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Internet access as a basic human right, not there yet

**INTERNET ADOPTION**

Indivduals using the internet as a percentage of total population

**Global Overview**

**Sources:** Kepios Analysis, ITU, ONSA Intelligence, Eurostat, Google’s Advertising Resources, CNNIC, KAMTA & MMAL, Government Resources, United Nations. **Note:** Regions based on the United Nations Geoscheme. **Comparable:** Source and base changes, all figures use the latest available data, but some sources do not publish regular updates, so figures may under-represent actual use. See notes on data.

**Global Average:** 66.2%

- **Northern Europe:** 97.6%
- **Eastern Europe:** 88.4%
- **Central Asia:** 76.2%
- **Eastern Asia:** 76.8%
- **South-Eastern Asia:** 71.5%
- **Oceania:** 77.5%

**Regional Statistics:**

- **Northern America:** 96.8%
- **Central America:** 78.8%
- **Caribbean:** 70.2%
- **Western Europe:** 94.5%
- **Southern Europe:** 90.2%
- **Central Africa:** 76.1%
- **Western Africa:** 42.3%
- **Middle Africa:** 32.1%
- **Eastern Africa:** 26.7%
- **Southern Africa:** 73.1%
http://ascoderu.ca/

Email for All by Lokole
Global Access to the Internet

- **For All**
  - US: High-speed Internet for all
    - [https://www.internetforall.gov/](https://www.internetforall.gov/)
    - A whole-of-nation approach to high-speed Internet
  - Canada: High-speed Internet for all Canadians
    - [https://ised-isde.canada.ca/site/high-speed-internet-canada/](https://ised-isde.canada.ca/site/high-speed-internet-canada/)
    - Goal: 98% by 2026 and 100% by 2030; Status: 93% by 2023
  - Other countries around the world
    - Also basic Internet access

- **Anywhere by any-tech**
  - **Wireline**
    - Cable, DSL, Fiber
  - **Wireless**
    - Cellular, Satellite
Starlink on school bus for indigenous kids

- Feasibility study
  - Sponsored by UVic VKURA
  - 2023: Sooke to Port Renfrew

- Pilot program
  - Sponsored by UVic VPRI and donors
  - 2024: Pacheedaht and Ditidaht First Nations
    - School buses to Port Renfrew and Alberni

- Regional program
  - Currently requesting funding from IEEE
  - 2024–25: for more communities
    - On the Vancouver Island not covered by CC
Global Access to the Internet for All, Anywhere

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Why satellites?

- For global coverage when terrestrial networks
  - Not available, too costly, damaged, shut down, etc
- GEO: geosynchronous equatorial orbit
  - 36 kkm above the earth, limited capacity, very large delay
  - HughesNet, Intelsat, ViaSat, etc: round-trip time (RTT) 600+ ms
- MEO: medium-earth orbit (between LEO and GEO)
  - SES O3b: 6 satellites operational now, 8 kkm, 200+ ms RTT
- LEO: low-earth orbit (below 2 kkm)
  - SpaceX’s Starlink: 6k+ satellites, mostly 550 km in 53° inclination
    - 3+ million users in 70+ countries by May 2024
  - Eutelsat OneWeb: 6h+ satellites, 1 kkm altitude in polar orbits
    - mostly targeting enterprise and government customers
  - Amazon Kuiper: two prototype satellites recently tested in space
  - Telesat Lightspeed: series test satellites for space demonstration
Why LEO satellites?

- Starlink as an example
Starlink in a nutshell

- An **outgoing** packet’s journey to the Internet (reverse for the incoming one)
  - User devices
    - 192.168.1.x if the default gateway at 192.168.1.1/24
  - **User router** (User Terminal Router, **UTR**, provided by Starlink, can be replaced or bypassed)
    - LAN: 192.168.1.1 (by default)
    - WAN: **100.64/10** (*unique per user dish*)
  - **User dish** (Antenna, **UTA**, provided by Starlink)
    - 192.168.100.1 (*fixed address as modem*)
  - **Satellite** (inter-satellite links, **ISLs**, possible)
  - Landing ground station (**GS**, transparent to IP)
  - **CGNAT** (Carrier-Grade NAT) gateway (**GW**)
    - **100.64.0.1** (*or public IP user’s gateway*)
  - Home **PoP** (Point-of-Presence) entry
    - 172.16/12
  - PoP, other PoPs/ISPs, ICPs, etc: the **Internet**

* UT-(space/ground tunnel)-GW-PoP-backbone: see https://arxiv.org/pdf/2307.06863
Ground station and infrastructure

- Inside a point-of-presence (PoP, e.g., Seattle)
  - Gateway: 172.16.250/23 expanded to 172.16.252/24 (also 172.16.248/23 in other PoPs)
    - Odd ending digit: toward CGNAT
    - Even ending digit: toward the PoP
  - Parallel links within the PoP: 206.224.64/23 expanded to 206.224.66/24 (some inter-PoP too)
    - UDP over ECMP; ICMP unique path; TCP unique path per flow
  - Interconnection to other PoPs (mostly 149.19.108/24), ISPs and ICP/CDNs (149.19.109/24)
Global backbone network and growing

info used by http://tinyurl.com/starlinkmap
courtesy of RIPE Atlas
From user device to their **gateway**

- Ping in 15-ms intervals
  - Victoria to Seattle PoP
    - On UVic ECS roof
  - **Louisville, CO**
    - Hosted by Matt
    - To Denver PoP
  - Oxford, MS
    - Shared by Feng
    - To Dallas PoP
  - **Iowa City, IA**
    - By Hammas
    - To Chicago PoP
  - Ottawa, ON
    - Hosted by Minming
    - To New York City

* minRTT jumps; ^ local WiFi; + dish obstruction

* more at http://pan.uvic.ca/webb/viewtopic.php?p=124670#p124670
Also around the world

- Ping in 15-ms intervals
  - Louvain, BE
    - Shared by Francois
    - To Frankfurt PoP
  - Perth, AU^*
    - By a Redditor
    - To Perth PoP
  - São Paulo, BR
    - By a Redditor
    - To São Paulo PoP
  - Seychelles (May 2023)
    - By Dominique
    - To Lagos PoP
  - Seychelles (Aug 2023)*
    - ISL improved

* GEO protection; ^ user population; MAC
From sequence to **frequency**

- **Cumulative** distribution
  - ISL, much **higher** RTT
  - Non-ISL
    - min RTT: ~20ms
    - Still high **jitter**

- **Inactive** dishes
  - IPv4 gateway
    - 100.64.0.1
    - By ARPing
  - IPv6 gateway
    - fe80::200:5eff:fe00:101
    - By Ping
  - **connect.starlink.com**
    - 34.107.166.226
    - By (HTT)Ping

*active* measurement on many **inactive** dishes
Up vs down link from user's viewpoint

- Victoria ⇔ Seattle
  - RTT by Ping to GW
  - *One-way* delay by IRTT
    - A VM near PoP
    - Time synced
  - Bidirectional tunnel
    - Same satellite(s)
    - And landing GS
  - Asymmetric bandwidth
    - Up: contention
    - Down: allocation
  - iPerf3 TCP throughput
    - Sat-GS handover
    - Packet reordering
    - Timeout

* TCP affected at 57, 12, 27 and 42 sec/minute
Community gateway

- **First** in Dutch Harbor
  - Unalaska, AK
  - A mini GS to aggregate
  - In Ka (not Ku) bands
  - 10Gbps symmetric
- **Outside-in** testing
  - From Victoria dish
    - UT-Sat-GS and
    - GS-Sat-GS
  - From Akamai VM
    - In Seattle
  - From Google VM
    - The Dalles, OR
    - Through Seattle

* capex: $1.25m; opex: $75k/gbps/month!
Comparing with another LEO network

- **Starlink**
  - Initially target consumer users
  - Mostly 53° inclination
  - Mostly 550km above the Earth
  - **Spotting** beams for individual dishes
    - Ku for UT and Ka for GS
  - Currently >6000 active satellites
    - All launched by SpaceX
  - Currently >100x ground stations
  - Many PoPs around the world
  - Lower but *relatively fluctuating* RTT
    - Due to Spotting beams
    - UT-Sat-GS shuffling every 15 seconds

- **OneWeb**
  - Currently target *enterprise* users
  - Polar orbits
  - Above 1000km in altitude
  - **Sweeping** beams for community dishes
    - Similarly Ku and Ka
  - Currently ~600 active satellites
    - Limited 3rd-party launch capacity
  - Currently ~10x ground stations
  - Very few customer PoPs now
  - High but *relatively stable* RTT to PoP

* Amazon Kuiper and Telesat Lightspeed?
Is Starlink+OneWeb+Kuiper+Lightspeed enough?

- **Starlink**
  - Personal: Residential, Roam, Boats
  - Business: Fixed Site, Land Mobility, Maritime, Aviation, Direct to Cell
  - Swarm: Space IoT?

- **Inter-Satellite Network: An Internet of satellites**
  - A testbed first!
Why a cross-country/continent satellite testbed?

● For network researchers, leveraging CANARIE/Internet2 but on LEO satellites
  ○ Geo-diversity needed for satellite network research
    ■ At least one site in each province/state and territory
  ○ Much more capable than RIPE Atlas
    ■ Container-based measurement modules
  ○ Possibly different satellite technologies besides GEO
    ■ Starlink, OneWeb, Kuiper, Telesat, etc

● For community users
  ○ In remote areas and indigenous communities
    ■ Improved Internet access capacity
  ○ No security and privacy affected
    ■ End-to-end encryption of user traffic
  ○ A level playground for a fair comparison
    ■ For vendors, operators and regulators
What are the challenges?

● A country/continent-wide testbed of each site including
  ○ Satellite dish(es): outdoor units with a clear view of the sky
    ■ Dish installation: roof or pole mount, cable routing, etc
    ■ Service cost: monthly subscription fee
  ○ Time-synchronized measurement nodes: indoor units
    ■ Mini PCs of multiple Ethernet ports, each to a different dish
    ■ Network adapter/switch, uninterruptible power supply (UPS)
  ○ Host and community access to the Internet
    ■ Access point for host coverage; mesh nodes for community
  ○ Additional equipment if needed
    ■ Solar panel, power generator, community cache server, etc

● Centralized control and coordination for collaboration
  ○ Measurement orchestration: container deployment/scheduling
  ○ Platform maintenance to minimize the overhead for the host
Why join us?

- Doing research in LEO Satellite Networks
  - Computing, communication and control
    - Multipath transport, congestion control, etc
  - Network security and user privacy
    - Anonymous communication
  - Network applications and improvement
    - Video streaming, online gaming, etc
- Gaining experience in various research testbeds
  - Starlink dishes in Victoria, Denver and Ottawa
    - Satellite dish, Ethernet adapter and switch, Mini PC
  - Community dishes around the world
    - Virtual machine, remote access, data collection/release
  - Outreach and broader impact
    - E.g., Starlink reddit, bug fixes adopted by Starlink, etc
For a LEO-Sat-Net testbed!

- As a (founding) member and supporter
  - Network/fleet operators: contributing hardware and service
    - Benefit: accessing user-perceived performance and comparison
  - Funding agencies: research and equipment grants
    - Fostering across-country academia-industry collaboration
  - Government organizations: community grant and citizen service
    - Connecting research and empowering remote communities
  - Academic, industry and government researchers and students
    - Access to a coast-to-coast-to-coast testbed for research and education

- As a (pilot) host in remote areas: much improved Internet access
  - A small space and basic power supply (solar panel if needed)
  - Other Internet connectivity if available for control redundancy
    - Minimum local maintenance with mostly central control
    - Local outreach and activities with strong central support
Other efforts around the world

- With a focus on (LEO) satellites
  - University of Surrey, UK
    - Hylas-4 GEO with 5/6G integration
    - LEOScope: an emerging global testbed
  - Virginia Tech and George Mason University, USA
    - NeTSat: NSF project recently approved
    - Starlink and OneWeb mentioned
  - Carleton University, Canada
    - UAV-HAP-LEO integration with 6G O-RAN
    - Collaboration with NRC, MDA, DRDC, etc
- Unique features of us as part of LEOScope
  - Geo-distributed: coast-to-coast-to-coast
  - LEO-focused: consumers and enterprises
  - User-oriented testbed: by and for researchers
LEOScope: A GLOBAL TESTBED for Low-Earth Orbit Satellite Networks

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Low Earth Network of Satellites

- https://github.com/clarkzjw/LENS
  - Our public datasets updated monthly

Starlink User Terminal models and hardware revisions
January 2024

**REV1 - Original Starlink "Dishy"**
- rev1_pre_production
- rev1_production
- rev_rev1_proto3
  - Years in production: 2020 - 2021

**REV2 - Mass production "Dishy"**
- rev2_proto1
- rev2_proto2
- rev2_proto3
- rev2_proto4
  - Years in production: 2021 - 2022

**High Performance**
- rev_hp1_proto0
- rev_hp1_proto1
  - Years in production: 2022 -

**Flat High Performance**
- rev_hp1_proto0
- rev_hp1_proto1
  - Years in production: 2022 -

**REV3 - Standard Actuated**
- rev3_proto0
- rev3_proto1
- rev3_proto2
  - Years in production: 2022 -

**REV4 - Standard**
- rev4_proto3
- rev4_proto4
- revd_prod1
  - Years in production: Q4 2023 -
Thanks!

- **Questions?**
  - Join us!

Active vs inactive vs *obstructed* dish in a cell

From Anchorage, AK to Seattle, WA: **Starlink vs OneWeb vs Fiber (% Mark)**

more at https://github.com/clarkzjw/LENS