IAB BIAS Workshop

Closing the Performance and Management Gaps with Satellite Internet: Challenges, Approaches and Future Directions

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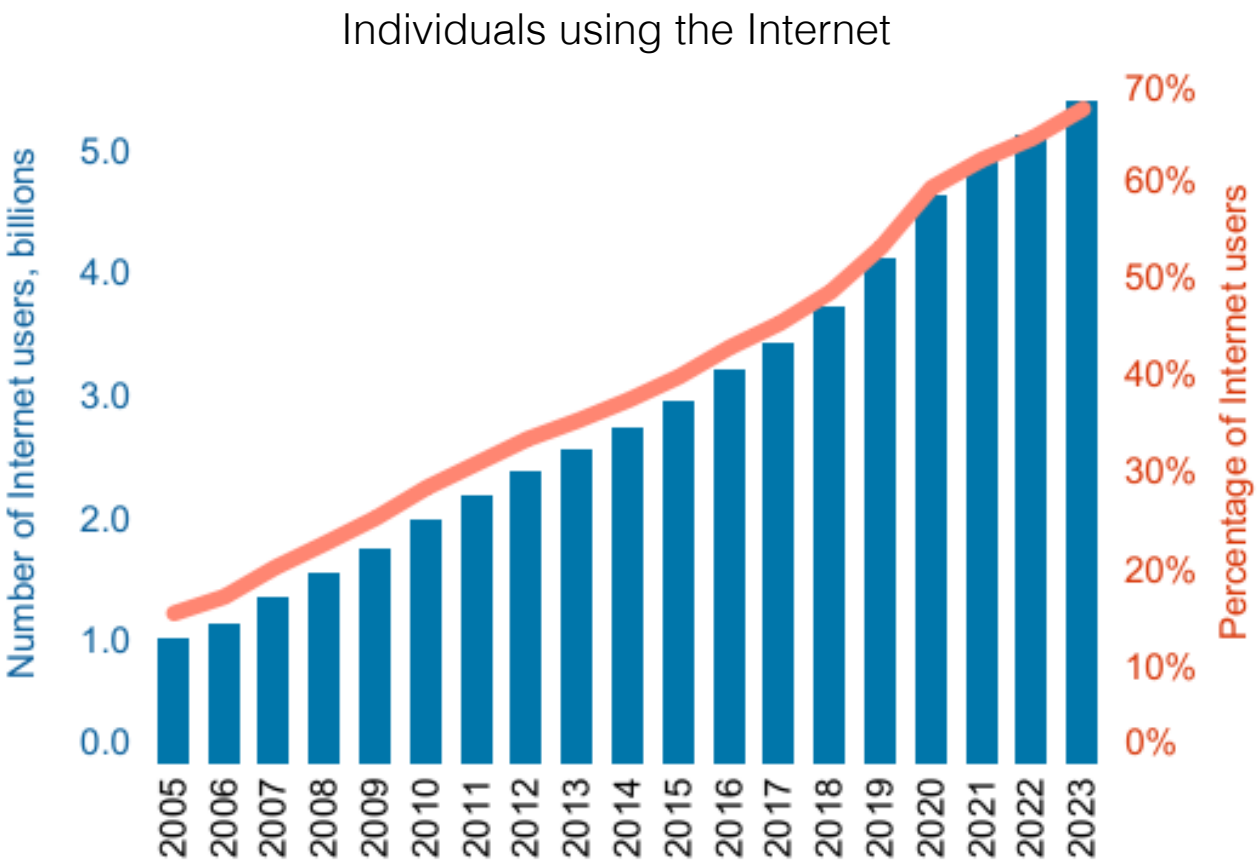
Internet Use



Source: ITU

ITU-D ICT Statistics (2023)

- 5.4 billion Internet users
  (67% of the world population)
- 2.6 billion not connected

Closing the Urban-Rural Divide with Satellite Internet

- Satellite Internet:
  - Enables high-quality Internet to everyone anywhere on Earth.
  - Supports solutions to societal and real-world challenges.
  - Can integrate with entities in non-terrestrial networks (NTNs) and terrestrial networks (TNs).
  - Has growing importance in beyond 5G & 6G telecommunications and ICT.

Closing the Urban-Rural Divide with Satellite Internet (cont'd)

Source: Canadian Radio-television and Telecommunications Commission (CRTC)

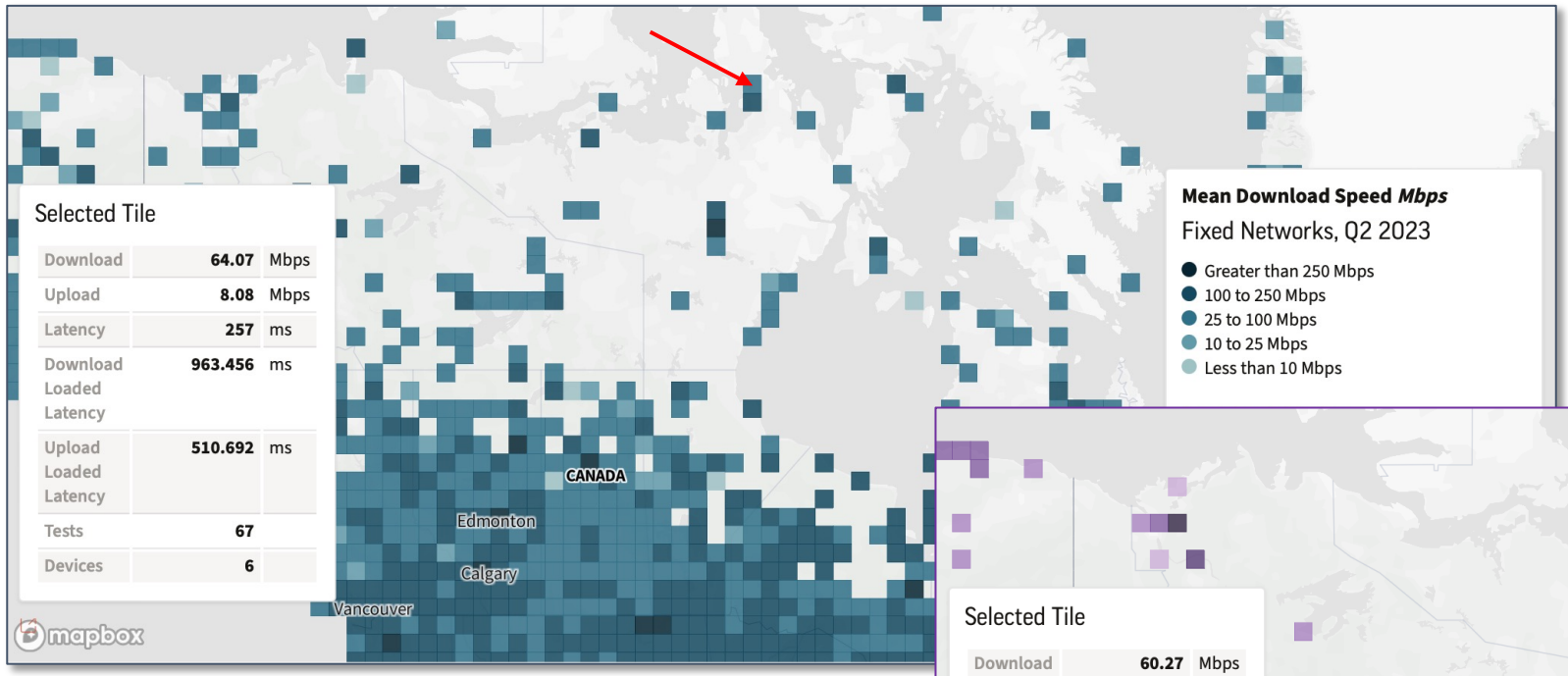
Satellite-dependent community

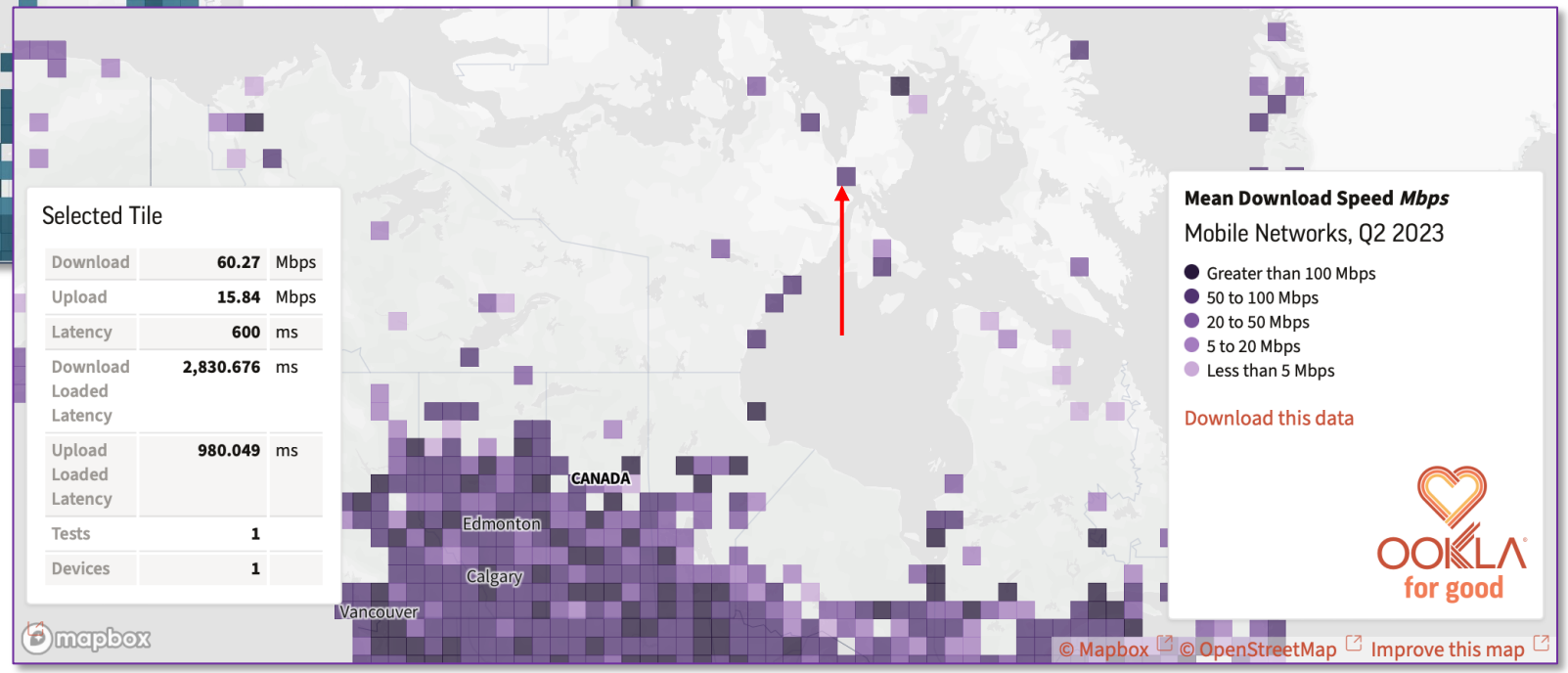
Satellite-dependent community networks (SDCNs): community networks with no terrestrially based telecommunications facilities for connection to the Internet and reliance on satellite transport to receive telecommunications services.

Performance Gap

- Equitable and high-quality Internet access through LEO satellites
- Performance gap: inconsistent end-to-end performance guarantees among users (including the users in rural, remote, northern, and arctic areas)

Performance Gap: Latency

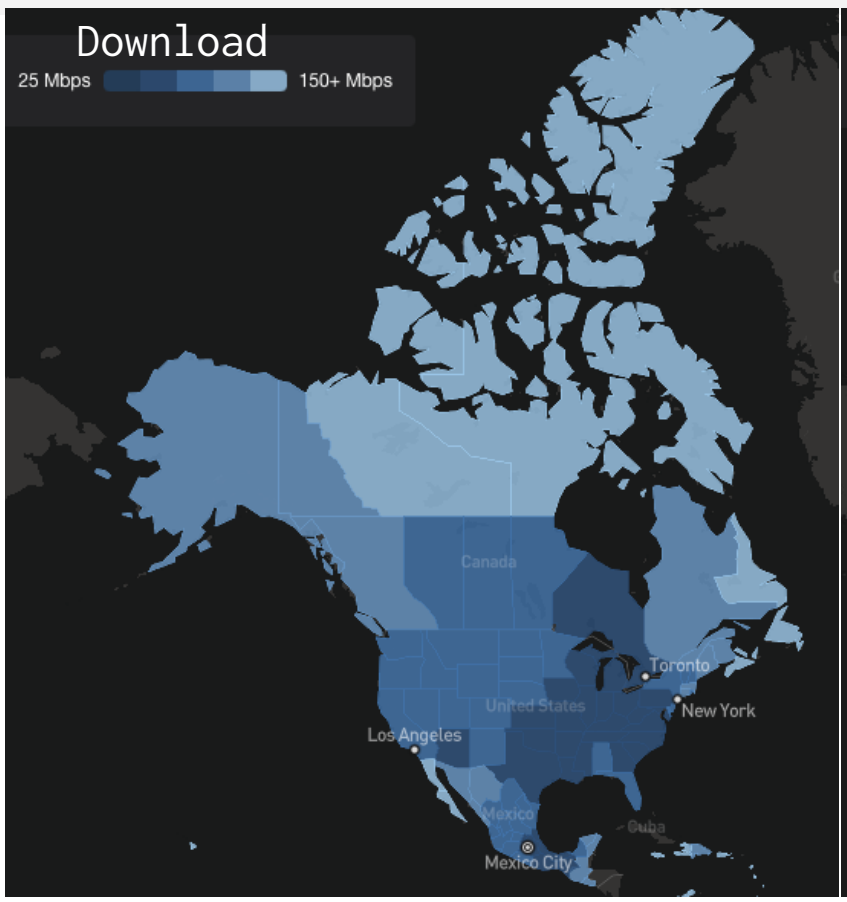


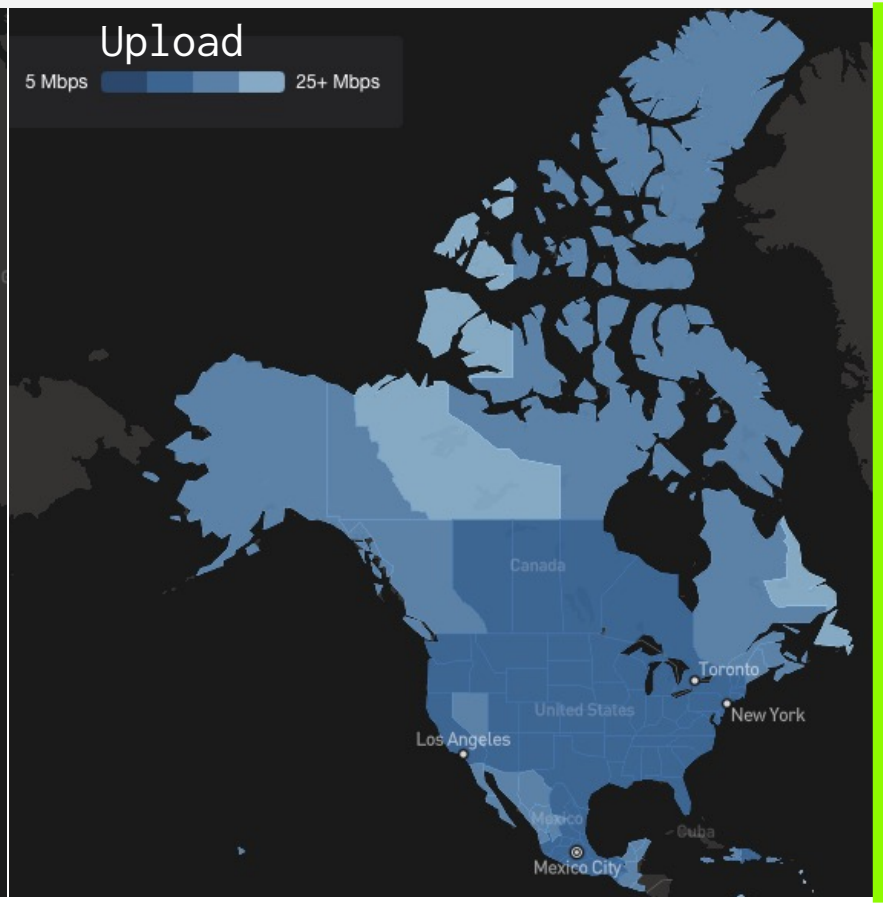


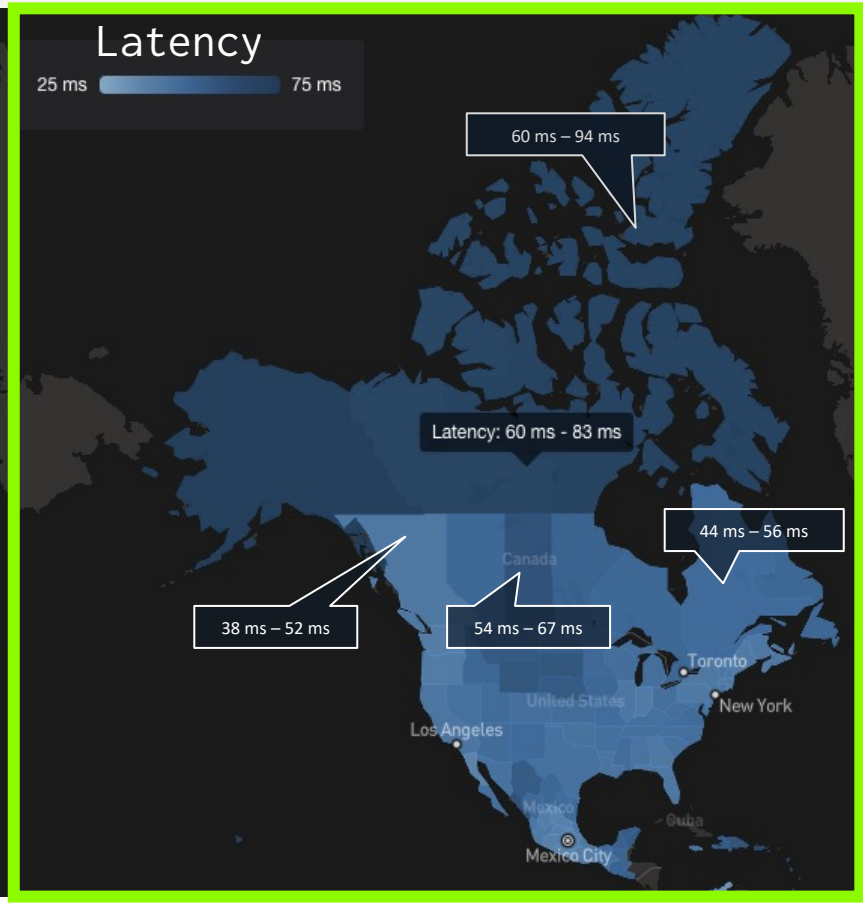
- The latency performance is inconsistent from area to area in Canada.
- Better latency performance is needed for many Internet services.

Source: https://www.ookla.com/ookla-for-good/open-data

Performance Gap: Latency (cont'd)







Source: https://www.starlink.com (Accessed on Sept. 5th, 2023)

Starlink Availability Map

Management Gap

- SDCNs are envisioned to be transformed into satellite-integrated community networks (SICNs) (Hu, 2021).
- Management gap: lack of efficient management and operations arising from the complexity, heterogeneity, and dynamic nature of non-terrestrial network (NTN) elements and SICN's requirements for responsive and cost-effective management and operations solutions.

- P. Hu, "Closing the Management Gap for Satellite-Integrated Community Networks: A Hierarchical Approach to Self-Maintenance," *IEEE Communications Magazine*, vol. 59, no. 12, pp. 43-49, December 2021.

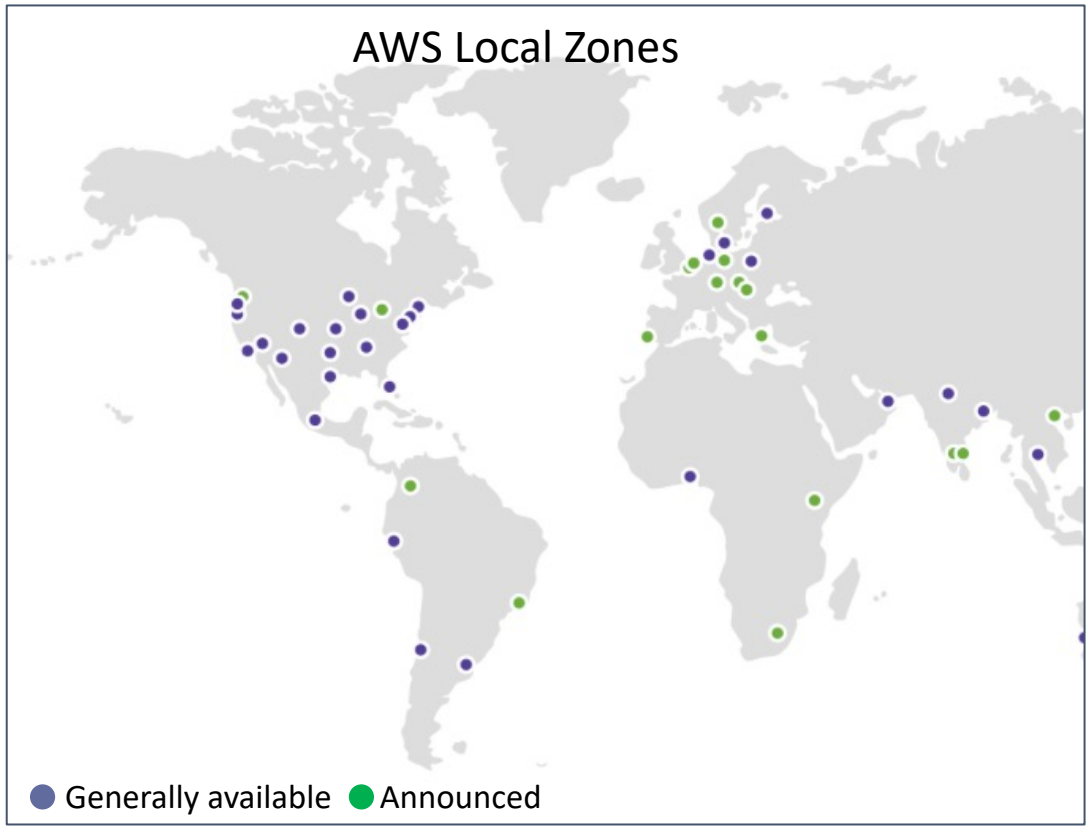
Deploying TN Entities: Placing PoP/IXP/EDC Closer to Communities

- TN entities being considered: PoPs, Internet exchange points (IXPs), and edge data centers (EDC).
- Placing PoPs/IXPs close to or within communities is a way to enhance the affordability, reliability, and equity of Internet access based on LEO satellites.
- IXPs make the Internet faster and more affordable (ISOC, 2023).
- Research directions:
  - New solutions to the optimal deployment of the TN entities on a satellite internet.
  - Deploy TN entities to guarantee consistent performance for Internet access and digital services.

- Internet Society (ISOC), “Internet Exchange Points (IXPs),” 2023, (accessed Sep. 5, 2023). [Online]. Available: https://www.internetsociety.org/issues/ixps/

Deploying TN Entities: Placing PoP/IXP/EDC Closer to Communities (cont'd)

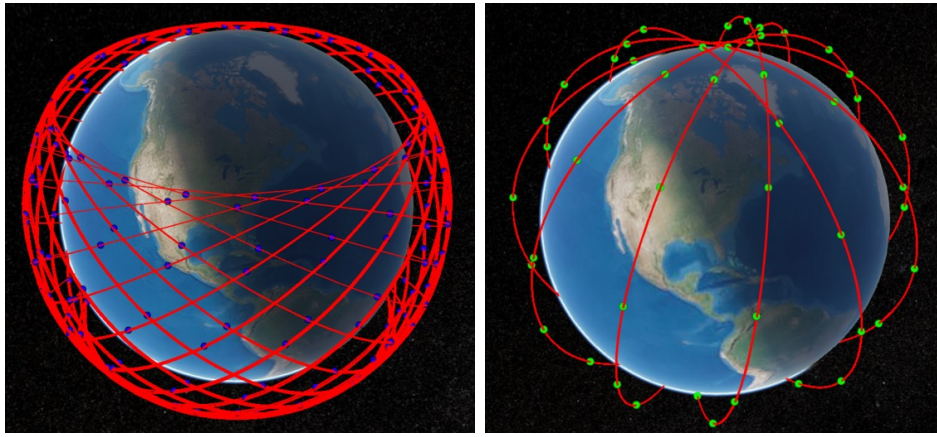
- Bring the edge data center (EDC) facilities close to the communities.
- Move the cloud and application services closer to the users.
- Example: AWS Local Zones



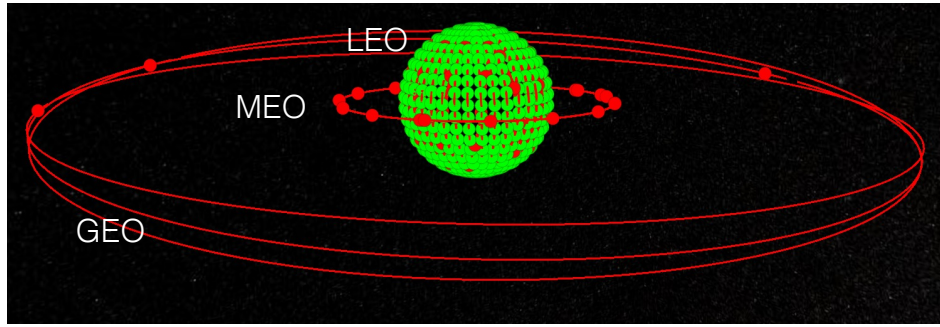
Source: Amazon AWS (Accessed on Sep. 1st, 2023)

Multi-layer Satellite Networking

- Multi-layer satellite networking (MLSN): satellite internetworking based on orbital shells and conceptual layers that can support performance-aware data transmission, intelligent space infrastructure, relay networks, efficient resource management, network operations, etc.
- Research directions:
  - Perform dynamic resource management for consistent performance guarantees.
  - Security countermeasures, resilience assurance, and efficient satellite network operations.
  - Satellite network management and operations missions.



LEO satellites in orbital shells

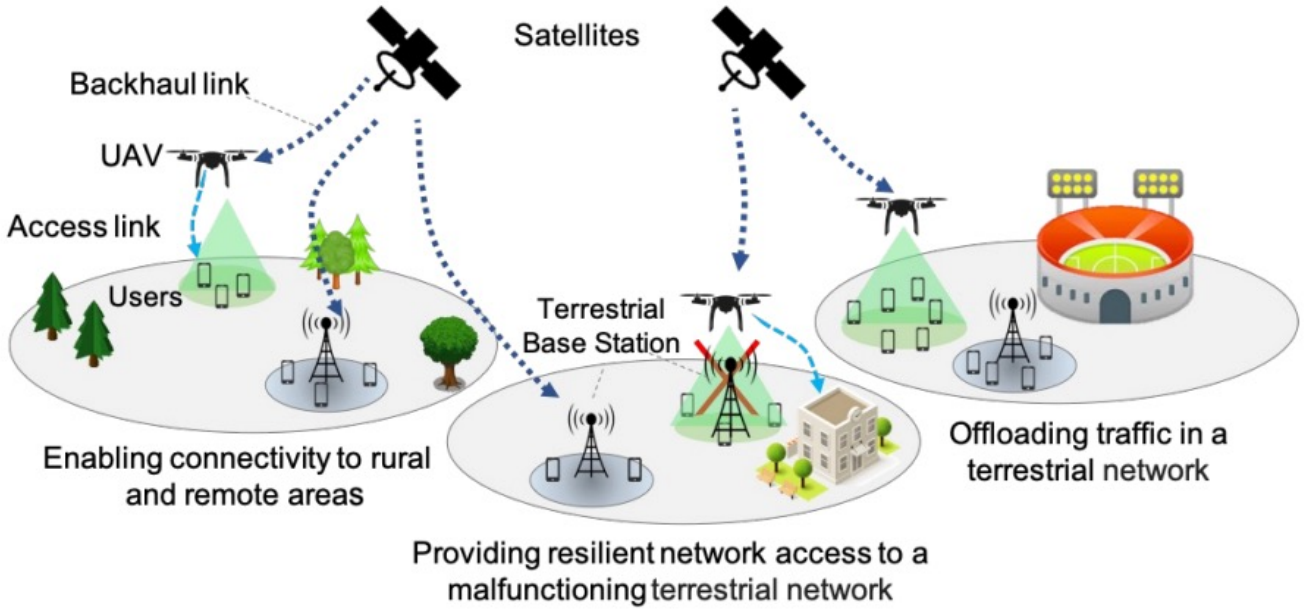


Autonomous Maintenance

- Equipping a satellite Internet infrastructure with autonomous maintenance (AM) capability offers ideal solutions to closing the management gap and providing uninterrupted Internet access.
- AM solutions can help ensure resilience and remove the barriers preventing users from accessing equitable and high-quality Internet connections.

Autonomous Maintenance (cont'd)

- Anomaly identification[1]-[4]
  - Space segment through time-series telemetry
  - Space-air-ground integrated networks
- Anomaly mitigation[5]-[7]
  - UAVs as aerial base stations to provide temporary connections to anomalous ground base stations.



[1] P. Hu, "Closing the Management Gap for Satellite-Integrated Community Networks: A Hierarchical Approach to Self-Maintenance," *IEEE Communications Magazine*, vol. 59, no. 12, pp. 43-49, December 2021.
[2] M. Sadr, Y. Zhu and P. Hu, "Satellite Anomaly Detection using Variance Based Genetic Ensemble of Neural Networks," *IEEE ICC 2023*, 28 May – 1 June 2023, Rome, Italy.
[3] M. Sadr, Y. Zhu and P. Hu, "An Anomaly Detection Method for Satellites Using Monte Carlo Dropout," *IEEE Transactions on Aerospace and Electronic Systems*, vol. 59, no. 2, pp. 2044-2052, April 2023.
[4] M. Sadr, Y. Zhu and P. Hu, "Multivariate Variance-based Genetic Ensemble Learning for Satellite Anomaly Detection," *IEEE Transactions on Vehicular Technology*, vol. 72, no. 11, pp. 14155-14165, Nov. 2023.
[5] A. Arani, P. Hu, and Y. Zhu, "HAPS-UAV-Enabled Heterogeneous Networks: A Deep Reinforcement Learning Approach," *IEEE Open Journal of the Communications Society*, vol. 4, pp. 1745-1760, 2023.
[6] A. Arani, M. Azari, P. Hu, et al., "Reinforcement Learning for Energy-Efficient Trajectory Design of UAVs," *IEEE Internet of Things Journal*, vol. 9, no. 11, pp. 9060-9070, 2022.
[7] A. Arani, P. Hu, and Y. Zhu, "Re-envisioning space-air-ground integrated networks: Reinforcement learning for link optimization," *IEEE ICC 2021*, 14–18 June 2021, Montreal, Canada.

Autonomous Maintenance

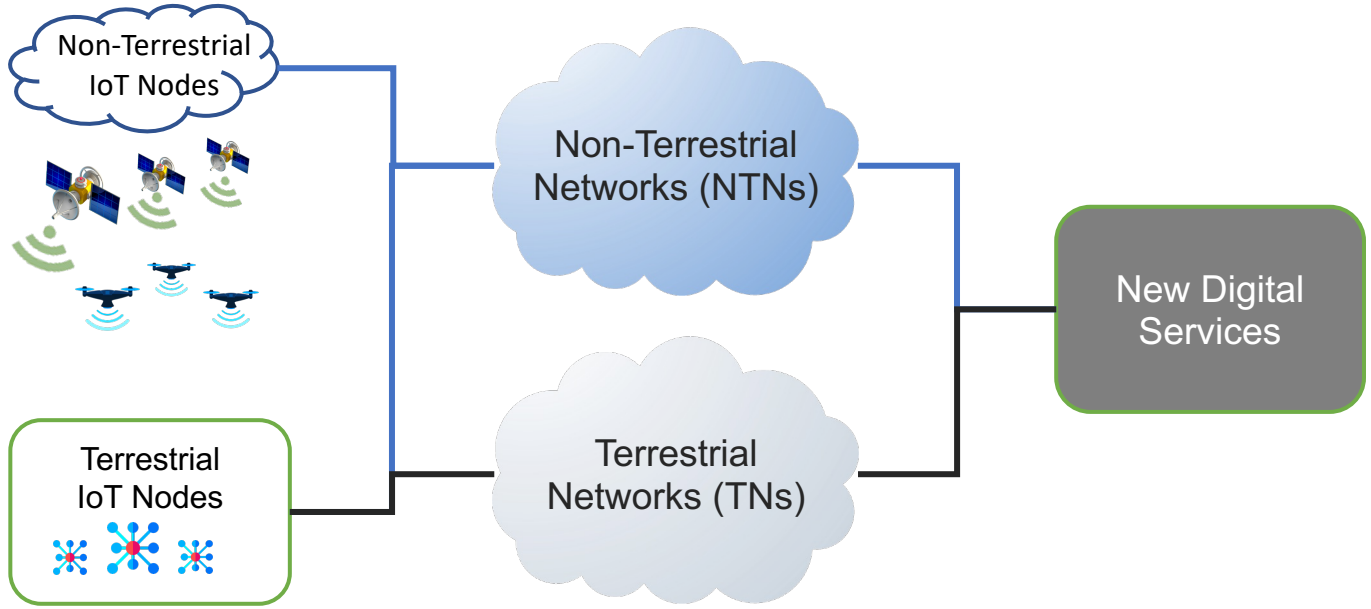
- Research directions:
  - Root cause analysis on LEO satellite networks.
  - Efficient anomaly identification and mitigation methods.
  - High-quality open dataset.

NTN-Integrated Networking

- NTN-integrated networking (NTN-IN): integrating NTN entities with TN entities for supporting network performance guarantees, management, and services.
- Research Directions:
  - Optimal placement of the ground infrastructures (e.g., IXPs, POPs, and EDCs) for consistent end-to-end performance assurance on the satellite Internet.
  - Software-defined networking-based LEO satellite networks: joint controller and gateway placement, flow setup time minimization, etc.
  - Resource management in the space-air-ground integrated networks.
  - NTN-based Open RAN can provide potential solutions to closing the management gap, while the architecture design, functional split optimization, and radio resource management are open research problems.

Support for New Digital Services

- New digital services:
  - New digital services that can utilize ubiquitous NTN-IN-based infrastructures.
  - New Internet of Things (IoT) deployments and applications in rural, remote, and hard-to-reach places.
  - Novel IoT applications in environmental monitoring, smart agriculture/aquaculture, etc.



Conclusion

- Advanced satellite Internet can help close the key urban-rural divide, but performance and management gaps must be resolved to close the digital divide.
- The proposed approaches can help close the proposed gaps and address the affordability and equity considerations.
- There is much room for improvement to achieve truly equitable, ubiquitous and high-quality Internet access and to unlock a broad spectrum of digital services for everyone.

THANK YOU!

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