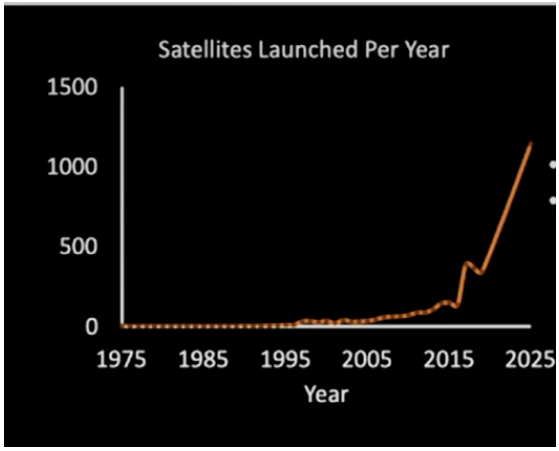
Lecture 24: Satellite Networks



Reduced cost to build and launch satellites in recent years

Applications

Satellite Internet is especially useful for rural connectivity (seas, oceans, forest), places where it is difficult or not cost effective to deploy infrastructure like cellular towers.

Orbits and Tradeoffs

Low Earth Orbit (LEO)	Geostationary Orbit (GEO)
500-1000 km	36000 km
Motion: 90 minutes, only overhead for a few minutes -> intermittent connectivity	Motion: 24 hour orbit, stationary with respect to the Earth
Coverage: Less coverage -> constellation needed	Coverage: More coverage because it is higher up so its beams cover a wider surface area -> less satellites needed
Latency: Quite a bit faster because it is closer to earth (10-20ms)	Latency: 240ms
Signal strength: Higher received power	Signal strength: Lower received power on the order of 60 Db

Major Satellite Internet Providers

Starlink: 5000 satellites launched, 42k planned
Amazon Kuiper: 3000
OneWeb: 1000

Bent-pipe architecture

You have a dish (ie. Starlink user terminal) that talks to the satellite, at 8-10 GHz (mm-level). Your devices talk to the dish over Wi-Fi. Satellite sends data to the ground station, which is connected to the internet.

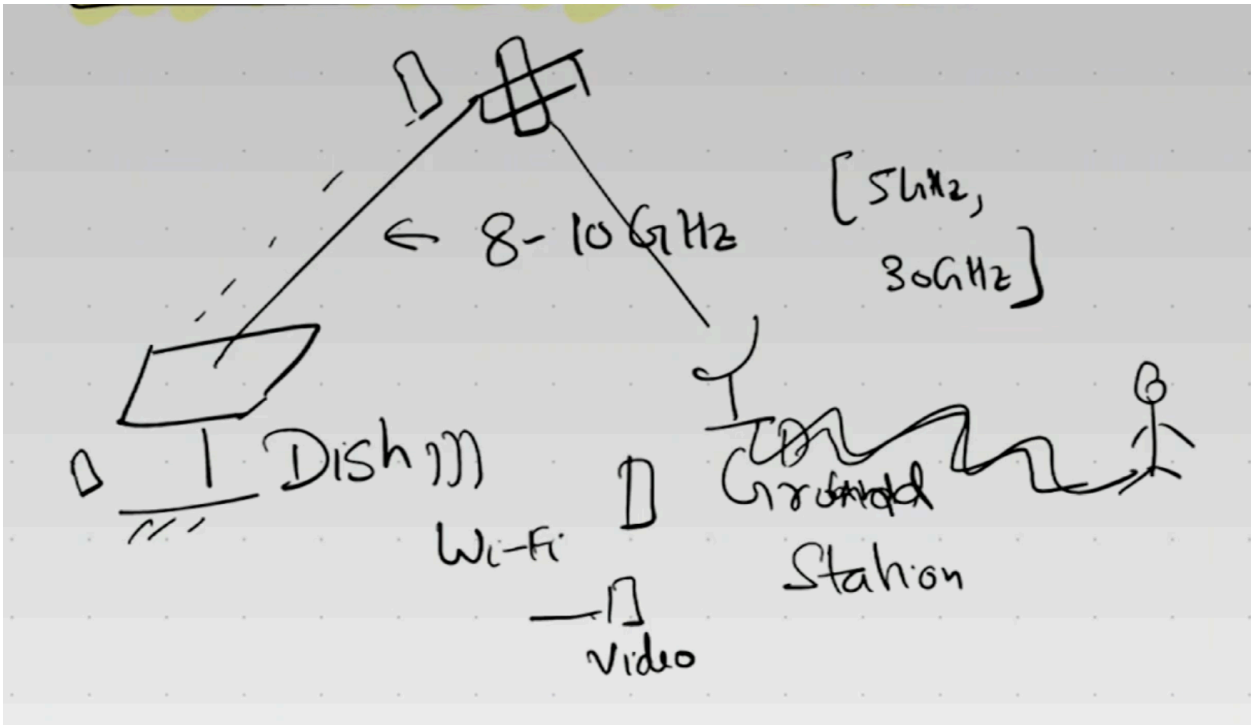
Pros

- Simple design

Cons

- Extensive ground station infrastructure needed for the satellite to relay the connection to the ground station -> how do you get connectivity in oceans

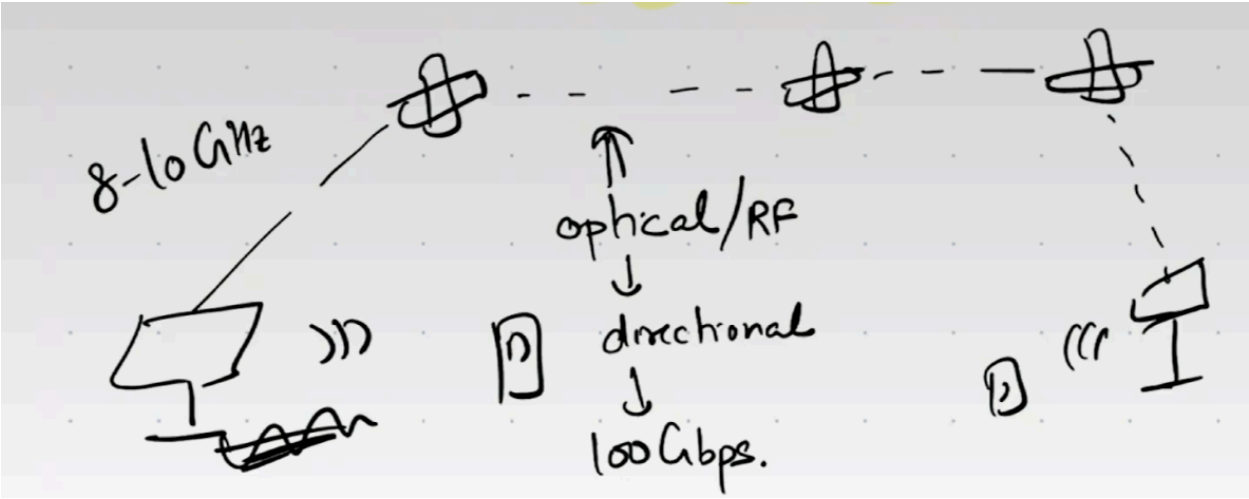
Is it faster? Speed of light over air is 50% faster than over wire (fiber)



Inter-satellite links

Instead of the satellite talking to only a ground station, the satellite can talk to other satellites. You don't have to go through fiber cables, so there is lower latency. The links between these satellites operate at 100 Gbps, are optical/RF and very directional.

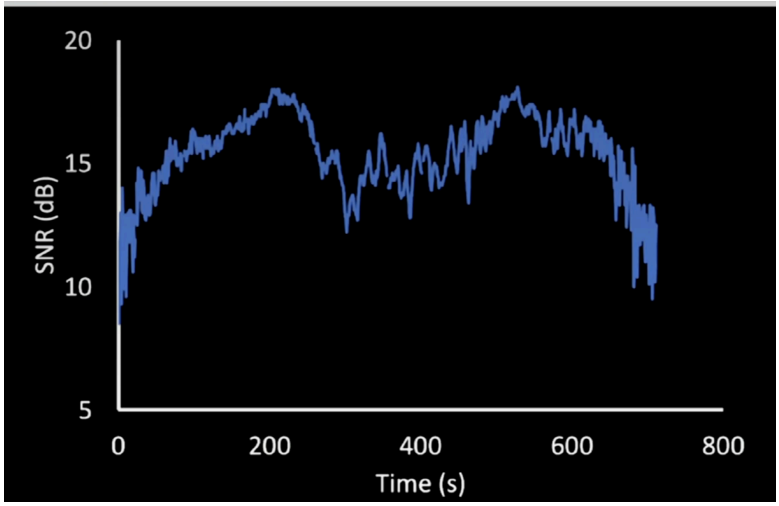
Largely limited to areas with not enough ground infrastructure

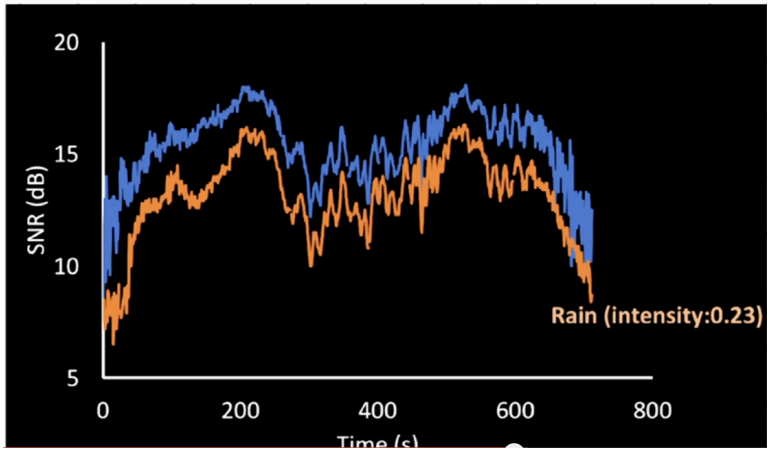


Link Variation

In the morning the SNR increases due to the increase in sun's radiation which energizes the ionosphere and allows for the signal to travel without much degradation in quality. During sunset it is the opposite

Obstructions and multipath are a big reasons for the variation

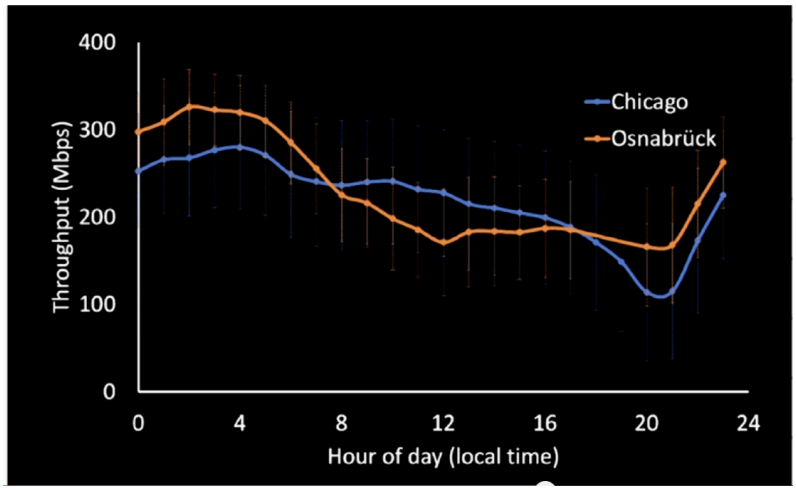




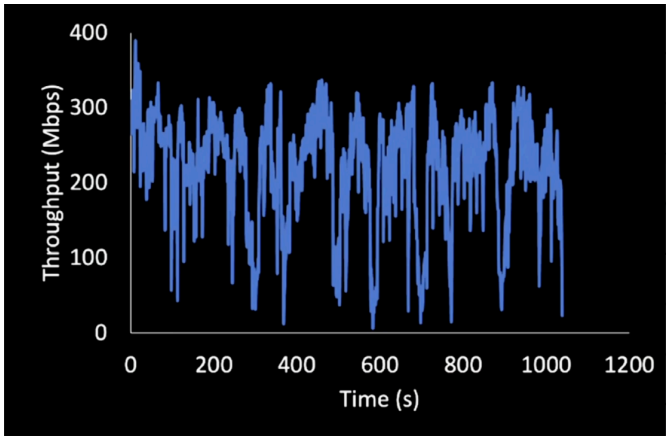
Rain and other weather conditions can impact SNR

Throughout Variation

A throughput dip in the evening, largely due to demand (in a consumer network). In an enterprise network, you would likely see a dip due to demand during working hours. These were measured on a single satellite.



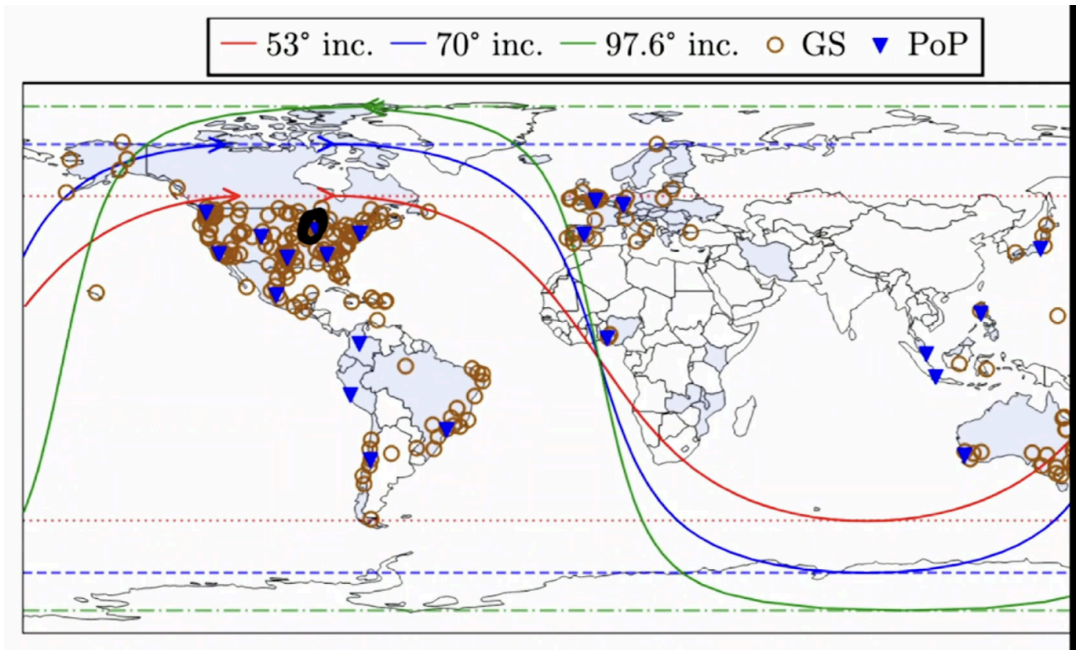
Large jumps in throughput at the network level (not just one satellite) due to handoffs. Every 15 seconds, a dish and satellite re-evaluate their connections. How do you design applications for this? How do you know if you are on a starlink network? You can look at your IP address and see if it is owned by Starlink, and then make optimizations from there, for example in video streaming you can buffer more to handle the 15-second reconfigurations.



Medium access
Can't use CSMA listen-before-talk because dishes can't monitor each other's transmit carriers. Instead, Starlink uses TDMA/FDMA.
Spatial multiplexing -> use phased arrays to create narrow beams, both on the dish and the satellite.

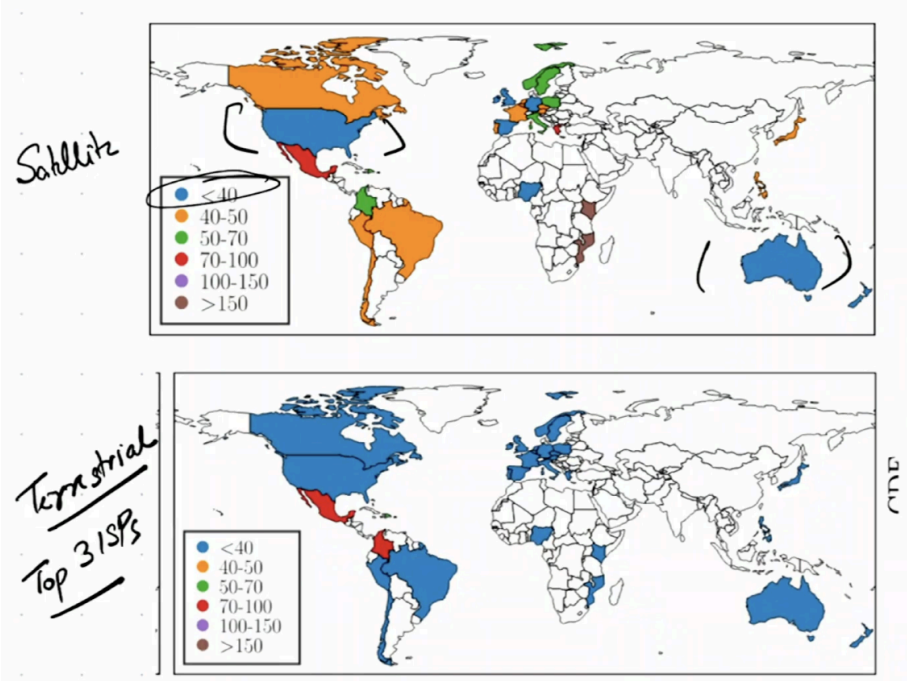
Global Measurements
A lot of ground stations near the edges of countries, for coverage in the ocean.
Point-of-presence (POP) is where the Starlink infrastructure connects to the rest of the internet.

The 53 degree inclination (with respect to the equator) covers the United States well. It is optimized for the US because they are the primary customer.



The chart is measuring min RTT in ms. It is lower on the 53 degree inclination. The satellite-based network has almost caught up to the Terrestrial network, which wasn't the case

10-20 years ago. For gaming, Starlink is comparable to cellular. For general throughput, it even outperforms cellular.



	Terrestrial	Cellular	Starlink
Idle RTT (ms)	9	46	40
Throughput (Mbps)	1000	150	220
Frames-per-second	59±1.51	59±1.68	59±1.63
Bitrate (Mbps)	23.08±0.38	22.82±4.24	22.81±2.16
Time at 1080p (%)	100	94.11	99.45
Freezes (ms/min)	0±0	0±220.34	0±119.74
Inter-frame (ms)	17±3.65	18±11.1	16±6.76
Game delay (ms)	133.53±19.79	165.82±23.55	167.13±23.12
RTT (ms)	11±13.41	39±17.06	50±16.28
Jitter buffer (ms)	15±3.27	12±1.33	15±3.35

Table 1: Luna gaming results over 150 mins playtime. Values denote median±SD and the worst performer is highlighted.