LEOs and GEOs

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APNIC

LEOs in the News

screenshot from starwatch app

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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

NIKKEI Asia

World Trending Business Markets Tech Politics Economy Featur

TELECOMMUNICATION

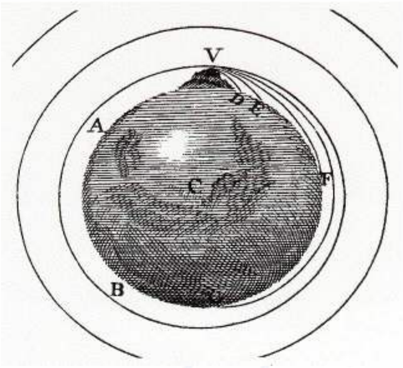
Elon Musk's Starlink launches satellite internet service in Japan

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

Newtonian Physics

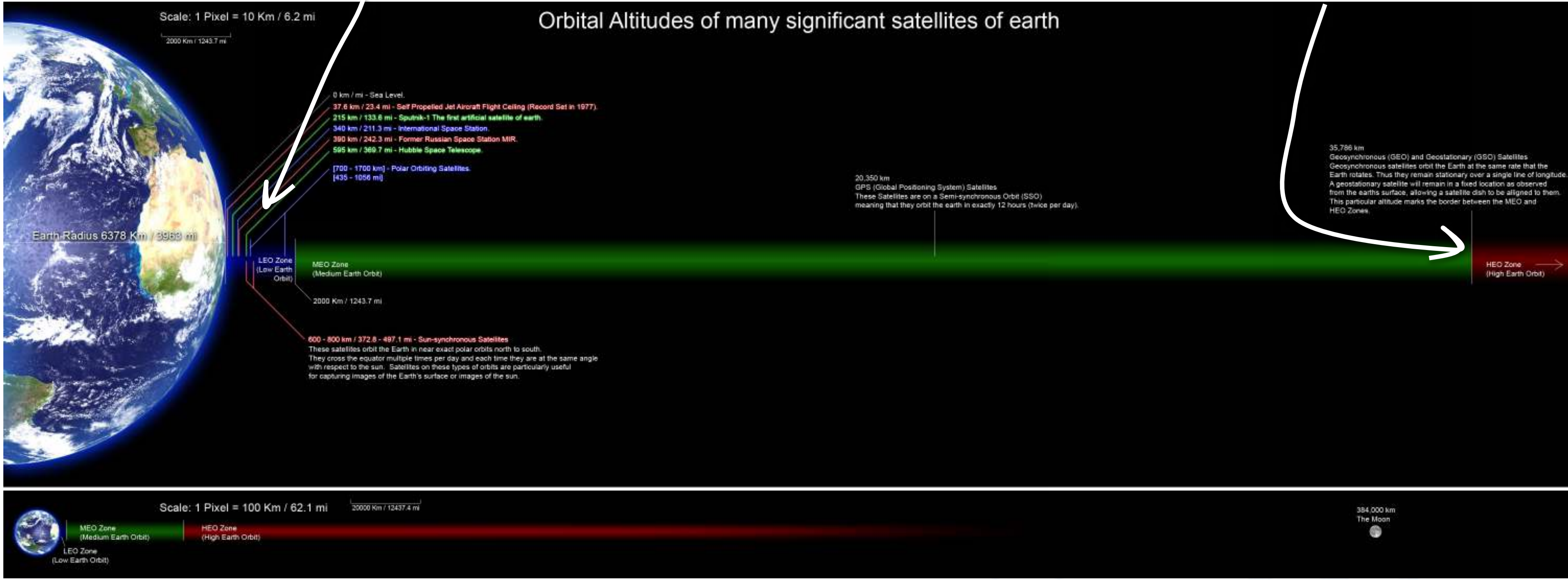
- If you fire a projectile with a speed greater than 11.2Km/sec it will not fall back to earth, and instead head away from earth never to return
- On the other hand if you incline the aiming trajectory and fire it at the critical speed it will settle into an orbit around the earth
- The higher the altitude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



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, Leos

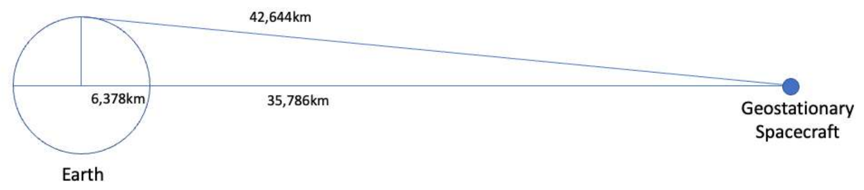
Geos



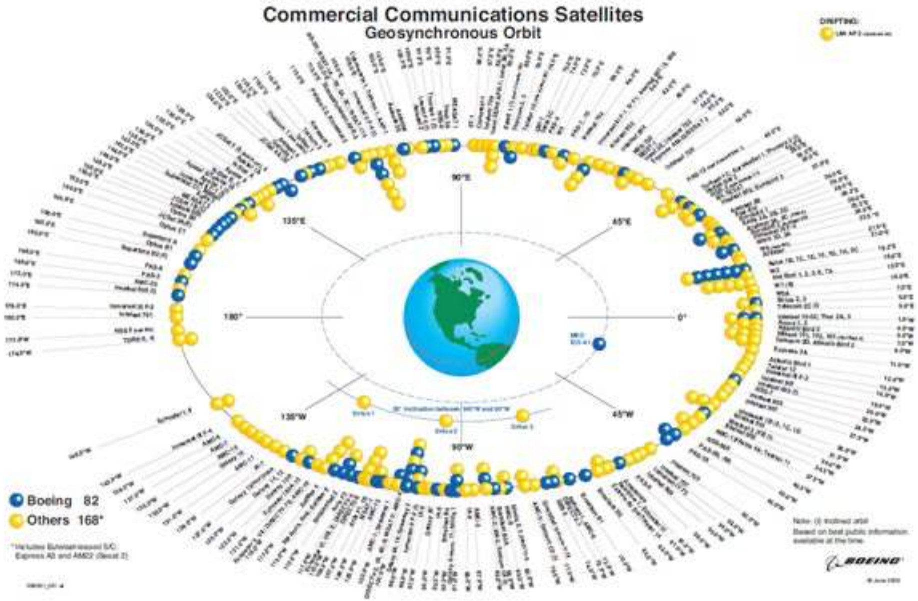
Scale: 1 Pixel = 10 Km / 6.2 mi
2000 Km / 1243.7 mi
Orbital Altitudes of many significant satellites of earth
0 km / mi - Sea Level.
37.6 km / 23.4 mi - Self Propelled Jet Aircraft Flight Ceiling (Record Set in 1977).
215 km / 133.6 mi - Sputnik-1 The first artificial satellite of earth.
340 km / 211.3 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)
Scale: 1 Pixel = 100 Km / 62.1 mi
20000 Km / 12437.4 mi
MEO Zone (Medium Earth Orbit)
HEO Zone (High Earth Orbit)
LEO Zone (Low Earth Orbit)
384,000 km
The Moon

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

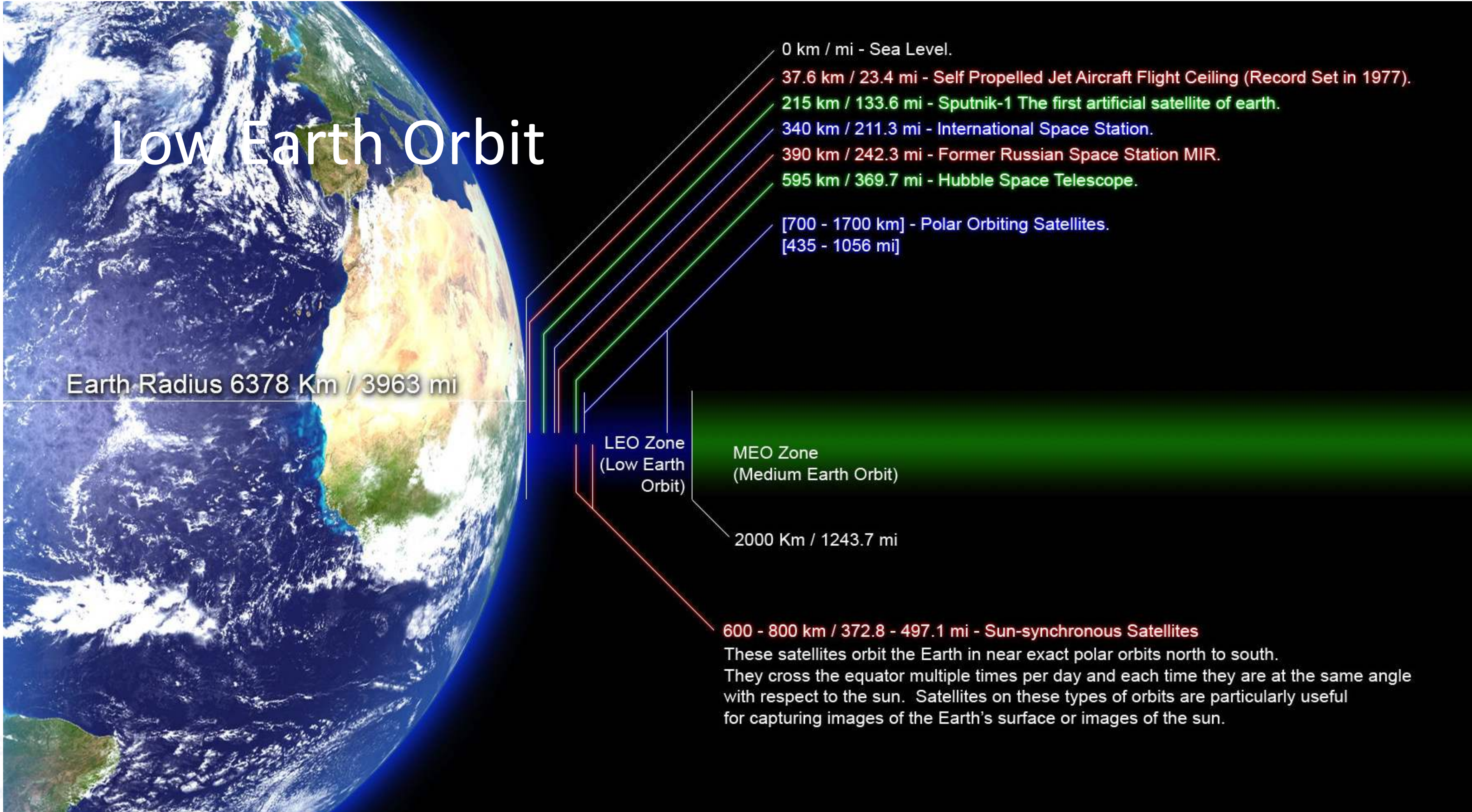


https://commons.wikimedia.org/wiki/File:Communications_satellite_with_TEMPO_spacecraft_model.png – public domain



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

Low Earth Orbit

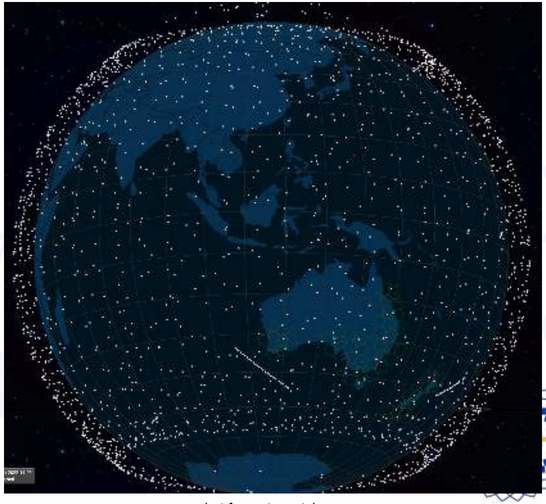


https://commons.wikimedia.org/wiki/File:Orbitalaltitudes.jpg *GNU Free Documentat*

Low Earth Orbit

- LEO satellites are stations between 160km and 2,000km in altitude. The objective is to keep the satellite's orbit high enough to stop it slowing down by "grazing" the denser parts of the earth's ionosphere, but 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.

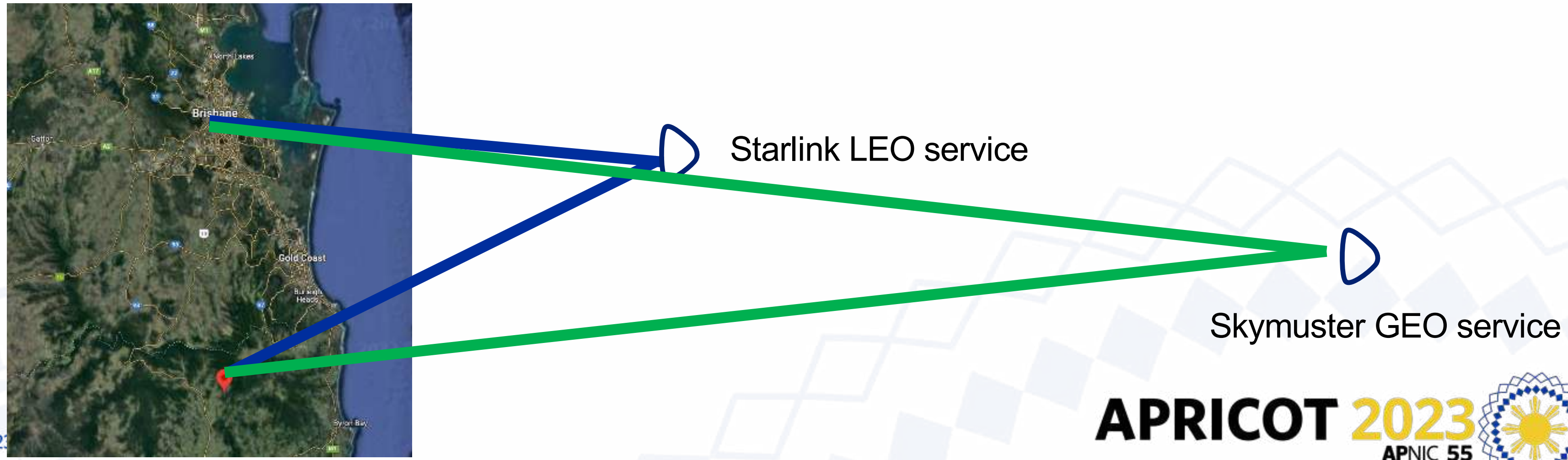
Image - spacex



screenshot from starwatch app

Measuring LEO and GEO services

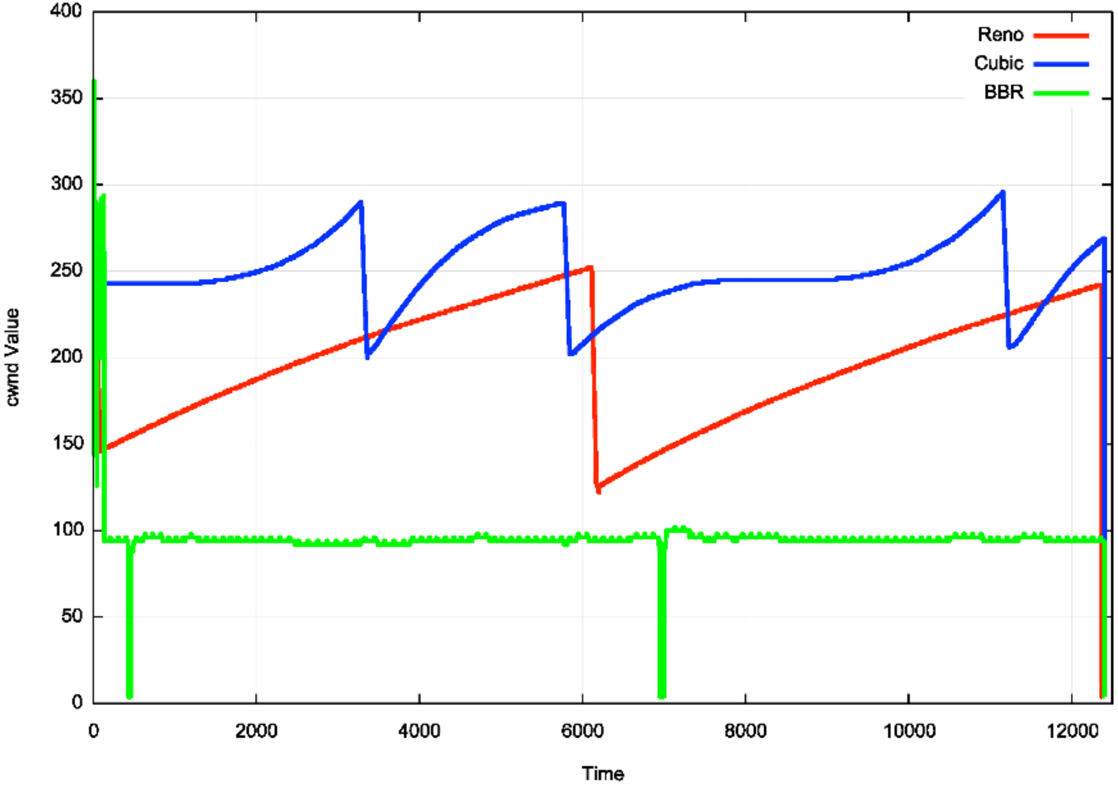
- Eastern Australia has both LEO and GEO services available
- Which provided us with a unique opportunity to test the LEO and GEO services with the same endpoints



Test Regime

- We’ll use 3 different TCP congestion control algorithms: Reno, Cubic and BBR
- We’ll compare three different access regimes: fibre, GEO (AUSsat) and LEO (Starlink)
- We used an Intel NUC running Debian 10, and *iperf3* to load the circuits

Flow Control Algorithms

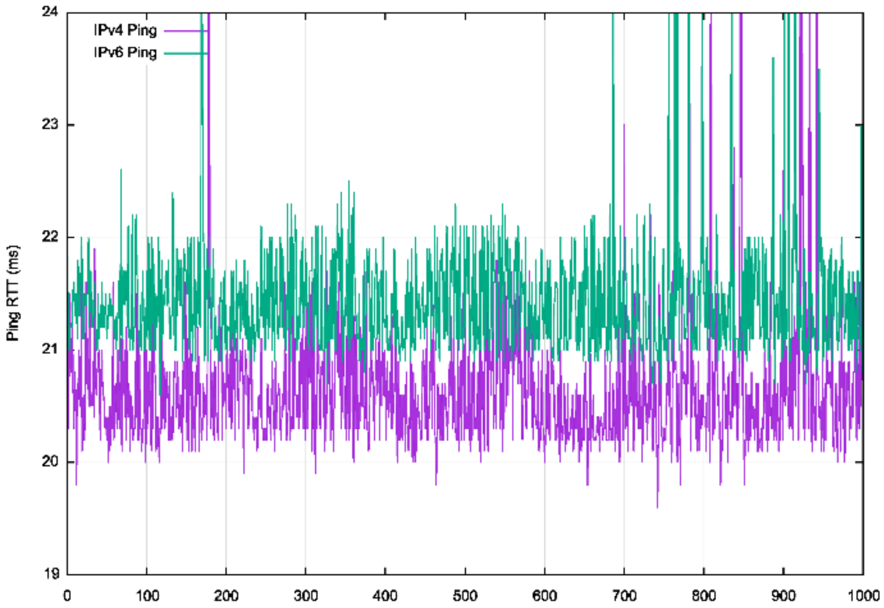


Terrestrial Fibre

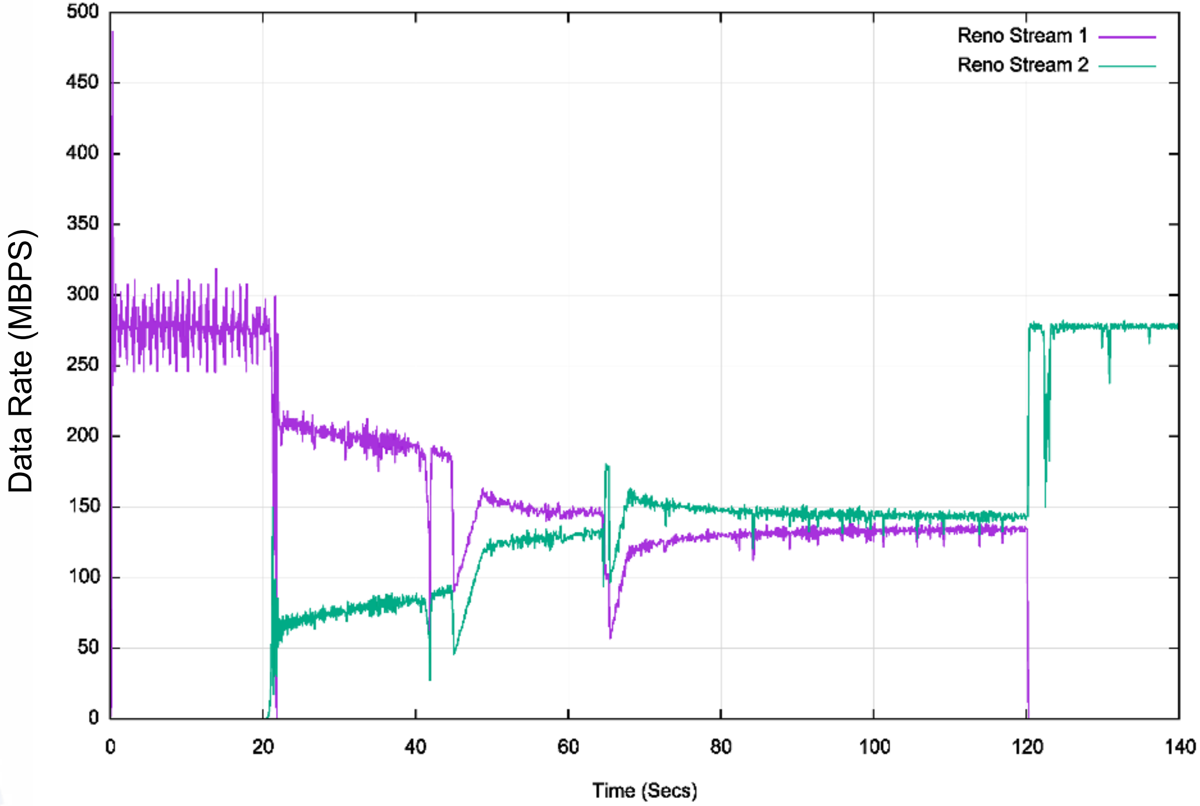
- Australian NBN FTTP service with a 275/25 Mbps access rate
- Server and client are some 1,000km apart
- Ping test:

IPv6 average 21.5ms

IPv4 average 20.5ms



Fibre – 2 Stream Reno



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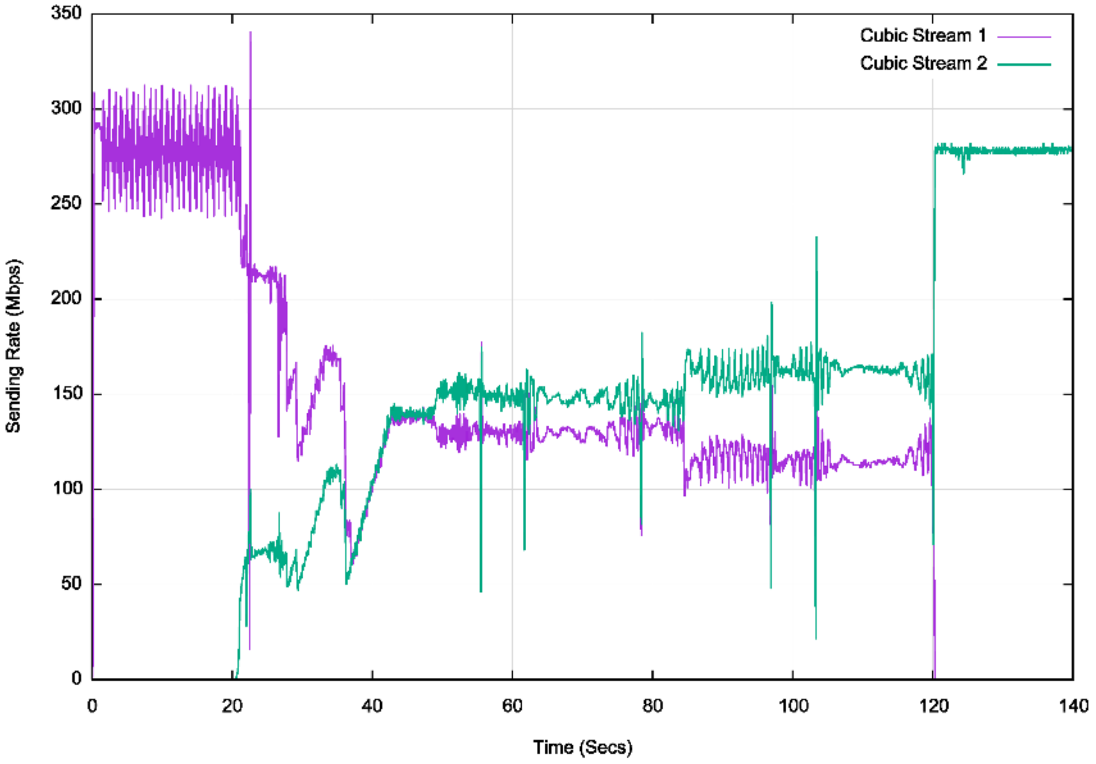
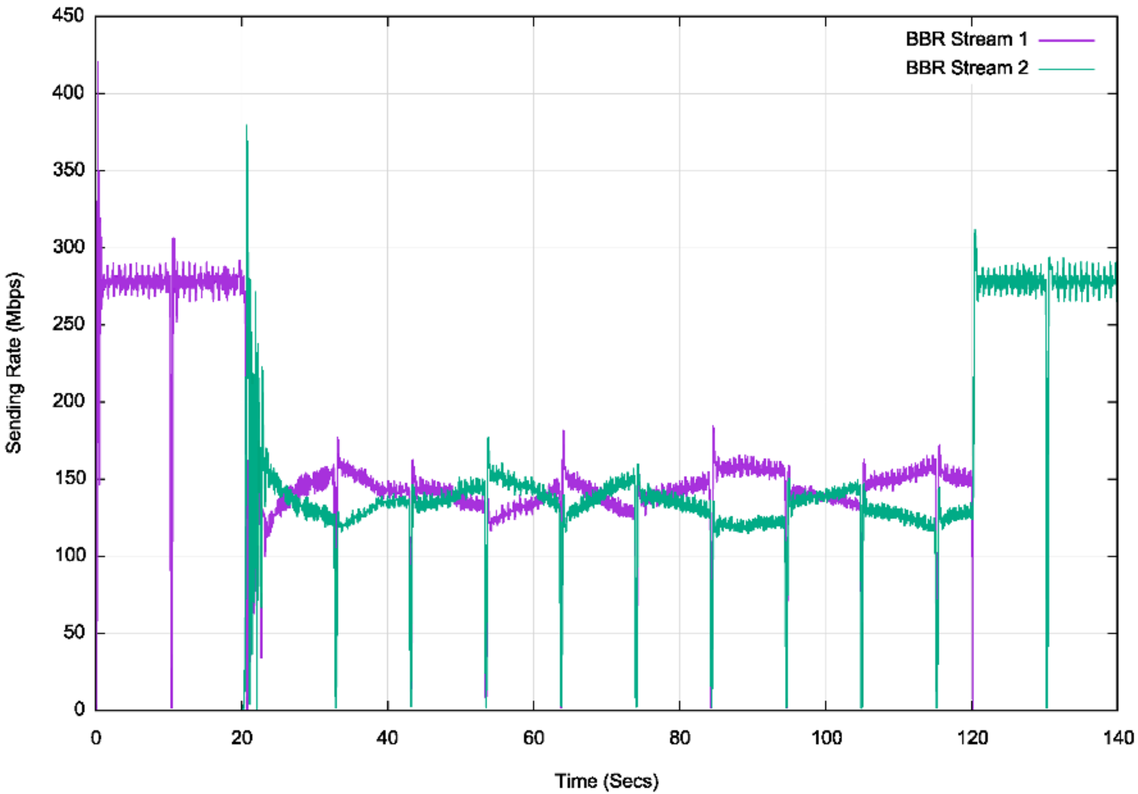
Fibre – 2 Stream Cubic



Fibre - 2 Stream BBR

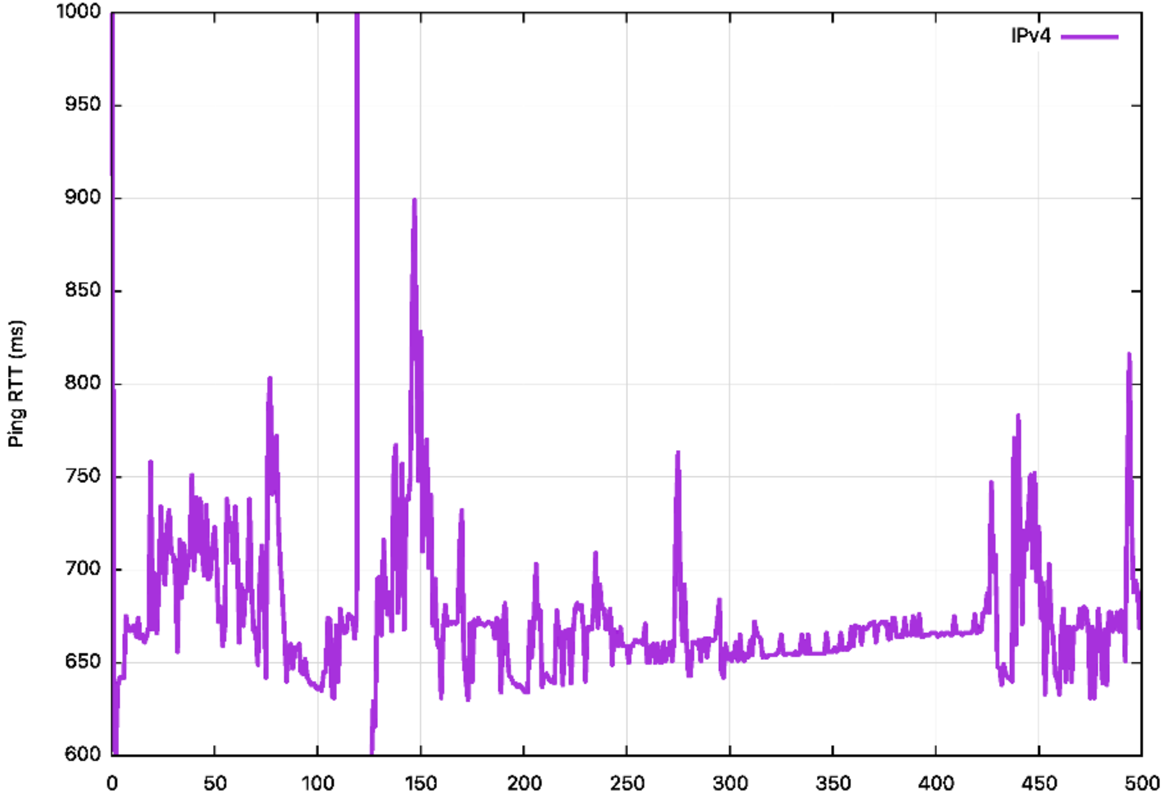


Protocol Performance over Fibre

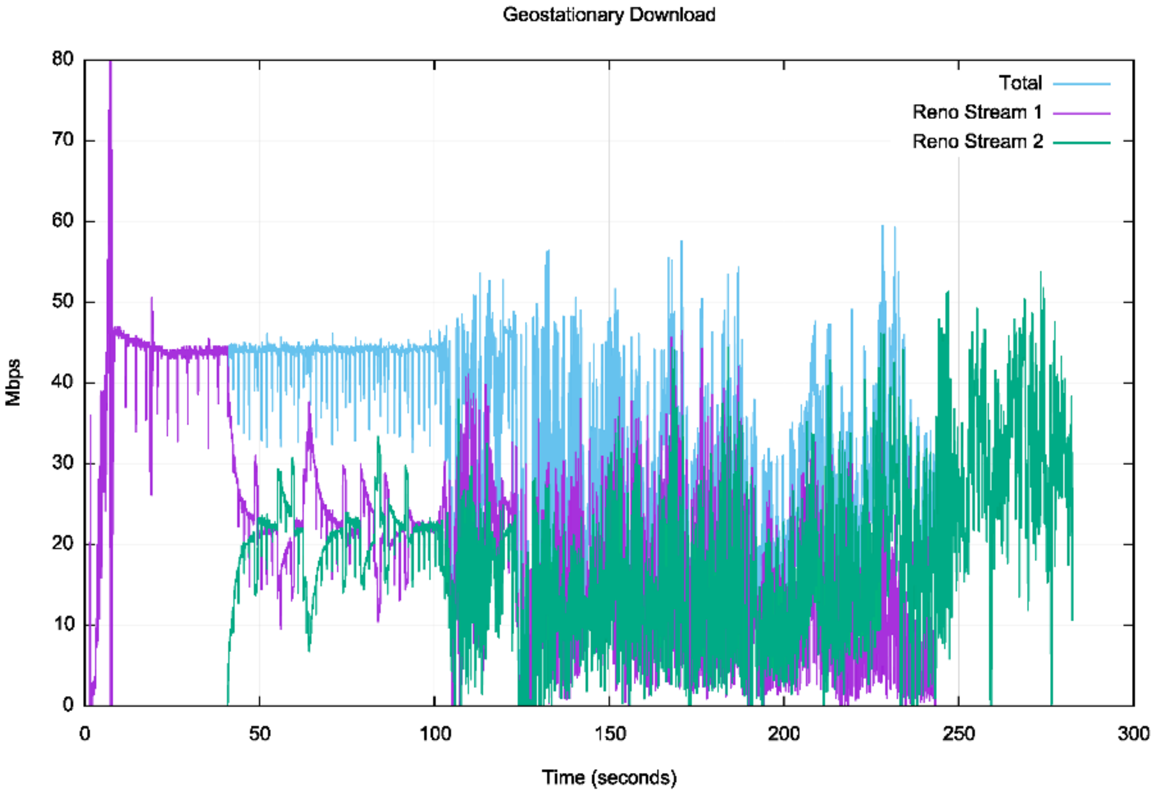
- All three congestion control algorithms are “well behaved” in this simple test
- Reno and BBR equilibrate to a 50/50 share when 2 sessions are active, while Cubic stabilises at a 60/40 split
- BBR operates with very small queue pressure, and stabilises at wire speed very quickly

GEO Service – sold as a 45Mbps service

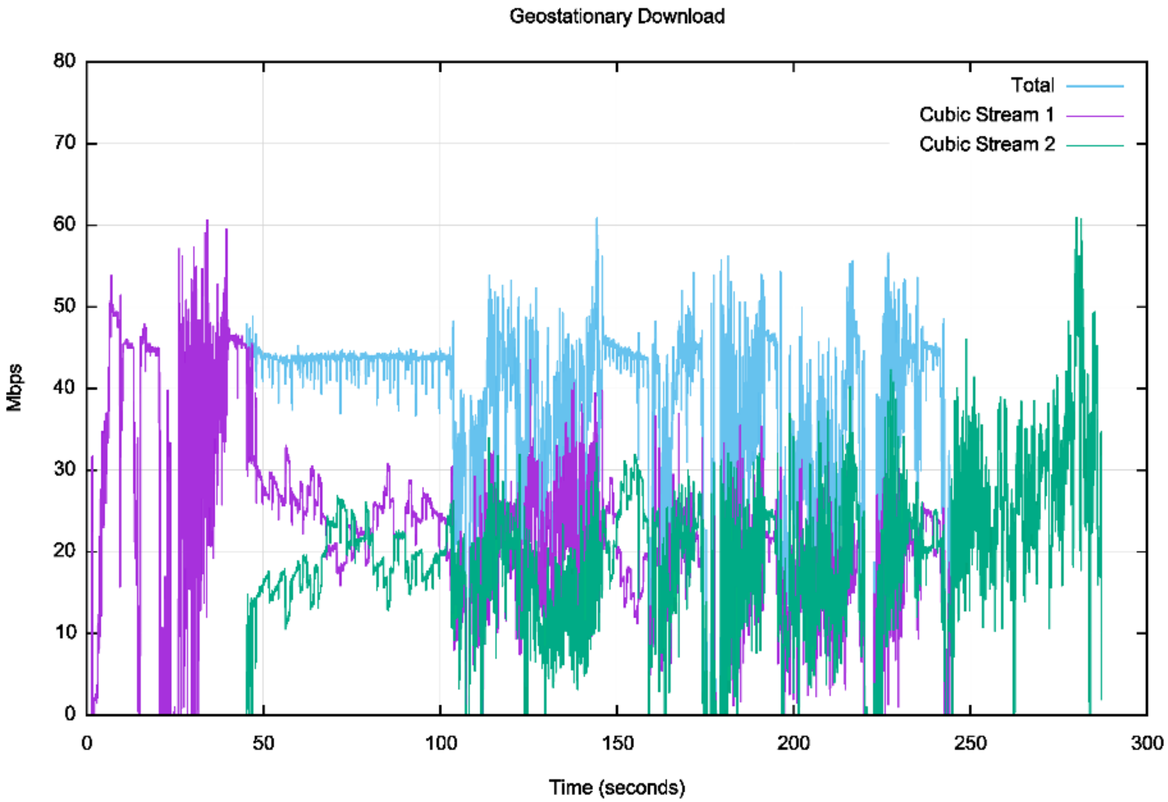
- Ping profile



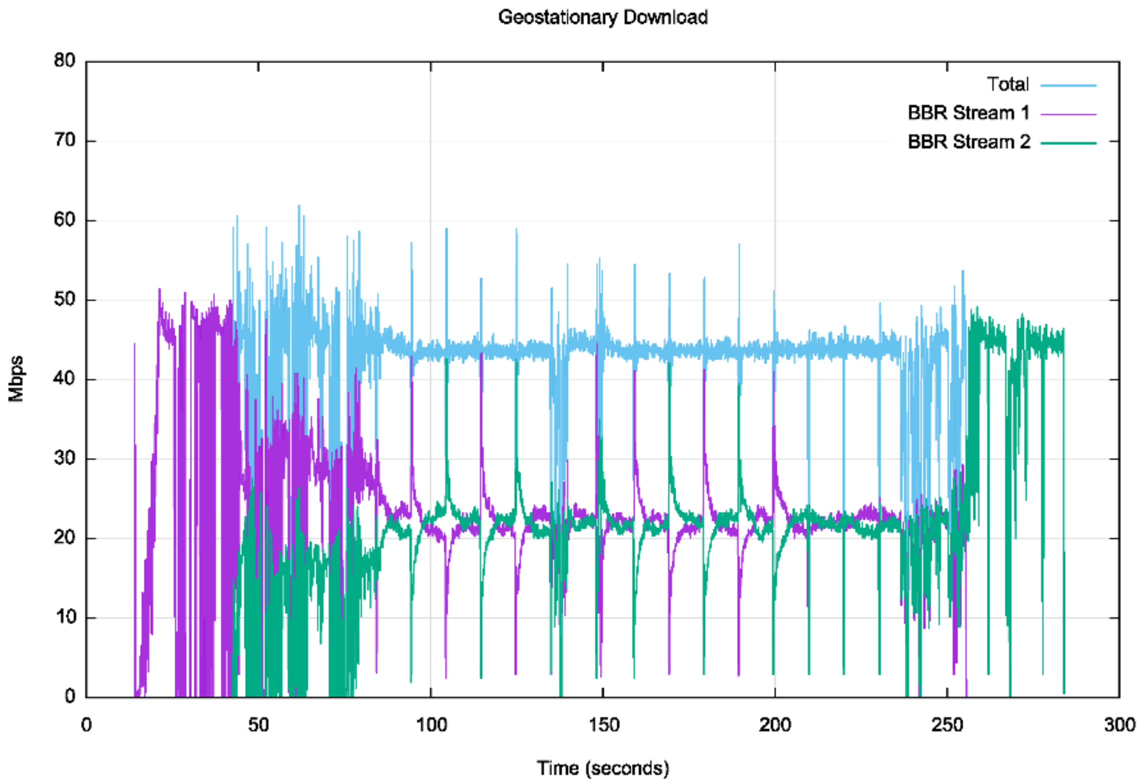
GEO – 2 Stream Reno



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

Would a TCP accelerator help when using a GEO service?

- Yes and No!

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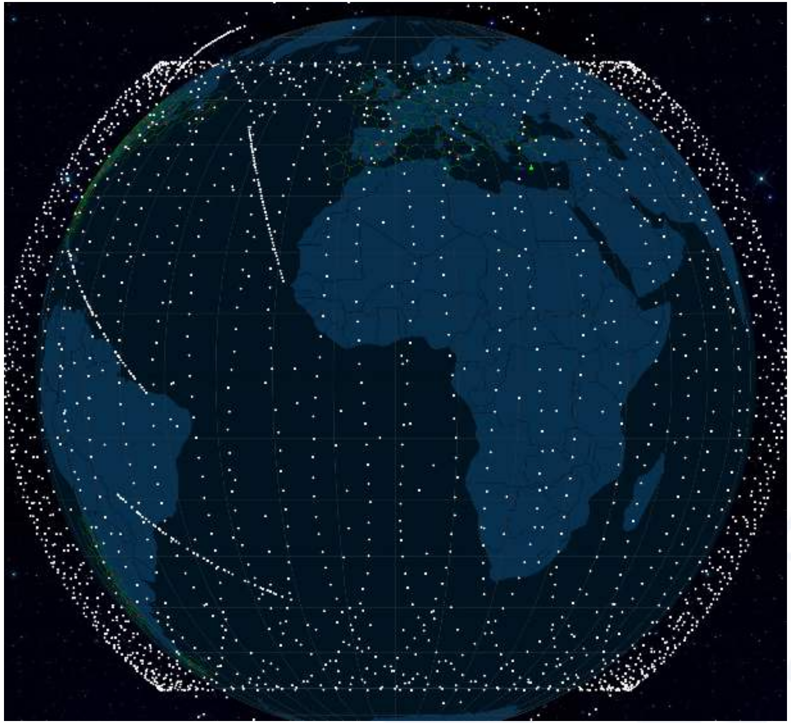
- Yes and No!

- If the sender has insufficient internal buffer space to store a delay x bandwidth product of data in its local store then the sender will be *buffer-limited* when sending bulk data – in this case the addition of a network unit that essentially provides additional buffer space will help
- But if the sender has sufficient local buffer space than the network unit will have no effect

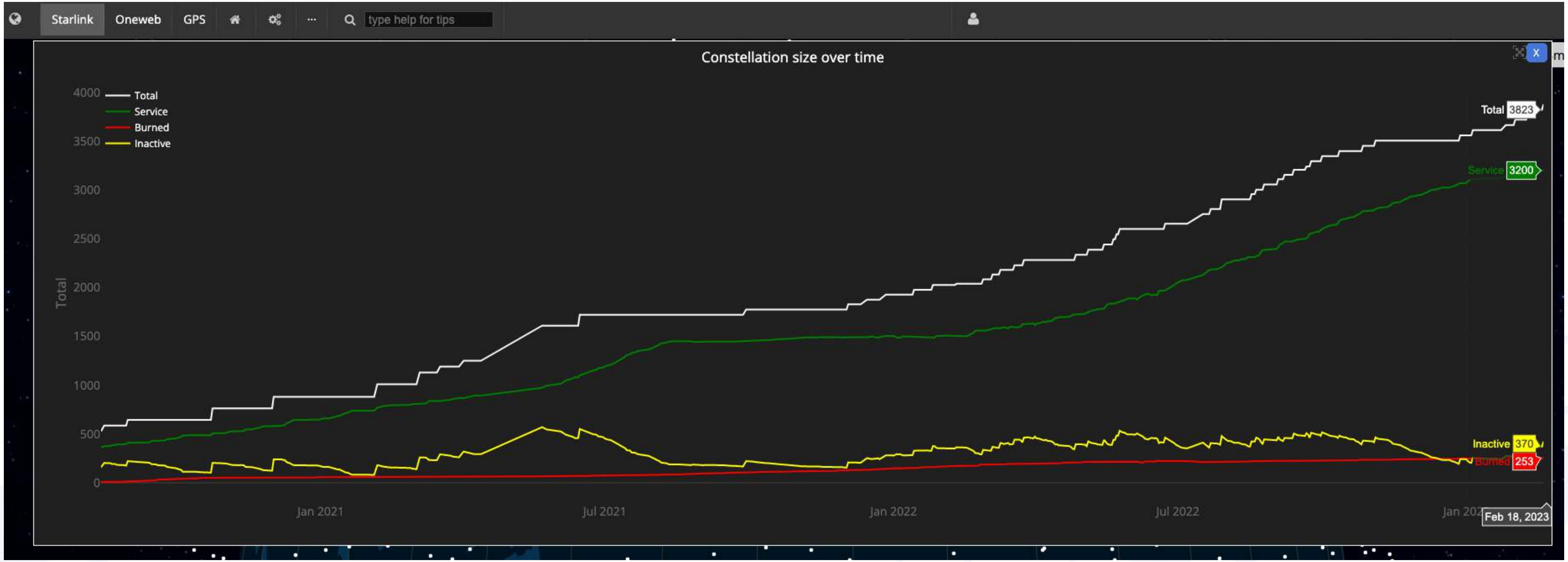
Starlink LEO service



https://satellitemap.space/

Starlink LEO service

- 3,200 in-service operational spacecraft, operating at an altitude of 550km



https://satellitemap.space/

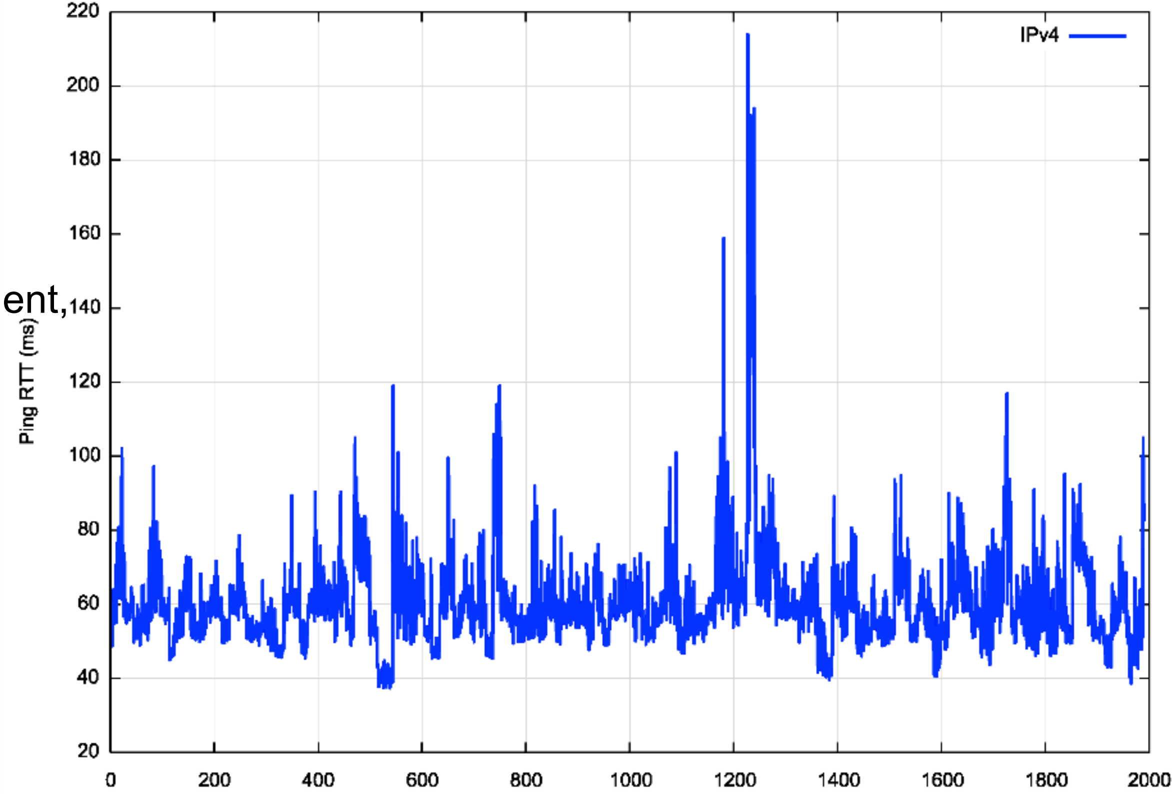
Starlink LEO service

- 3,200 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

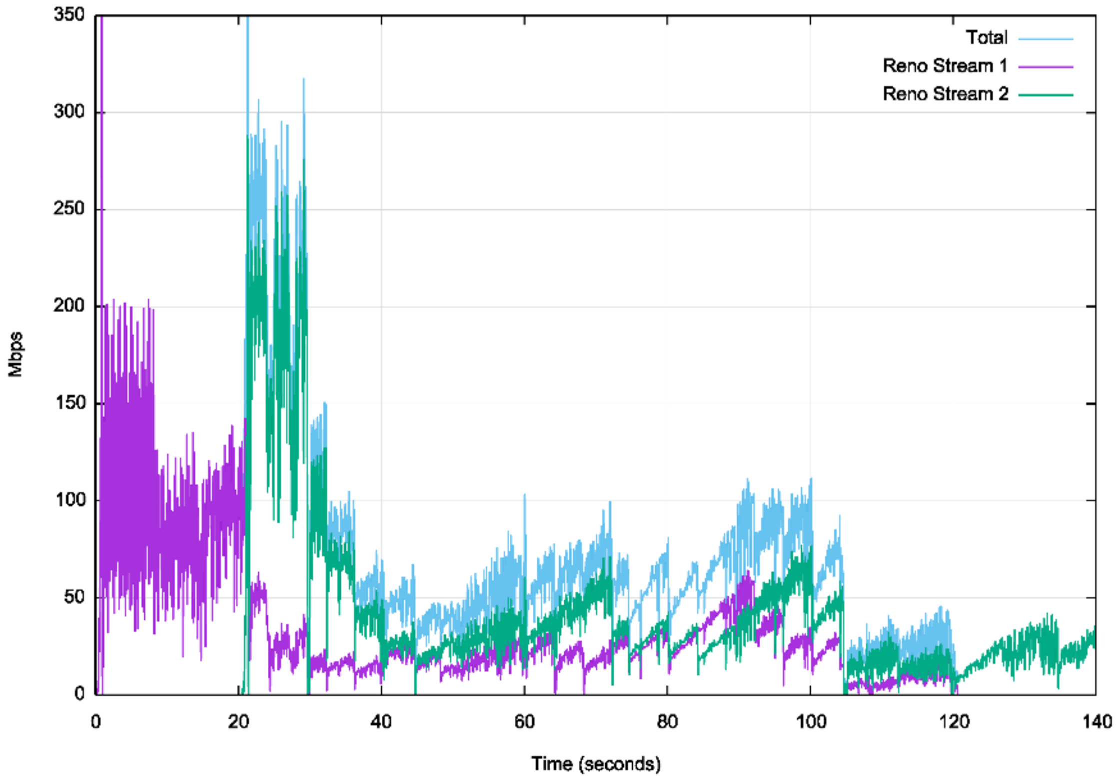
We are seeing:
12ms terrestrial component,
7ms/14ms propagation component,
30ms for codec/fec/switching



Starlink - 2 Stream Reno

Relatively unimpressive performance.

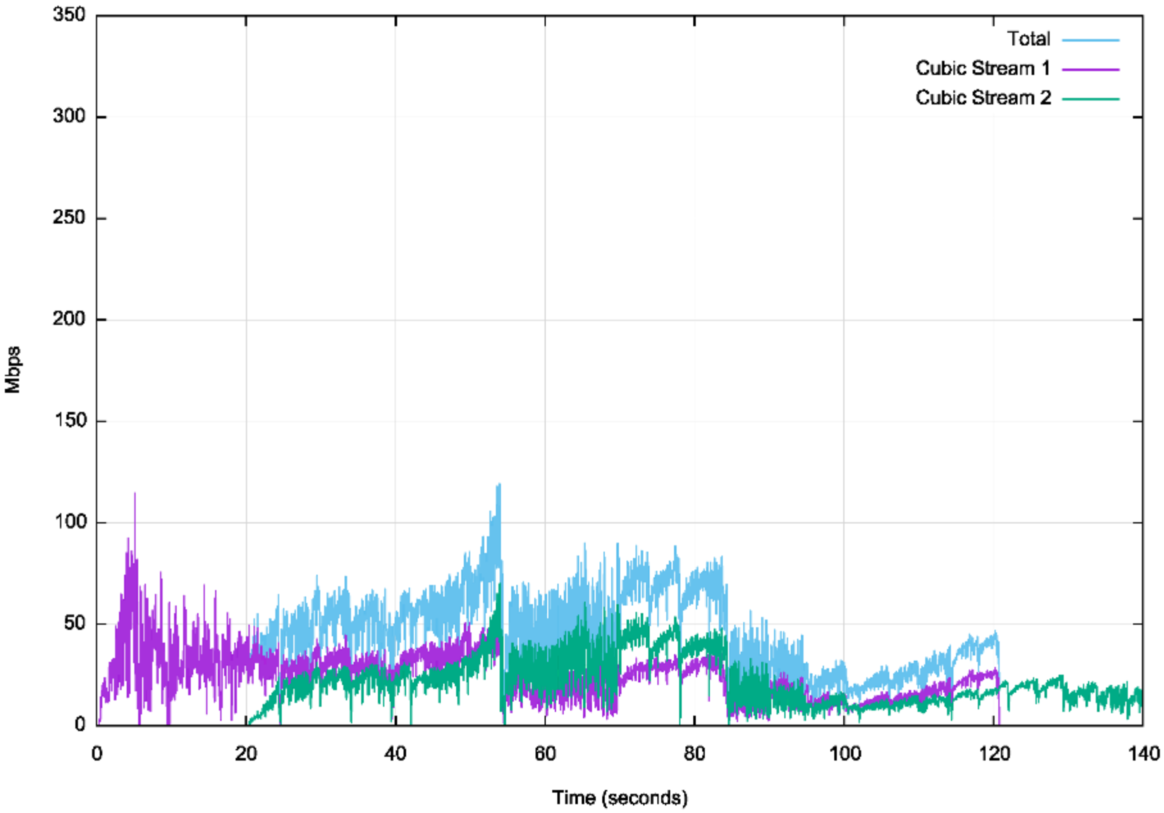
There appears to be imposed packet loss events that hampers Reno inflating the sending rate



Starlink - 2 Stream Cubic

Also unimpressive performance.

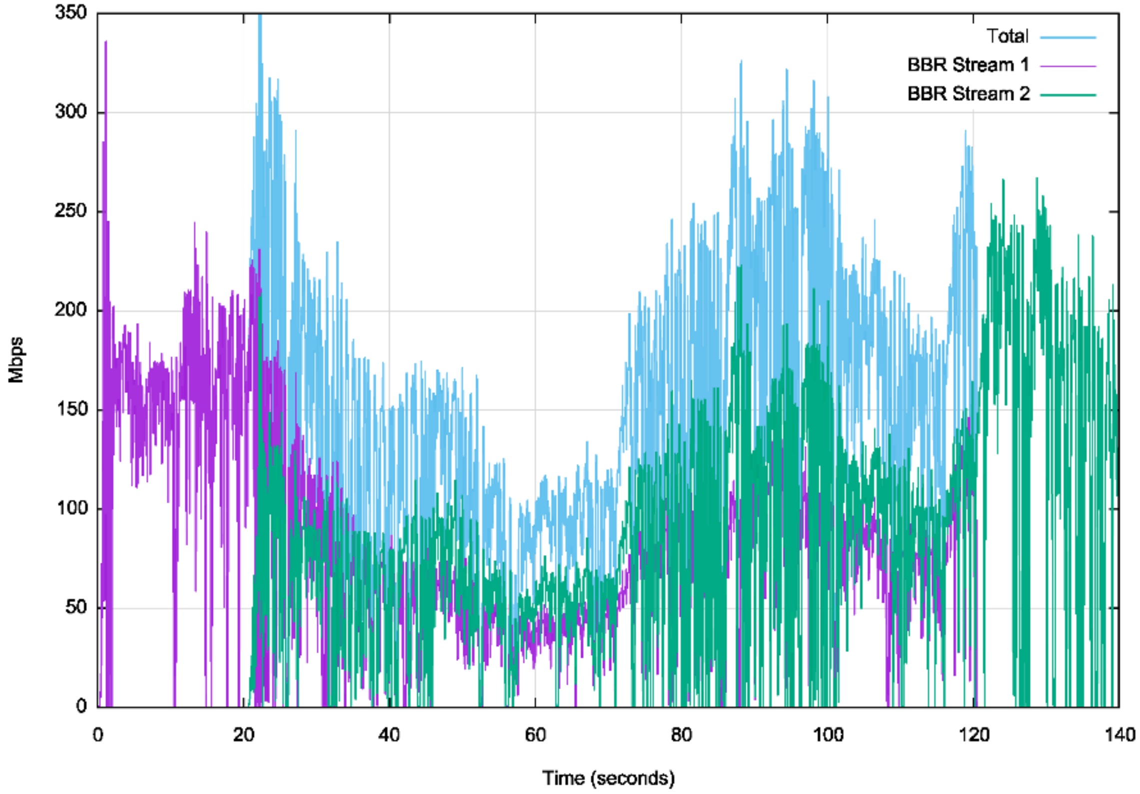
Cubic appears to be more stable than Reno, but still fails to open up its sending rate over time, so the higher stability is achieved at a cost of lower overall throughput



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.



Observations from this data

- LEO services should clearly out-perform a GEO service – but the results are not so clearly differentiated

  The GEO services appear to operate with a highly level of stability which tend to allow the loss-based TCP protocols to operate efficiently even with the extended delay

  The LEO services have a far more responsive feedback loop due to the lower RTT

- BBR is still clearly a better flow algorithm than loss-based TCP in this space: this applies to Fibre, LEO and GEO!

- Don't throw away your terrestrial fibre!

  Capacity, stability and protocol performance on fibre-based system are clearly better than satellite paths, if they are available and suit your needs

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 retranmission into the service at the cost of a higher delay overhead?

Does it scale?

Fibre – well yes, just bury more cable!

Geo – 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, IRTU 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

What about Starlink V2?

- These satellites are larger, heavier and operate at a higher power level
- More bandwidth available, and high achievable data speeds
- Incorporate 5G cellular services
- Intended to use inter-satellite laser connectors to support packet routing across satellites – details sparse so far

Questions?

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20 February – 2 March 2023

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