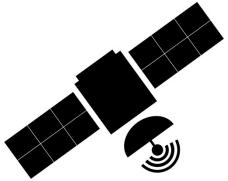
Computer Networks and Communication Systems

Friedrich-Alexander-Universität Erlangen-Nürnberg

Würzburg Workshop on Next-Generation Communication Networks

Next-Generation Satellite Communication Networks



Jörg Deutschmann, Kai-Steffen Hielscher, Reinhard German

joerg.deutschmann@fau.de

2022-07-12

Supported by:

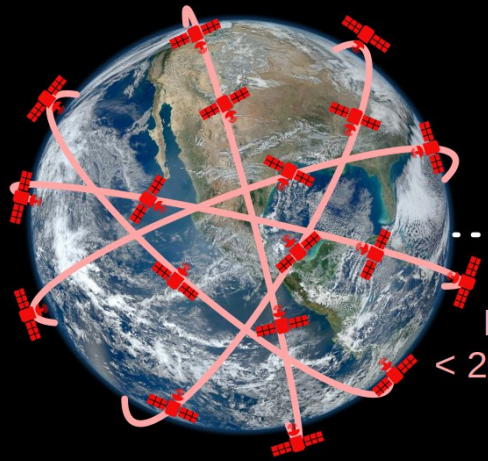
Federal Ministry for Economic Affairs and Climate Action

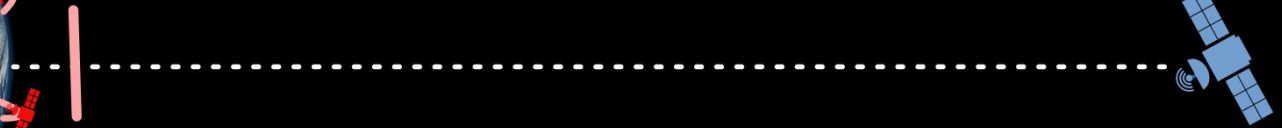
on the basis of a decision by the German Bundestag

Outline

- Satellite communication basics
  - Satellite orbits
  - Geostationary (GEO) satellites
  - Low Earth orbit (LEO) megaconstellations (e.g., Starlink)
- Performance measurements
  - Measurement setup
  - GEO
  - GEO vs. LEO
- Satellite / terrestrial multipath communication
- Summary and outlook

Satellite orbits





LEO
< 2000 km

MEO
2000 – 35786 km

GEO
35786 km

Geostationary satellite Internet access

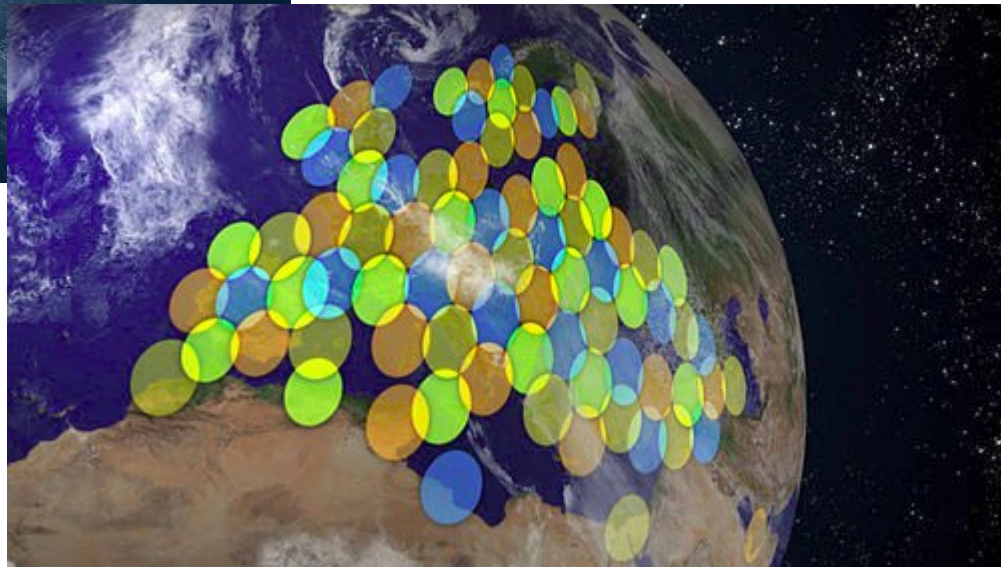
https://www.eutelsat.com/en/satellites/future-launches.html

Forward link Mbit/s	Return link Mbit/s	RTTs ms	Costs per month
100	5	≳ 600	~70 €
50			~45 €
30			~30 €

https://europe.konnect.com

Satellite e.g., Eutelsat	Total capacity
KA-SAT (2011)	~80 Gbit/s
Konnect VHTS (2023)	~500 Gbit/s

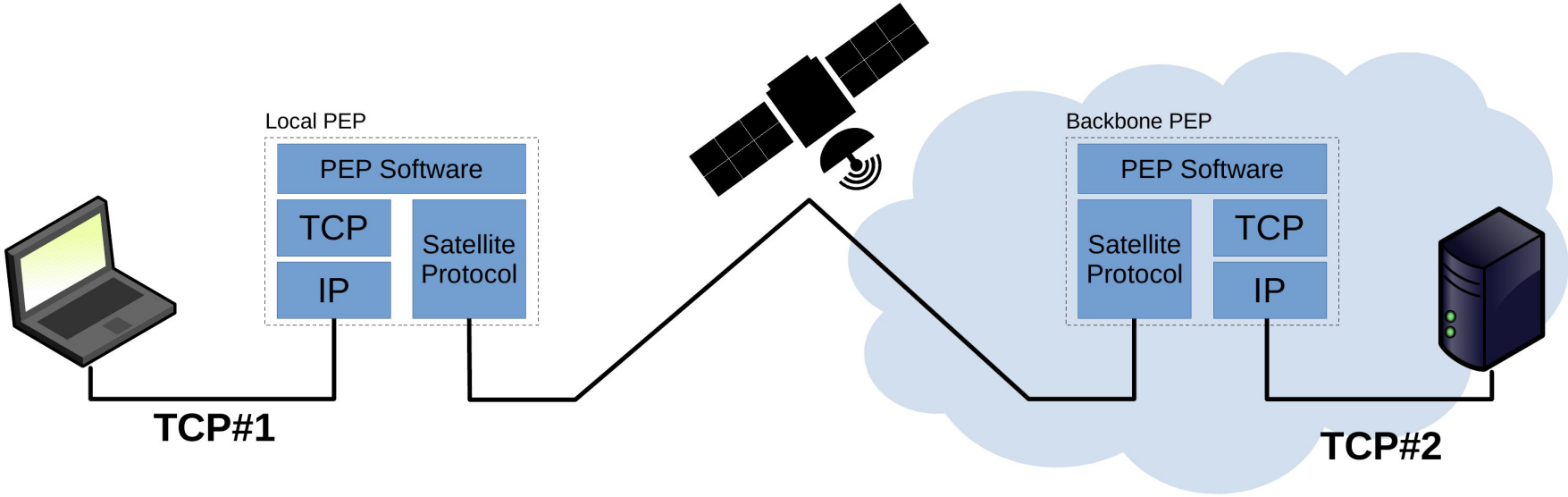
https://en.wikipedia.org/wiki/Tooway



https://en.wikipedia.org/wiki/KA-SAT

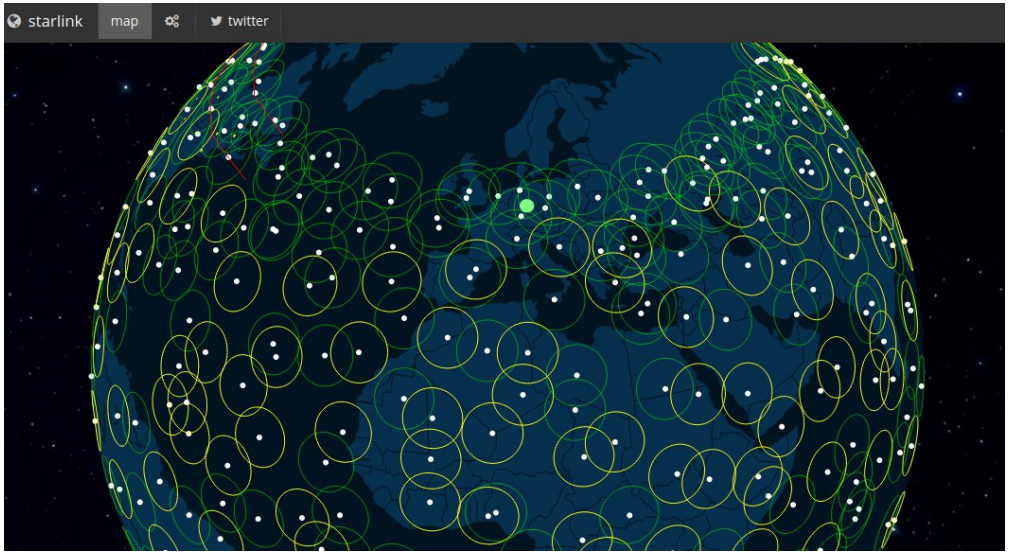
Geostationary satellite Internet access

- Default TCP parameters not very suitable for high latency links
  - Deployment of Performance Enhancing Proxies (PEPs) – RFC 3135

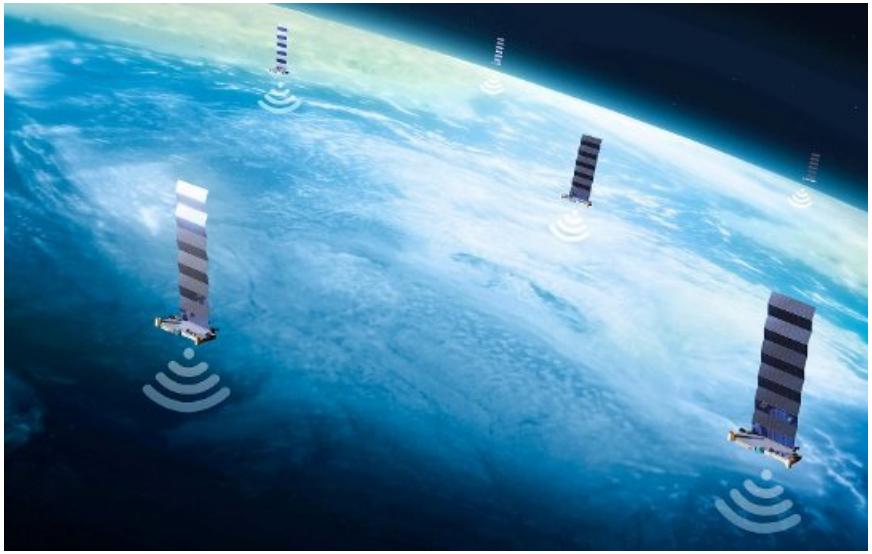


  - Not possible if TCP headers are encrypted (e.g., VPNs or QUIC)

Low Earth orbit (LEO) satellite megaconstellations



https://satellitemap.space



Science Photo Library/imago images

Capacity per satellite e.g., Starlink
~10 Gbit/s

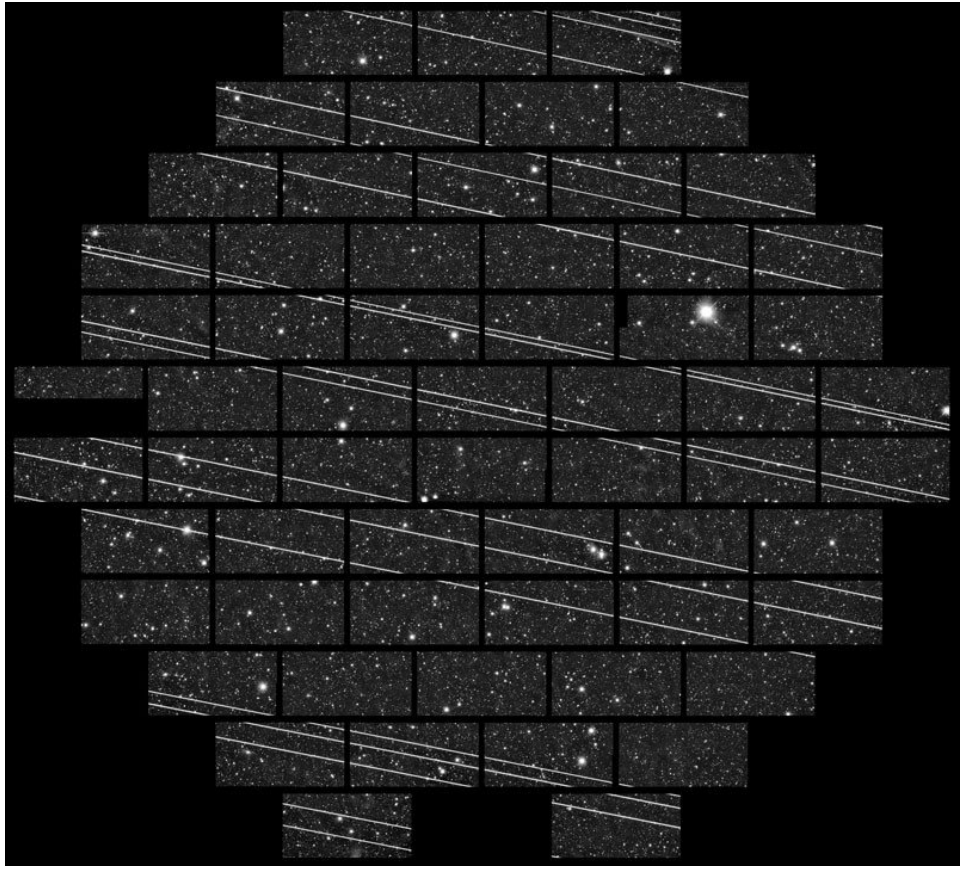
Erc X @ErcXspace via Twitter

Forward link Mbit/s	Return link Mbit/s	RTTs ms	Costs per month
0 - 400	0 - 75	~45	~100 €

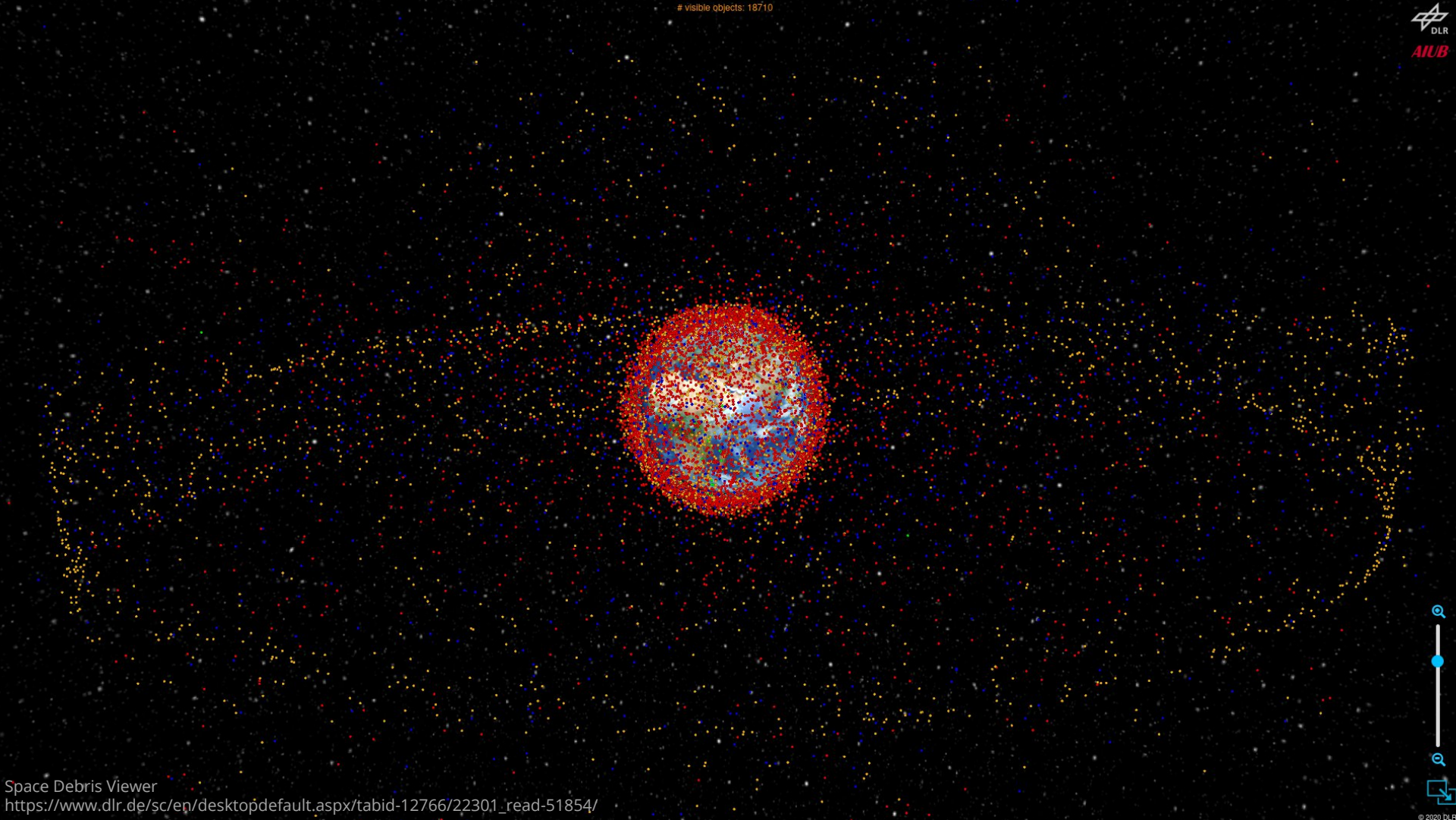
Low Earth orbit (LEO) satellite megaconstellations

- Problematic for observational astronomy

- Risk of space debris
  - Cf. Kessler syndrome
  - (Non-active) deorbiting depends on altitude:
    - 500 km: less than 25 years
    - 1200 km: ~2000 years



CTIO/NOIRLab/NSF/AURA/DECam DELVE Survey (CC BY 4.0)
https://www.nature.com/articles/d41586-020-02480-5

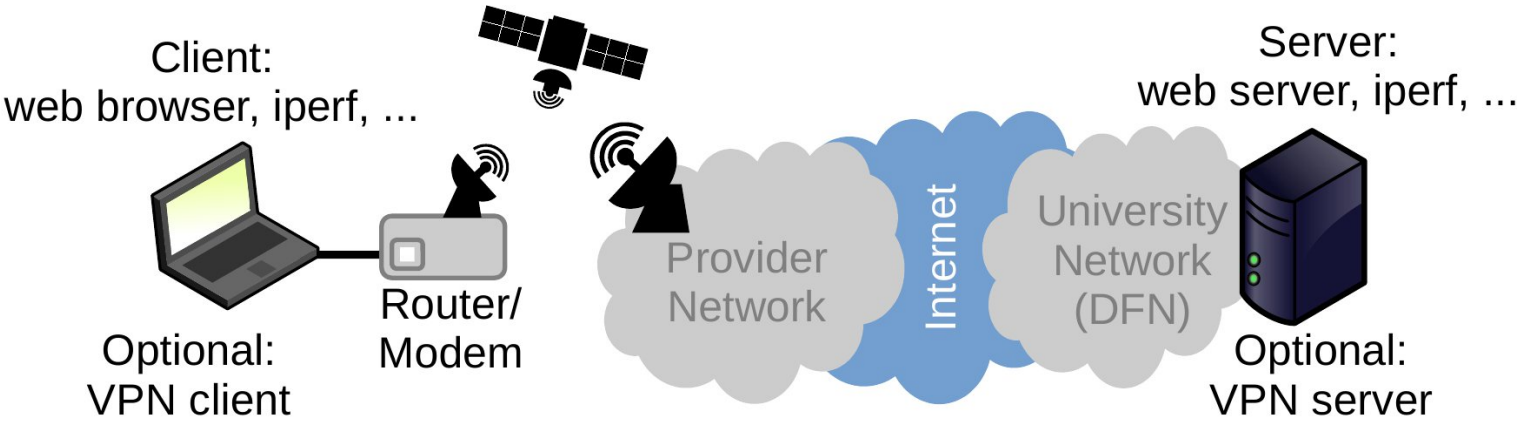

visible objects: 18710
DLR
AIUB
Space Debris Viewer
https://www.dlr.de/sc/en/desktopdefault.aspx/tabid-12766/22301_read-51854/

Outline

- Satellite communication basics
  - Satellite orbits
  - Geostationary (GEO) satellites
  - Low Earth orbit (LEO) megaconstellations (e.g., Starlink)
- Performance measurements
  - Measurement setup
  - GEO
  - GEO vs. LEO
- Satellite / terrestrial multipath communication
- Summary and outlook

Measurement setup

- Emulated and real satellite links
- Measurement setup used throughout following slides
  - Satellite dishes mounted at FAU campus – single vantage point

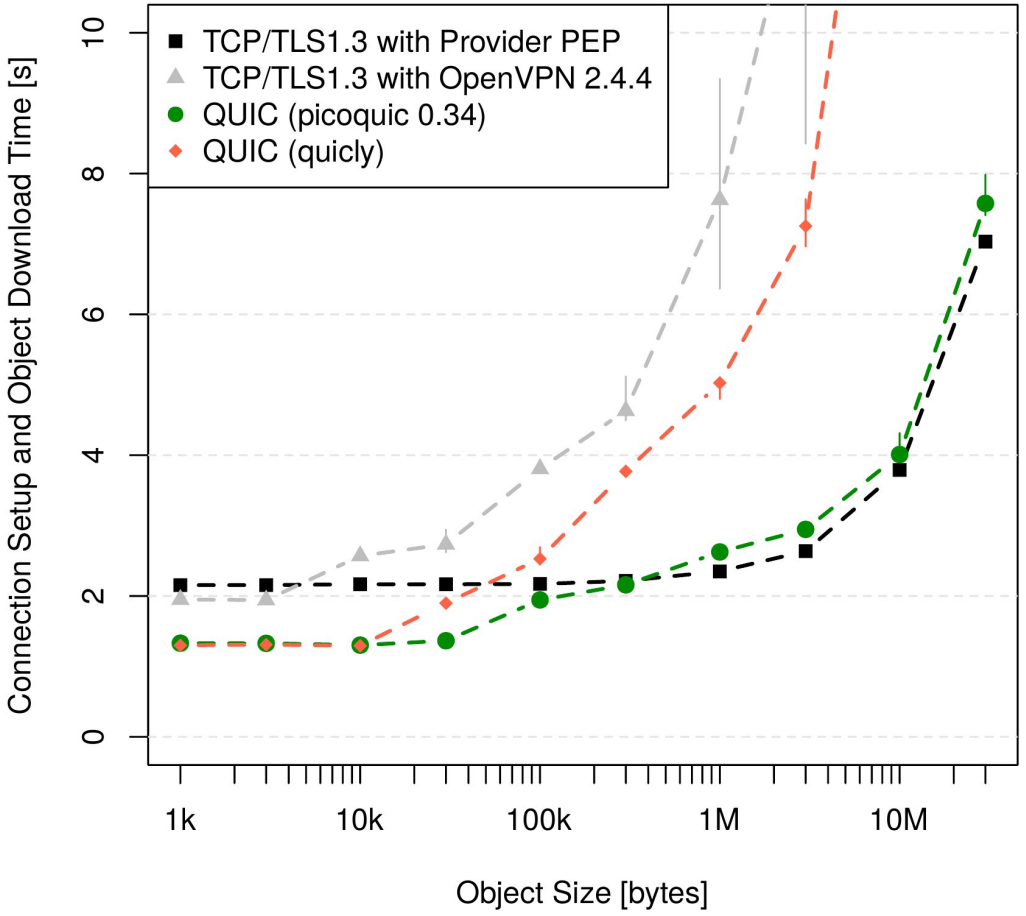


GEO performance measurements [2]

- Connection setup and object download time for varying object sizes

Setup	PEPs applicable?
TCP without VPN	✔
TCP with VPN	✘
QUIC	✘

- VPNs are problematic
- QUIC is both a problem and a chance

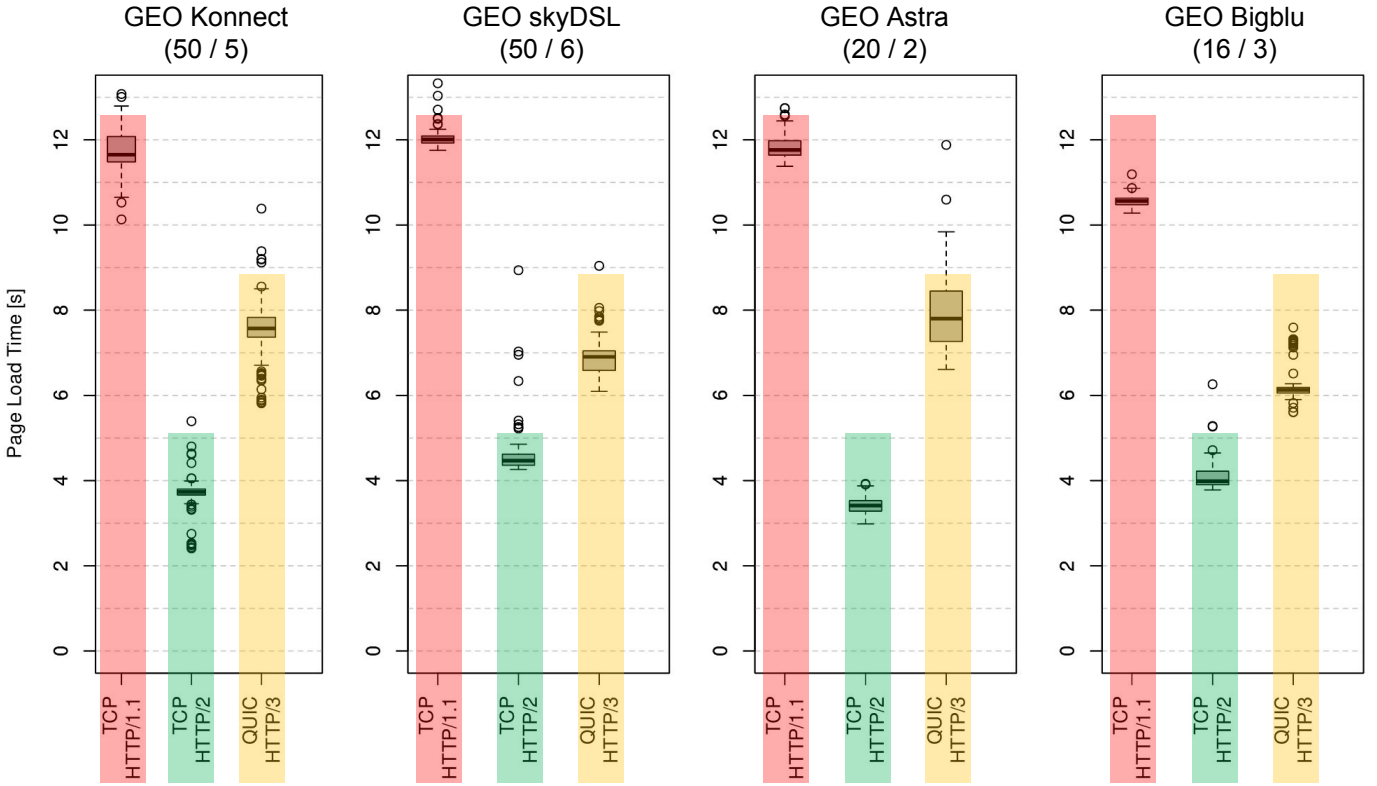


GEO performance measurements – HTTP versions [3]

- Comparison of different HTTP versions
- Four different geostationary satellite providers
- Simplified artificial website 
  - 70 objects * 30 kbyte = 2.1 Mbyte
    (assumptions based on httparchive.org statistics)
- Client: Google Chrome 94, automated with Selenium ChromeDriver
- Server: OpenLiteSpeed 1.7.4 with QUIC (IETF v1) and HTTP/3 (draft)
- Optional: Wireguard to disable PEPs

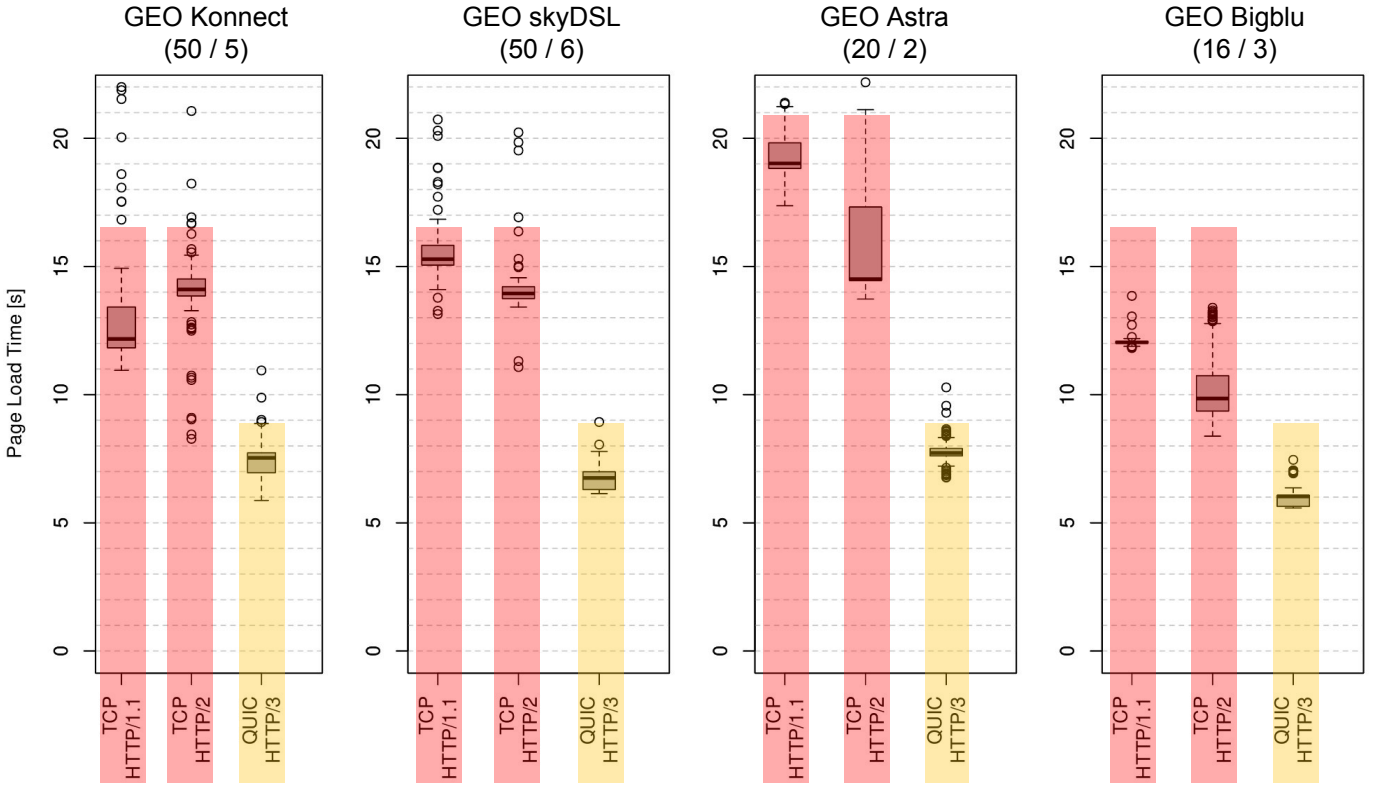
GEO performance measurements – HTTP versions [3]

- Without VPN
  = PEPs enabled
  - TCP / HTTP/1.1
    poor
  - TCP / HTTP/2
    good
- PEPs not
  applicable
  - QUIC / HTTP/3
    mediocre



GEO performance measurements – HTTP versions [3]

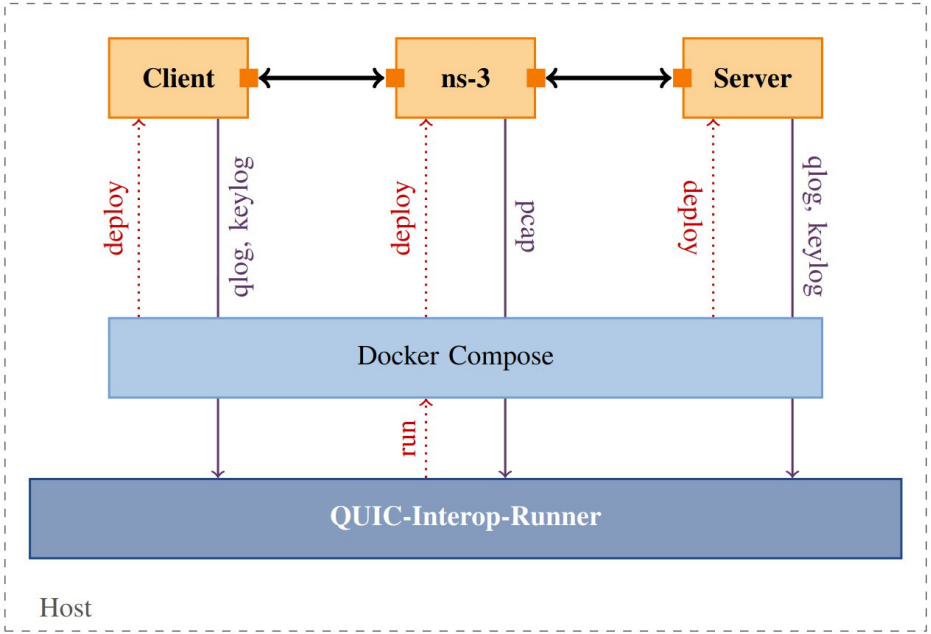
- With VPN
  = PEPs disabled
  - TCP / HTTP/1.1 poor
  - TCP / HTTP/2 poor
- PEPs not applicable
  - QUIC / HTTP/3 mediocre



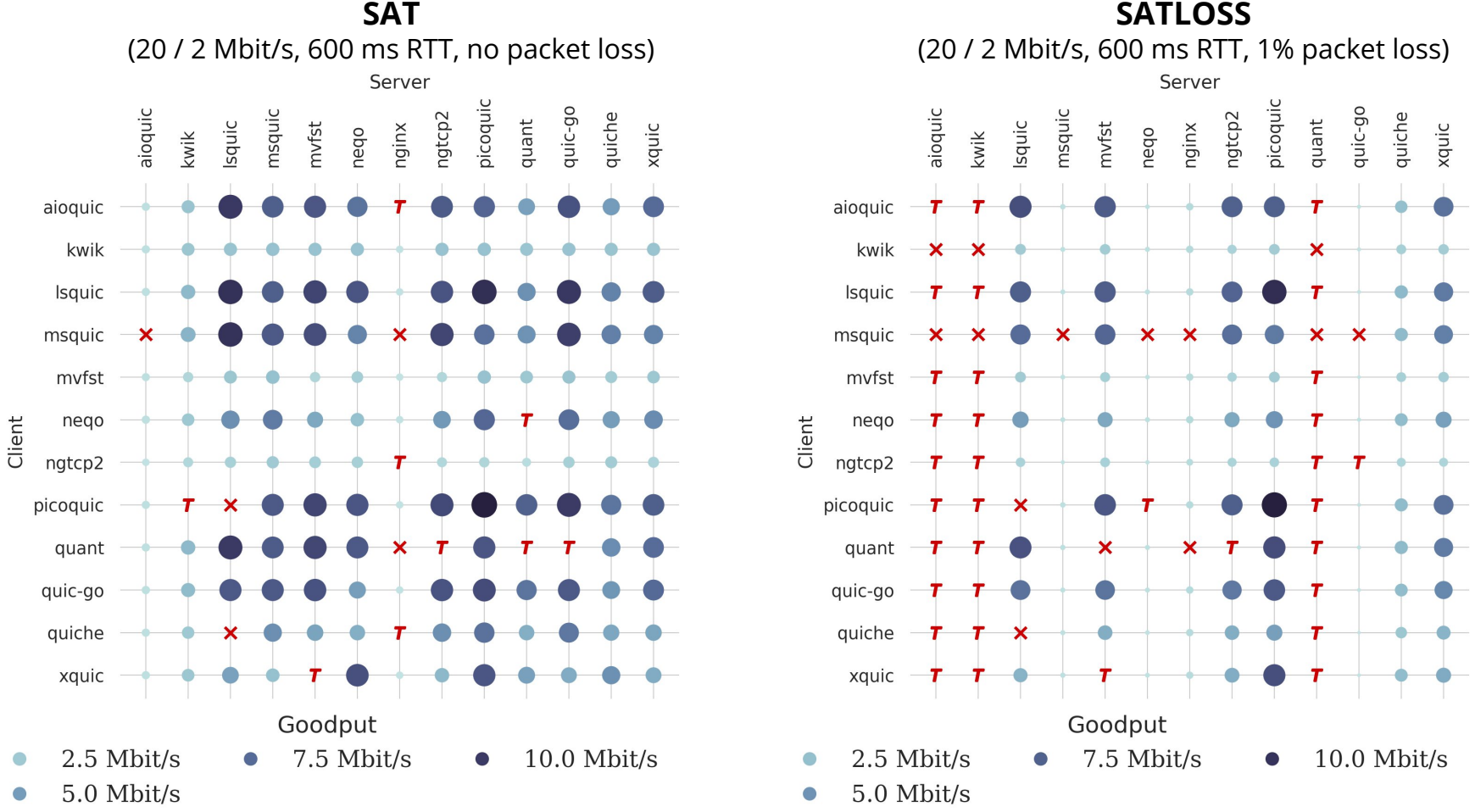
GEO performance measurements – QUIC [4]

- Testing of QUIC Implementations with GEO satellite links using the QUIC Interop Runner – https://interop.cs7.tf.fau.de
- Presented at IETF113 maprg
- 10 Mbyte file download
- Emulated satellite links

Name	RTT ms	Link Rate Mbit/s	PLR %
TERR.	30	20 / 2	0
SAT	600	20 / 2	0
SATLOSS	600	20 / 2	1



GEO performance measurements – QUIC [4]



Outline

- Satellite communication basics
  - Satellite orbits
  - Geostationary (GEO) satellites
  - Low Earth orbit (LEO) megaconstellations (e.g., Starlink)
- Performance measurements
  - Measurement setup
  - GEO
  - GEO vs. LEO
- Satellite / terrestrial multipath communication
- Summary and outlook

Performance measurements GEO vs. LEO/LTE/DSL [5]

- Measurement campaign
  - Many metrics and applications
    - Latency, bulk data, packet loss
    - Samba file sharing, web browsing, video streaming, VoIP
  - Many providers
    - 4x geostationary satellite
    - Starlink
    - DSL, LTE

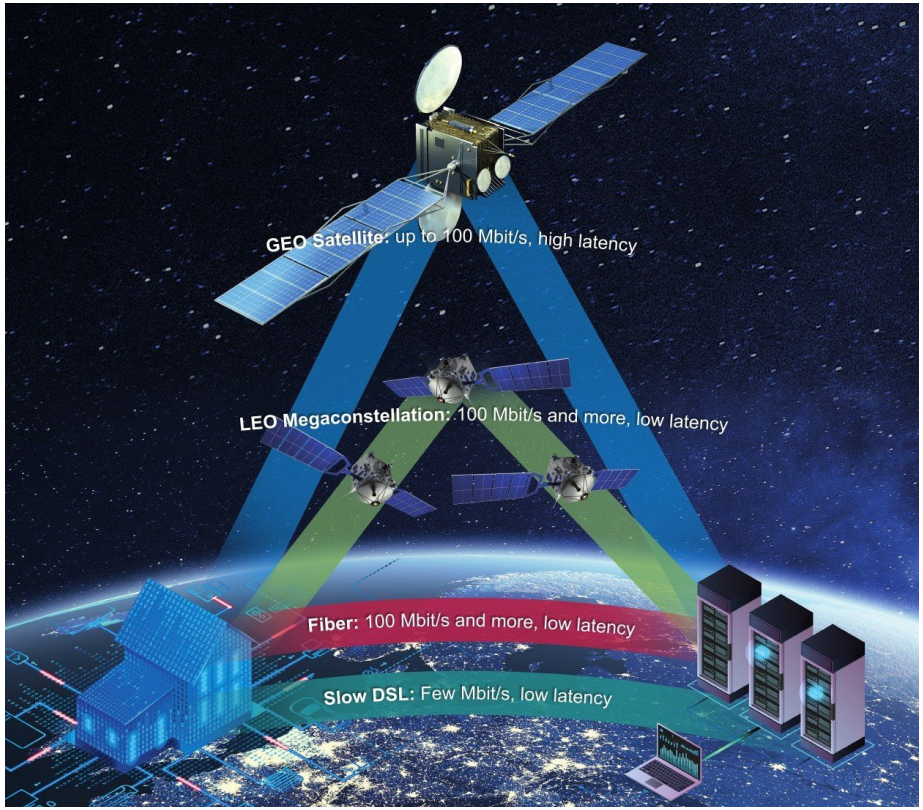
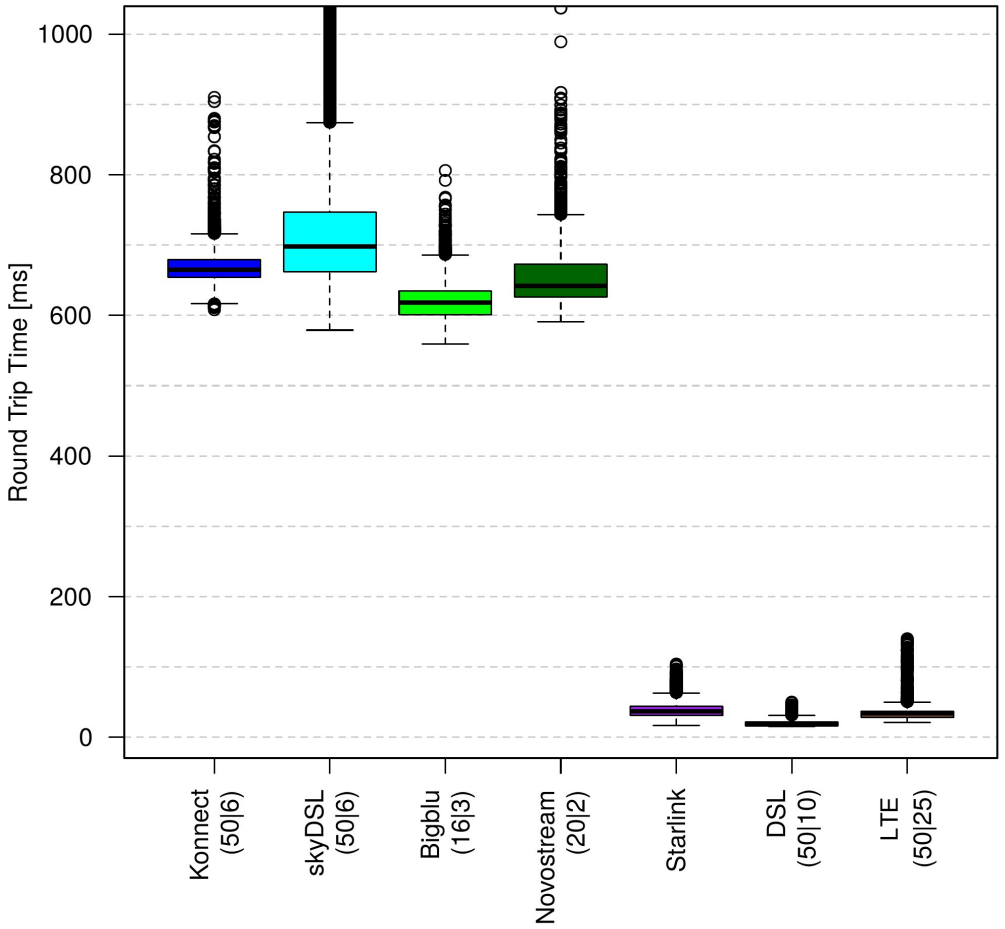


Image Copyright: Deutsches Zentrum für Luft- und Raumfahrt

See also European Electronic Communications Code - *Universaldienst*
https://www.bundesnetzagentur.de/DE/Fachthemen/Telekommunikation/Grundversorgung/start.html

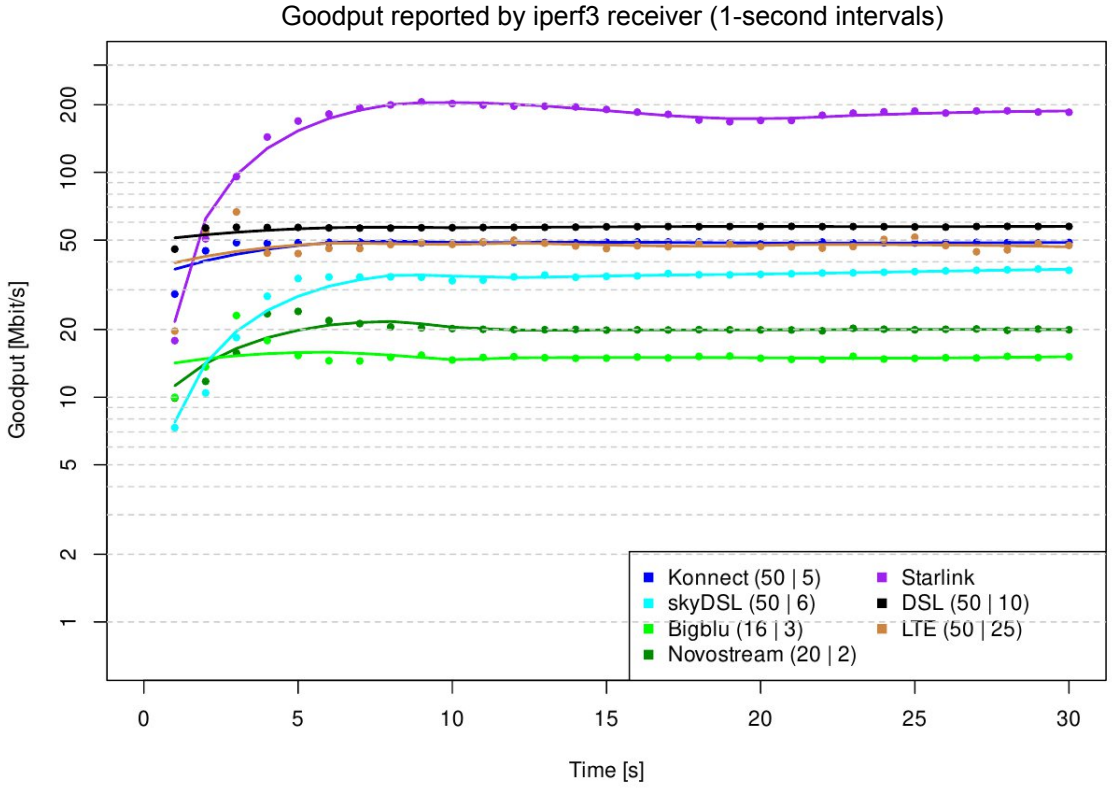
Performance measurements GEO vs. LEO/LTE/DSL [5]

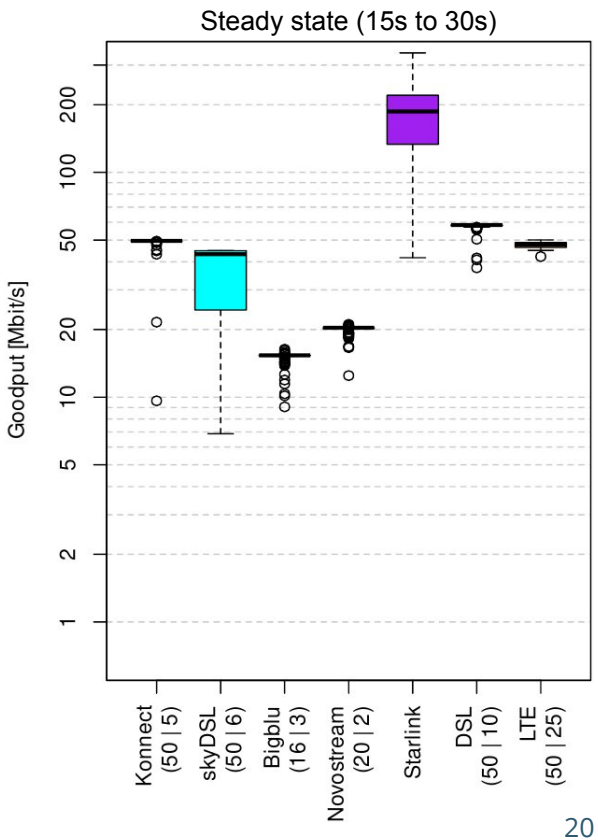
- Round trip times (UDP packets with different sizes and inter-departure times)
- GEO: high latency and jitter
- Starlink comparable with terrestrial Internet access links



Performance measurements GEO vs. LEO/LTE/DSL [5]

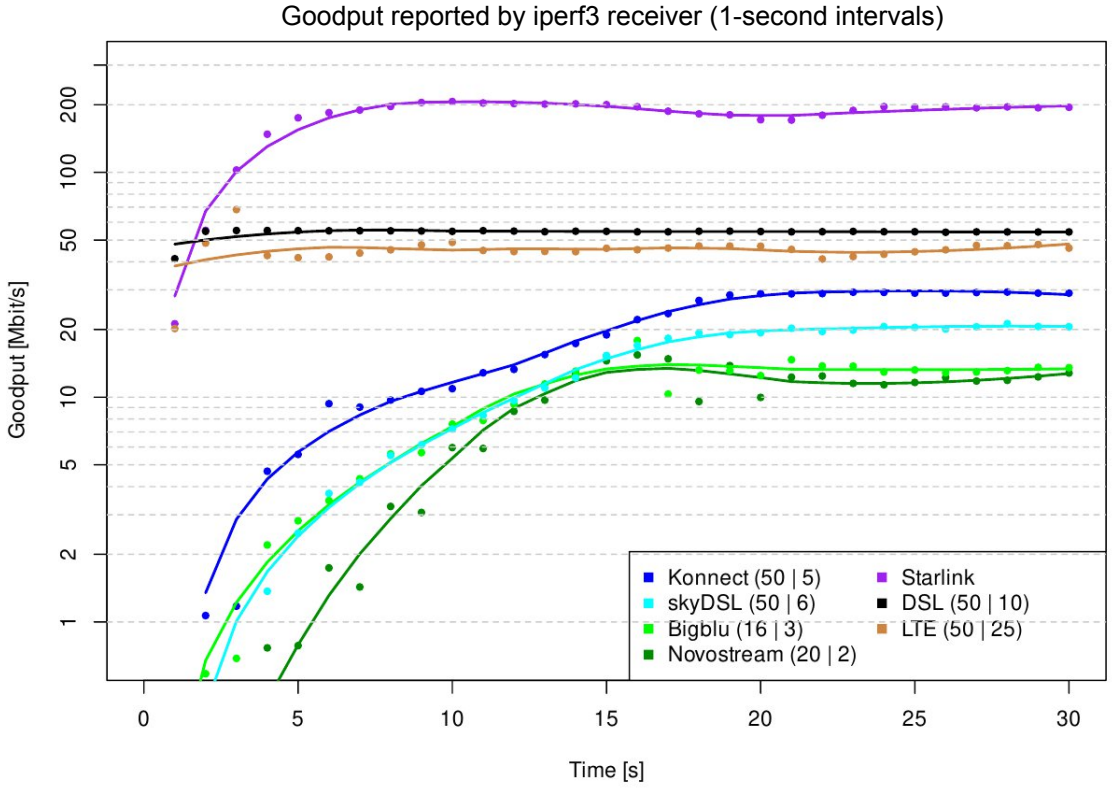
- Bulk data transfer download (single flow, without VPN)

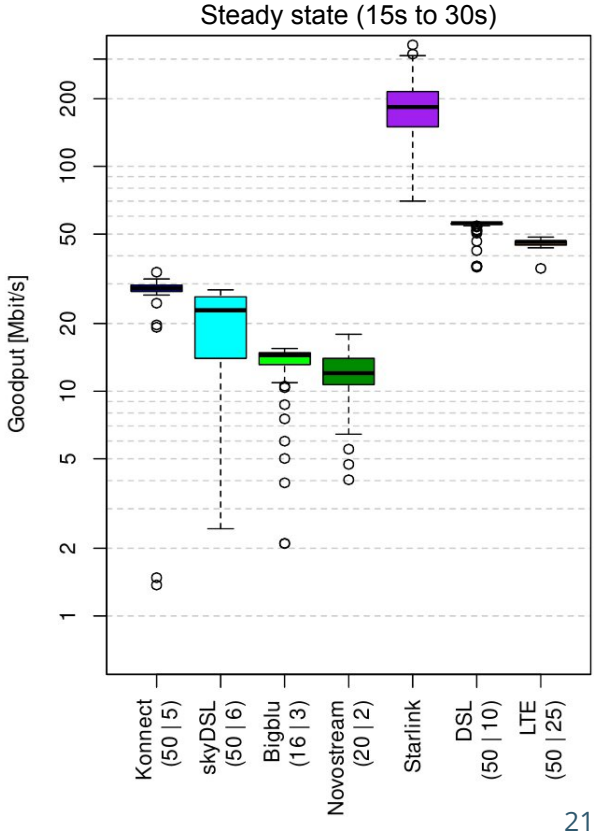




Performance measurements GEO vs. LEO/LTE/DSL [5]

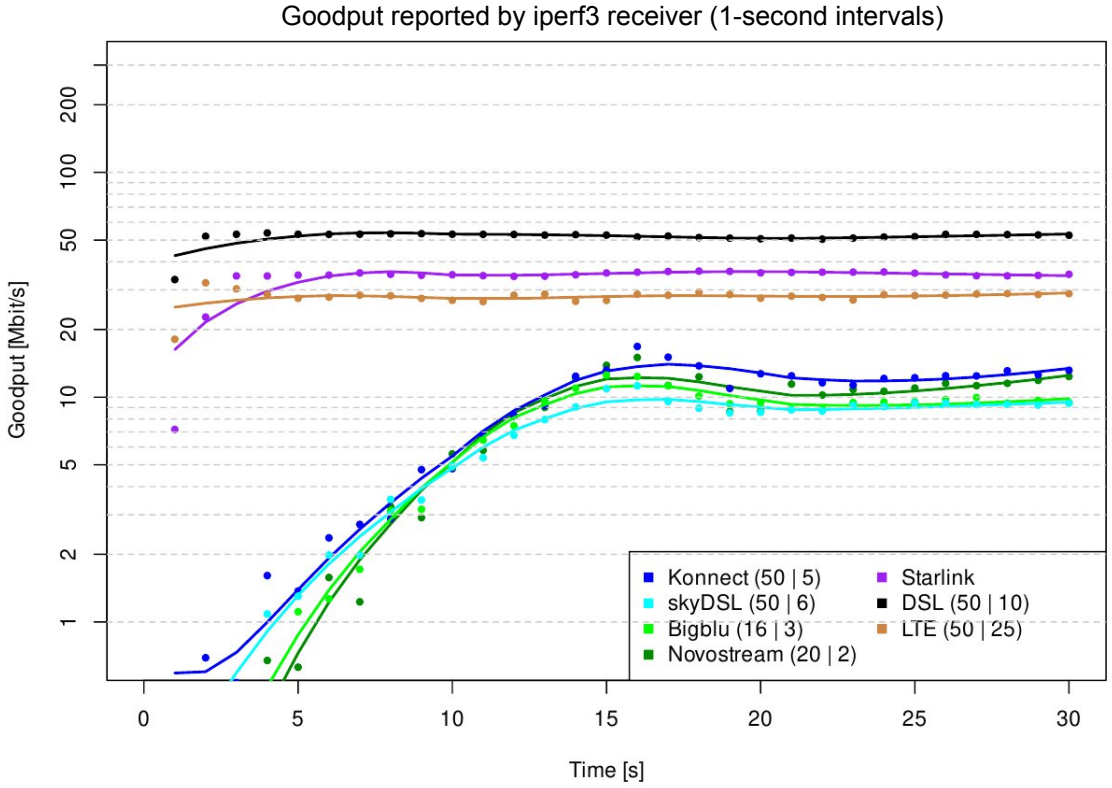
- Bulk data transfer download (single flow, Wireguard)

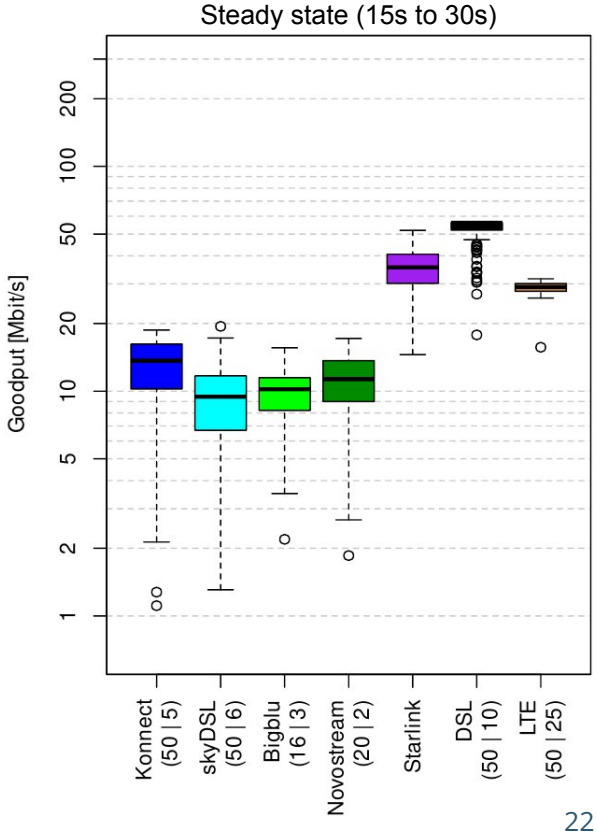




Performance measurements GEO vs. LEO/LTE/DSL [5]

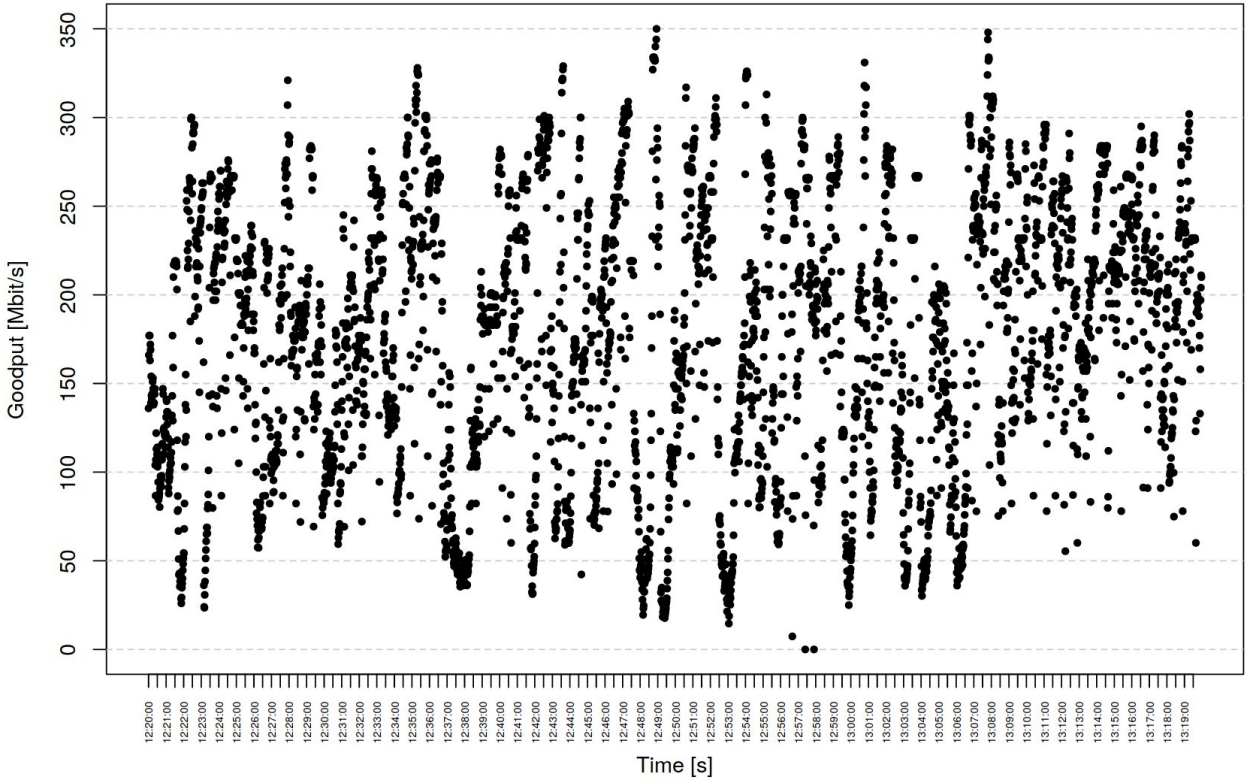
- Bulk data transfer download (single flow, OpenVPN)





Performance measurements GEO vs. LEO/LTE/DSL [5]

- Starlink measurements early 2021
  - iperf3, single flow, download goodput in 1-second intervals



Performance measurements GEO vs. LEO/LTE/DSL [5]

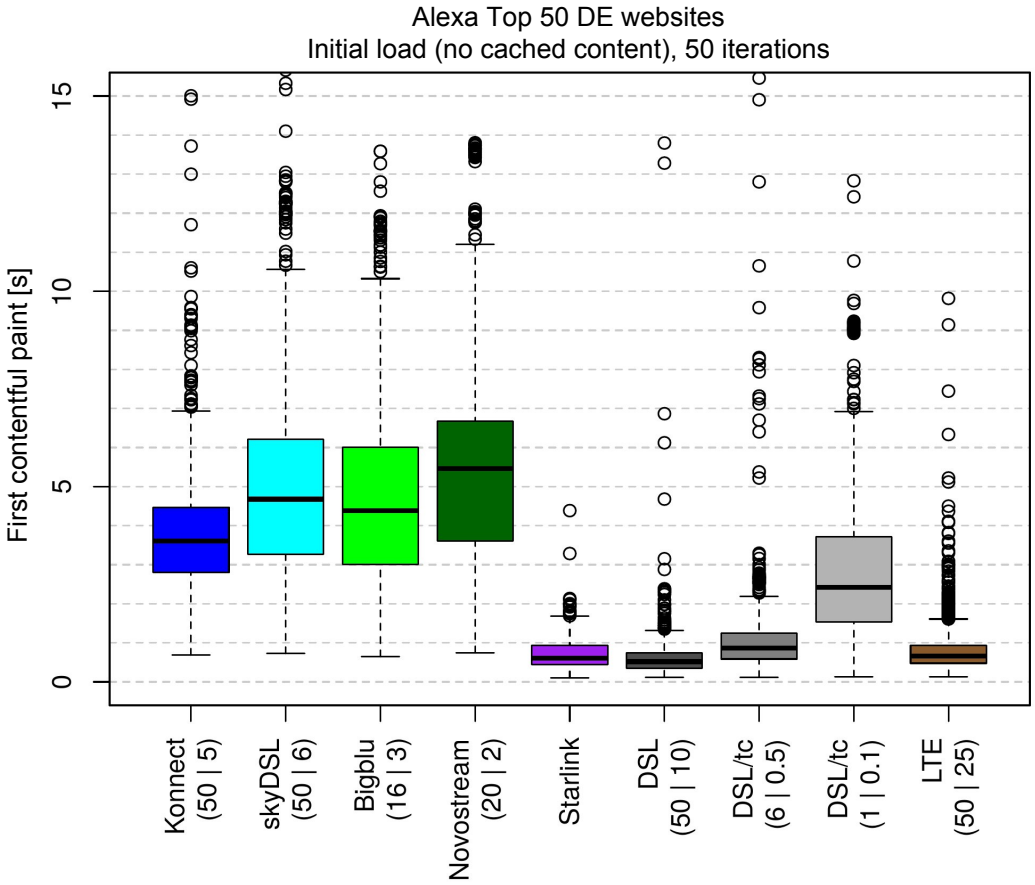
- Samba file sharing
  - Directory listing
  - File copying

… see screencasts

https://www7content.cs.fau.de/~deutschmann/eecc/

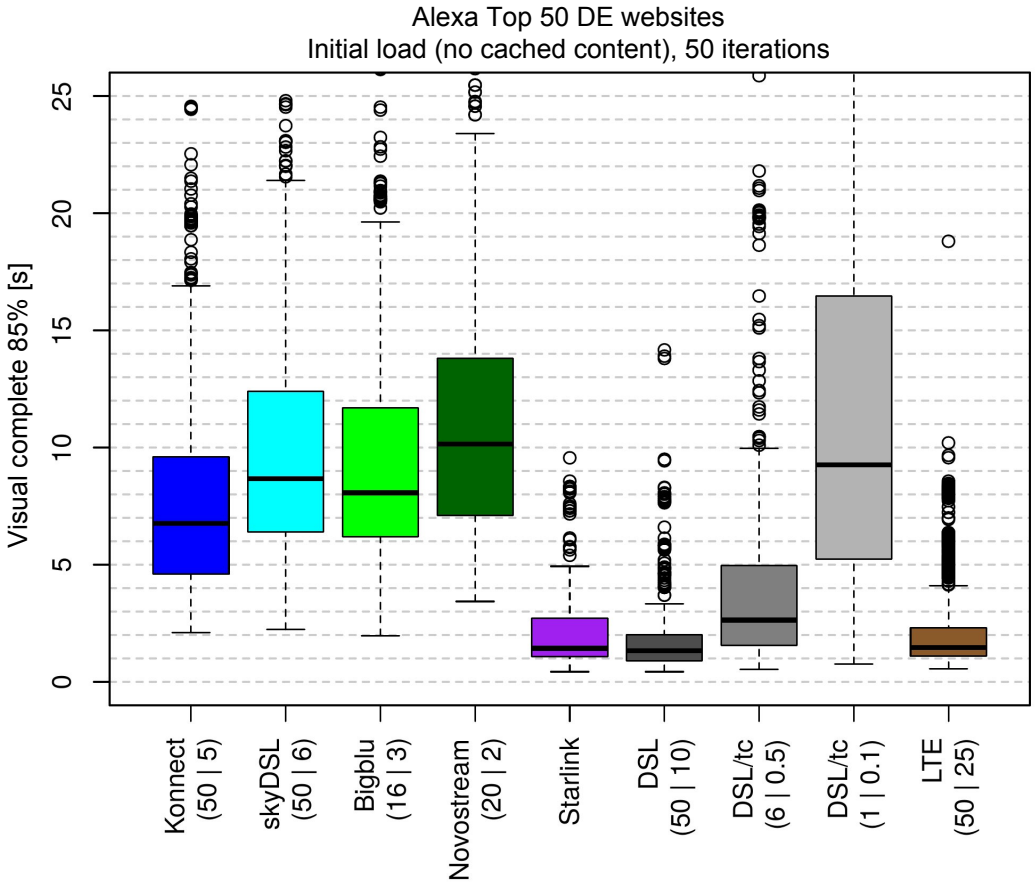
Performance measurements GEO vs. LEO/LTE/DSL [5]

- Web browsing
  - `browsertime 11.6.1`
  - DSL with additional netem traffic control
    - 6 Mbit/s down, 0.5 Mbit/s up
    - 1 Mbit/s down, 0.1 Mbit/s up
  - Metrics
    - First contentful paint
    - Visual complete 85%
    - Page load time



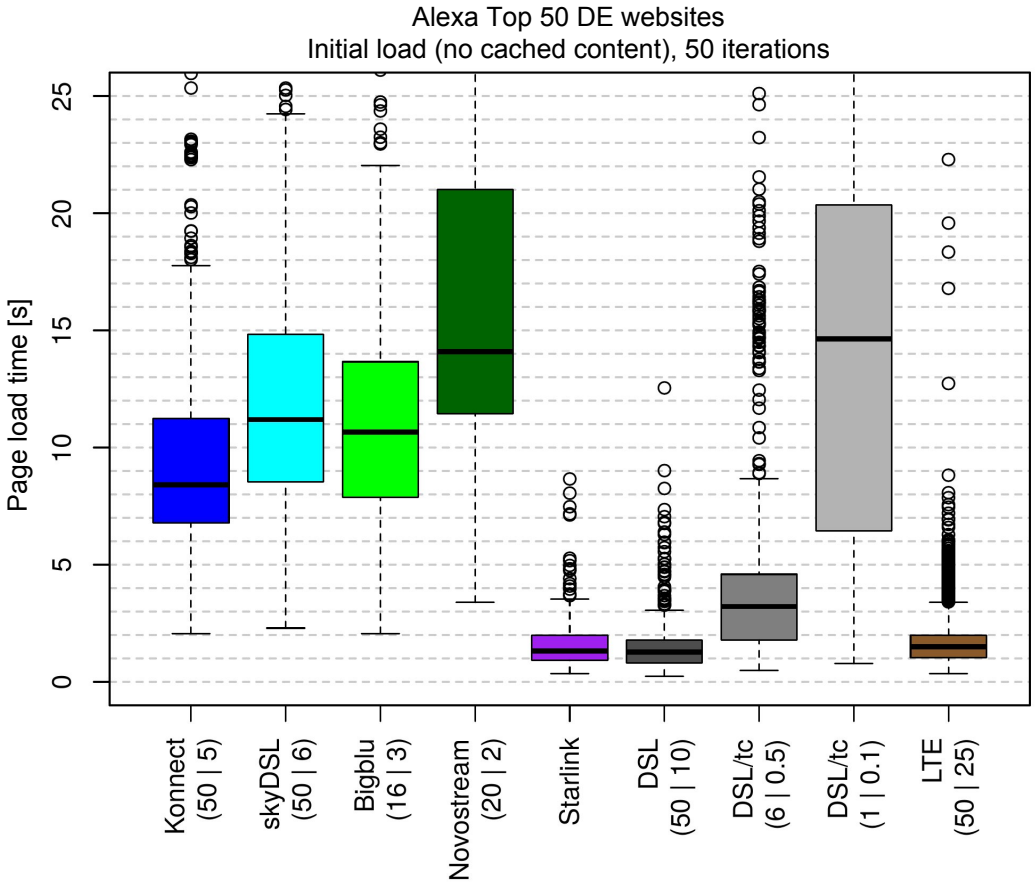
Performance measurements GEO vs. LEO/LTE/DSL [5]

- Web browsing
  - `browsertime 11.6.1`
  - DSL with additional netem traffic control
    - 6 Mbit/s down, 0.5 Mbit/s up
    - 1 Mbit/s down, 0.1 Mbit/s up
  - Metrics
    - First contentful paint
    - Visual complete 85%
    - Page load time



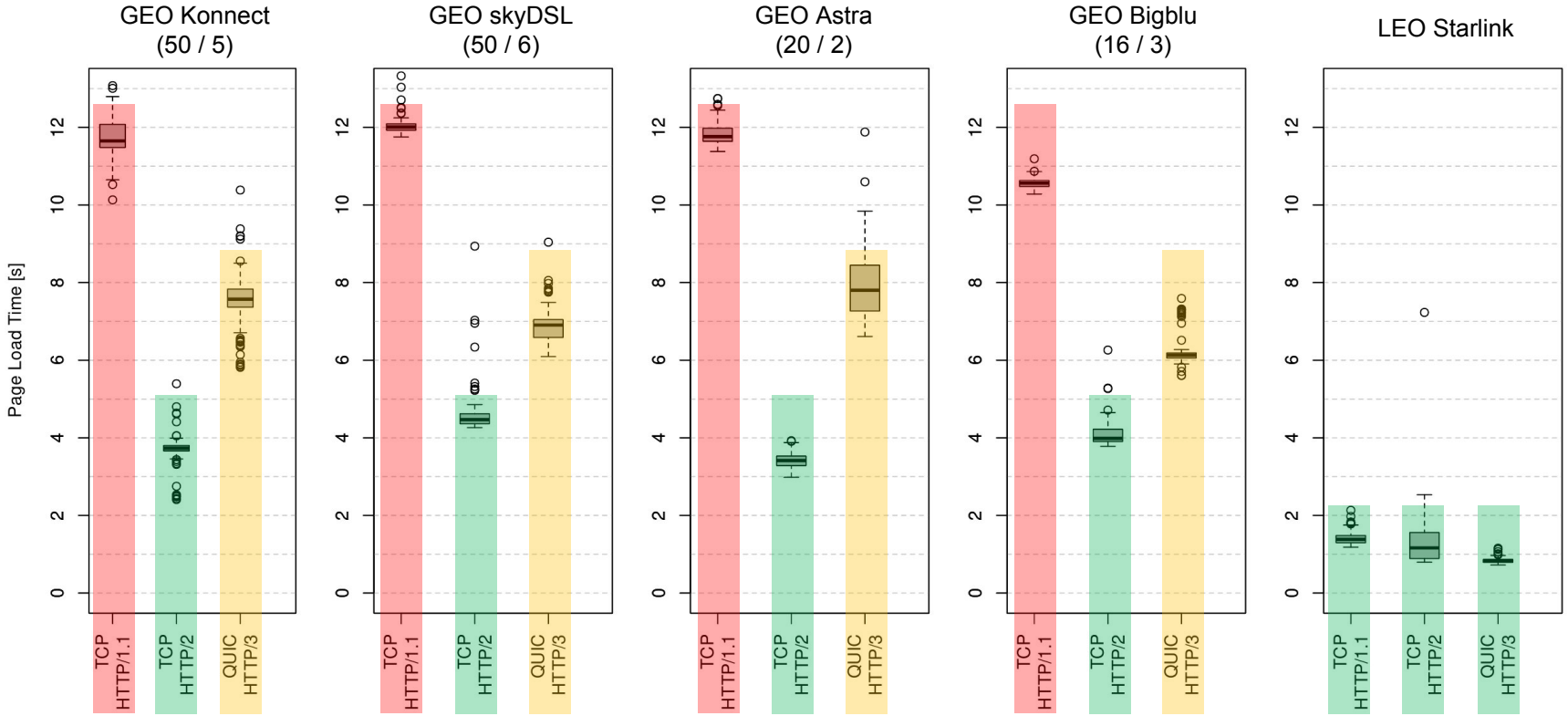
Performance measurements GEO vs. LEO/LTE/DSL [5]

- Web browsing
  - `browsertime 11.6.1`
  - DSL with additional netem traffic control
    - 6 Mbit/s down, 0.5 Mbit/s up
    - 1 Mbit/s down, 0.1 Mbit/s up
  - Metrics
    - First contentful paint
    - Visual complete 85%
    - Page load time



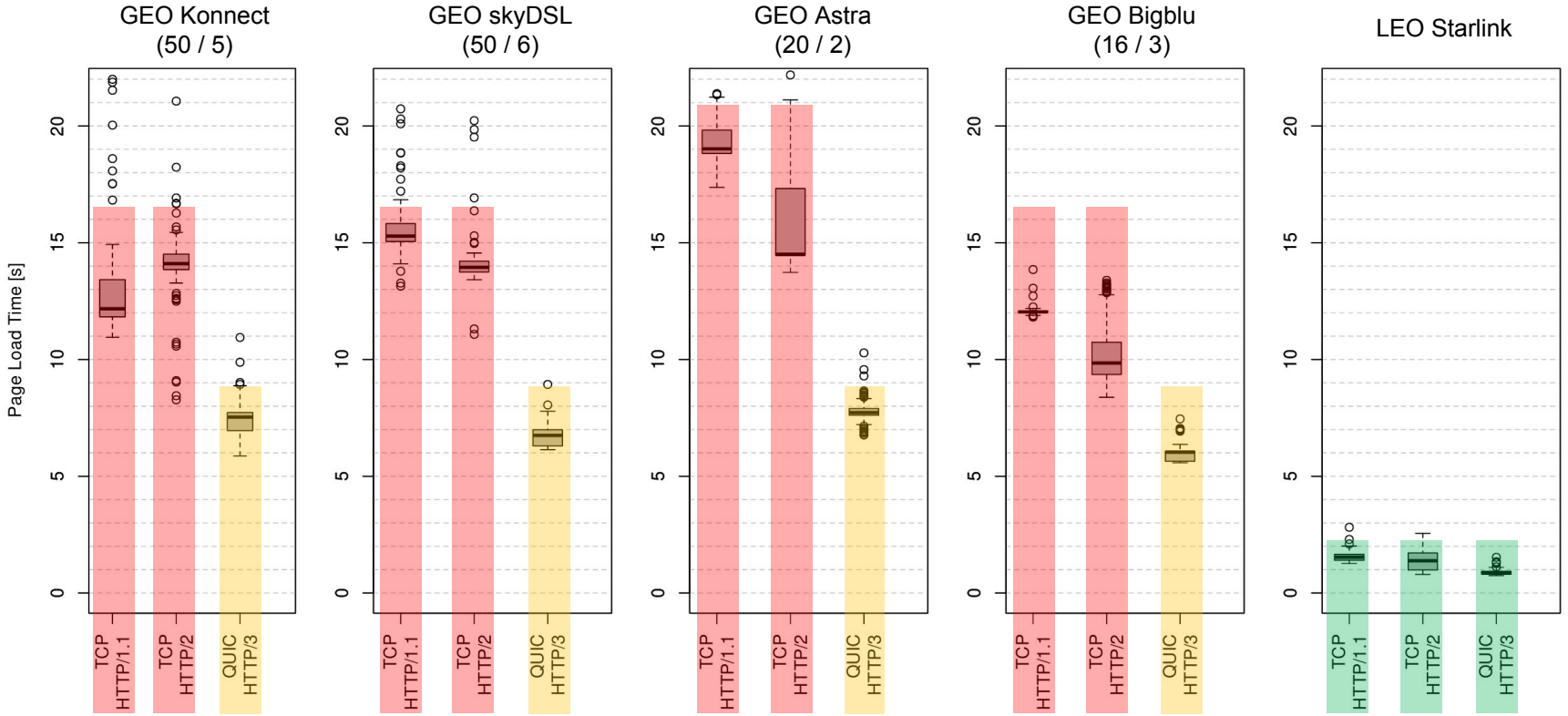
Performance measurements GEO vs. LEO [3]

- Again: comparison of different HTTP versions (without VPN)



Performance measurements GEO vs. LEO [3]

- Again: comparison of different HTTP versions (with Wireguard VPN)

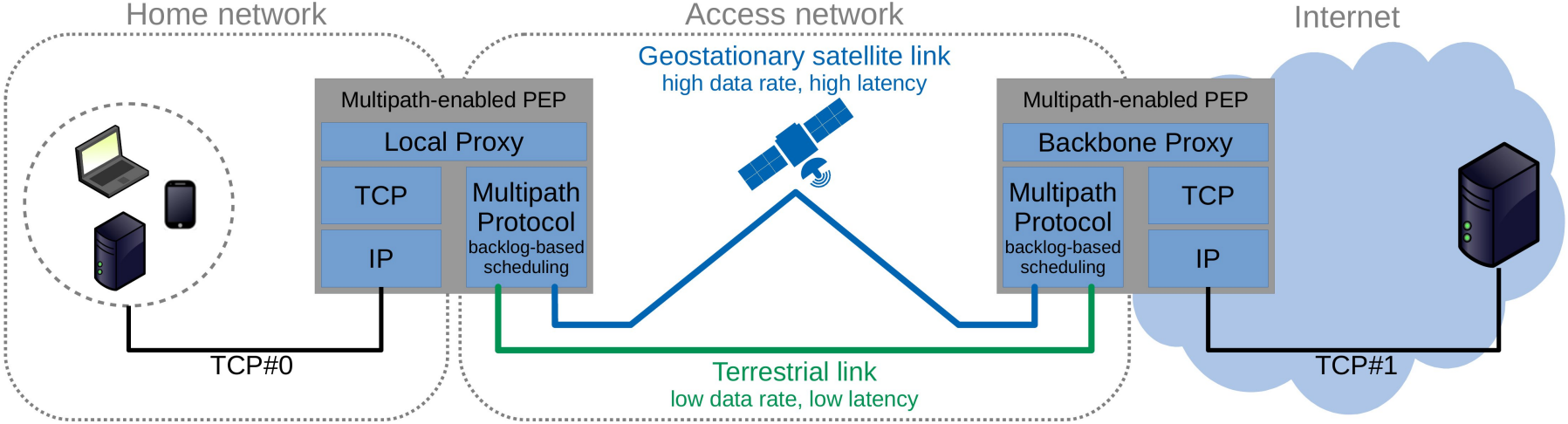


Outline

- Satellite communication basics
  - Satellite orbits
  - Geostationary (GEO) satellites
  - Low Earth orbit (LEO) megaconstellations (e.g., Starlink)
- Performance measurements
  - Measurement setup
  - GEO
  - GEO vs. LEO
- Satellite / terrestrial multipath communication
- Summary and outlook

Satellite / terrestrial multipath communication [6]

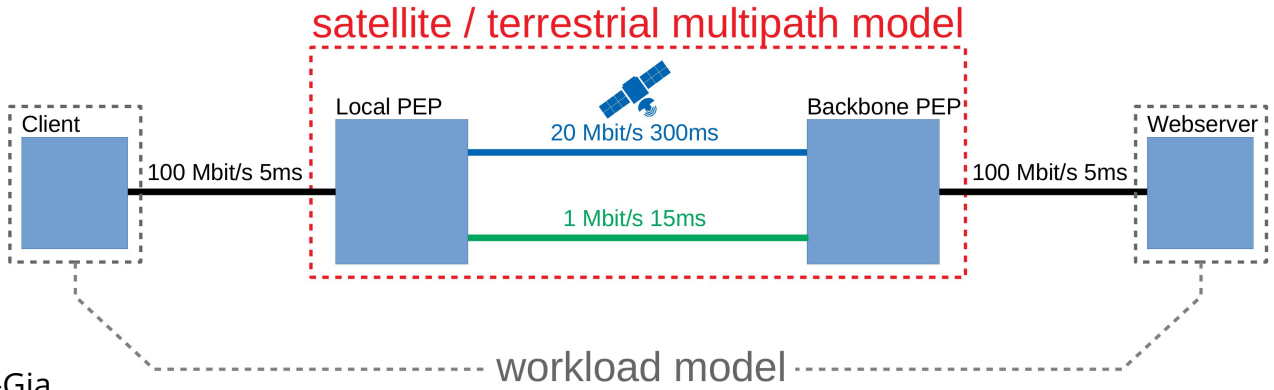
- Combine heterogeneous communication paths
  - High data rate, high latency geostationary satellite link
  - Low data rate, low latency terrestrial link (e.g., DSL light)

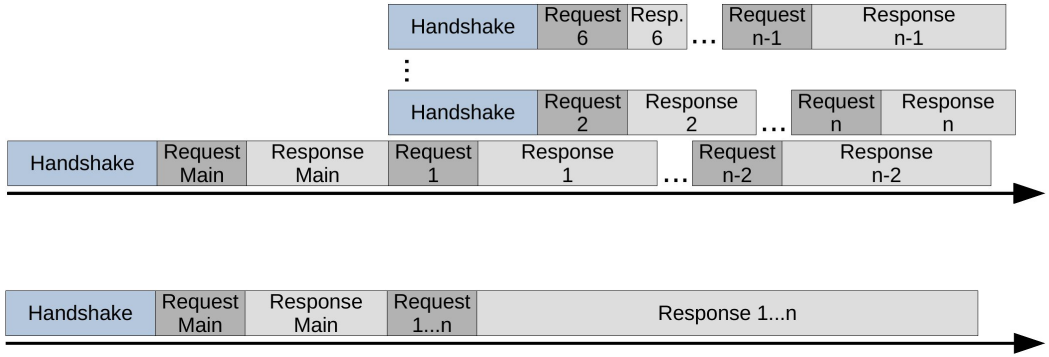


  - Backlog-based scheduling
    - Connection setup and small objects on the terrestrial link
    - Large objects on the satellite link

Satellite / terrestrial multipath communication [6]

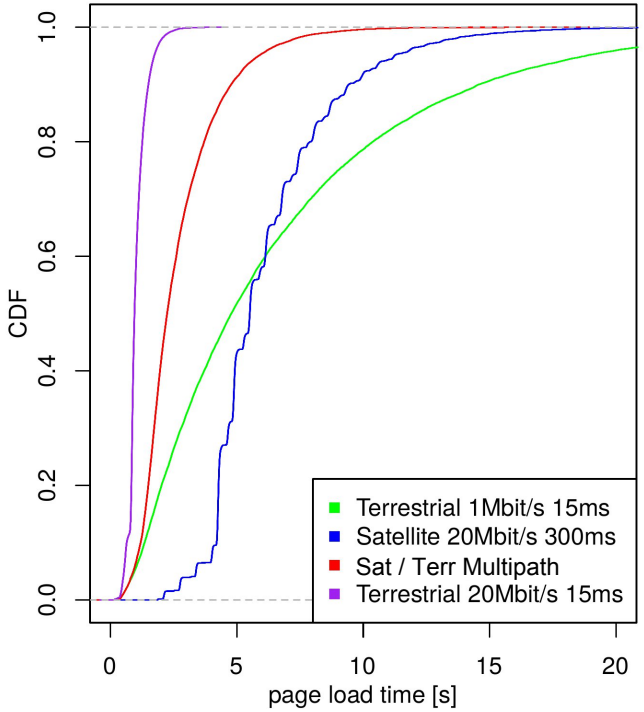
- ns-3 simulation
  - Multipath model with backlog-based scheduling (no randomness)
  - Workload model
    R. Pries, Z. Magyari and P. Tran-Gia, "An HTTP web traffic model based on the top one million visited web pages," NGI 2012, doi: 10.1109/NGI.2012.6252145
    - Added TCP/TLS handshake
    - HTTP/1.1 sequential requests/responses and eight parallel connections
    - HTTP/2 with single request/response



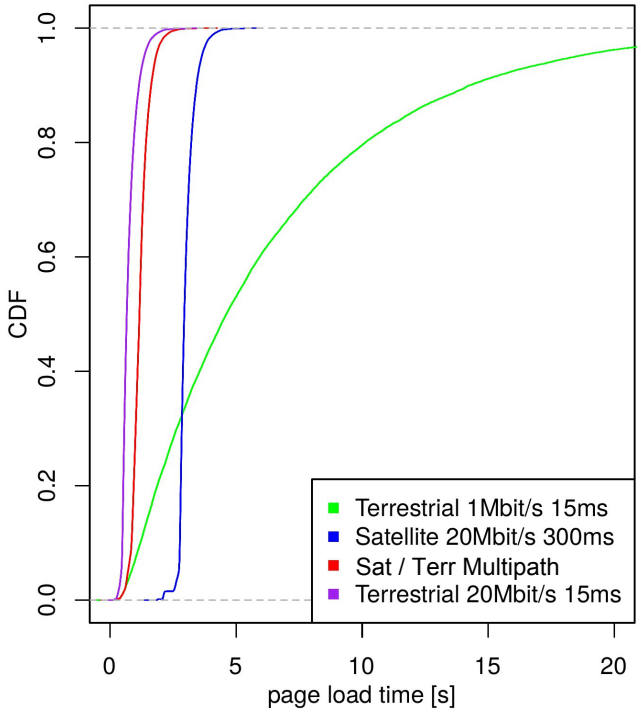


Satellite / terrestrial multipath communication [6]

- ns-3 simulation results



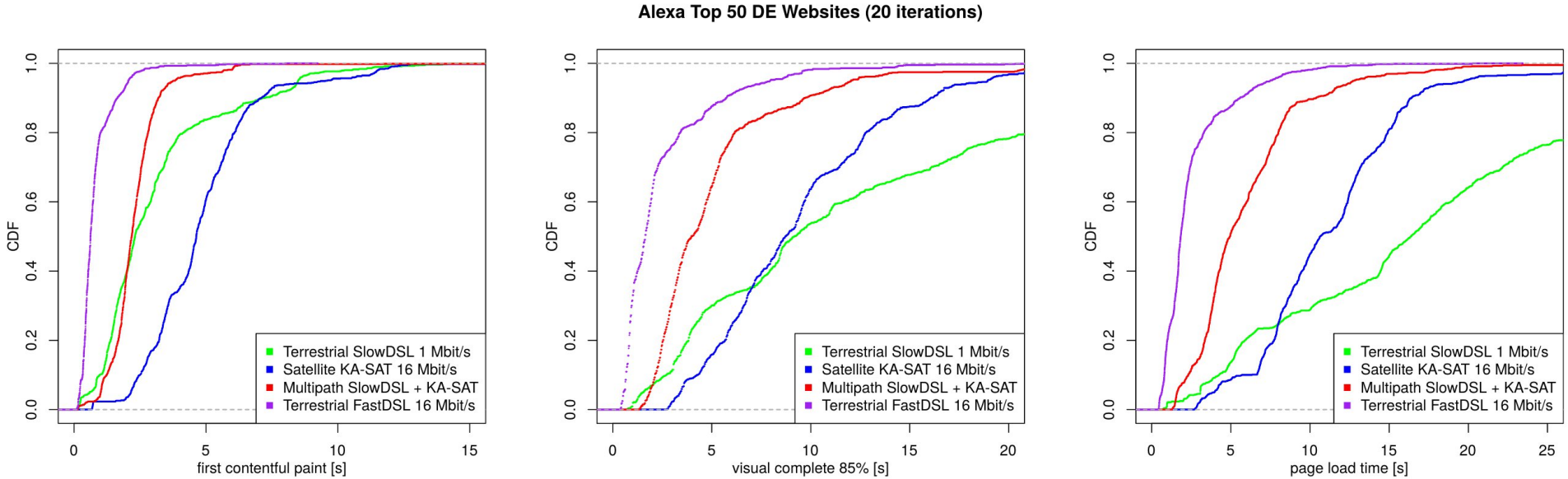
HTTP/1.1 sequential requests/responses and eight parallel connections



HTTP/2 with single request/response

Satellite / terrestrial multipath communication

- Results with Linux-based prototype (work in progress)
  - Loading real websites using `browsertime v10.1.0`



Outline

- Satellite communication basics
  - Satellite orbits
  - Geostationary (GEO) satellites
  - Low Earth orbit (LEO) megaconstellations (e.g., Starlink)
- Performance measurements
  - Measurement setup
  - GEO
  - GEO vs. LEO
- Satellite / terrestrial multipath communication
- Summary and outlook

Summary and outlook

- Satellite communication
  - GEO networks are challenging because of high latencies, PEPs not applicable for VPNs and QUIC
  - LEO megaconstellations are a game changer
- Satellite / terrestrial multipath communication

- Further measurements and parameter evaluation / optimization
  - E.g., Bufferbloat, HyStart++, congestion control algorithms, `draft-kuhn-quic-careful-resume-02`, …
  - Interested in IETF activities
- Related to 5G
  - Non-terrestrial networks (NTN)
  - Access Traffic Steering Switching and Splitting (ATSSS)

References

[1]	"Satellite Internet Performance Measurements," 2019 International Conference on Networked Systems (NetSys), 2019, https://doi.org/10.1109/NetSys.2019.8854494
[2]	"Broadband Internet Access via Satellite: State-of-the-Art and Future Directions," Broadband Coverage in Germany; 15th ITG-Symposium, 2021, https://ieeexplore.ieee.org/document/9399712
[3]	"Performance of modern web protocols over satellite links," 38th International Communications Satellite Systems Conference (ICSSC 2021), 2021, pp. 154-158, https://doi.org/10.1049/icp.2022.0564
[4]	"Performance of QUIC Implementations Over Geostationary Satellite Links," Preprint, https://arxiv.org/abs/2202.08228
[5]	"Broadband Internet Access via Satellite: Performance Measurements with different Operators and Applications," Broadband Coverage in Germany; 16th ITG-Symposium, 2022, to be published See also https://www.cs7.tf.fau.de/forschung/quality-of-service/forschungsprojekte/sat-internet-performance/
[6]	"An ns-3 Model for Multipath Communication with Terrestrial and Satellite Links," In: Hermanns, H. (eds) Measurement, Modelling and Evaluation of Computing Systems. MMB 2020. Lecture Notes in Computer Science(), vol 12040. Springer, Cham. https://doi.org/10.1007/978-3-030-43024-5_5