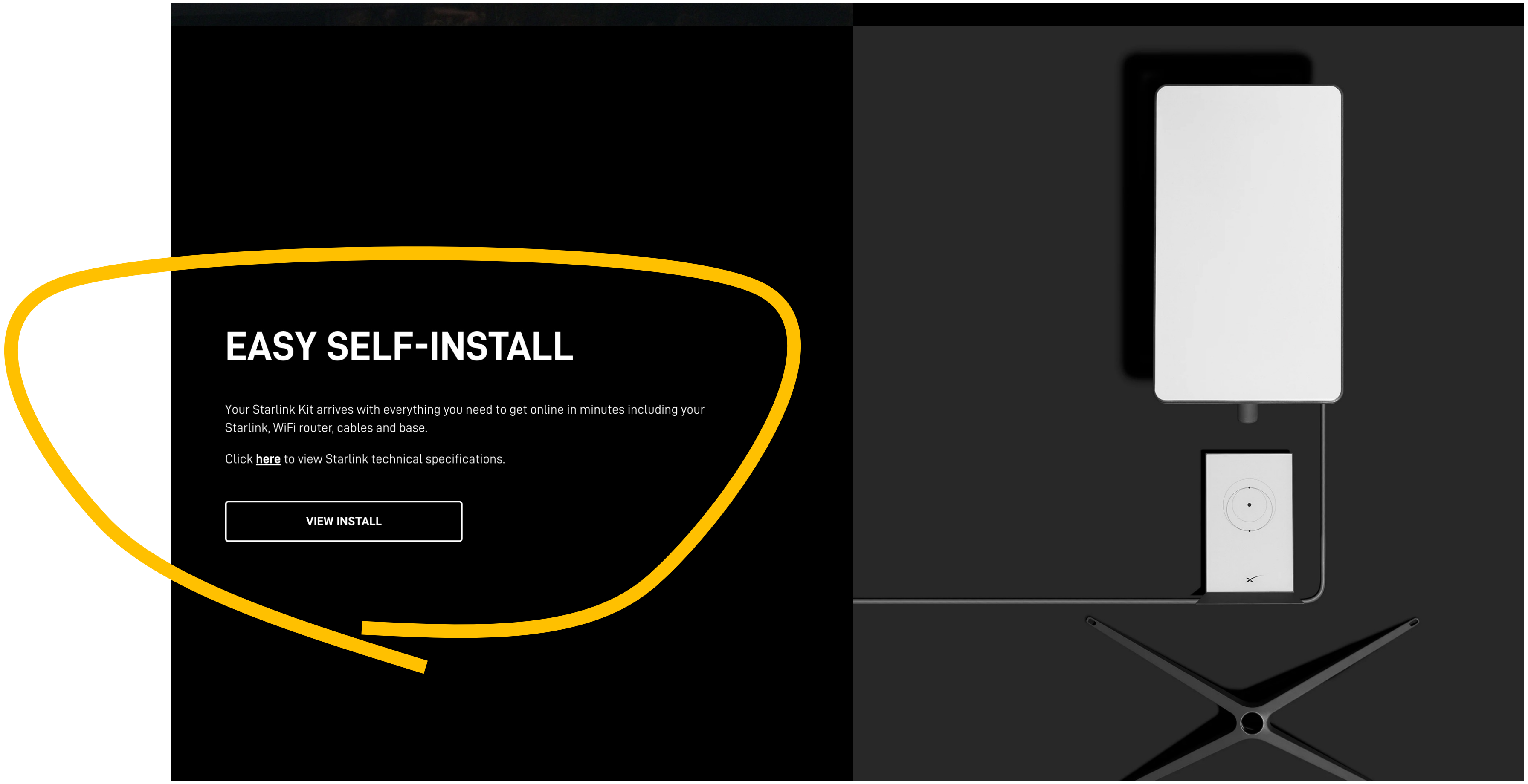
Phased array antennae

An array of smaller antenna with software-controlled phase alignment means that the dish can steer its focal angle in two dimensions with minimal lag

This is ideal for LEO systems which use low power but high traversal speed

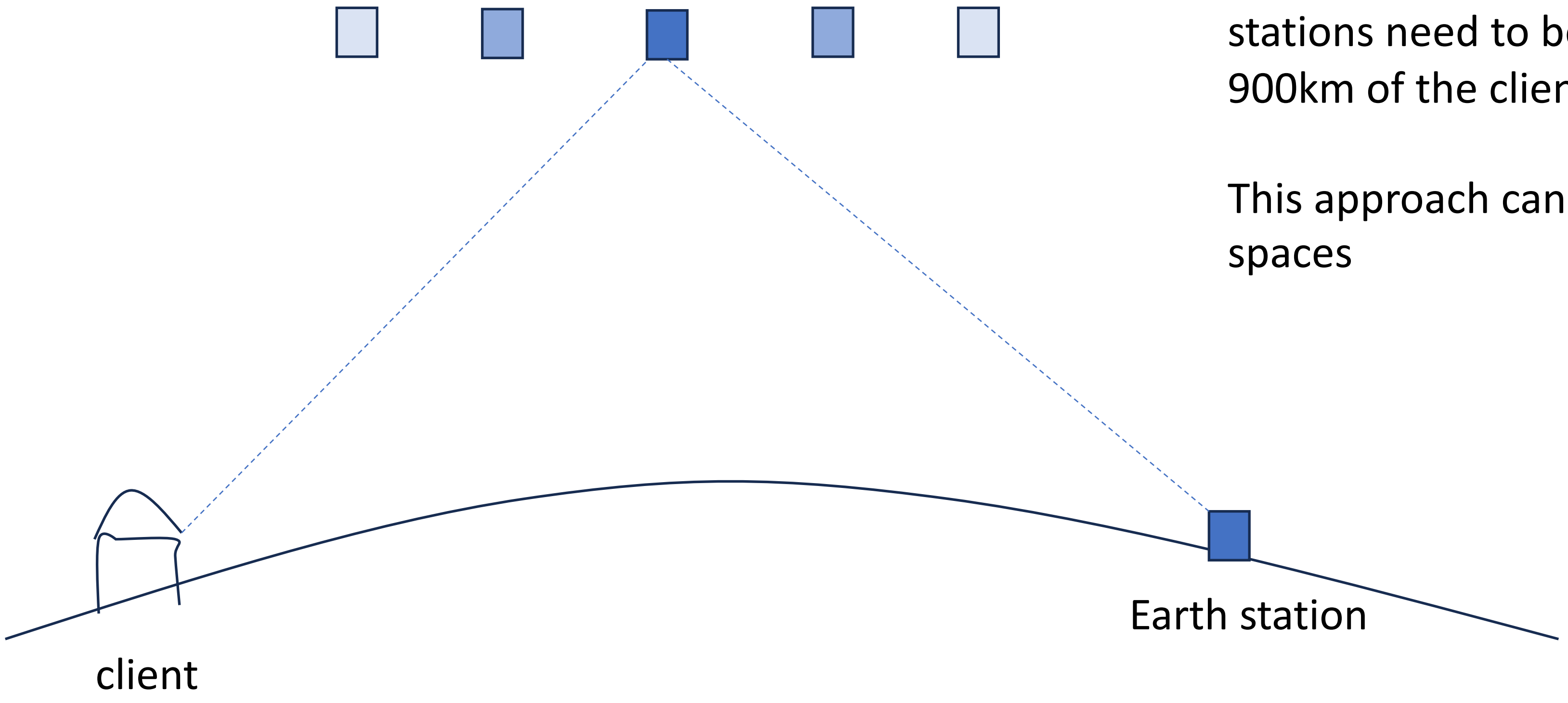
Small, light, cheap, self-aligning!

Self Installed!



Gen1 vs Gen2

GEN 1 – “mirror in the sky”

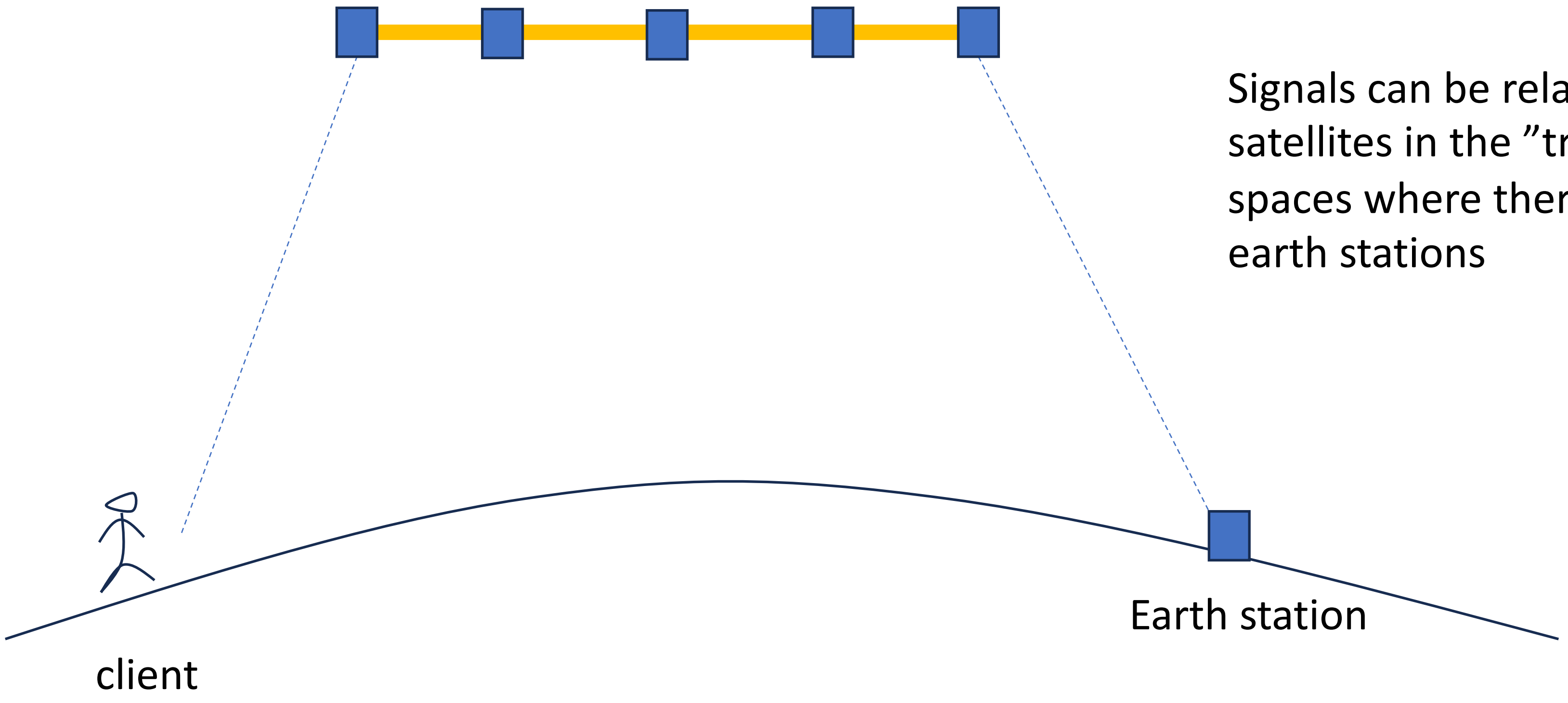


This approach is limited by the number and location of earth stations. Earth stations need to be located within 900km of the clients

This approach cannot span large ocean spaces

Gen1 vs Gen2

GEN 2 – Inter-Satellite laser Links



This approach equips the satellites with laser transmitters and receivers

Signals can be relayed to adjacent satellites in the ”train” to hop across spaces where there is no coverage by earth stations

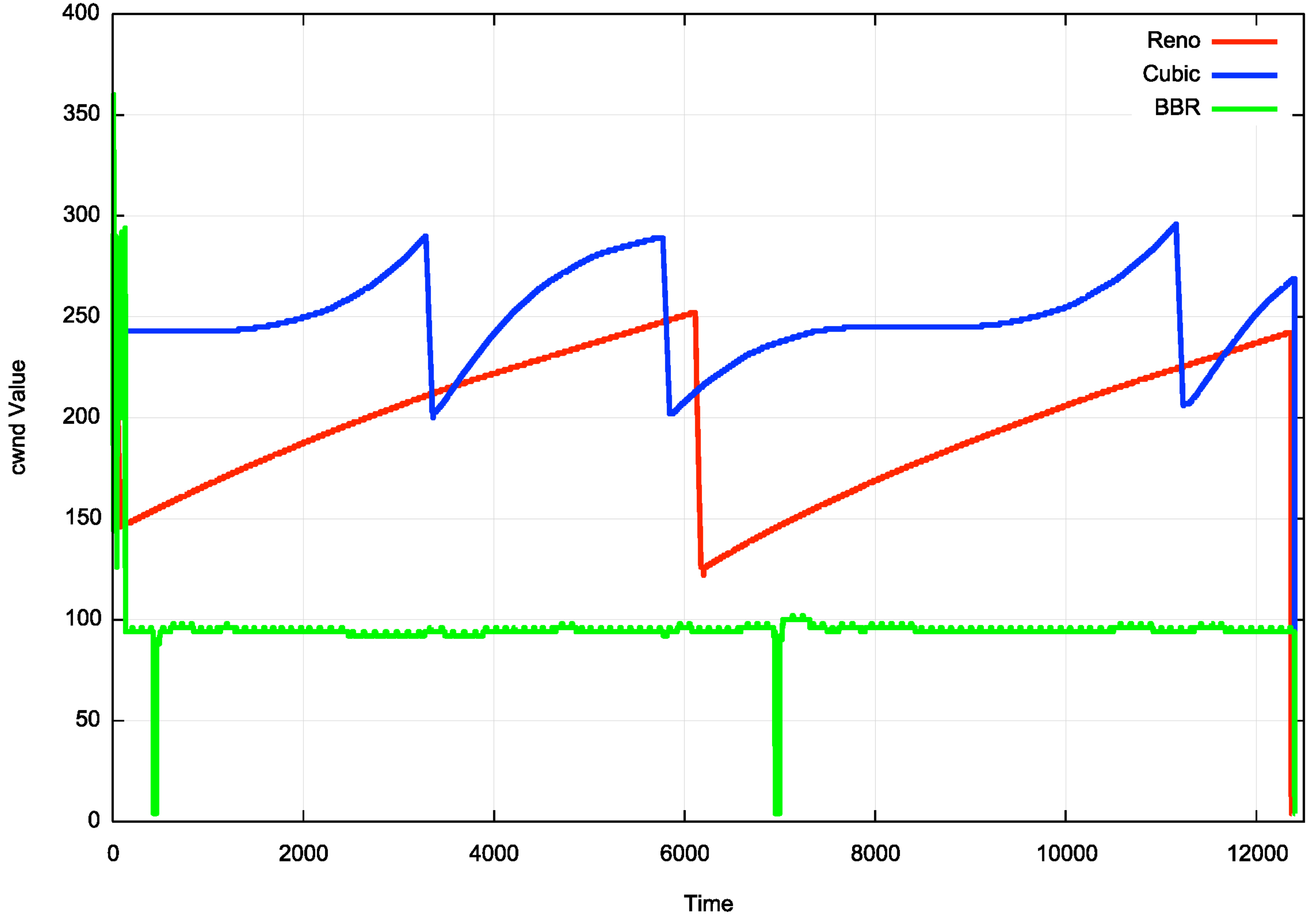
ISL in action

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

How well does all this work?

- Let’s measure it!
- We use three services between the same endpoints:
  - Terrestrial fibre connection (control)
  - GEO satellite service
  - Starlink service
- We also use three TCP flow control algorithms to compare their performance

TCP Flow Control Algorithms



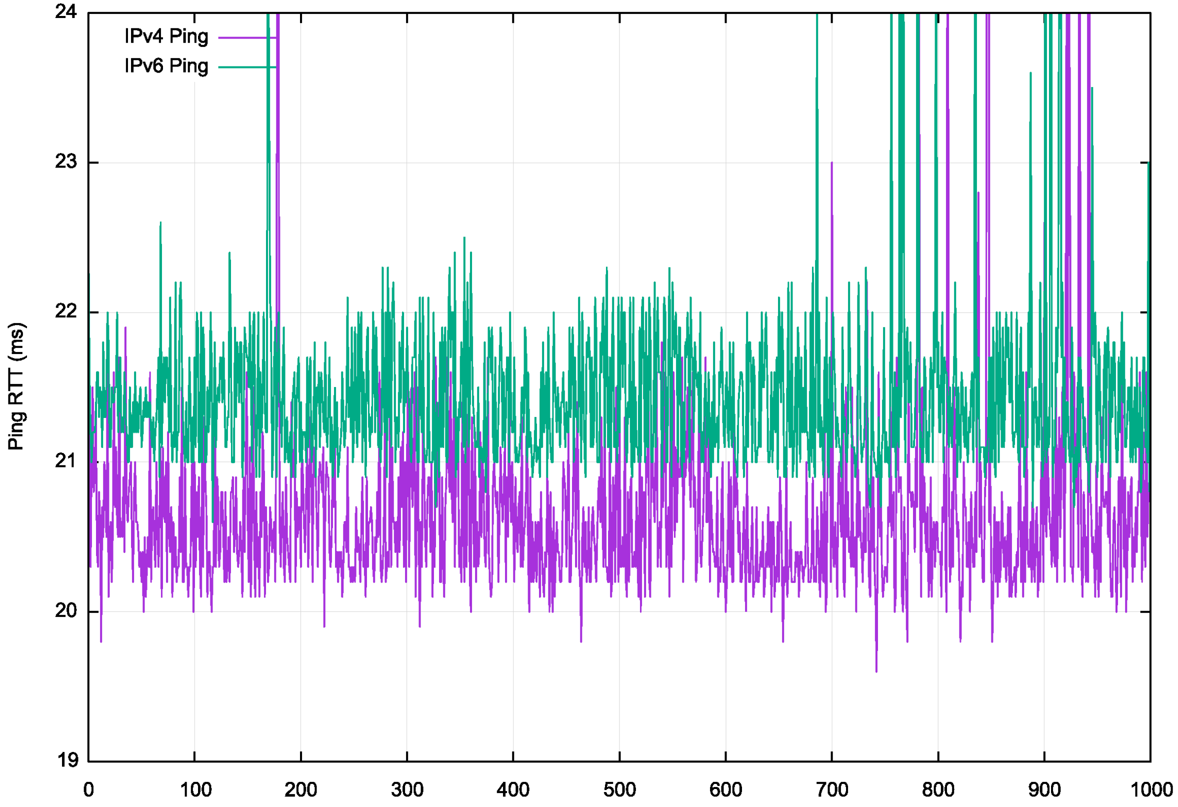
"Ideal" Flow behaviour for each protocol

Terrestrial Fibre

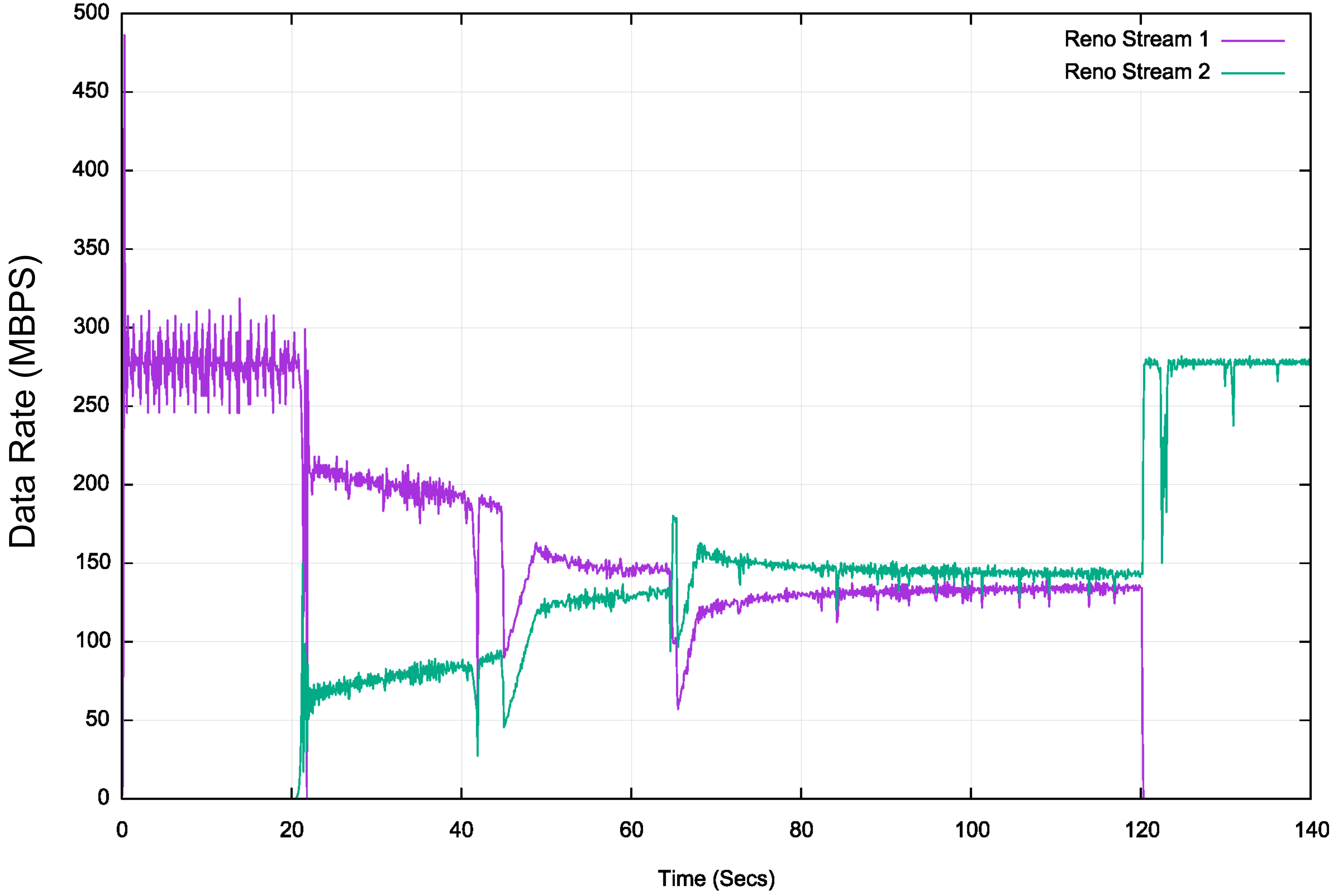
- Australian NBN FTTP service with a 275/25 Mbps access rate
- Server and client are some 1,000km apart
- Ping test:

IPv6 average 21.5ms

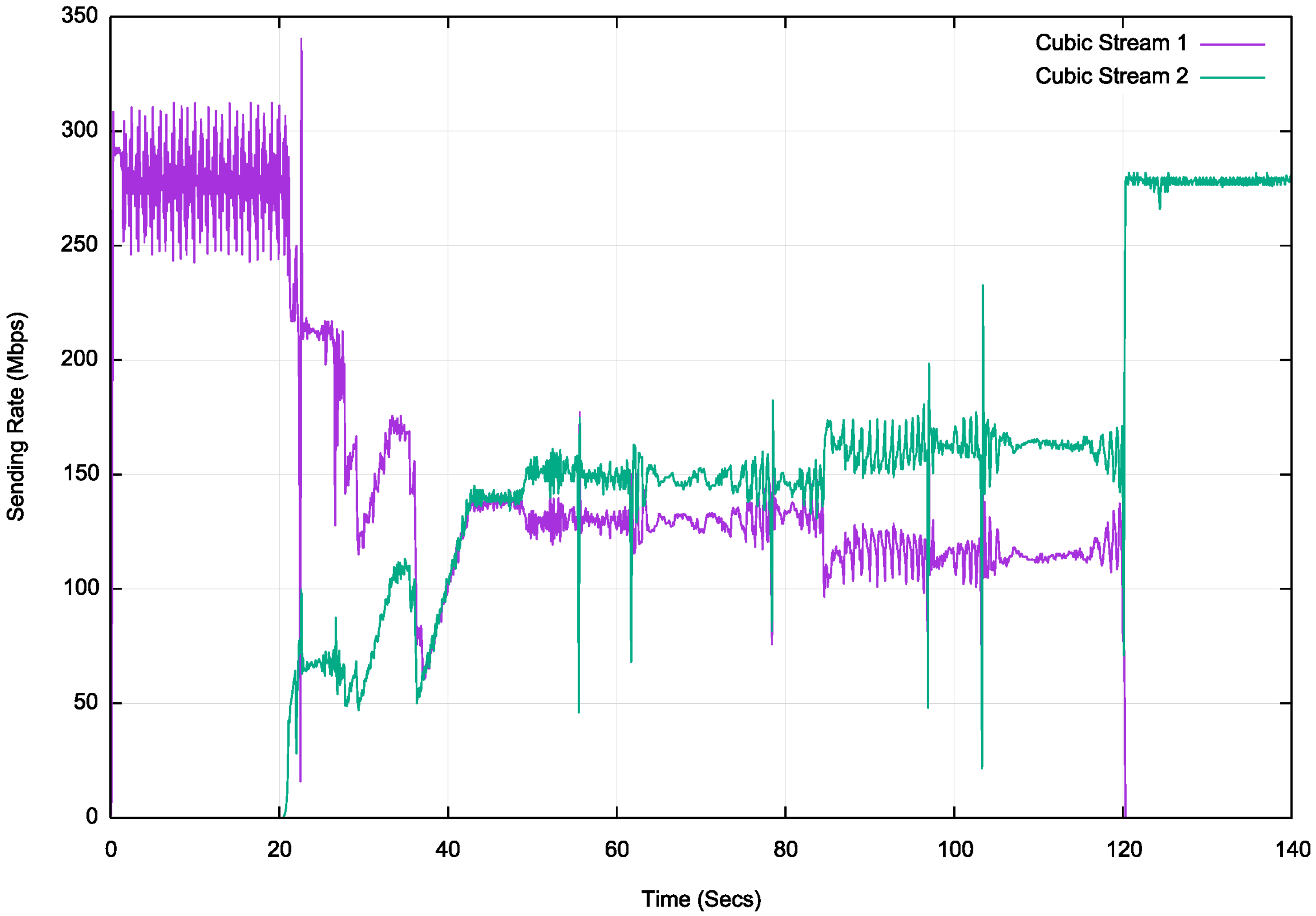
IPv4 average 20.5ms



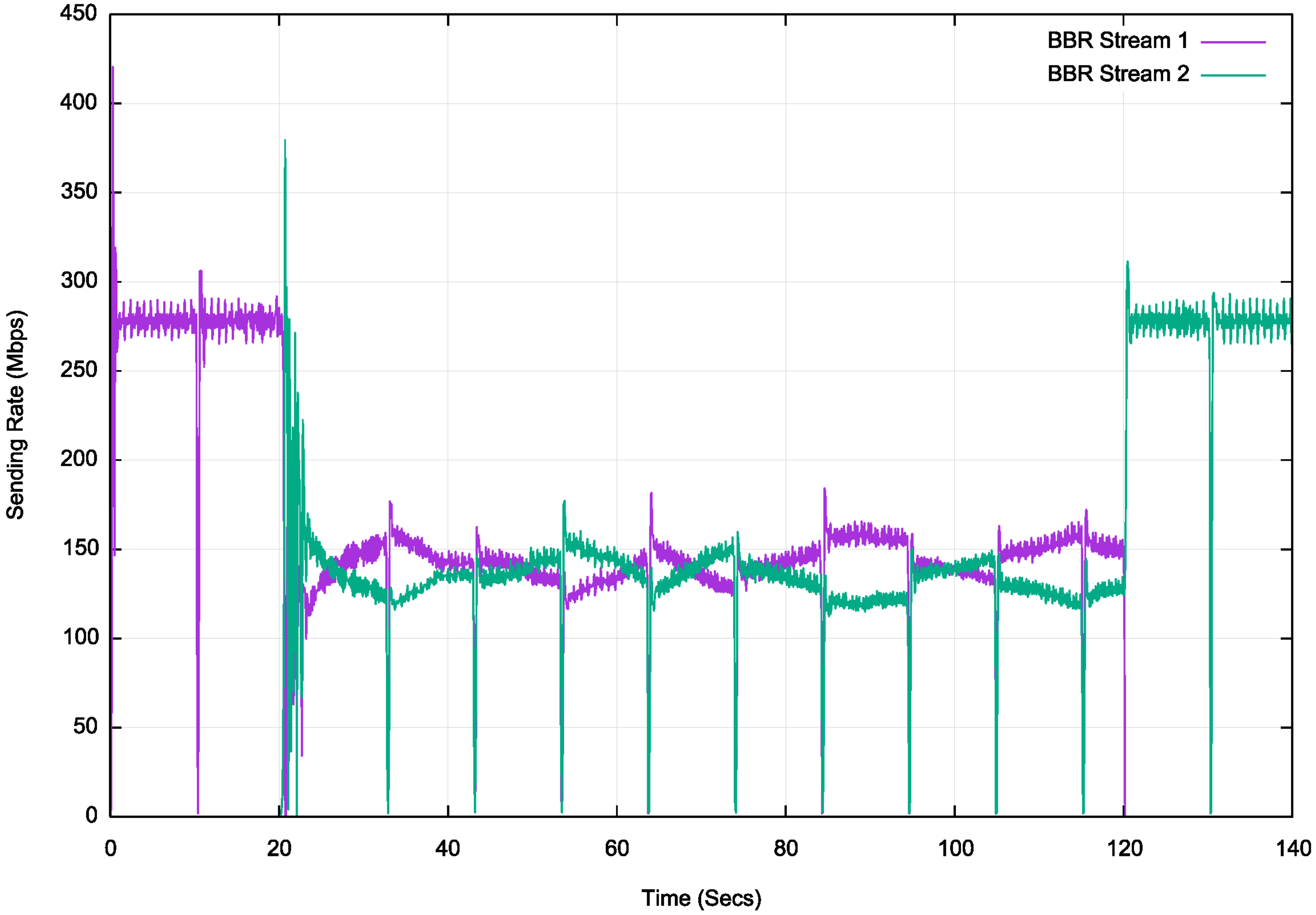
Fibre - 2 Stream Reno



Fibre - 2 Stream Cubic



Fibre - 2 Stream BBR

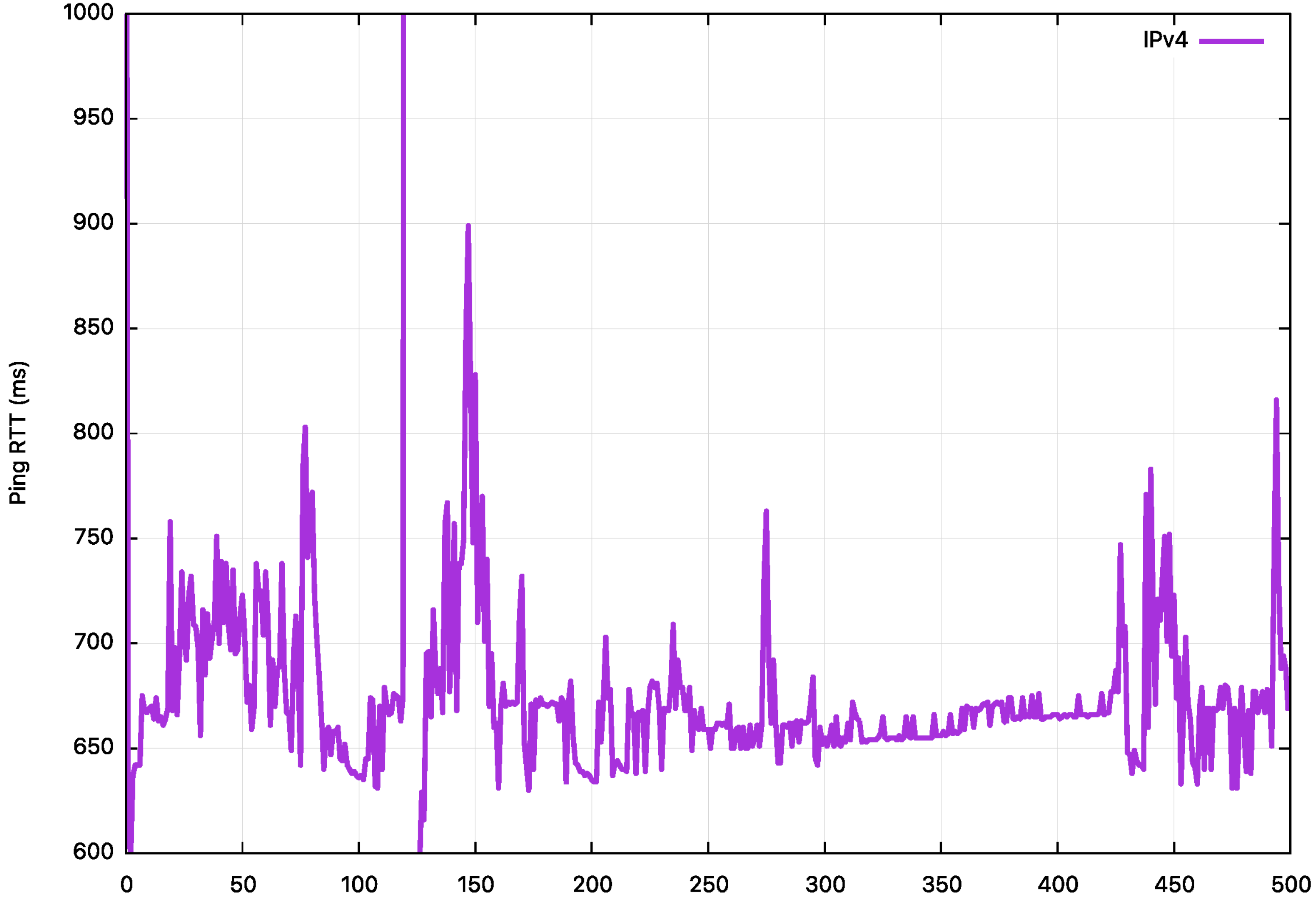


Protocol Performance over Fibre

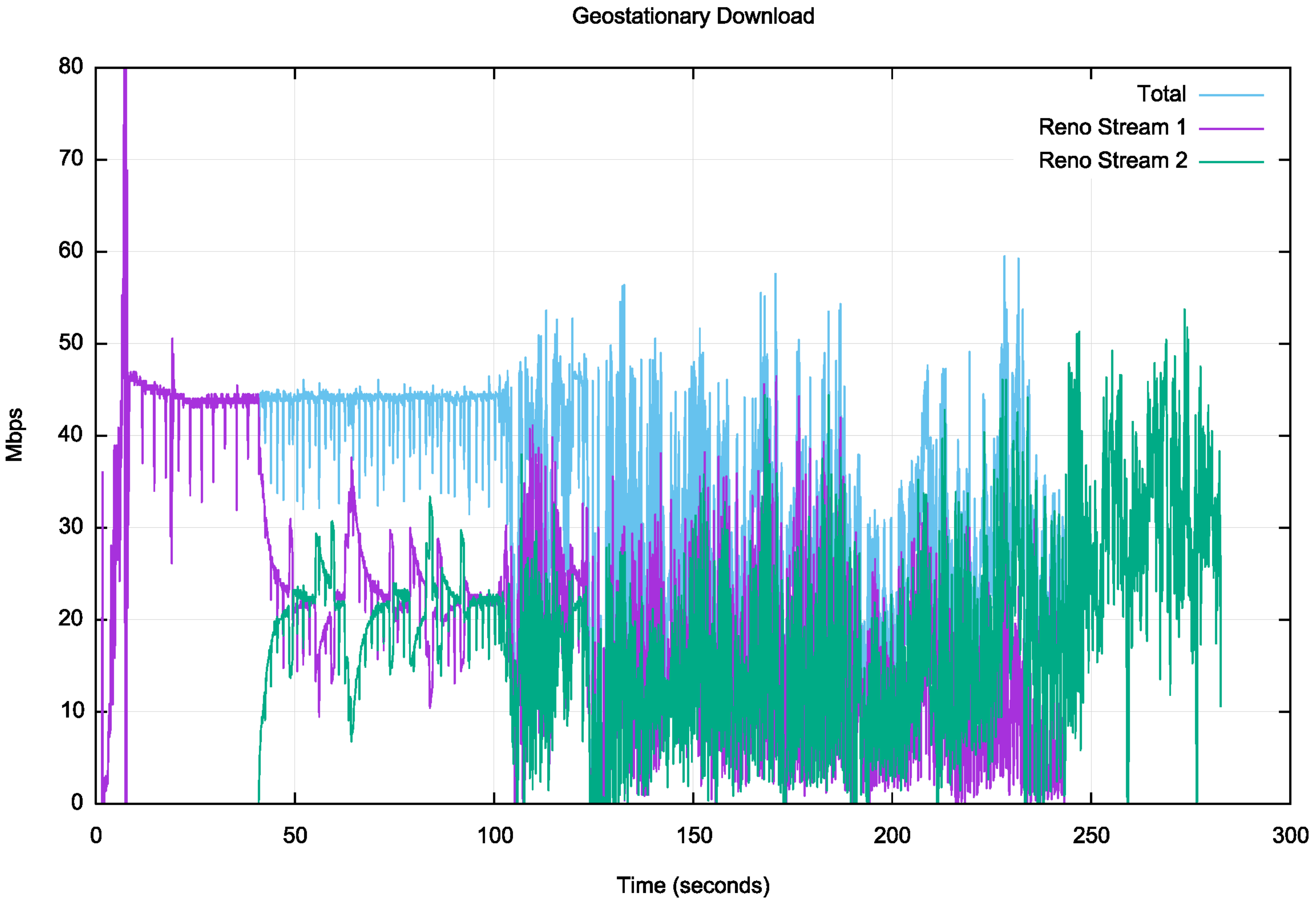
- All three congestion control algorithms are "well behaved" in this simple test
- Reno and BBR equilibrate to a 50/50 share when 2 sessions are active, while Cubic stabilises at a 60/40 split
- BBR operates with very small queue pressure, and stabilises at wire speed very quickly

GEO Service – (45Mbps service)

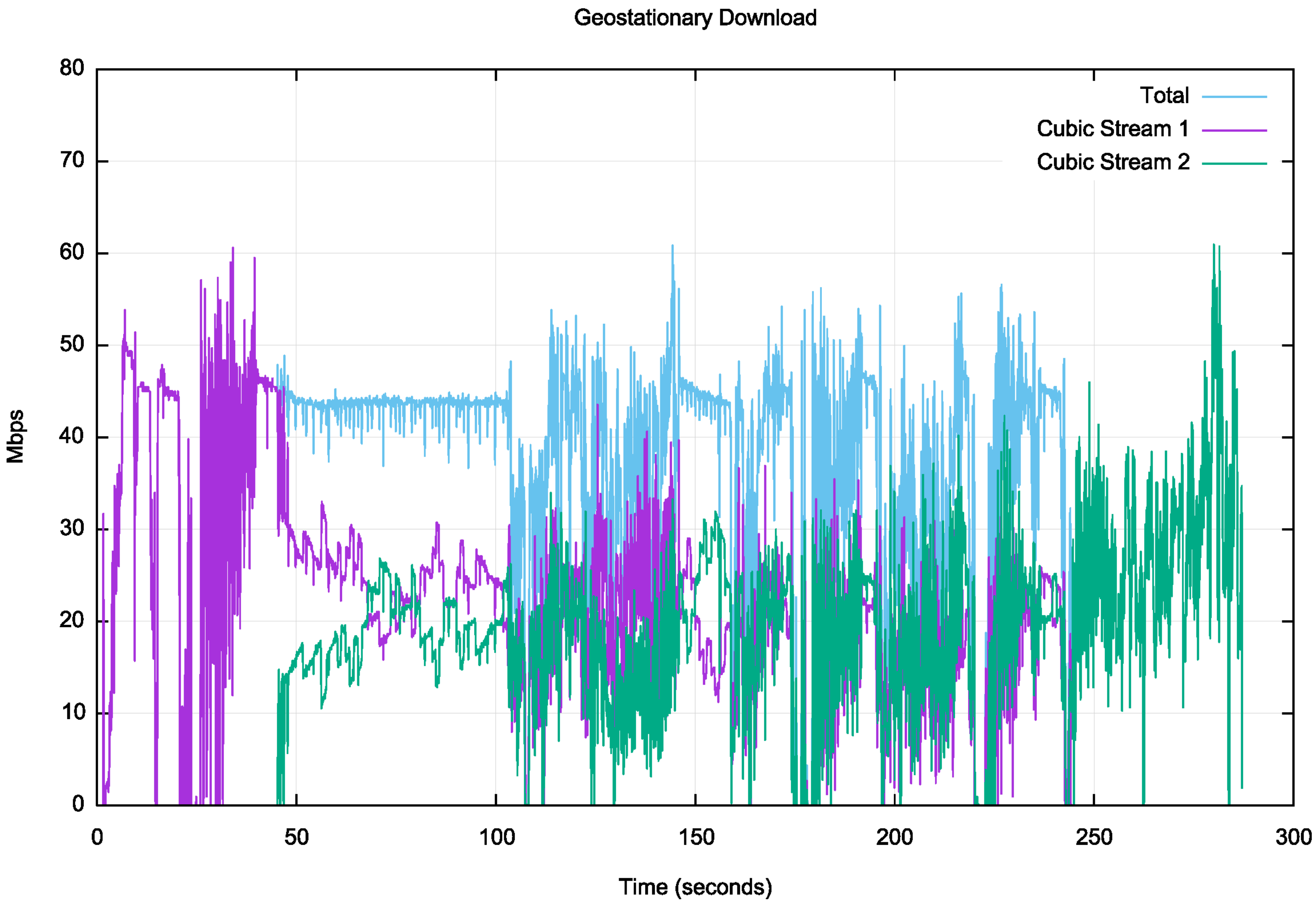
- Ping profile



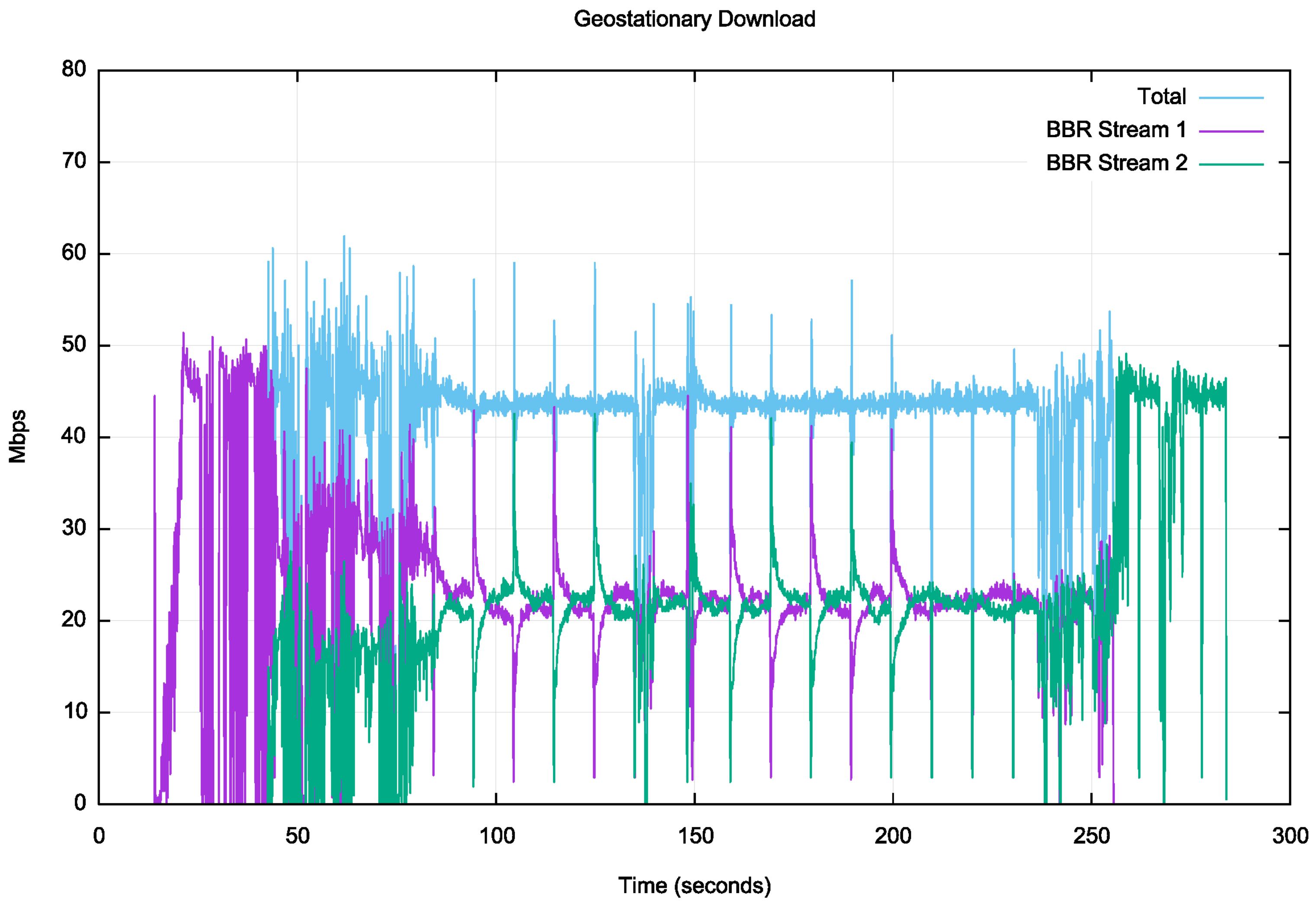
GEO - 2 Stream Reno



GEO - 2 Stream Cubic



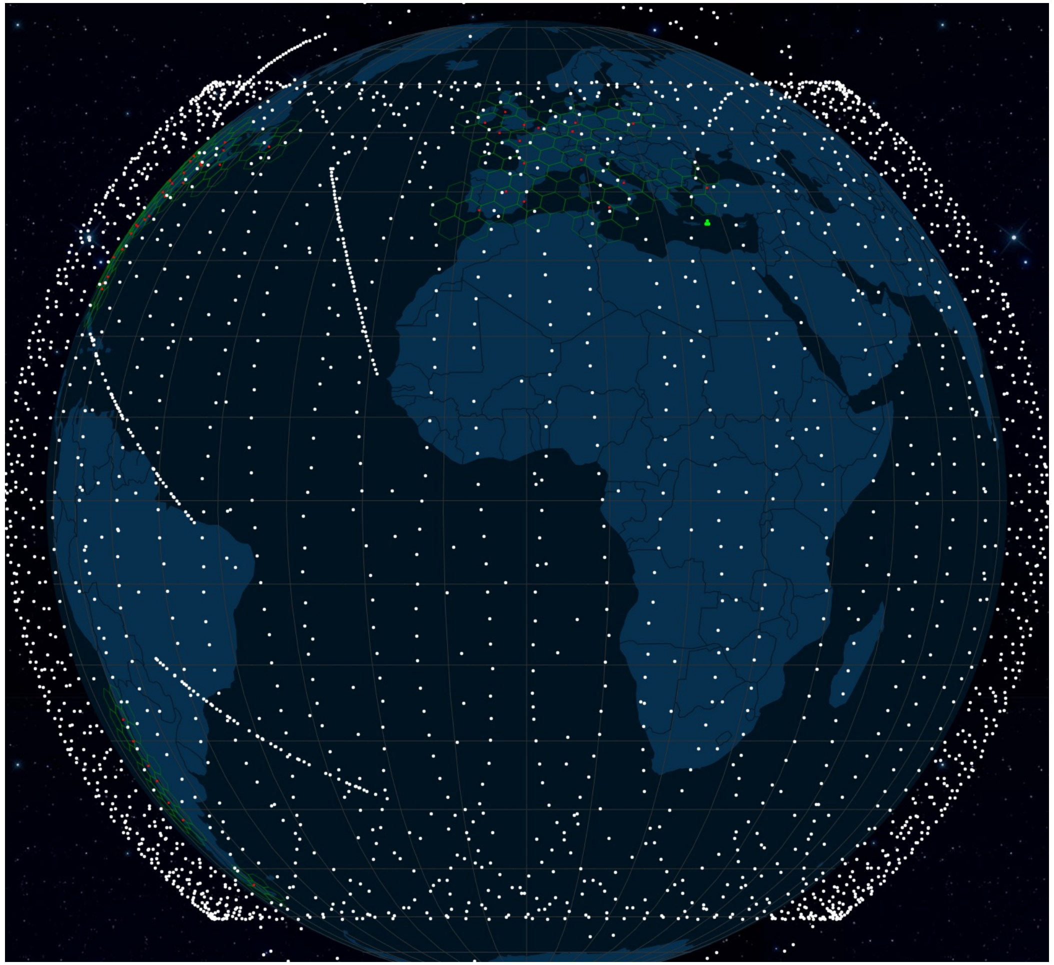
GEO - 2 Stream BBR



Protocol Performance over a GEO circuit

- While the ping times are relatively stable, the extended RTT time pushes the congestion protocol into areas of instability – this is likely due to the presence of deep queues in this product, in conjunction with the high delay of the path
- Both Reno and Cubic drop into instability after some 60 seconds. It is unclear whether this is protocol breakdown, or the impact of cross traffic on the tested flows within the GEO system
- BBR operates remarkably efficiently across this system, driving the link to the delivered capacity without the build up of a standing queue - clearly BBR out-performs Reno and Cubic in this context

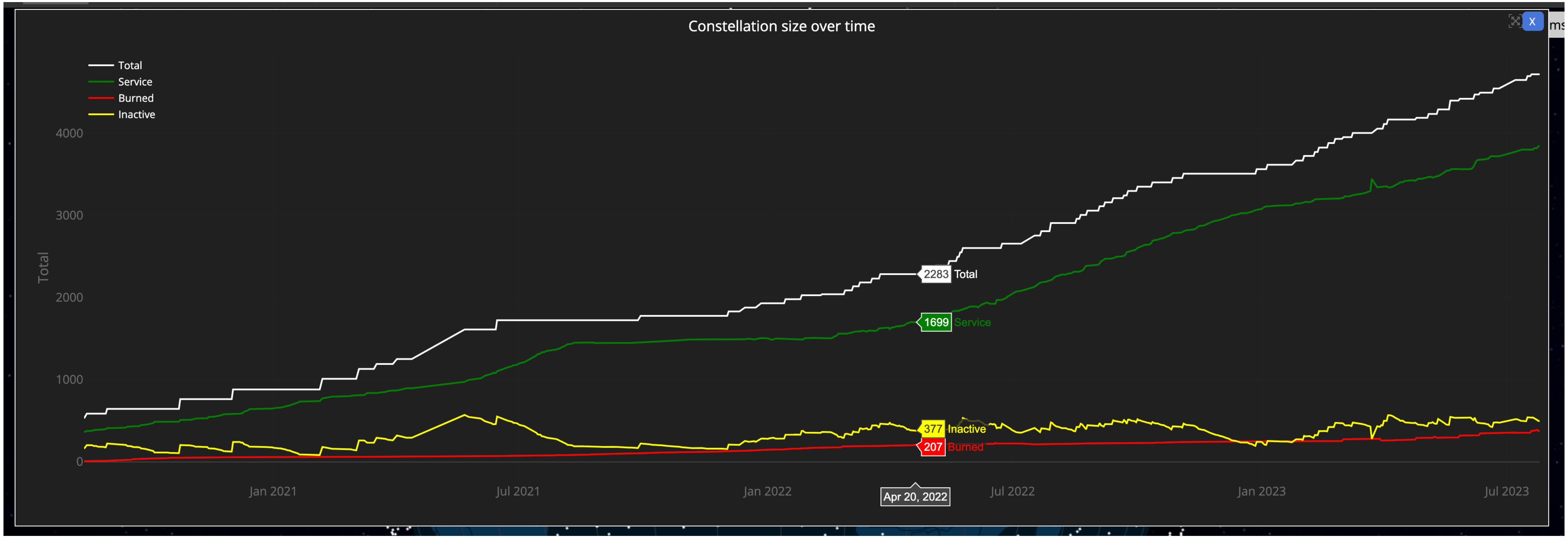
Starlink service



https://satellitemap.space/

Starlink service

- 3,840 in-service operational spacecraft, operating at an altitude of 550km



https://satellitemap.space/

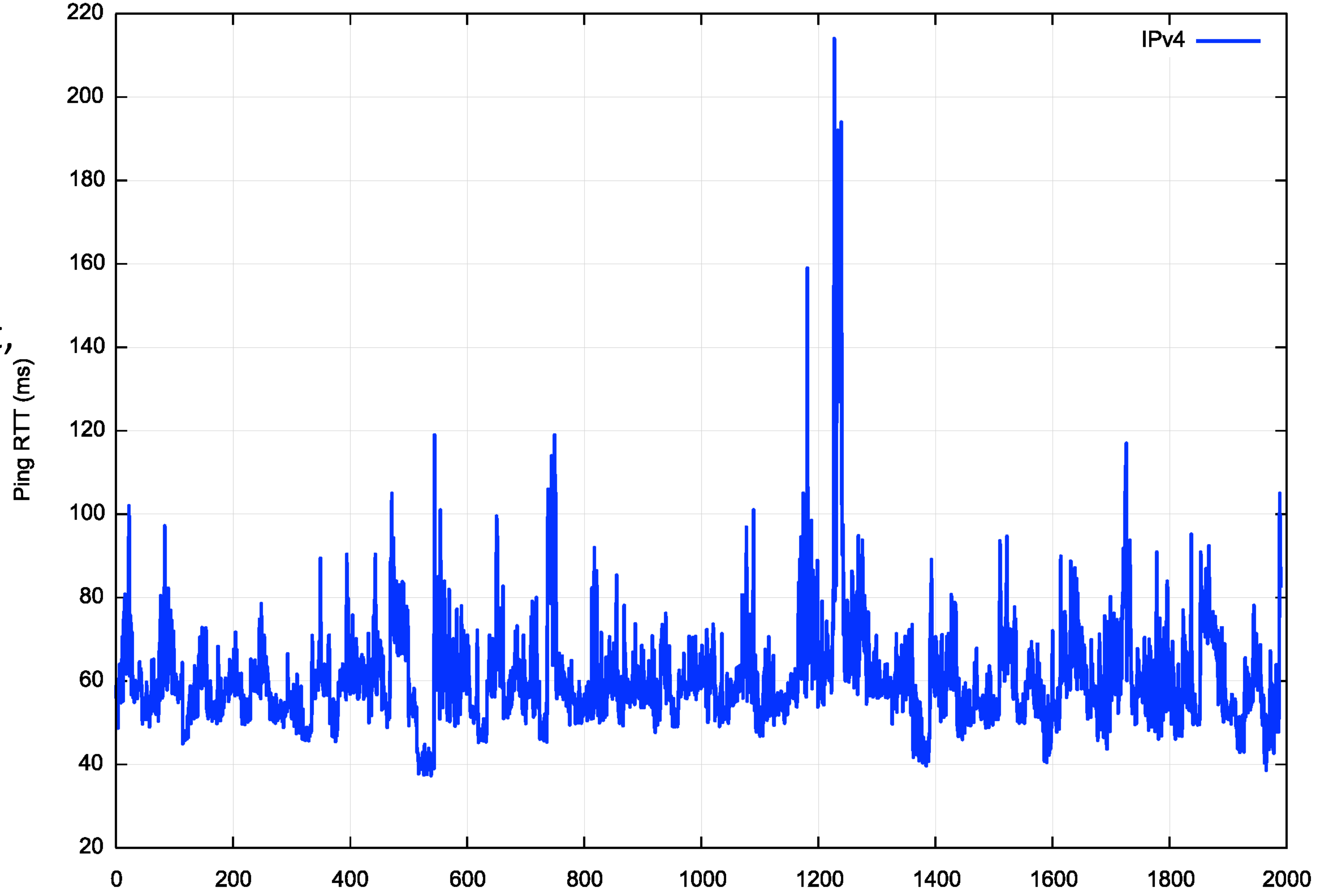
Starlink service

- 3,840 operational spacecraft, operating at an altitude of 550km
- One-way signal propagation time to reach the spacecraft varies between 1.8ms and 3.6ms (equivalent RTT of 7.3ms to 14.6ms)
- But that’s not what we see:

```
2000 packets transmitted, 1991 received, 0.45% packet loss, time 2009903ms
rtt min/avg/max/mdev = 37.284/60.560/214.301/13.549 ms
```

Starlink RTT Ping Times

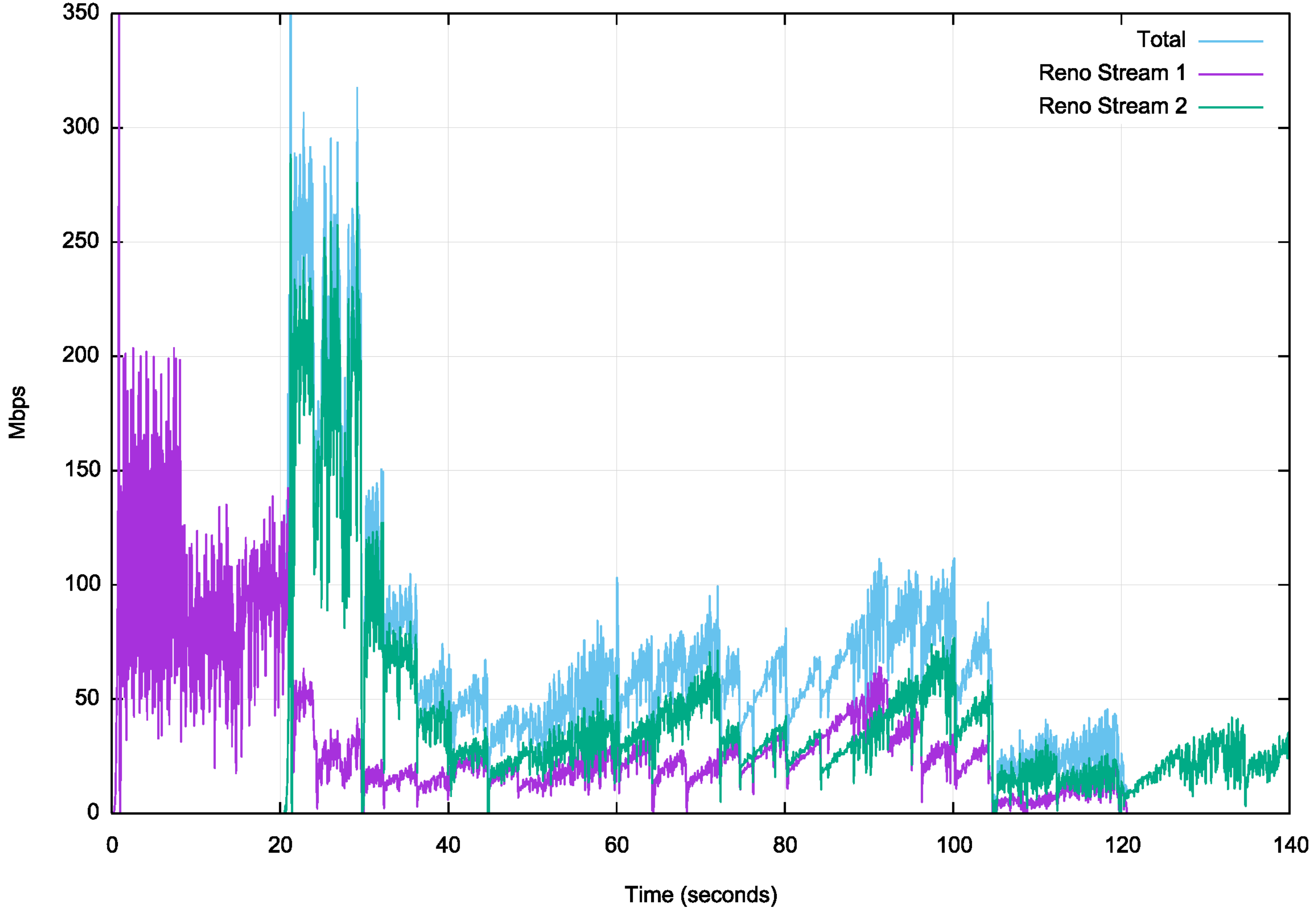
We are seeing:
12ms terrestrial component,
7ms/14ms propagation component,
30ms for codec/fec/switching?



Starlink – 2 Stream Reno

Relatively unimpressive performance.

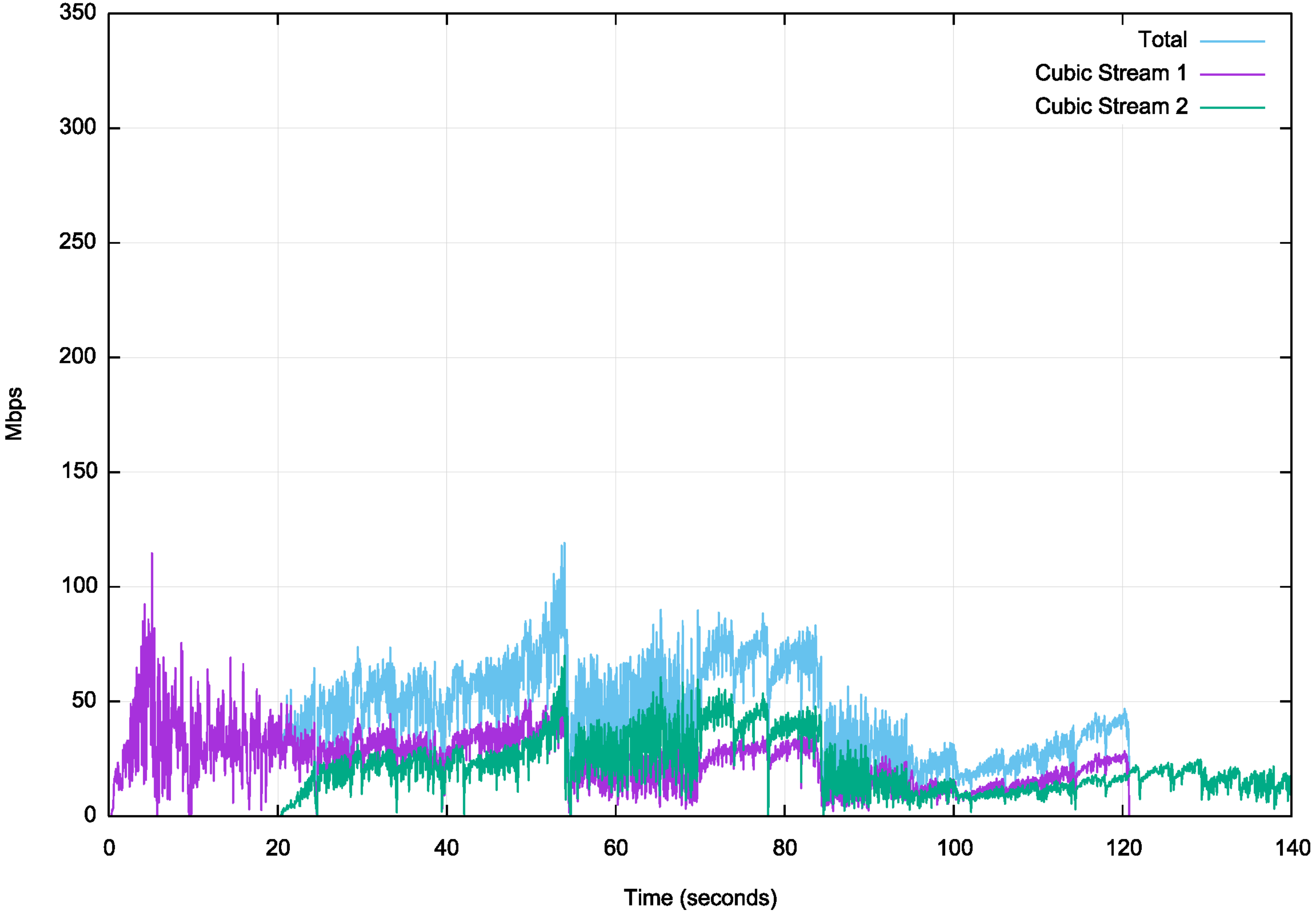
There appears to be imposed packet loss events that hampers Reno inflating the sending rate



Starlink - 2 Stream Cubic

Also unimpressive performance.

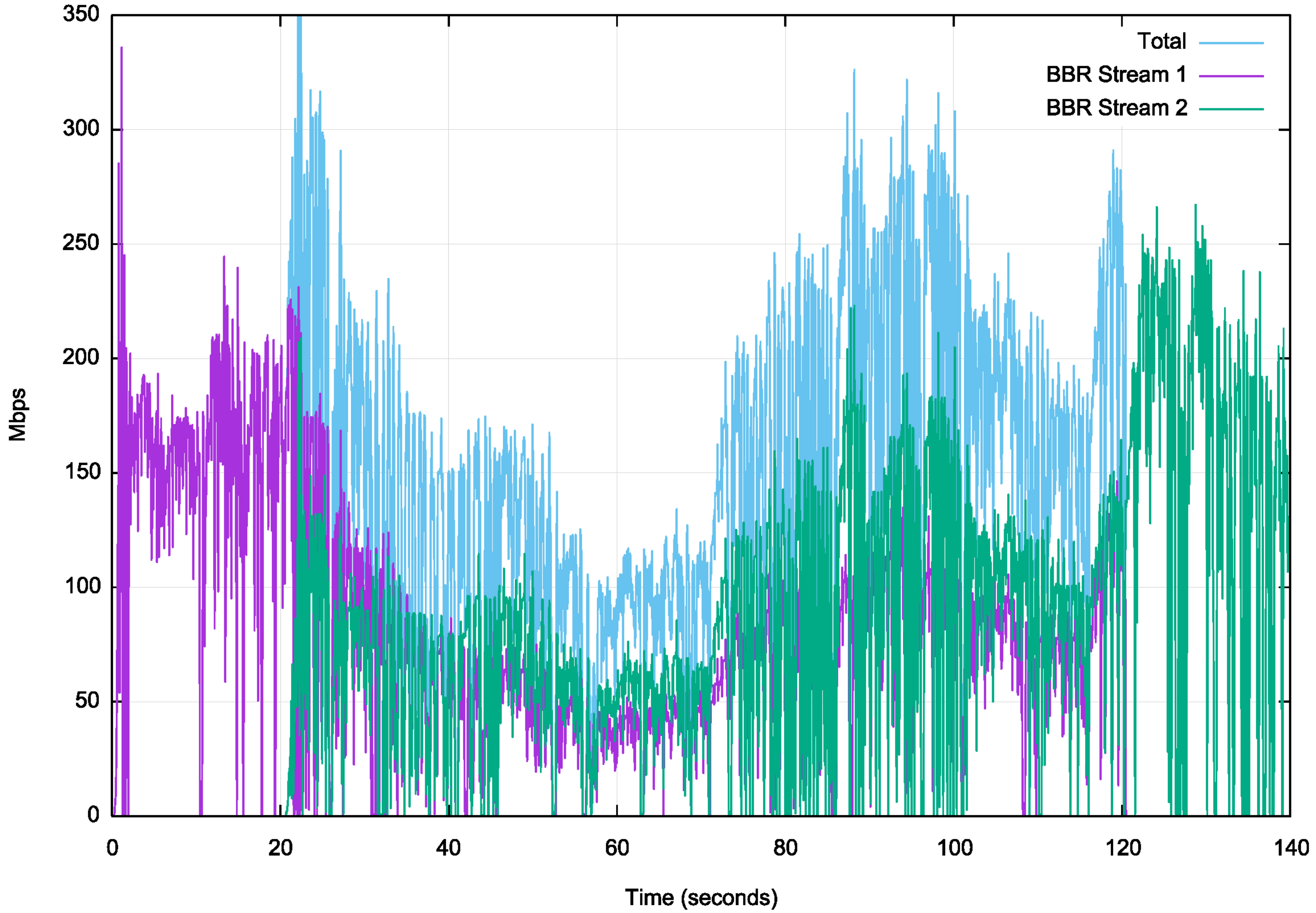
Cubic appears to be more stable than Reno, but still fails to open up its sending rate over time, so the higher stability is achieved at a cost of lower overall throughput



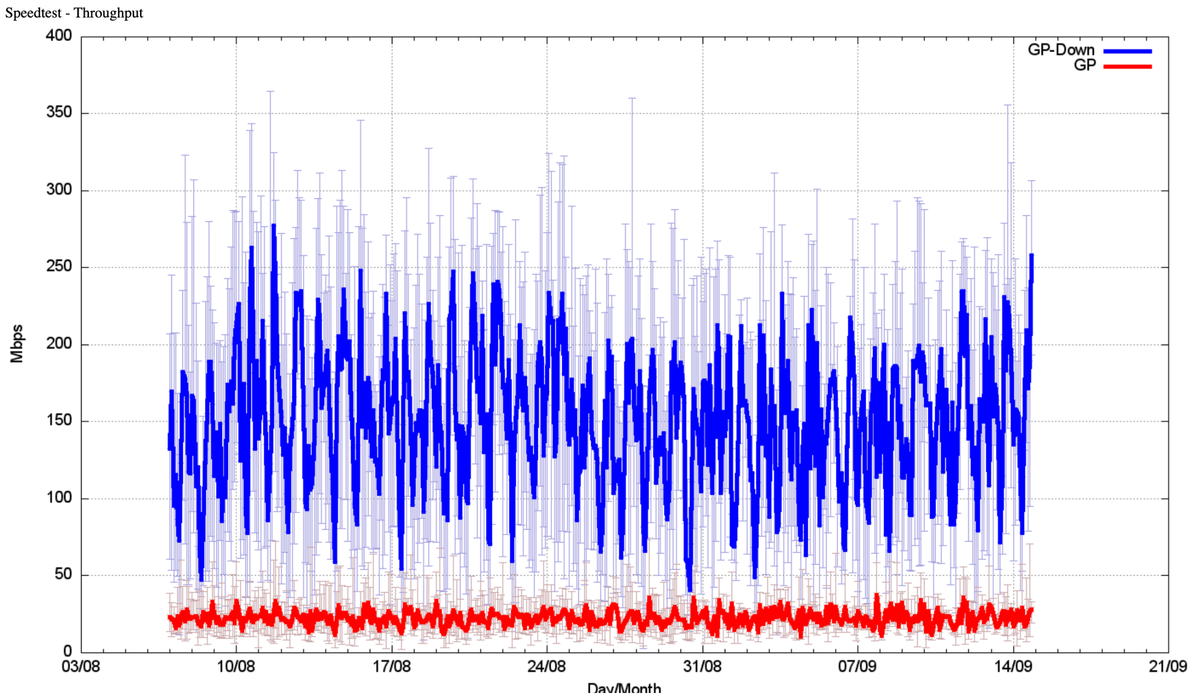
Starlink – 2 Stream BBR

BBR seems to be better positioned to extract performance from a variable platform in loss and jitter terms- **it is able to operate 3 – 5 times the speed of Cubic or Reno between the same endpoints**

The packet loss rate is higher than expected, and this may be an outcome of the combination of using phase array antennae that are tracking satellites that are moving through the sky at a relative speed of 1 degree of elevation every 15 seconds, together with the need to perform satellite handover at regular intervals.

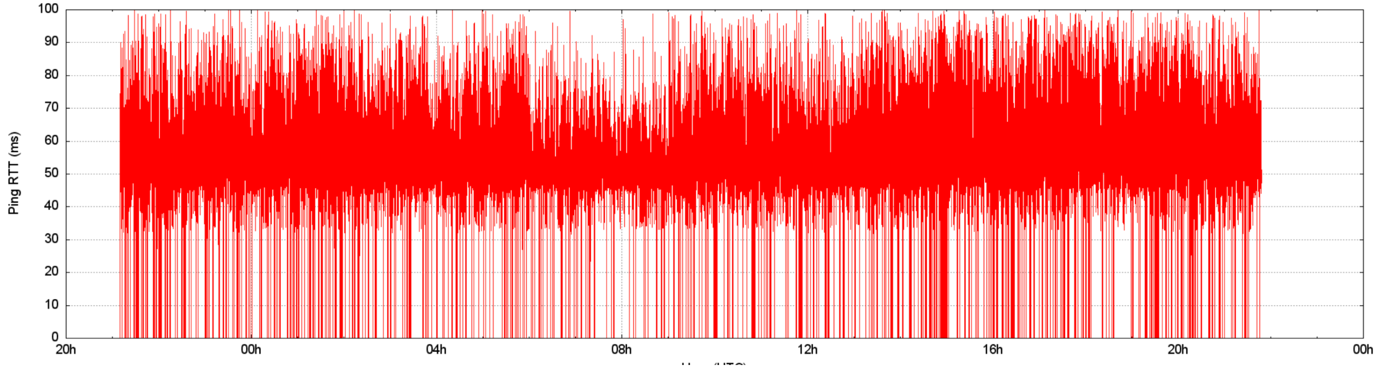


Performance



Speedtest-measuremed capacity

1 second ping

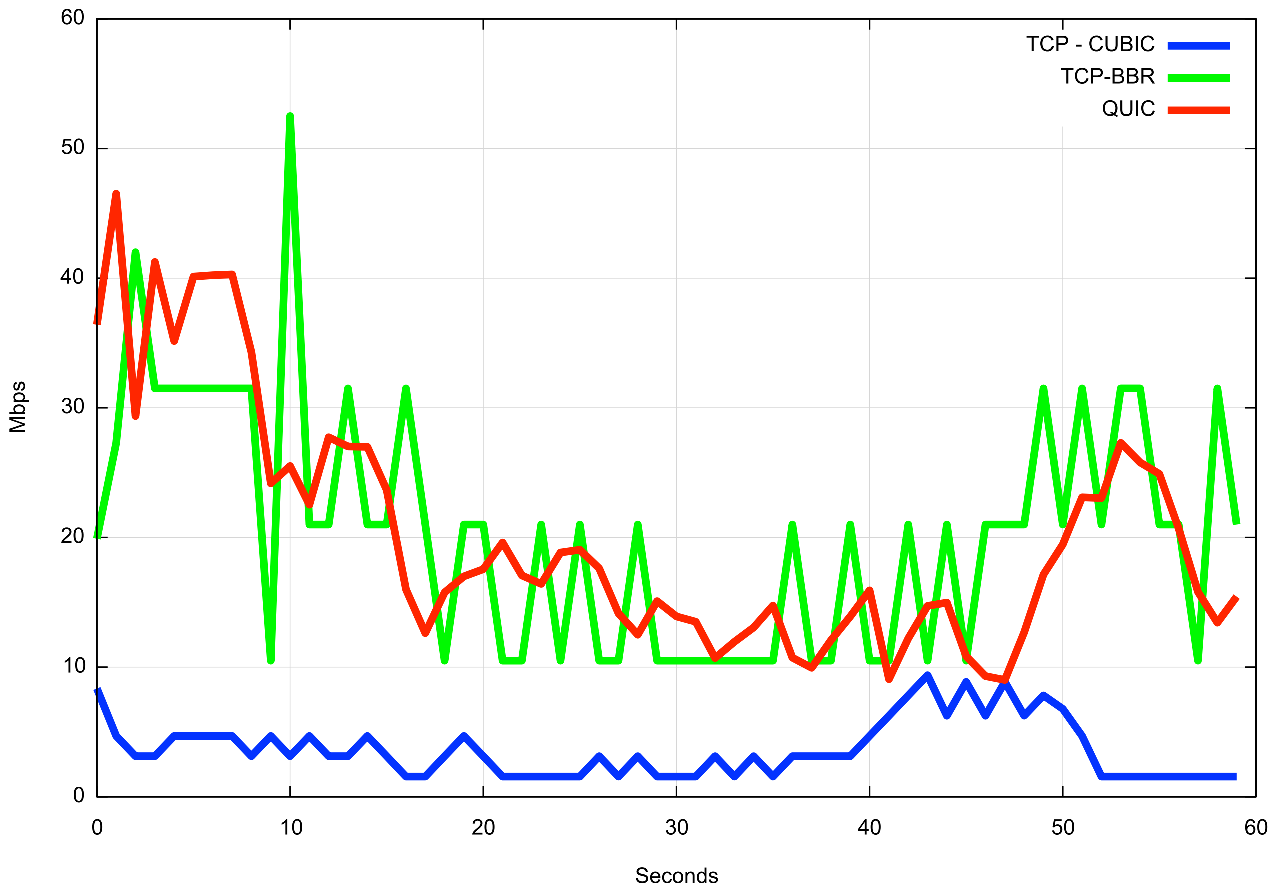


Micro-drops →

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
  - Short transactions work well
  - Paced connections (voice, zoom) tend to work well most of the time
  - Bulk data transfer not so mucj
- You need to move to less sensitive flow control algorithms, such as BBR to get good performance out of these services

Measuring QUIC Performance



In this test (between the same endpoints) over a Starlink circuit, TCP CUBIC underperforms badly, while TCP BBR and QUIC both perform reasonably well

More measurements needed …

- Is *iperf3* on Linux the right measurement tool?
- Can we bypass the Linux kernel baggage and measure the 'raw' TCP protocol performance?
- Would using QUIC provide a different view of protocol performance?
- How do LEO services compare to 5G?
- Speed vs stability?
  - Should a LEO service expose the underlying jitter and loss to the application, or should it integrate smoothing, and even basic retransmission into the service at the cost of a higher delay overhead?

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

Does it scale?

Fibre – well **yes**, just bury more cable!

GEO – **no**, not really

- Geostationary spacecraft are normally separated by 2 – 3 degrees or arc, so there are some 120 – 180 viable slots. The radio frequencies are also limited to the C, Ku and Ka bands. The on-craft transponders are not steerable so the capacity is provided to a pre-designed footprint

LEO – unclear, but **probably not**

- LEO constellations use low altitude eccentric orbits so the number of space craft in a constellation is determined by the inter-craft distance, horizontally and vertically.
- Starlink plan for 12,000 craft, Kuiper (Amazon) place for 3,200, Telesat 188, ITU-R filings indicate China is planning a constellation with 13,000 craft
- There is an issue with space junk at LEO orbits. Any collision will generate more junk, and the risk of a runaway effect is high if the altitude slots are densely packed


Questions?

Questions?