Connectivity from Space – What Quality can you expect from Satetelite Internet

Hakan Ekmen, Ralf Pabst

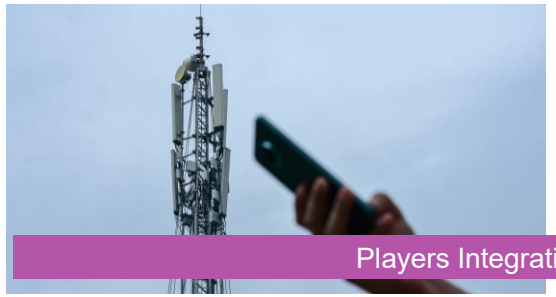
Competing and Complementing Solutions in the Wireless Access Market

Internet access is converging with market players starting to integrate different means of terrestrial and non-terrestrial access.

Terrestrial

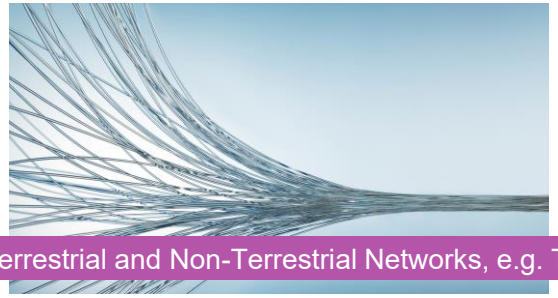
Mobile: LTE/5G/6G

- sub-10ms Latency achievable (depending on Core + backhaul architecture)
- dedicated spectrum per Operator,
- subject to national regulations,
- used for Public Land Mobile Networks, Private networks, Fixed Wireless Access
- >1Gbps DL speeds
- Medium speed and cost of deployment
- Players: National MNOs



Fixed: Fiber & Co.

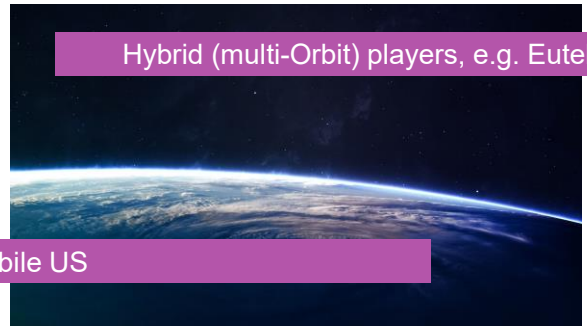
- DSL, Cable, Fiber, WiMAX, etc.
- locally distributed through WiFi CPEs
- sub-10ms Latency achievable (depending on access technology & core)
- up to 10Gbps consumer products available (e.g. XGS-PON)
- Slow, very costly deployment
- Players: National and Global ISPs



Non-Terrestrial

Low Earth Orbit (LEO) Satellites

- Native service offerings to CPEs, using spectrum between 10 and 80GHz
- Direct-to-Cellular service offerings, using 3GPP spectrum, emulating Base Stations (currently only very low bitrate services, e.g. Messaging)
- sub-100ms Latency achievable
- Players: Starlink, Amazon (Kuiper), Iridium, Globalstar, ...



Hybrid (multi-Orbit) players, e.g. Eutelsat, Viasat, EchoStar (Hughes), SES

Players Integrating Terrestrial and Non-Terrestrial Networks, e.g. T-Mobile US

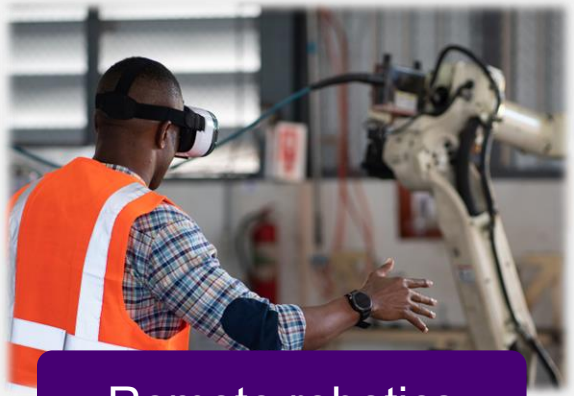
Focus of performance views

Geosynchronous Equatorial Orbit (GEO) Satellites

- Satellite Services, 35786 km orbit
- Severall hundreds of miliseconds of Latency
- Limited capacity (due to limited number of satellites), hard to scale
- Traditionally used for e.g. Aircraft and Ship service
- Players: Viasat, Intelsat, ...

Applications & Use Cases beyond personal Connectivity

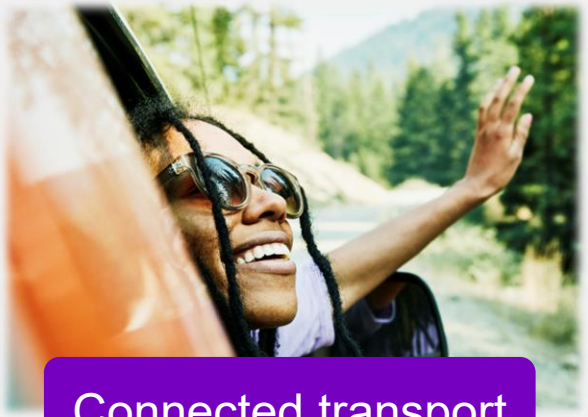
Benefits: Global Reach, Enhanced Connectivity, Disaster Resilience



Remote robotics

Remote human control

- Remote robotic surgery
- Remote driving of military vehicles
- Remote operation of robots in dangerous environments



Connected transport

Vehicles at sea, land and in the air

- Suburban and rural connectivity
- Fleet tracking and logistics
- Ships at sea

Emergency response

Remote locations and disaster resilence

- Mountainous regions
- Suburbs and rural áreas
- Disaster relief coordination

Machine to machine

Factory controlling and monitoring

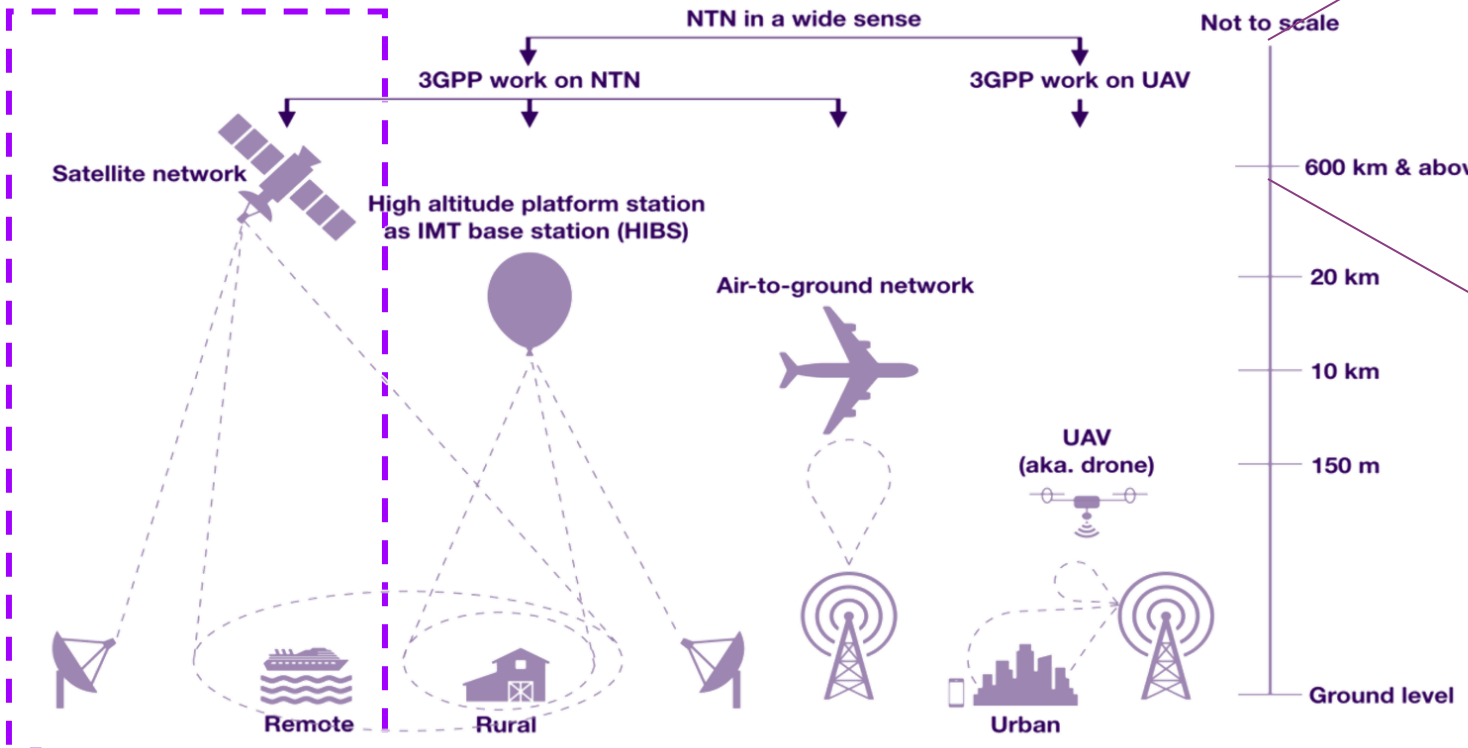
- Remote operations
- Supply chain coordination
- Critical situation response

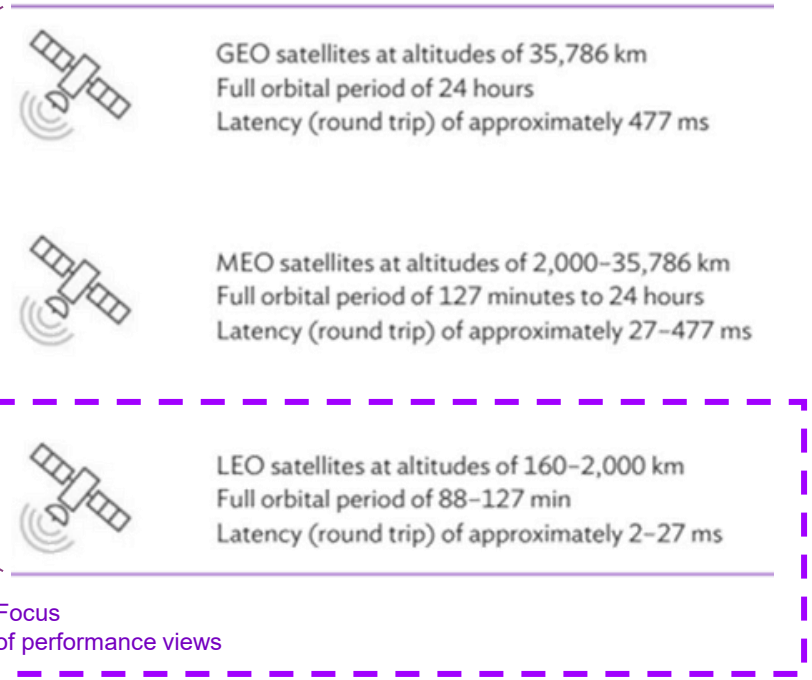
Leveraging Private 5G Networks with Satellite Support: Real-World Applications Across Key Sectors

- **Industry 4.0**: satellite support to connect and monitor machinery in smart factories located in remote areas. Inter-factory connect could use NTN backhaul.
- **Precision Agriculture**: satellite support to monitor crops and soil conditions in real-time, optimizing resource usage.
- **Transport and Logistics**: Maersk employs private 5G networks with satellite connectivity to enhance fleet management and cargo tracking in ports and airports.
- **Energy and Utilities**: satellite support in mines and other remote locations to manage critical infrastructure.
- **Emergency and Public Safety**: "cells on wings" (COWs) to expand access in disaster zones, using satellite support to ensure connectivity.

Non Terrestrial Network Architectures I

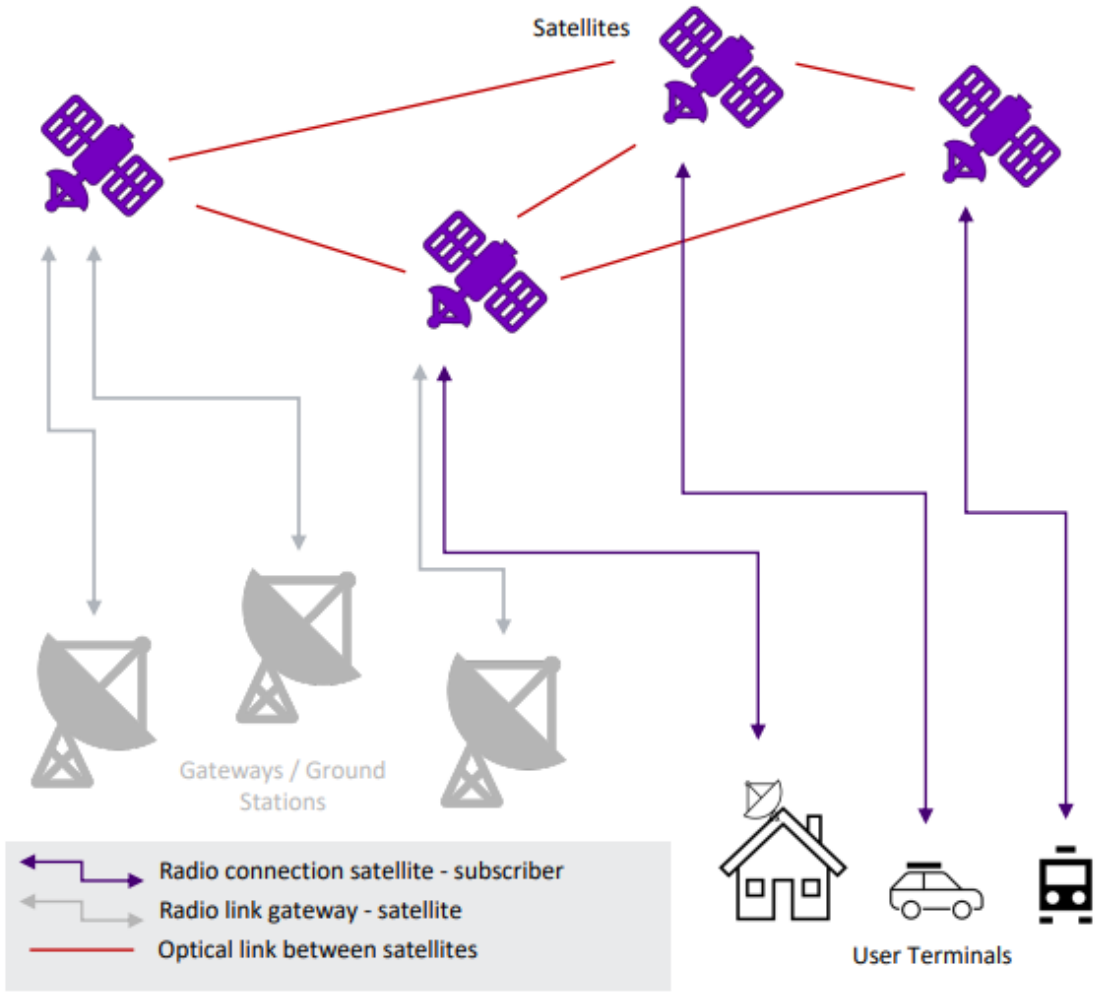
Overview of non-terrestrial Network implementations





Non Terrestrial Network Architectures II

Hardware and link types in the satellite system



Connection of LEO constellations to the Internet

- Gateways connect satellite network to (local) Internet
- Terminals select the connection via satellites with the best performance (e.g., capacity, latency)
- Connections via several satellites to the next gateway on Earth are also possible

Receivers for LEO constellations

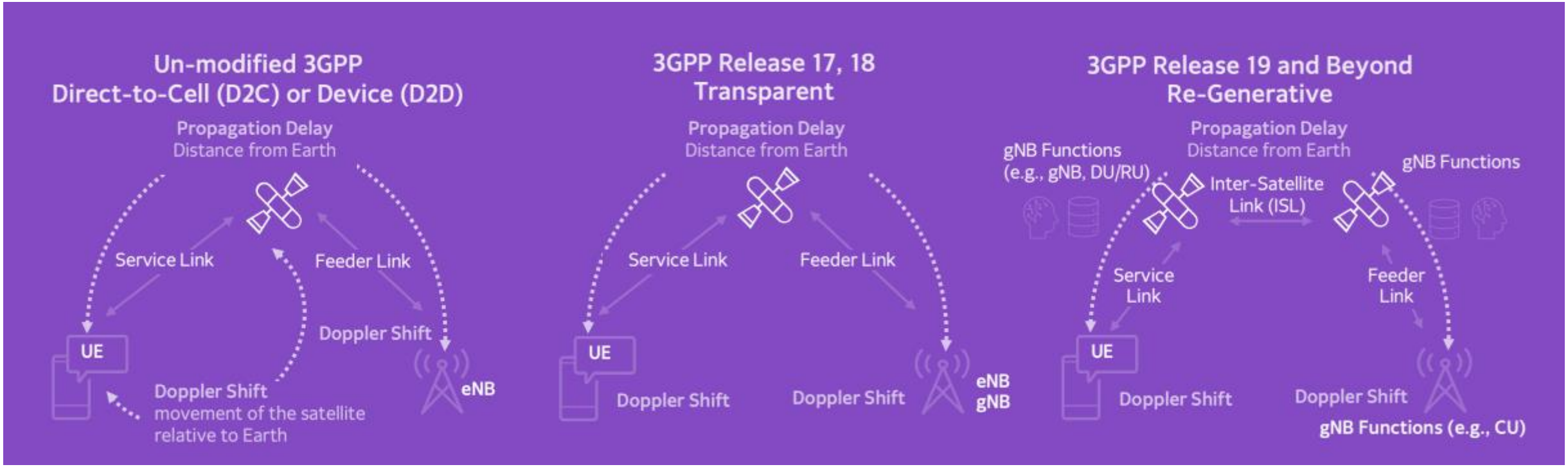
- Antennas for LEO constellations are "User Terminals"
- Parabolic antennas ("satellite dishes") are mechanically moved and aligned with satellites
- Electronically controllable flat antennas ("Phased Array Antenna") ensure alignment without mechanics

Uplink, downlink and crosslink

- Different uplink (ground to satellite) and downlink (satellite to ground) frequencies are used to avoid interferences
- Crosslinks are a direct communication between two satellites without the need of a ground station
- Crosslink communication or Inter Satellite Links (ISL) can take place either via radio waves or lasers

Non Terrestrial Network Architectures III

3GPP NTN Architecture, satellites appearing as Node Bs, directly serving UE



Source: Keysight

- Direct-to-Cell (D2C) service – Example: T-Mobile US+SpaceX „T-Satellite“
- Satellite appears to the UE as a Base Station (Node B) – using MNO spectrum
- Frequent Handovers, as LEO satellites are in constant movement relative to the UE position
- Challenges due to high relative speed between Base Station and UE

Progress and adoption of NTN

Source: New developments and advances in 5G and NTN, a 5G Americas white paper. Feb 2025

Operator	Satellite system (deployed)	Spectrum	Technology	Operational	Services
Dedicated providers					
Space X	2016 LEO (257)	MNO spectrum/ 2GHz MSS	Pre Rel-17 3GPP	2024	Messaging, speech, broadband
AST SpaceMobile	243 LEO (5)	MNO spectrum	Pre Rel-17 3GPP	2024	Messaging, speech, broadband
Lynk	5000 LEO (3)	MNO spectrum	Pre Rel-17 3GPP	2Q2023	Messaging, LDR (low-data rate)
Sateliot	250 LEO (5)	2.0GHz MSS	Rel-17 NB-IoT (NB-NTN)	TBD	NB-IoT
Iridium	66 LEO (66)	L-band	Proprietary	Yes	LDR/Messaging
Orbcomm	31 LEO	137-150 MHz	Proprietary	Yes	Assets tracking
GlobalStar	48 LEO (25)	L/S-band	Proprietary	Yes	Assets tracking
Ligado	1 GEO	L-band	Rel-17 NB-IoT (NB-NTN)	TBD	NB-IoT
Partnerships					
T-Mobile/SpaceX	2016 LEO (257)	MNO spectrum	3GPP-Rel 12	2024	Messaging, Data, Voice, Video
AT&T/AST	243 LEO (5)	MNO spectrum	3GPP-Rel 12	2024	Messaging, Data, Voice, Video
Verizon/Kuiper	3236 (0)	Ka band	Proprietary	TBD	Ground sites backhaul - LTE and 5G
Apple/Globalstar	24 LEO	L-band, S-band	Proprietary	4Q2022	Emergency Messaging
Mediatek/ Skylo/Bullitt	6 GEO (Inmarsat)	L-band	3GPP-NTN	1Q2023	Messaging
Skylo/Ligado/ Viasat/Verizon	1 GEO (Ligado)	L-band	3GPP-NTN	2H2023	NB-IoT, Messaging, LDR
Rogers/SpaceX	2016 LEO (257)	MNO Spectrum	3GPP-Rel 12	2024	Messaging, Data, Voice, Video
Rogers/Lynk	5000 LEO (3)	MNO Spectrum	3GPP-Rel 12	2024	Messaging, Data, Voice, Video

- The Total Addressable Market for telecommunications revenues via wholesale satellite partnerships is expected to exceed **US$28 billion by 2030** (GSMA: Addressable telco revenues via wholesale satellite partnerships.)

- 3/3/25 Industria militar: Hito en el uso de redes satelitales para expandir el 5G en zonas remotas
- Ericsson, Grupo Oesía y UC3M integran 5G y NTN
- https://oneweb.net/

Not comprehensive . Oct 31st, 2024

Satellite Bands

(and usage by Starlink)

Band	Frequency Range (GHz)	Key Characteristics	Typical Applications
L-band	**1–2**	**Reliable, with excellent resistance to atmospheric conditions like rain fade. Requires less pointing accuracy for antennas but has limited bandwidth.**	**Mobile satellite services (e.g., Inmarsat and Iridium), GPS and other global navigation satellite systems (GNSS), and low Earth orbit (LEO) satellite tracking.**
S-band	2–4	Stable and resilient, with good penetration through atmospheric conditions. Used for tracking, telemetry, and control (TT&C).	Space research (e.g., James Webb Space Telescope), weather radar, and mobile satellite communications.
C-band	4–8	Favored for its low susceptibility to rain fade, making it ideal for high-rainfall regions. Requires larger antennas for reception.	Satellite TV broadcasting, enterprise Very Small Aperture Terminal (VSAT) networks, and long-distance telecommunications.
X-band	8–12	Protected and highly stable for mission-critical operations. Less susceptible to atmospheric interference than higher-frequency bands.	Military satellite communications (MILSATCOM), radar imaging, and government applications.
Ku-band	**12–18**	**Supports high-capacity services with smaller antennas than C-band, but is more susceptible to signal degradation from rain fade.**	**Direct-to-home (DTH) satellite TV, in-flight connectivity, and commercial VSAT services.**
K-band	18–26	A portion of this band (around 22 GHz) is heavily attenuated by water vapor, limiting its use for long-distance satellite links.	Short-range links for data transfer and specific radar applications. The atmospheric absorption makes parts of this band unsuitable for long-range communication.
Ka-band	**26–40**	**Enables very high-speed data transmission but is highly sensitive to rain fade. Provides massive bandwidth capacity. Atmospheric attenuation, massive capacity**	**High-throughput satellite (HTS) internet, satellite-based 5G backhaul, and high-resolution applications.**
E-Band	**71-86**		

L-Band:
D2C Service

Ku/Ka Band:
Satellite to User Terminals

E-Band:
Gateway to Satellite

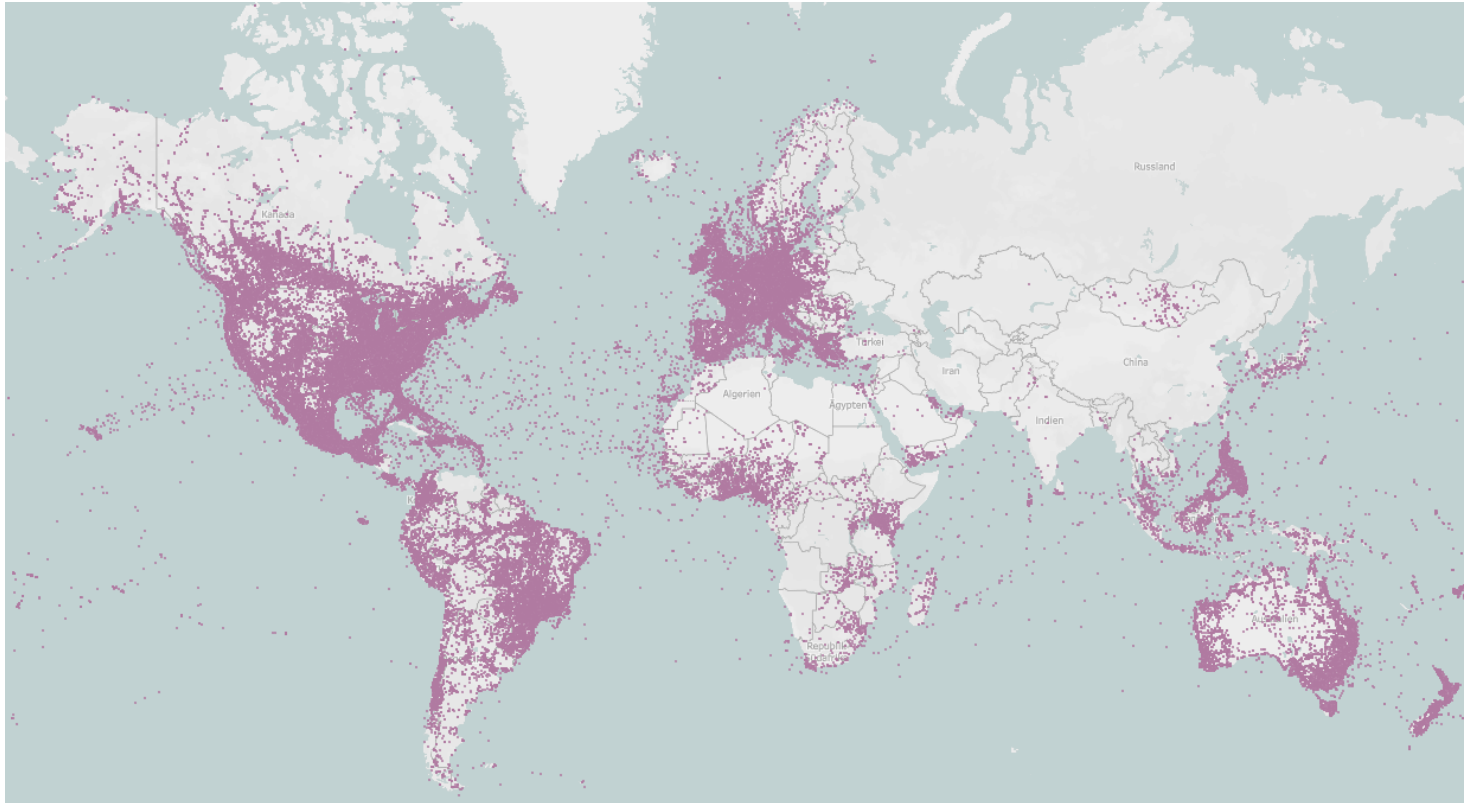
PETER DRUCKER

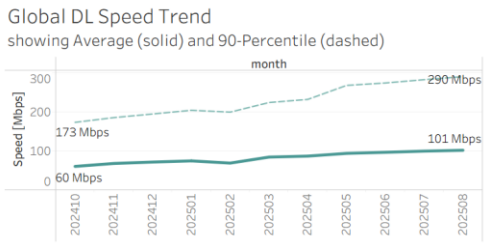
(1909-2005)

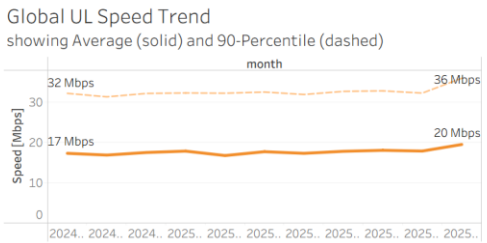
“What gets measured gets improved”<

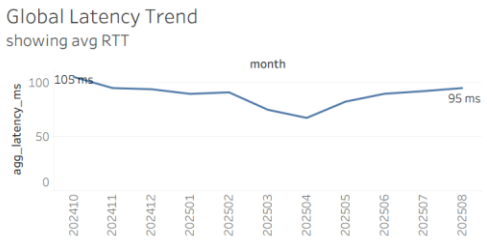
The trick is to measure the right things, with the right set of data, and make the proper investment decisions .

Global Data Availability and Trends from Crowd Sourcing - Example: SpaceX „Starlink“









Based on 1y of umlaut crowdsourcing data

collected >1M samples from Smartphones UEs which connect to the internet via any WiFi that has a Starlink Backhaul - residential, vehicular, airborne, offshore, etc.

Dots indicate availability of DL/UL Speedtest information.

usage not just found in sparsely populated areas (sampled areas account for ~500M).

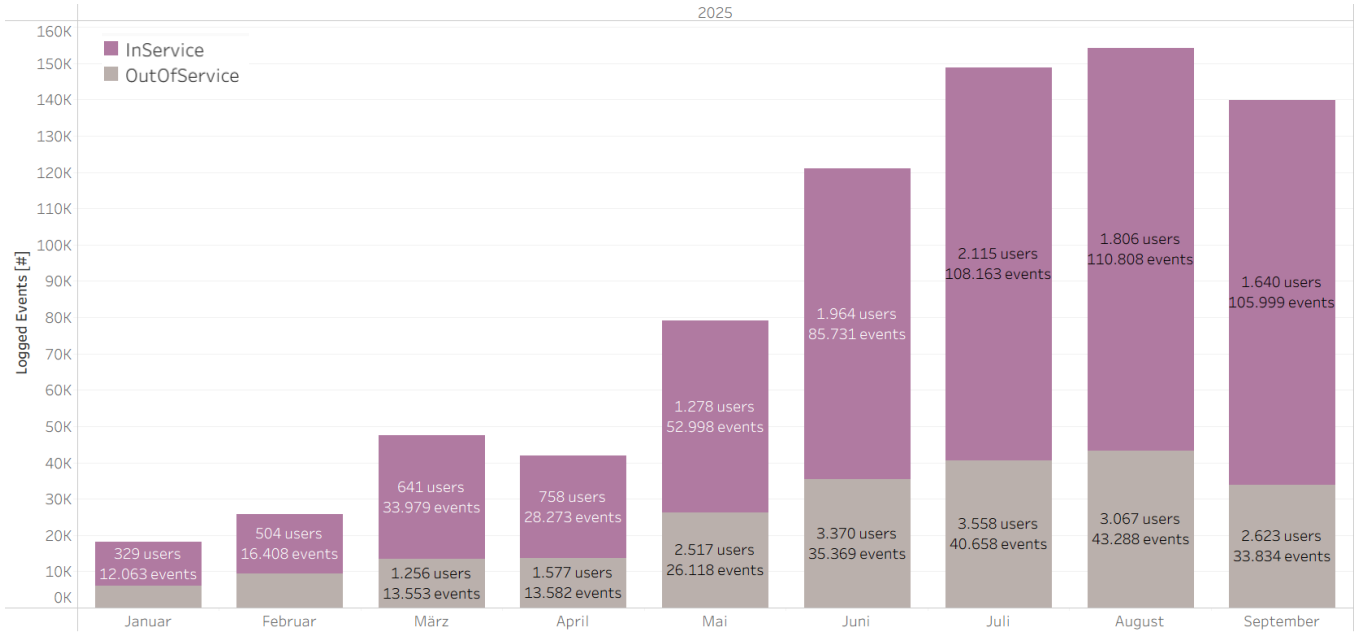
1% share of samples collected offshore

<1% connectivity share among fixed line ISPs in US and DE and 2-3% in NZ and AU

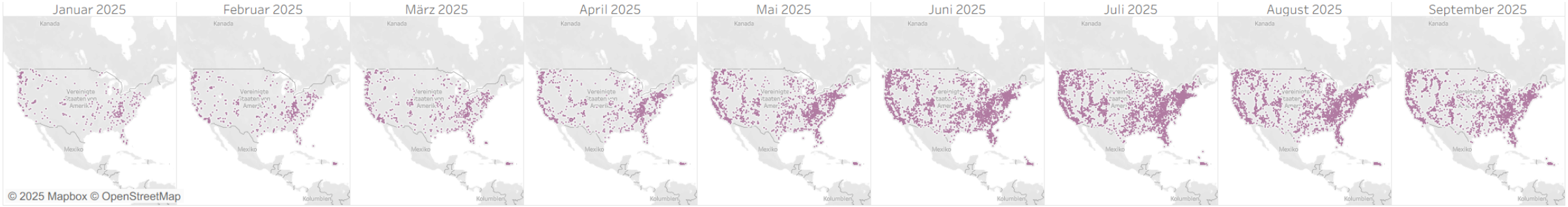
Direct-2-Cellular (D2C) service

Example: „T-Satellite“ usage in US

- T-Satellite is a cooperation between T-Mobile US & SpaceX
- Satellites act as 3GPP eNB, using 1900Mhz band
- Selected devices can connect/roam on MCC/MNC=310/830
- Supported by premium plans or for a markup fee
- Service officially launched July 2025 after Beta Phase
- Currently supporting selected messaging and mapping services
- Barchart (right) shows number of users and connection events logged per month in umlaut crowd data.



- Charts (below) show locations where T-Mobile crowd users were „In Service“ on the T-Satellite network.



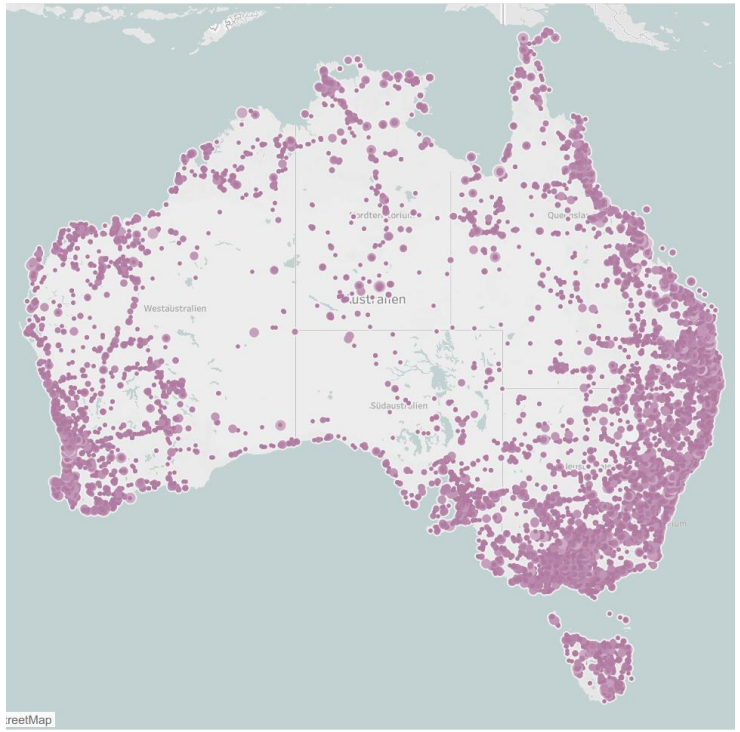
Selected Market Data

KPI results taken CW15-CW38 of 2025

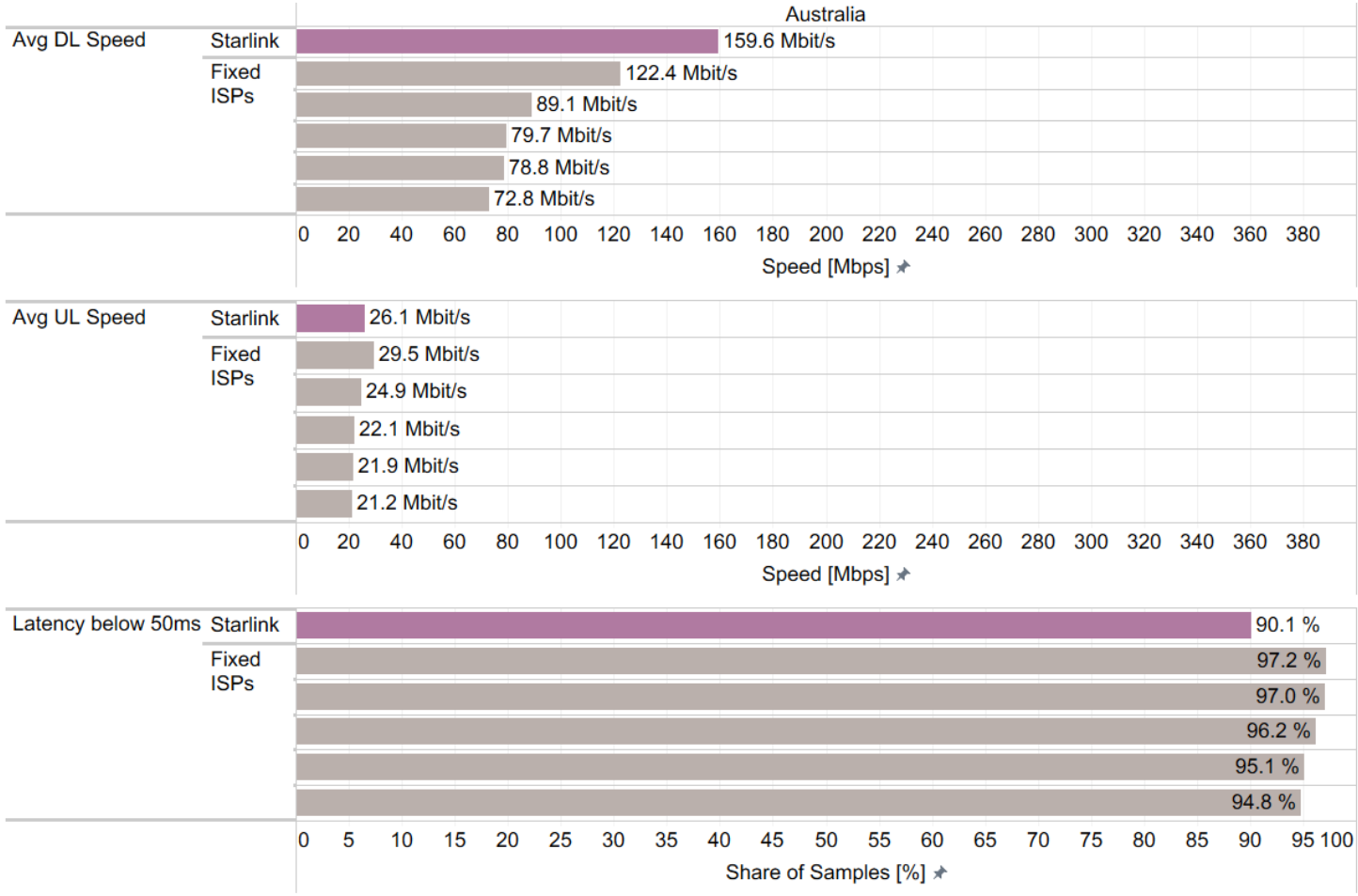
Australia Dashboard

Starlink WiFi vs. Fixed ISPs, selected KPIs

Starlink
DL/UL Speed Test Sample locations



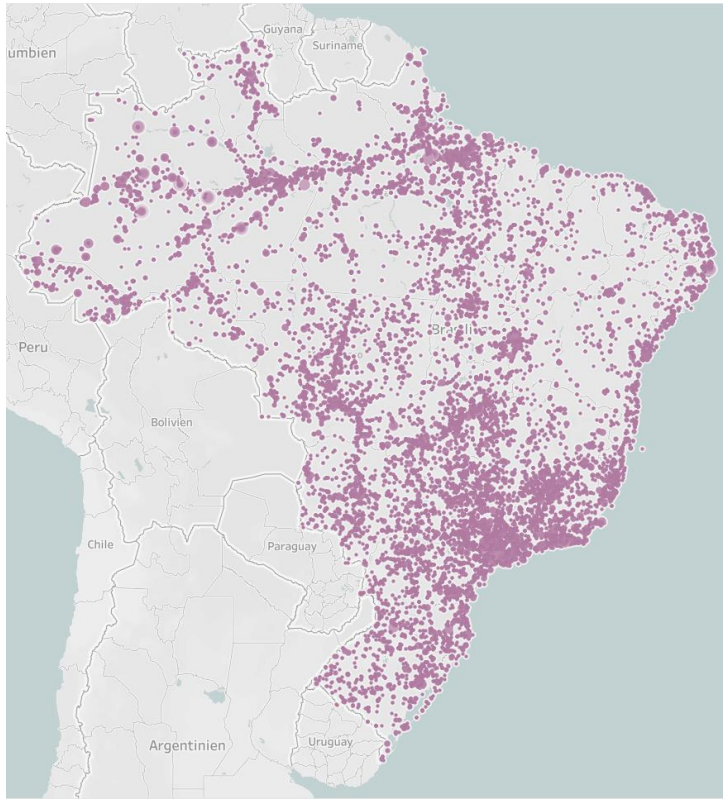
Selected KPs
compared to National Fixed Line ISPs



Brazil Dashboard

Starlink WiFi vs. Fixed ISPs, selected KPIs

Starlink
DL/UL Speed Test Sample locations



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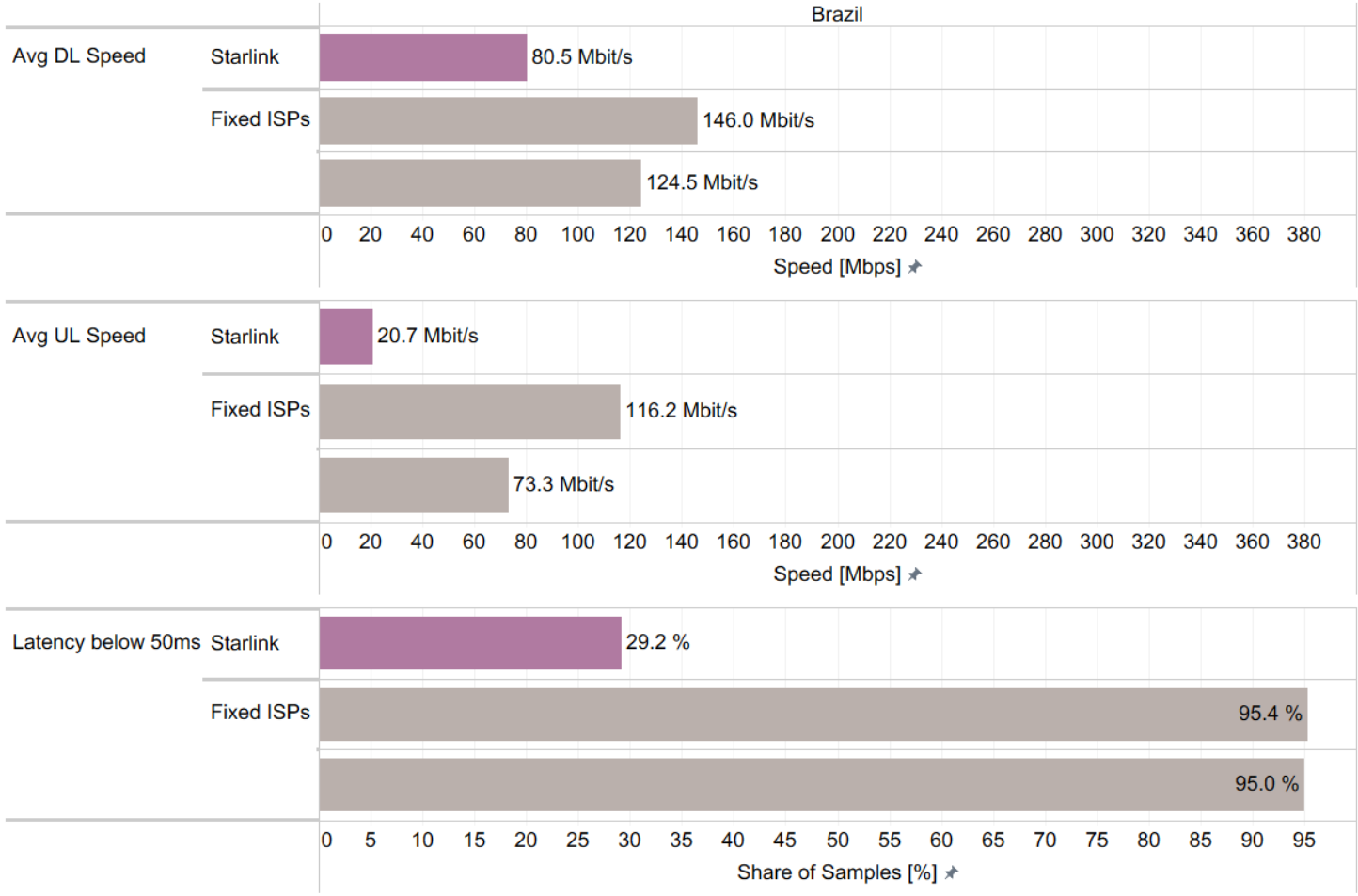
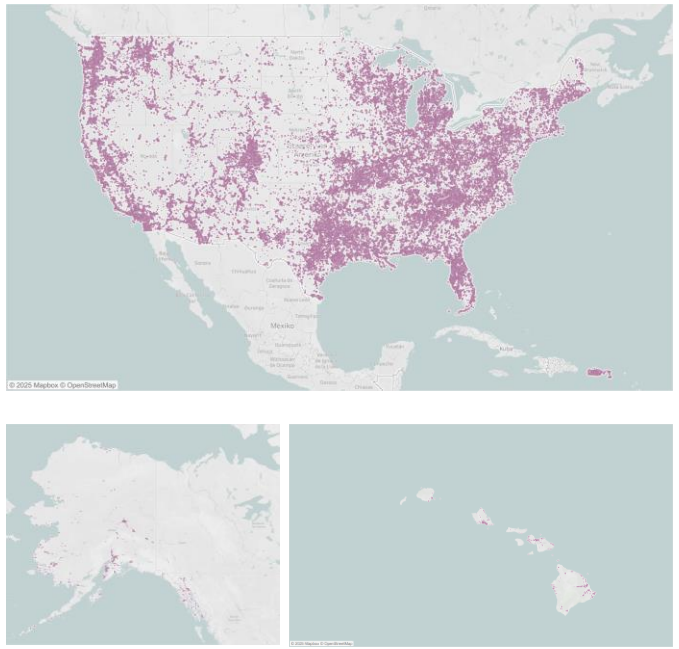


USA Dashboard

Starlink WiFi vs. Fixed ISPs, selected KPIs

Starlink
DL/UL Speed Test Sample locations



Selected KPs
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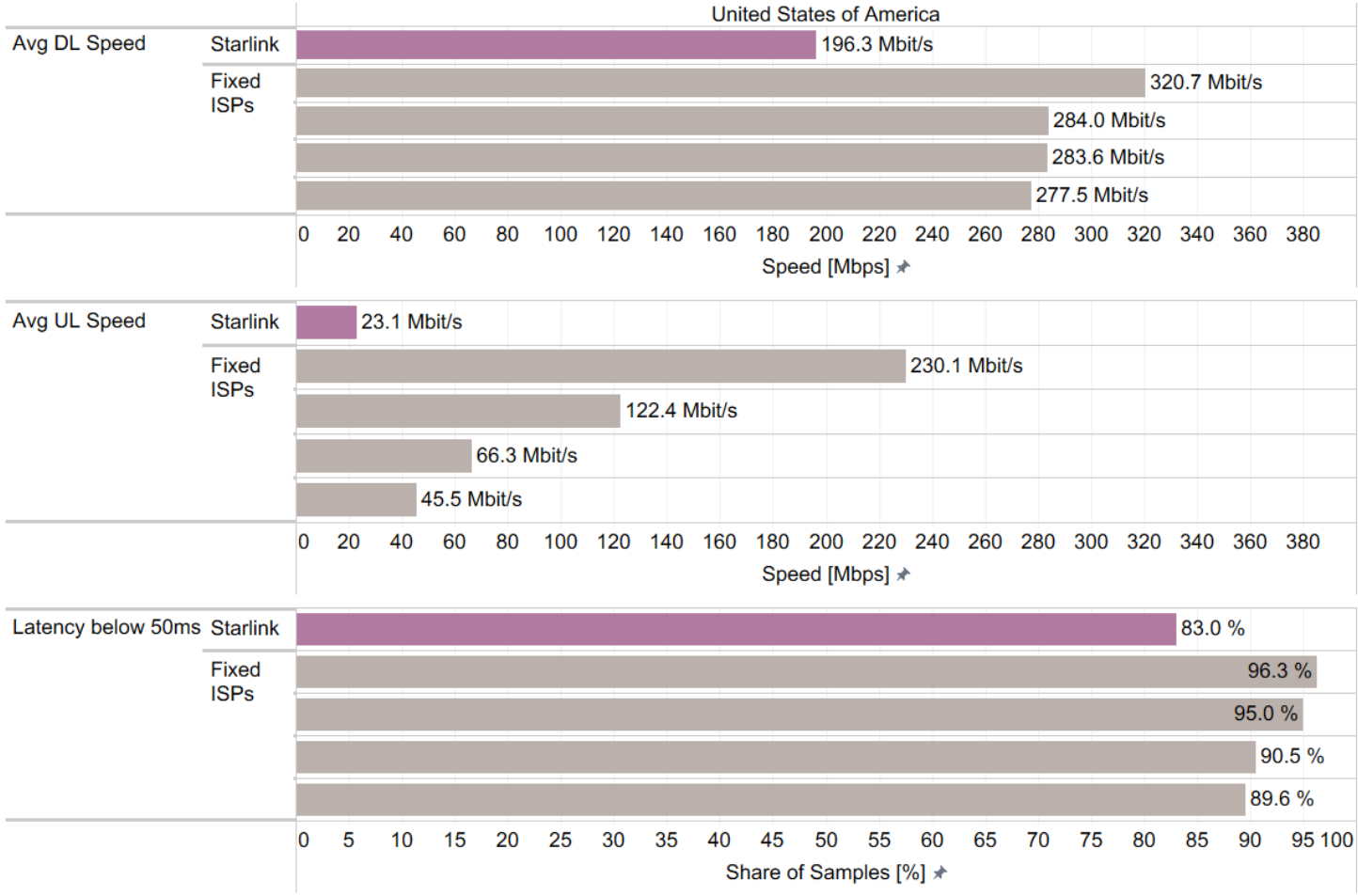
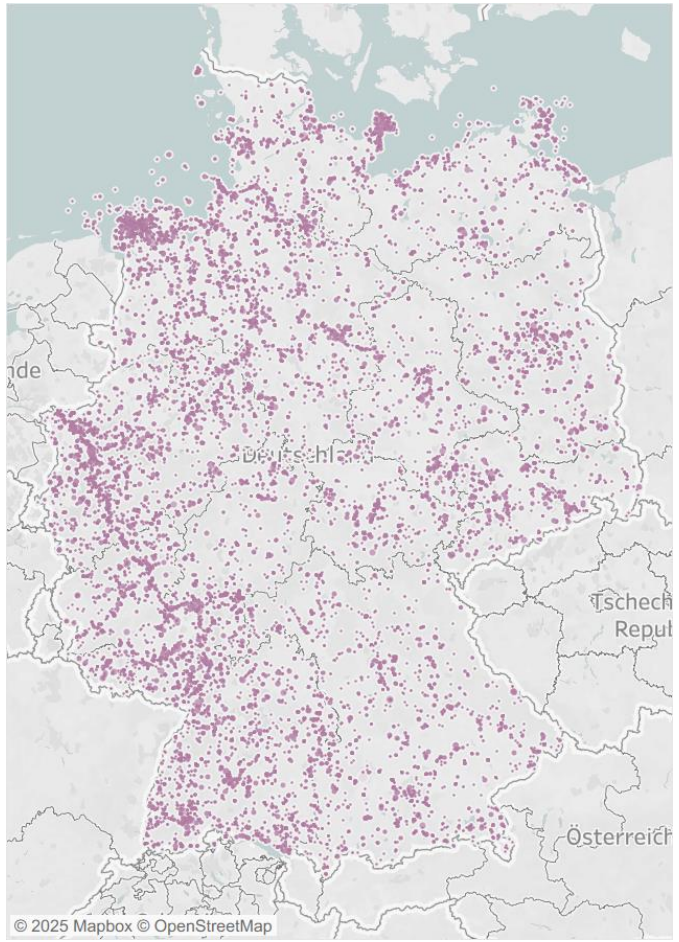


Germany Dashboard

Starlink WiFi vs. Fixed ISPs, selected KPIs

Starlink
DL/UL Speed Test Sample locations



Selected KPs
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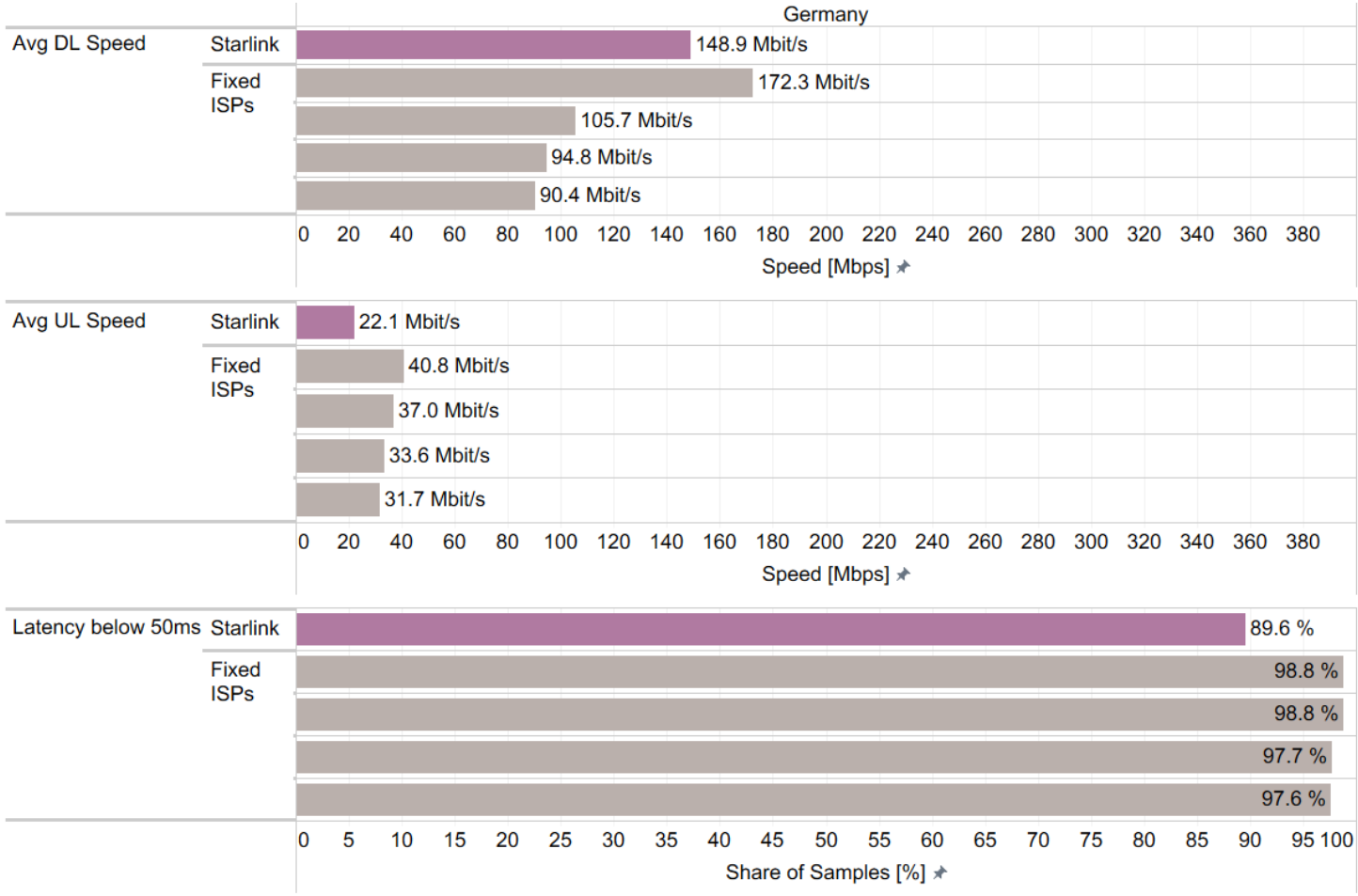
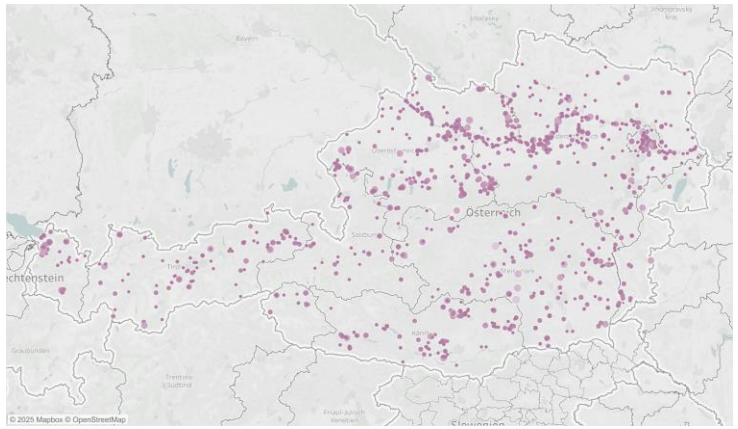


Austria Dashboard

Starlink WiFi vs. Fixed ISPs, selected KPIs

Starlink
DL/UL Speed Test Sample locations



Selected KPs
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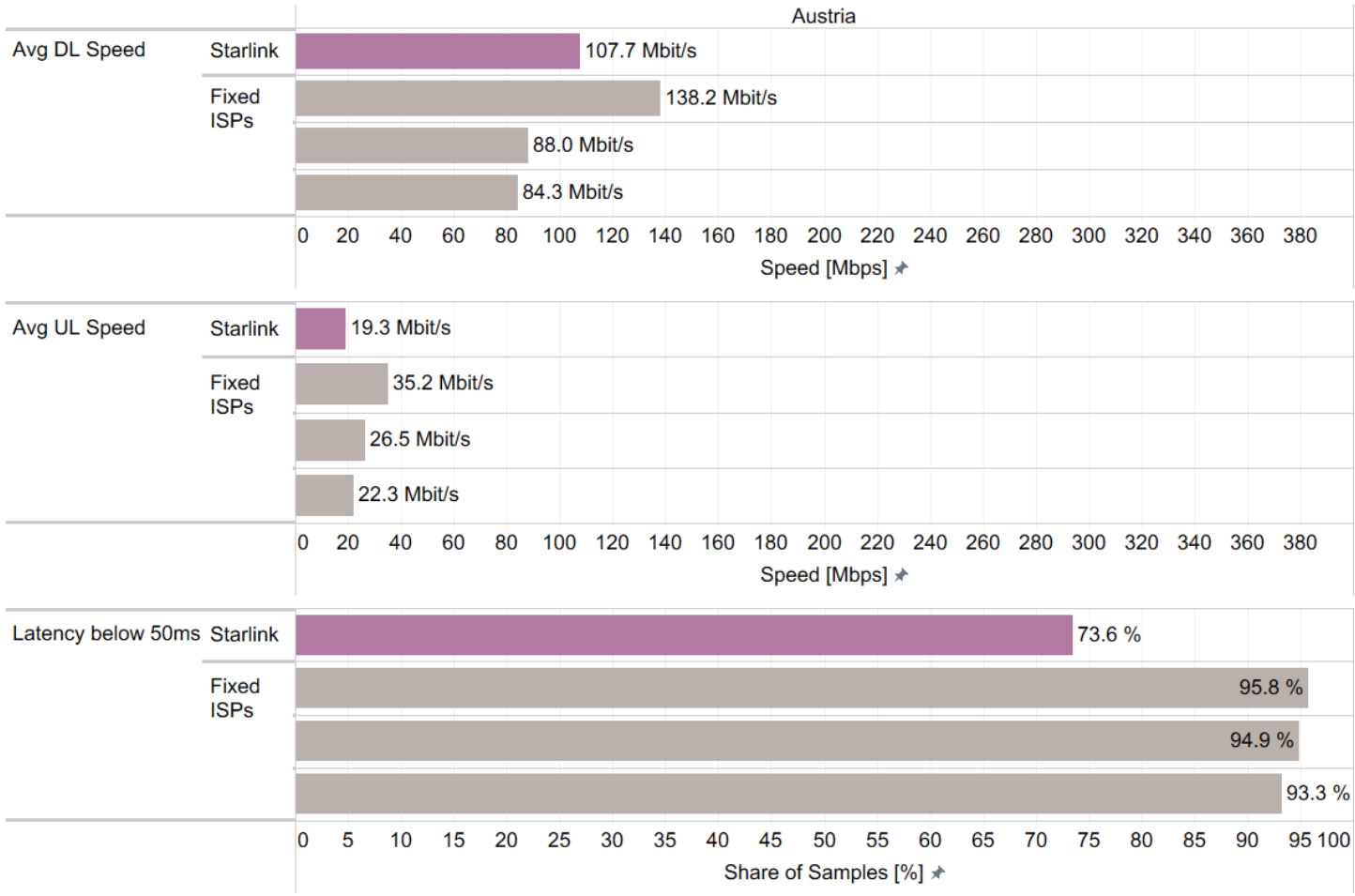
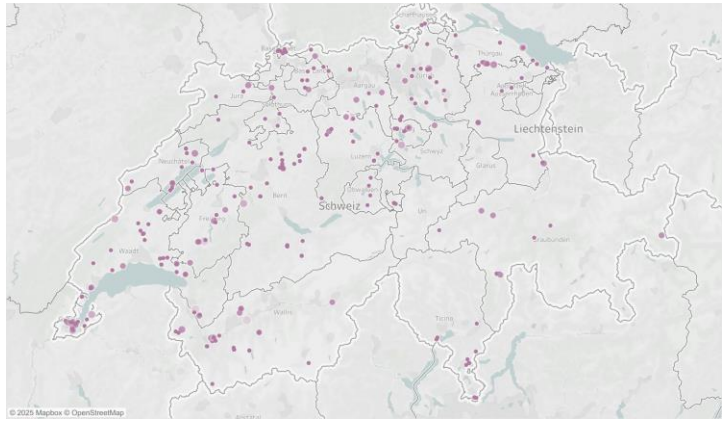


Switzerland Dashboard

Starlink WiFi vs. Fixed ISPs, selected KPIs

Starlink
DL/UL Speed Test Sample locations



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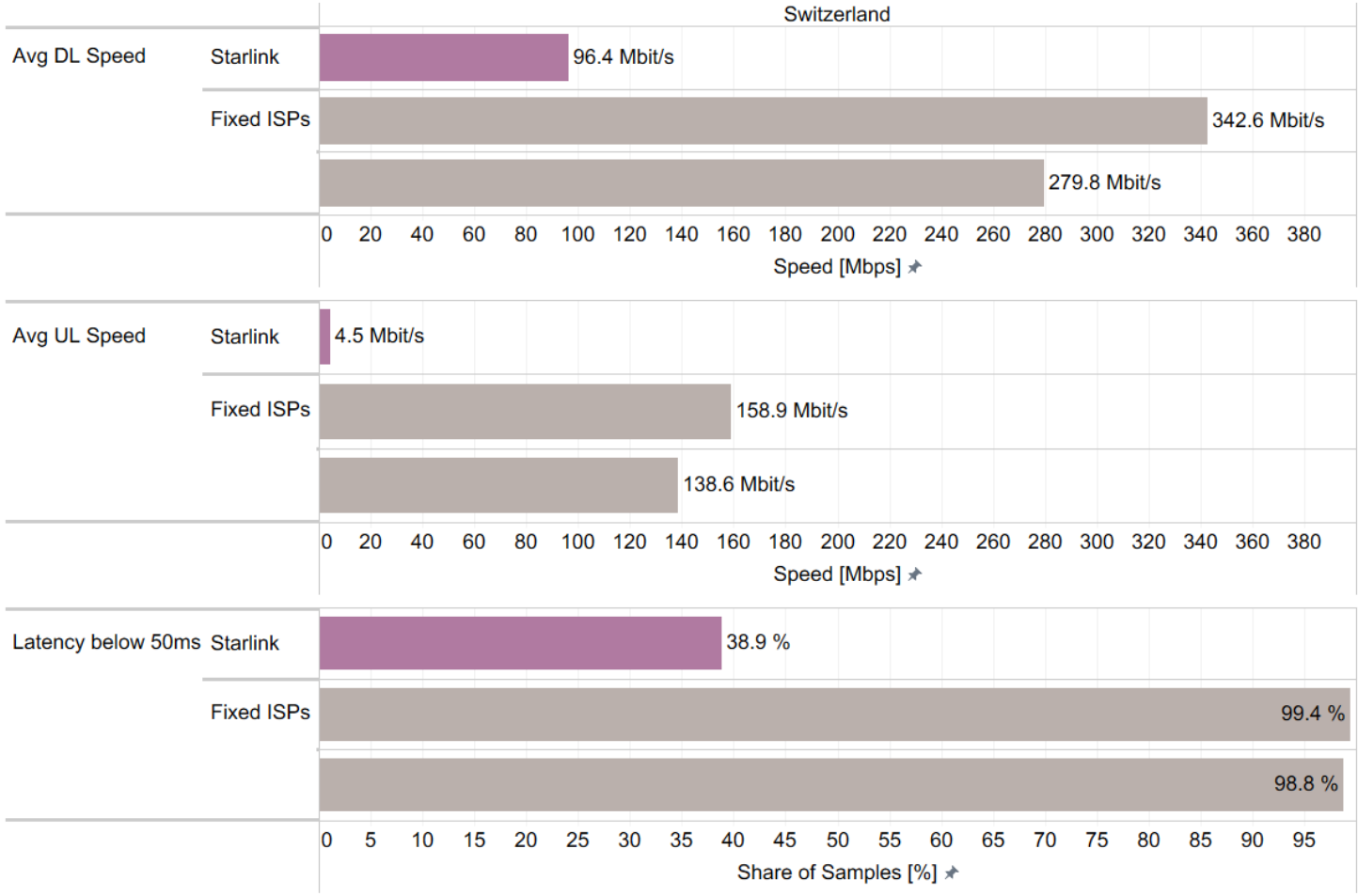

Thank You