A brief comparison of the next generation of Satellite Communications

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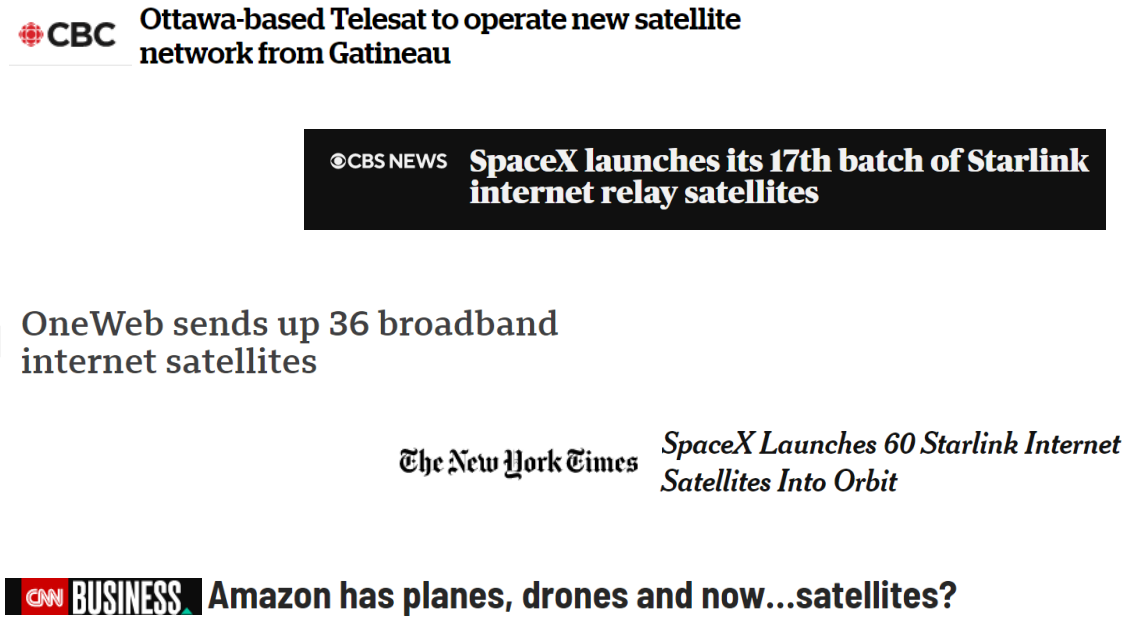
Based on: An Updated Comparison of Four Low Earth Orbit Satellite Constellation Systems to Provide Global Broadband (Nils Pachler, Inigo del Portillo, Edward F. Crawley, Bruce G. Cameron), In *IEEE International Workshop*, 2021.

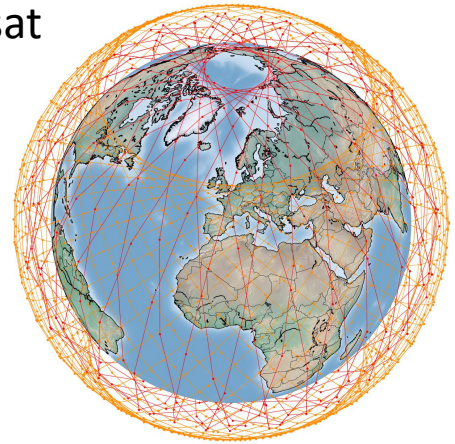
Introduction



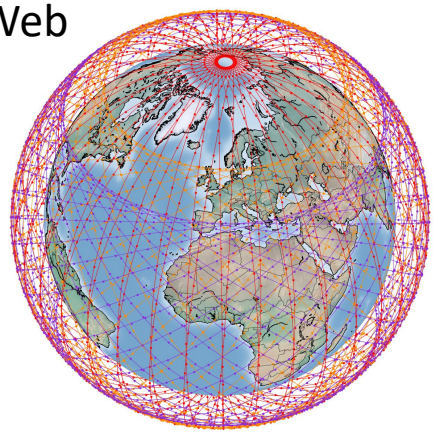
- Over the past few years, many companies have applied for non-geosynchronous orbit (NGSO) mega-constellations to offer global broadband access from space.
- The different companies attempt to service the communications market with different strategies: LEO / MEO, polar / inclined, thousands / tens of satellites
- What are the technical characteristics and performance of each design?

The 4 mega-constellations

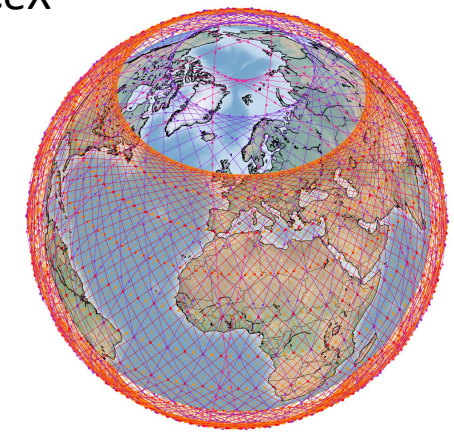
Telesat



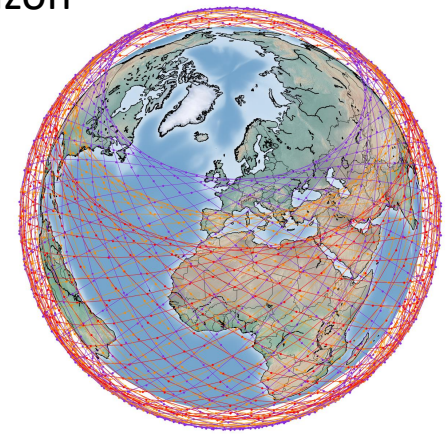
OneWeb



SpaceX

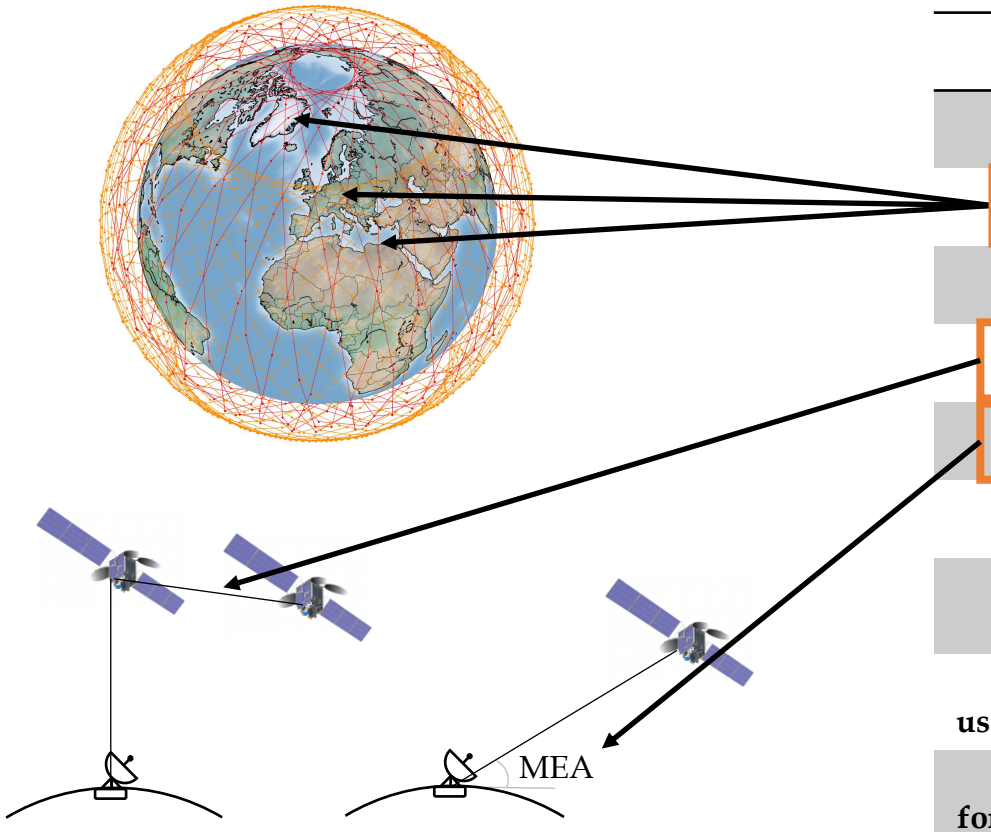


Amazon



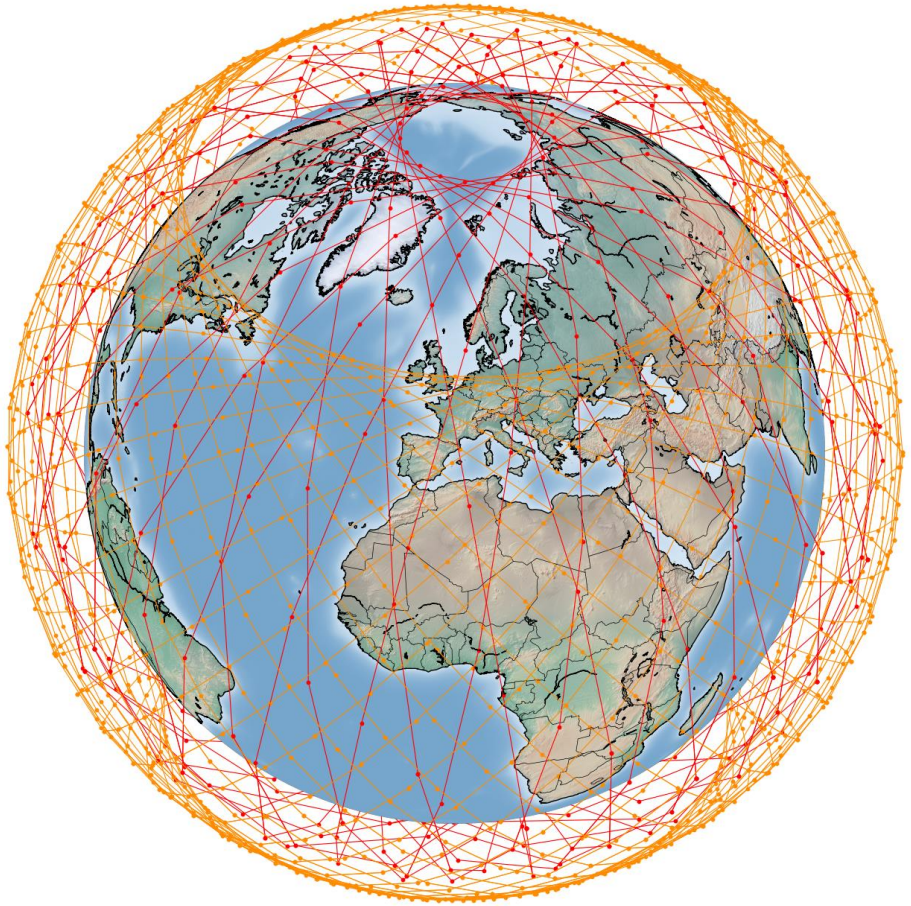
- From all the different companies attempting to operate in non-geosynchronous orbits (NGSO), four breach the thousand-satellite mark: Telesat, OneWeb, SpaceX, and Amazon
- Each company proposes a different design that combine different types of orbits, payload characteristics, and number of satellites

Parameter description



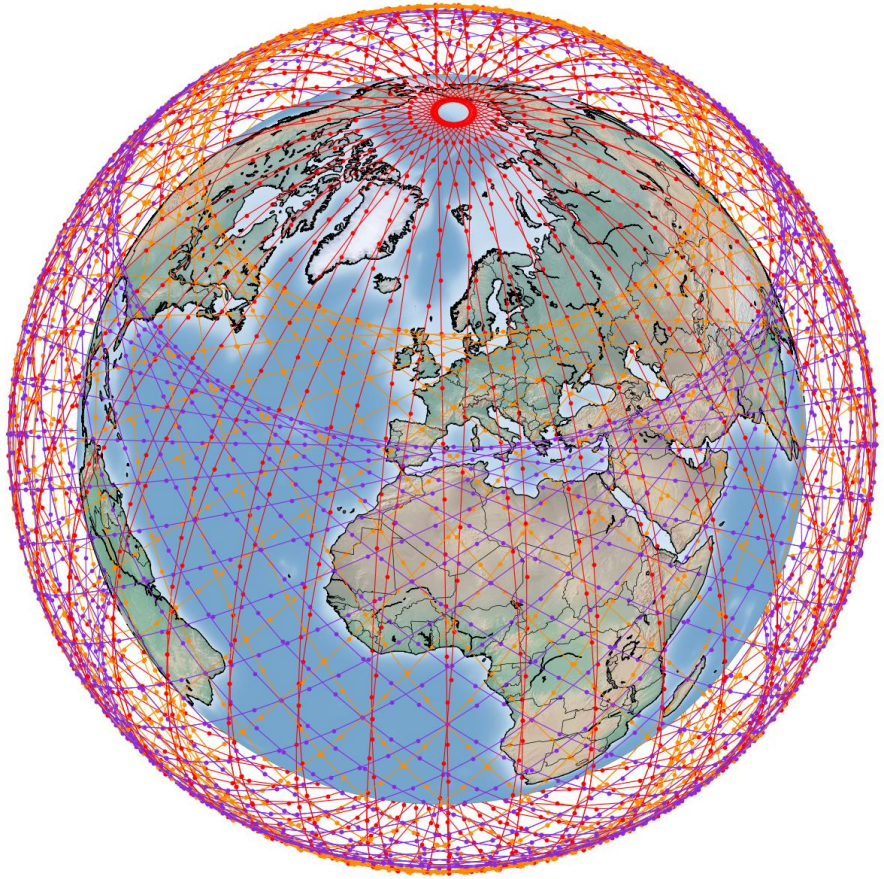
	Initial operations	Final design
Altitude range (km)	-	-
Orbital planes	-	-
Number of satellites	-	-
Inter-satellite links	-	-
Elevation angle	-	-
Polar orbits	-	-
Number of gateway antennas	-	-
Downlink / Uplink usable bandwidth (MHz)	-	-
Average / Maximum forward data-rate (Mbps)	-	-

Telesat



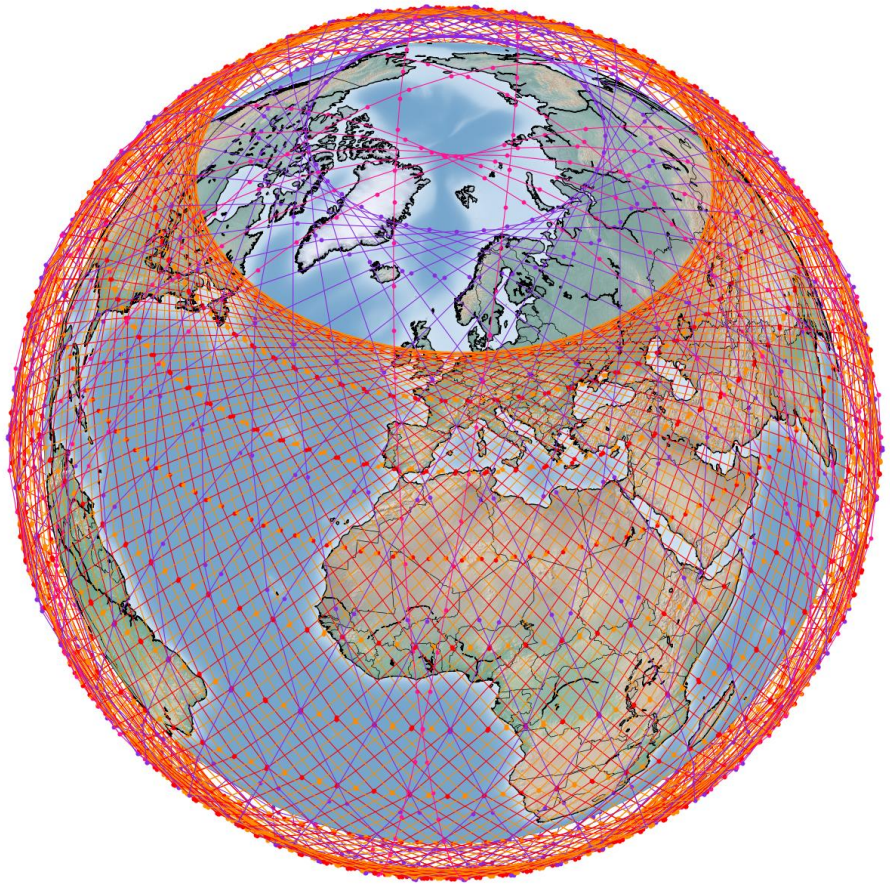
	Initial operations	Final design
Altitude range (km)	1,015-1,325	
Orbital planes	26	67
Number of satellites	298	1,671
Inter-satellite links	Yes	
Elevation angle	10	
Polar orbits	Yes	
Number of gateway antennas	2	
Downlink / Uplink usable bandwidth (GHz)	1.8 / 2.1	
Average / Maximum forward data-rate (Mbps)	25.9 / 34.4	

OneWeb



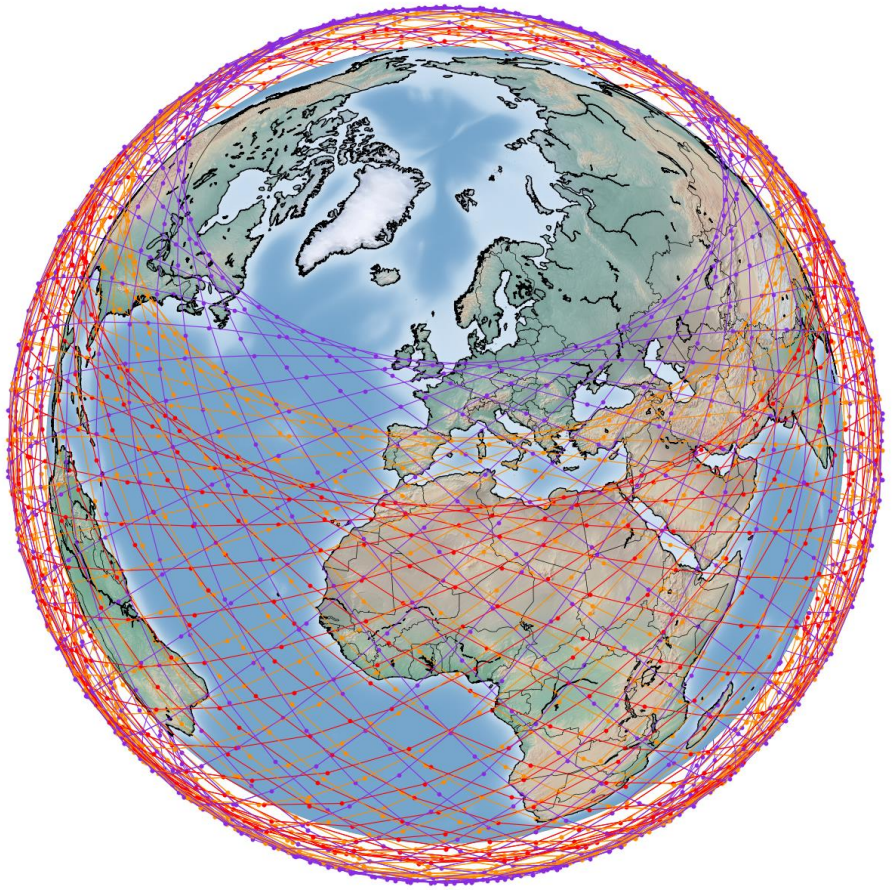
	Initial operations	Final design
Altitude range (km)	1,200	
Orbital planes	20	100
Number of satellites	716	6,372
Inter-satellite links	No	Undefined
Elevation angle	25	
Polar orbits	Yes	
Number of gateway antennas	1	
Downlink / Uplink usable bandwidth (GHz)	1.3 / 2.1	
Average / Maximum forward data-rate (Mbps)	8.80 / 9.97	17.0 / 19.7

SpaceX



	Initial operations	Final design
Altitude range (km)	540 - 570	
Orbital planes	72	190
Number of satellites	1,584	4,408
Inter-satellite links	No	Yes
Elevation angle	25	
Polar orbits	Yes	
Number of gateway antennas	1	
Downlink / Uplink usable bandwidth (GHz)	1.3 / 2.1	
Average / Maximum forward data-rate (Mbps)	13.7 / 19.7	

Amazon



	Initial operations	Final design
Altitude range (km)	590 - 630	
Orbital planes	17	98
Number of satellites	578	3,236
Inter-satellite links	Undefined	
Elevation angle	35	
Polar orbits	No	
Number of gateway antennas	2	
Downlink / Uplink usable bandwidth (GHz)	2.5 / 2.5	
Average / Maximum forward data-rate (Mbps)	48.1 / 50.8	

Methodology

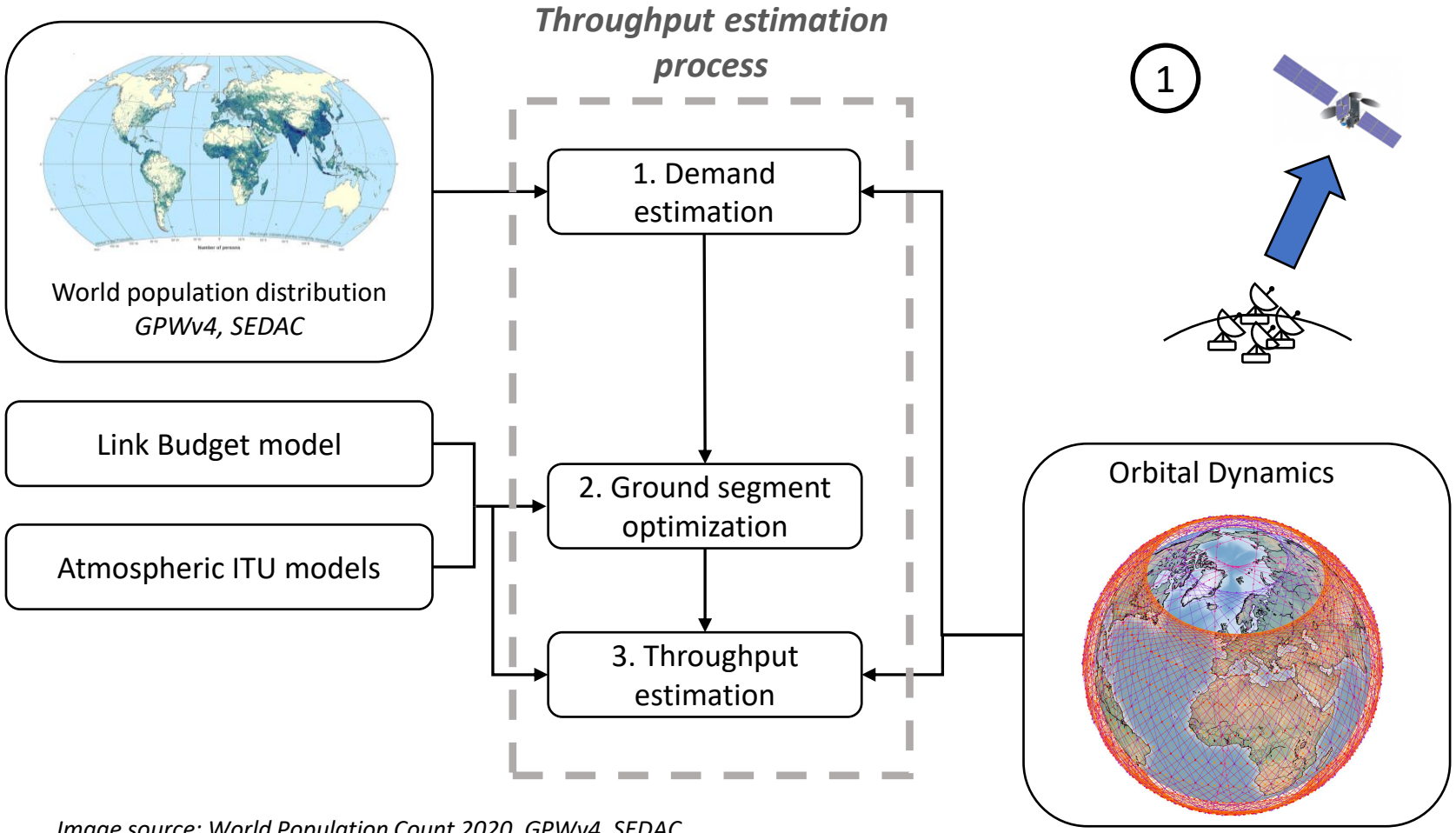
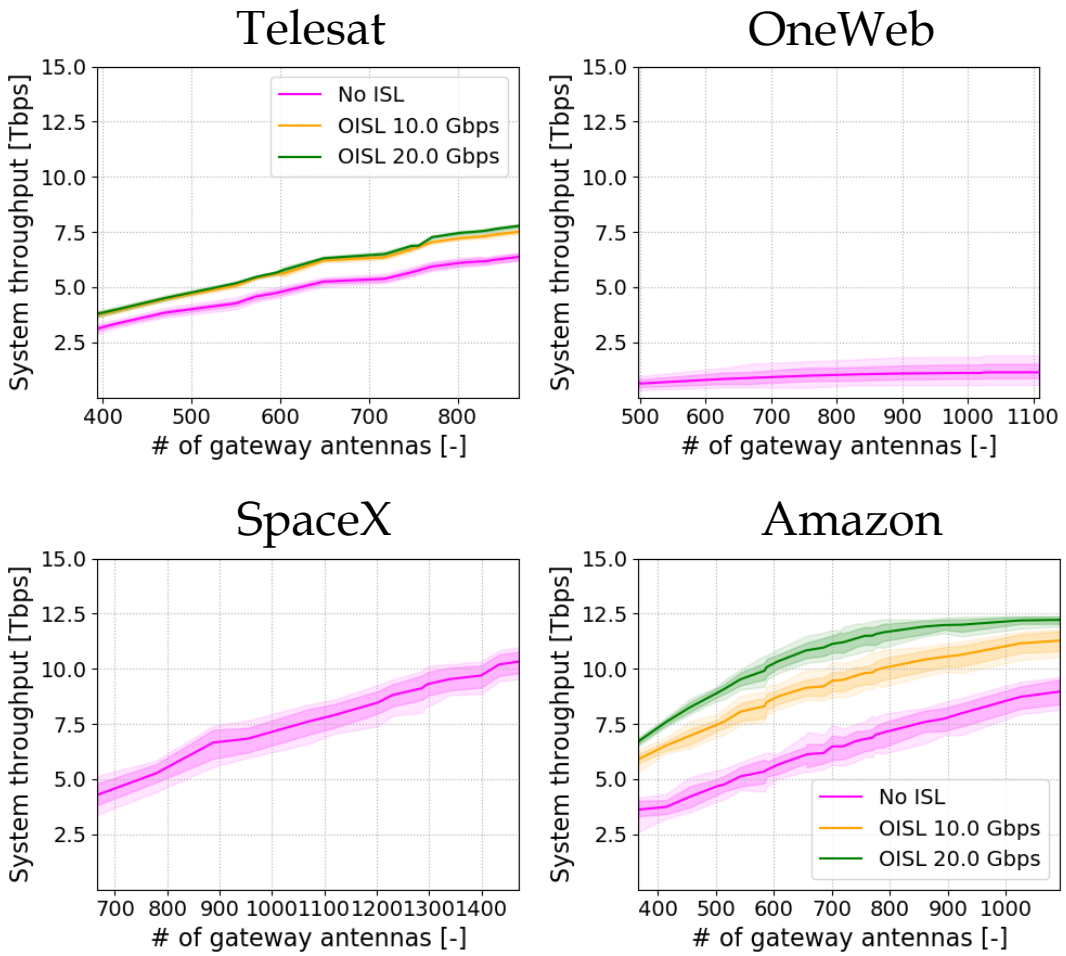


Image source: World Population Count 2020, GPWv4, SEDAC

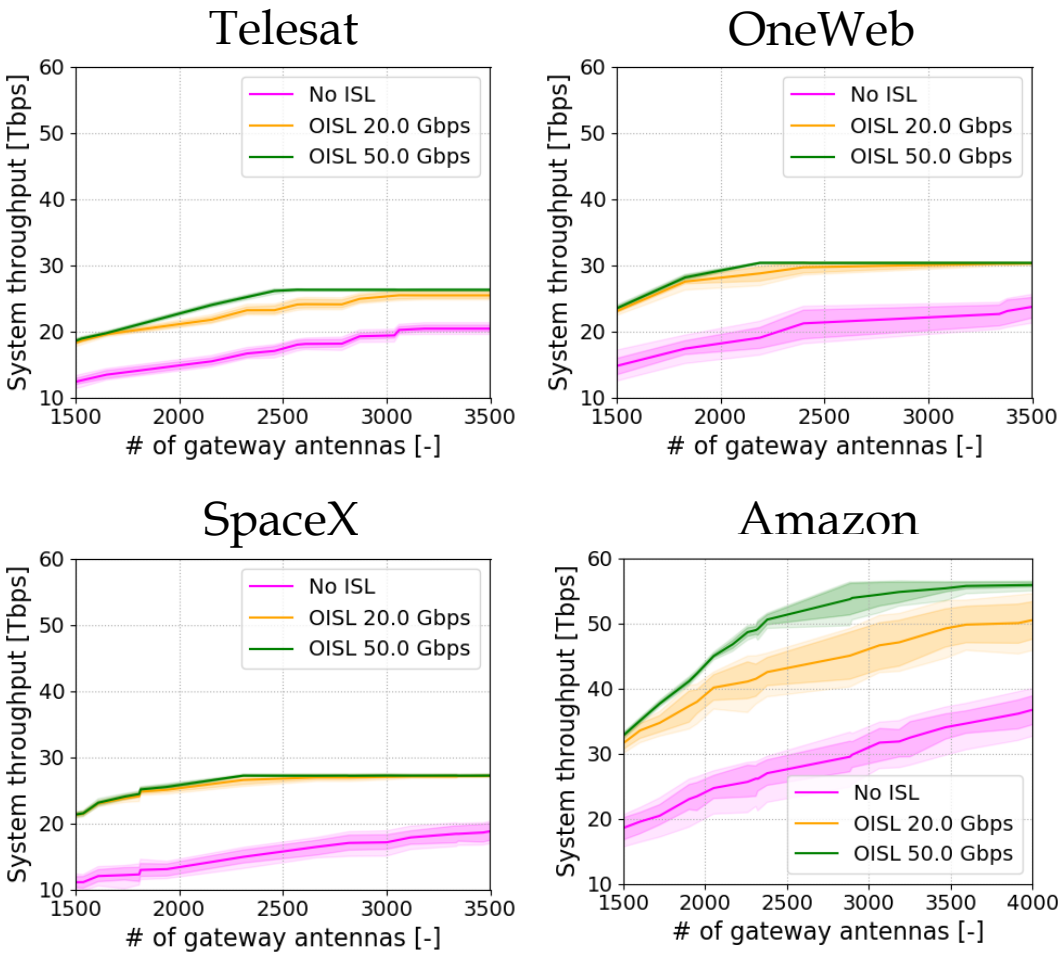
Results: Initial constellations



- Telesat achieves **7.52 Tbps (25 Gbps / sat.)** maximum throughput when using 20 Gbps ISL, thanks to the **dual feeder connection** and **low minimum elevation angle**.
- OneWeb only achieves **1.44 Tbps (2.3 Gbps / sat.)** due to **less flexibility in their satellite design**.
- Despite using around 1,600 satellites (5x Telesat's number) **SpaceX only achieves 10.3 Tbps** (6.5 Gbps / sat.) maximum throughput due to the **non-usage of ISL**.
- Amazon achieves the **highest throughput** when using 20 Gbps ISL (12.5 Tbps, 22 Gbps / sat.), but obtains **significantly less capacity** (8.97 Tbps) **when not using it**.

ISL: Inter-Satellite Links

Results: Final constellations



- Telesat achieves **25.4 Tbps maximum throughput** when using 20 Gbps ISL, which they can achieve with about 2500 gateway antennas.
- Thanks to a **more flexible satellite design** and **a larger network**, OneWeb manages to increase their throughput to **30.3 Tbps**.
- SpaceX **improves previous results by 4 Tbps** thanks to the combination of **lower altitude** and **lower minimum elevation angle**.
- Despite being second-to-last in number of satellites, Amazon achieves the **highest throughput at 53.4 Tbps** when using 20 Gbps ISL. However, they suffer a 25% loss (to 41.4 Tbps) when not using it.

ISL: Inter-Satellite Links

Results: Satellite utilization

Initial constellation

	Telesat	OneWeb	SpaceX	Amazon	
ISL (Gbps)	20	0	0	0	20*
# of sat.	298	716	1,584	578	
Max. Throughput (Tbps)	7.52	1.44	10.3	8.97	12.5
Avg. data-rate per sat. (Gbps)	25.2	2.01	6.50	15.5	19.6
Max. data-rate per sat. (Gbps)	34.4	9.97	19.7	50.8	
Satellite utilization (%)	73.4	20.2	33.0	30.5	38.5

Final constellation

	Telesat	OneWeb		SpaceX	Amazon	
ISL (Gbps)	20	0	20*	20	0	20*
# of sat.	1,671	6.372		4,408	3,236	
Max. Throughput (Tbps)	25.4	26.9	30.3	27.2	41.4	53.4
Avg. data-rate per sat. (Gbps)	15.2	4.22	4.76	6.16	12.8	16.5
Max. data-rate per sat. (Gbps)	34.4	19.7		19.7	50.8	
Satellite utilization (%)	44.3	21.4	24.2	31.3	25.2	32.5

** Note: Hypothesized values since OneWeb and Amazon don't specify if they will use ISL*

- Telesat has the **highest satellite utilization** thanks to their dual feeder connection, low minimum elevation angle and higher altitude.
- Despite doubling the data-rate per satellite, OneWeb **utilization is not improved** due to the higher data-rate capacity of their final satellites.
- SpaceX manages to achieve a **utilization above 30%** thanks to their **low minimum elevation angle**.
- **Amazon's satellite utilization is similar to SpaceX** due to the similarities in orbital configuration and minimum elevation angle. However, they suffer a 7% drawback when not using ISL.

ISL: Inter-Satellite Links

Conclusions

- **Telesat** achieves a **high throughput** and **high satellite utilization** thanks to three factors: dual gateway antenna, low minimum elevation angle, and usage of ISL.
- Despite **OneWeb** achieving the **lowest throughput** in the **initial constellation**, the combination of an improved satellite design and a larger network allows OneWeb to achieve **higher throughput** than Telesat and SpaceX in their **final architecture**.
- **SpaceX improves prior results** thanks to the combination of lower minimum elevation angle and lower altitude.
- **Amazon's throughput** is the **highest** of the four systems. However, they also need the **largest ground segment** with more than 4,000 gateway antennas.
- Both **OneWeb** and **Amazon** experience **significantly lower throughput** if they choose **not to use ISL**. They could achieve 13% and 25% increase in capacity by using 20 Gbps ISL.

ISL: Inter-Satellite Links

Thank you!

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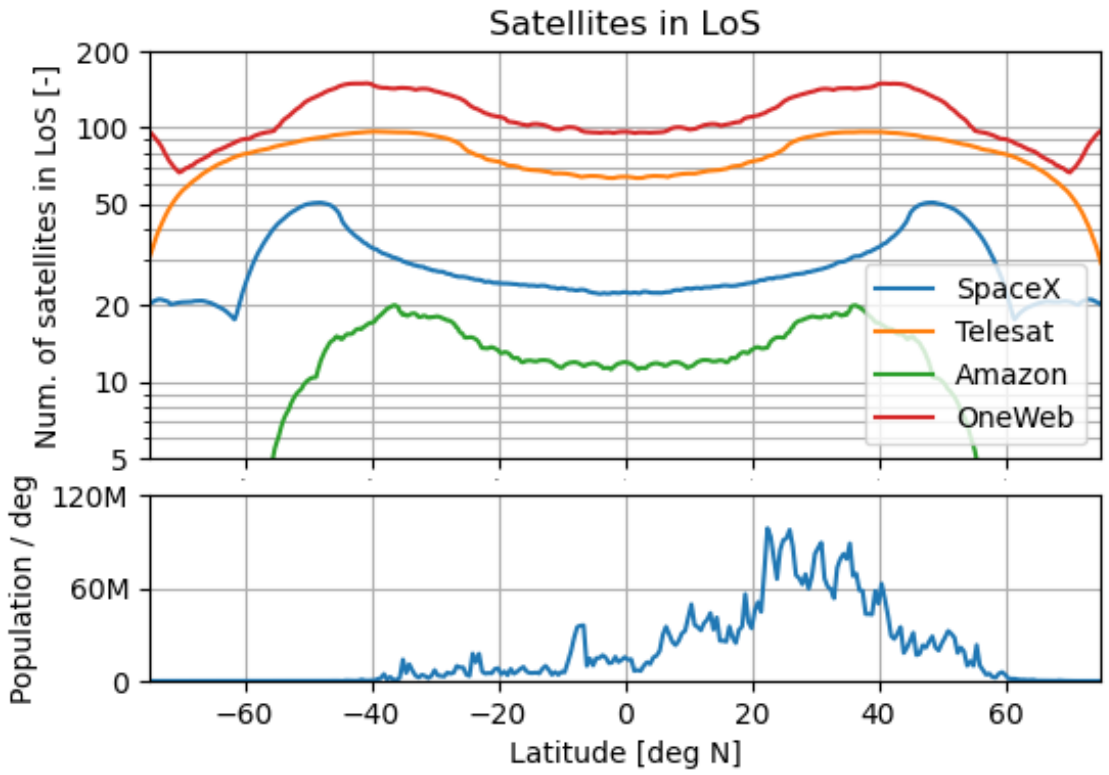
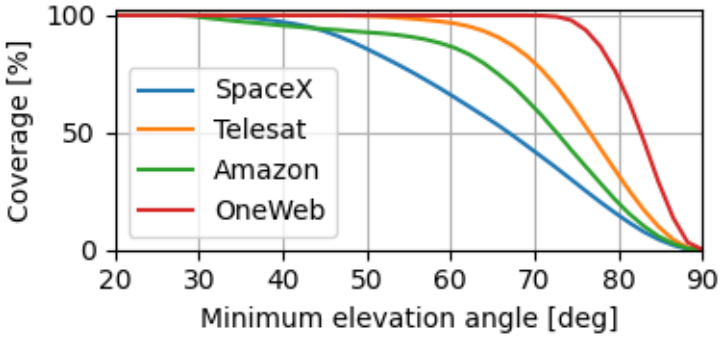
Minimum elevation angle discussion



- According to the minimum elevation angle (MEA) specified in the filings, Telesat, OneWeb, and SpaceX have a **large number of satellites in line of sight** (LoS)
- However, using a low elevation angle results in low throughput.
- For the final designs, we **estimated the MEA** that will likely be used in operations by finding the **maximum MEA that guarantees full coverage** (40°, 70°, 35°, and 35° for Telesat, OneWeb, SpaceX, and Amazon, respectively).



MEA: Minimum elevation angle

Constellation overview

Constellation design

System	Altitude range (km)	Initial design			Final design			UT min. elevation angle (°)	Uses polar orbits?
		Planes	# of sat.	ISL	Planes	# of sat.	ISL		
Telesat	1,015 – 1,325	26	298	Yes	67	1,671	Yes	10	Yes
OneWeb	1,200	20	716	No	100	6,372	Undef.	25	Yes
SpaceX	540 - 570	72	1,584	No	190	4,408	Yes	25	Yes
Amazon	590 - 630	17	578	Undef.	98	3,236	Undef.	35	No

Satellite design

System	# of simultaneous gateway antennas	Avg. forward data-rate (Gbps)	Max. forward data-rate (Gbps)
Telesat	2	25.9	34.36
OneWeb*	1	8.80 (I) 17.0 (F)	9.97 (I) 19.7 (F)
SpaceX	1	13.7	19.7
Amazon	2	48.1	50.8

** Note: OneWeb's initial (I) and final (F) data-rate per satellite are different since they specify different satellite designs*

UT: User Terminals
ISL: Inter-Satellite Links

New entrants are aiming to disrupt the landscape

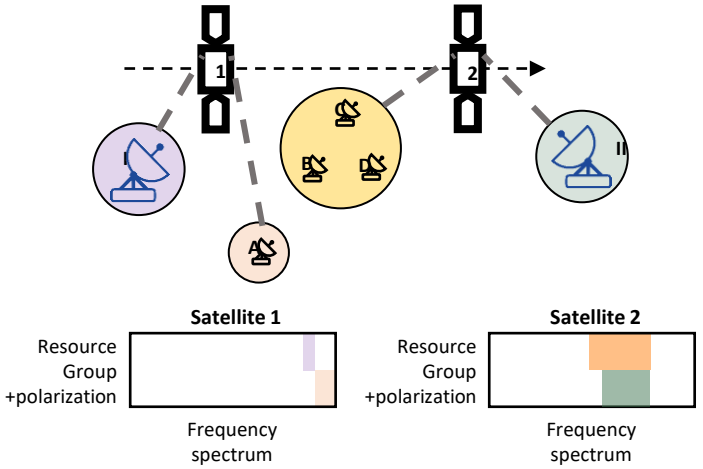
	Round-trip latency			
Throughput	≈50 ms (LEO)		≈150 ms (MEO)	≈1000 ms (GEO)
Mbps/Kbps	Globalstar, iridium, SPACE NORWAY			
10-100 Gbps	LEOSAT, Karousel LLC		inmarsat, SES, Telesat, INTELSAT, eutelsat	hispasat, Embratel, THAICOM, USAT
Multiple 100 Gbps			SES O3b	ECHOSTAR, Viasat
Tbps	OneWeb, BOEING, SPACEX	Telesat, amazon		

Thanks to Dr. Markus Guerster

Disruptors **Incumbents**

Dynamic Resource Management

One of the most challenging problems for mega-constellations is frequency assignment:



From an operation perspective, we must

For each beam (000s of beams),

decide which resource group, polarization, and beamchannels to use

in both uplink and downlink

while respecting frequency, handover, and gateway constraints

and mobile users' constraints

In addition, we look for

Frequency Plans that minimize DC power consumption

and the capacity to make changes to the plan in real-time if necessary

With thanks to Juan Jose Garau Luis

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