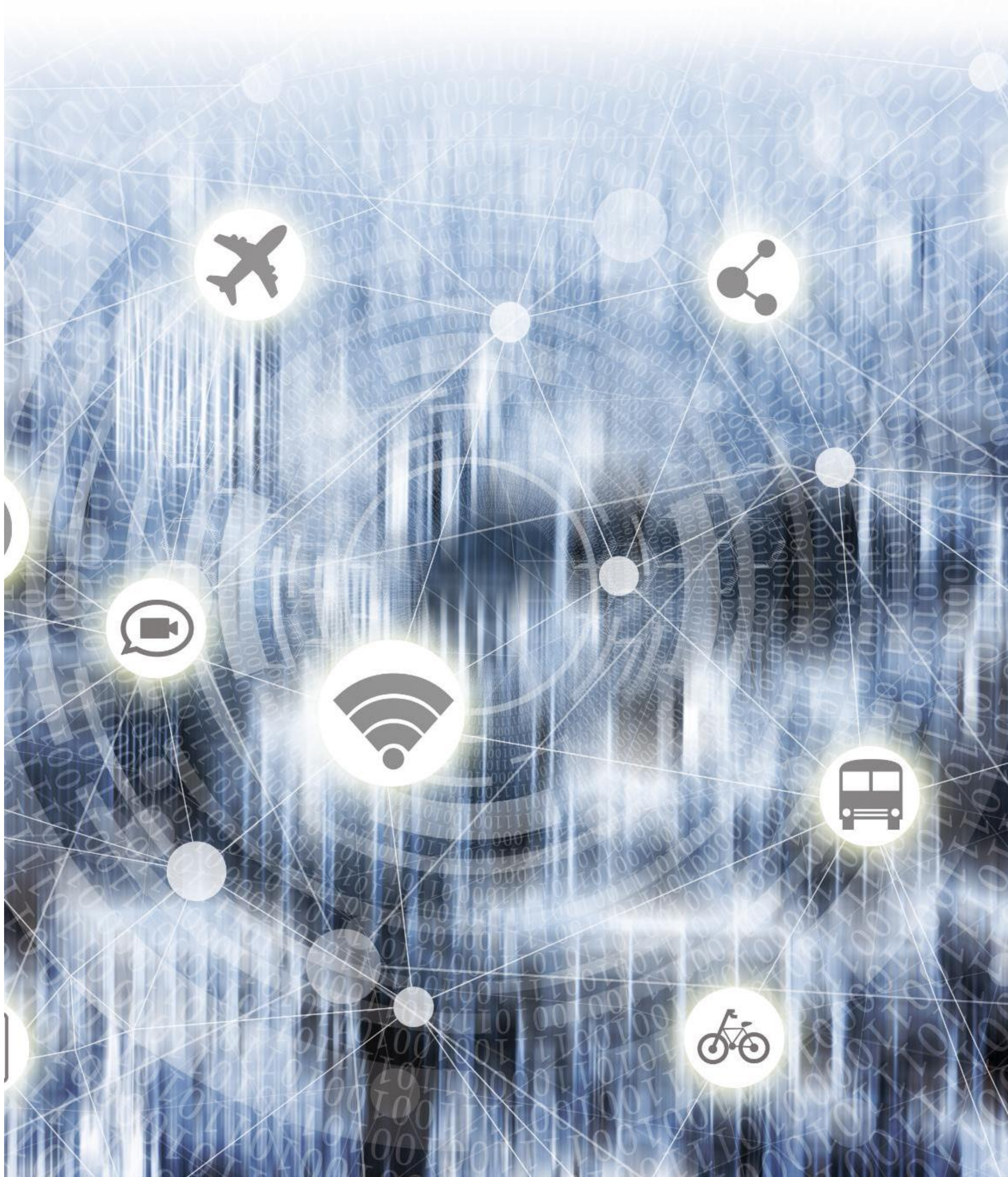
Connecting The Unconnected: Solving The Last-mile Challenge

Invited Talk

IEEE Connecting the Unconnected (CTU) Summit
Washington DC, 26 Sep 2025

Professor Saifur Rahman, IEEE Life Fellow
2023 IEEE President
ECE Dept., Virginia Tech



Date	Recent and Upcoming Presentations and Webinars	Webinar/Presentation Slides

26 September 2025

Washington DC

Connecting the Unconnected: Solving the Last-Mile Challenge
Invited Talk, IEEE Connecting the Unconnected (CTU) Summit

Globally there are numerous programs undertaken by UN agencies, national governments and NGOs to give last mile digital access to dispersed communities. The Green Digital Action Program run by the International Telecommunication Union is an example of such activities. The available technologies can be classified as follows.

Wireless Technologies

a. Fixed Wireless Access (FWA)
b. Mobile Networks (4G, 5G)
c. Wi-Fi Mesh Networks
d. TV White Space (TVWS)

Read more

Technology Options

Wireless Technologies

- Fixed Wireless Access (FWA)
- Mobile Networks (4G, 5G)
- Wi-Fi Mesh Networks
- TV White Space (TVWS)

Satellite Internet

- GEO Satellites (e.g., ViaSat, HughesNet)
- LEO Satellites (e.g., Starlink)

Hybrid and Emerging Technologies

- Community Networks
- Balloons/Drones (e.g., Project Loon, HAPS)
- Li-Fi (Light Fidelity)

Wireless Technologies

- Fixed Wireless Access (FWA)
- Mobile Networks (4G, 5G)
- Wi-Fi Mesh Networks
- TV White Space (TVWS)

Fixed Wireless Access (FWA)

Broadband Delivery Method
FWA provides high-speed internet using wireless signals between fixed base stations and customer equipment.

Last-Mile Connectivity Solution
FWA is ideal for suburban and rural or underserved areas where fiber or cable deployment is costly or difficult.

Rapid and Cost-effective Deployment
FWA enables quick and affordable internet rollout, helping bridge the digital divide globally.

Leveraging Cellular Infrastructure
FWA uses existing LTE or 5G cellular networks to deliver reliable and fast internet access.

Latency and Performance
Provides moderate latency suitable for video streaming and VoIP, but less ideal for ultra-low latency applications.

Mobile Networks (4G, 5G)

4G Network Capabilities
4G networks provide high-speed data transmission for video streaming, online gaming, and real-time communication.

5G Network Advancements
5G offers enhanced speed, lower latency, and higher capacity to support AR, VR, autonomous vehicles, and smart cities. 5G architecture includes small cells, massive MIMO, and beamforming to improve coverage and network efficiency.

Network Scalability and Access
Both 4G and 5G utilize existing cellular infrastructure, making networks scalable and accessible in urban and peri-urban areas. Deployment requires high budgets for infrastructure and licenses, yet user costs remain low due to economies of scale.

Regulatory Challenges
Spectrum auctions and licensing impose significant regulatory challenges on mobile network deployment and operation.

Latency and Applications
5G reduces latency below 10 milliseconds, enabling real-time applications like autonomous vehicles and remote surgery.

Wi-Fi Mesh Networks

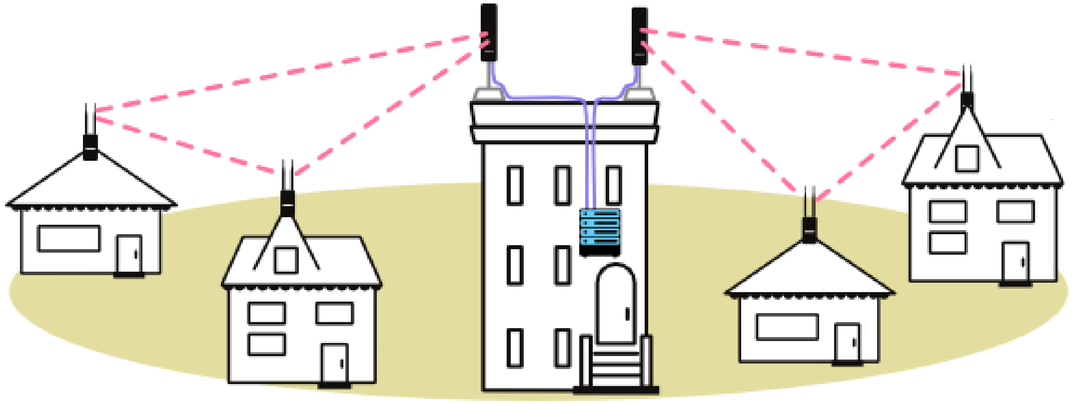
Multiple Interconnected Nodes
Mesh networks use multiple nodes to create a large wireless coverage area, unlike a single router setup.

Self-Healing, Adaptive and Consistent
If one node fails, traffic is rerouted automatically through other nodes, maintaining network stability. Mesh architecture distributes signals evenly, removing dead zones and ensuring consistent connectivity.

Geographical and User Suitability
These networks are ideal for high user density areas with short-range connectivity needs like campuses and communities.

Cost and Regulatory Benefits
Mesh networks are cost-effective using consumer hardware and open-source software, with minimal regulatory constraints

Performance and Latency Considerations
Latency is low within mesh, but may degrade with multiple hops or poor node placement impacting performance



Mesh antennas

TV White Space (TVWS)

Unused TV Frequencies
TVWS refers to unused television spectrum frequencies repurposed for wireless internet delivery. TVWS uses dynamic spectrum access to avoid interference with licensed TV broadcasts.

Long-Range Signal Reach
TVWS signals travel long distances and penetrate obstacles, ideal for remote and rural connectivity.

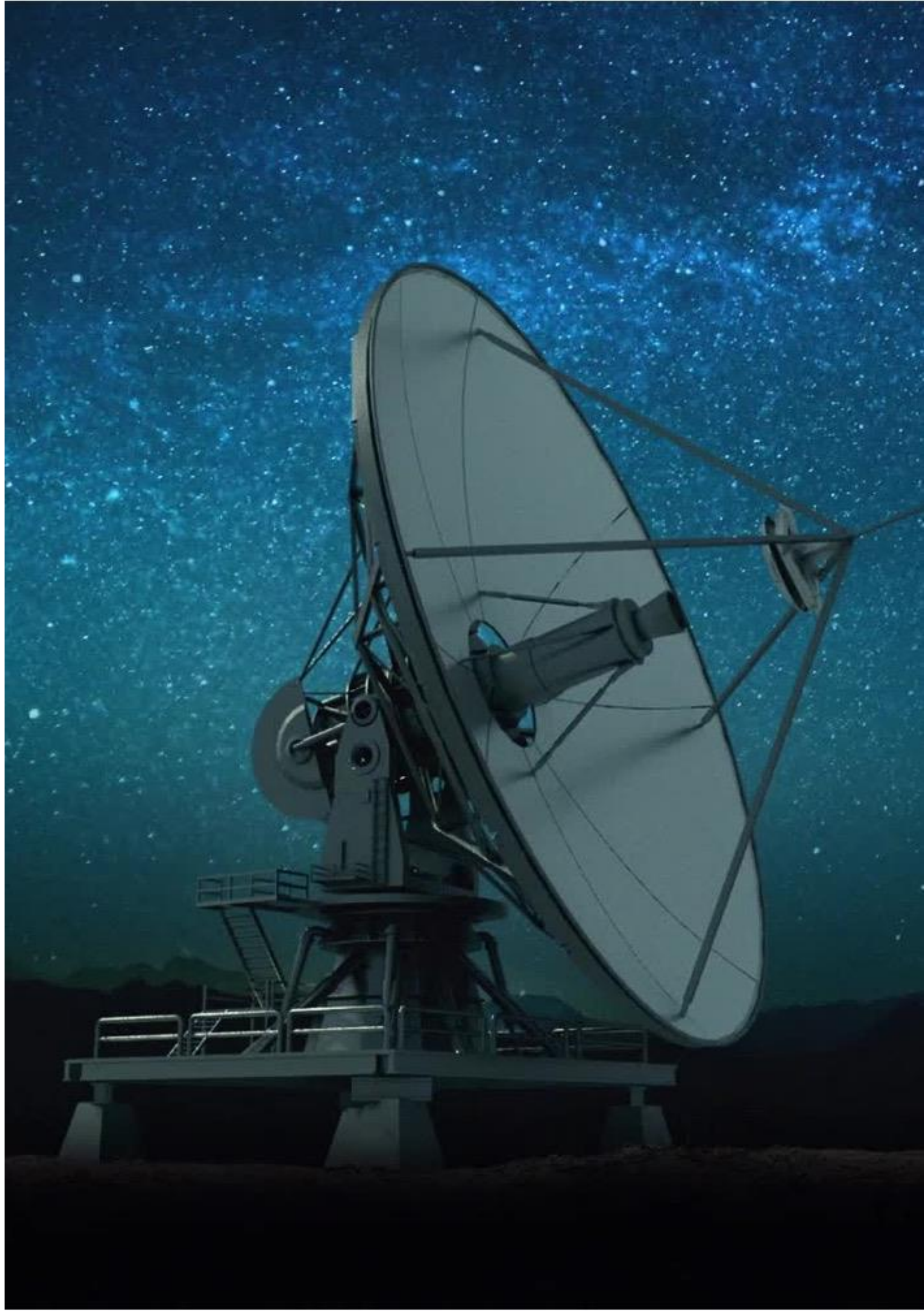
Affordable Internet Access
TVWS supports community networks and pilot projects to provide affordable internet in underserved areas.

Moderate Investment
TVWS requires moderate costs mainly for specialized radios and antennas to deploy connectivity.

Regulatory and Latency Considerations
Dynamic spectrum access requires regulatory approval; latency is moderate, suitable for basic internet uses.

Satellite Internet

- GEO Satellites (e.g., ViaSat, HughesNet)
- LEO Satellites (e.g., Starlink)



GEO Satellites (e.g., ViaSat, HughesNet)

Satellite Positioning and Coverage

GEO satellites orbit at 35,786 km, maintaining fixed positions to cover vast geographic areas providing broadband services effectively.

Internet Service Providers

Providers like ViaSat and HughesNet use GEO satellites to deliver broadband across remote and underserved regions.

Latency Challenges

High altitude causes latency around 600 milliseconds, impacting real-time applications such as video calls and gaming.

Cost-Effectiveness and Infrastructure

GEO satellites cover large regions cost-effectively but require significant investment in ground stations and technology.

Regulation

Strict regulatory compliance with international and national bodies.

LEO Satellites (e.g., Starlink)

LEO Satellite Characteristic
LEO satellites orbit between 500 and 2,000 km, moving rapidly across the Earth's sky enabling fast data transmission. SpaceX (7800+), Eutelsat (648), Amazon (100), China (3200+?)

Constellation Coverage
A constellation of LEO satellites provide continuous and scalable global coverage ideal for real-time communication, internet, cloud services, and connectivity in remote and rural areas.

Low Latency Benefits
LEO satellites deliver latency between 20-40 milliseconds, ideal for video calls, gaming, and real-time data.

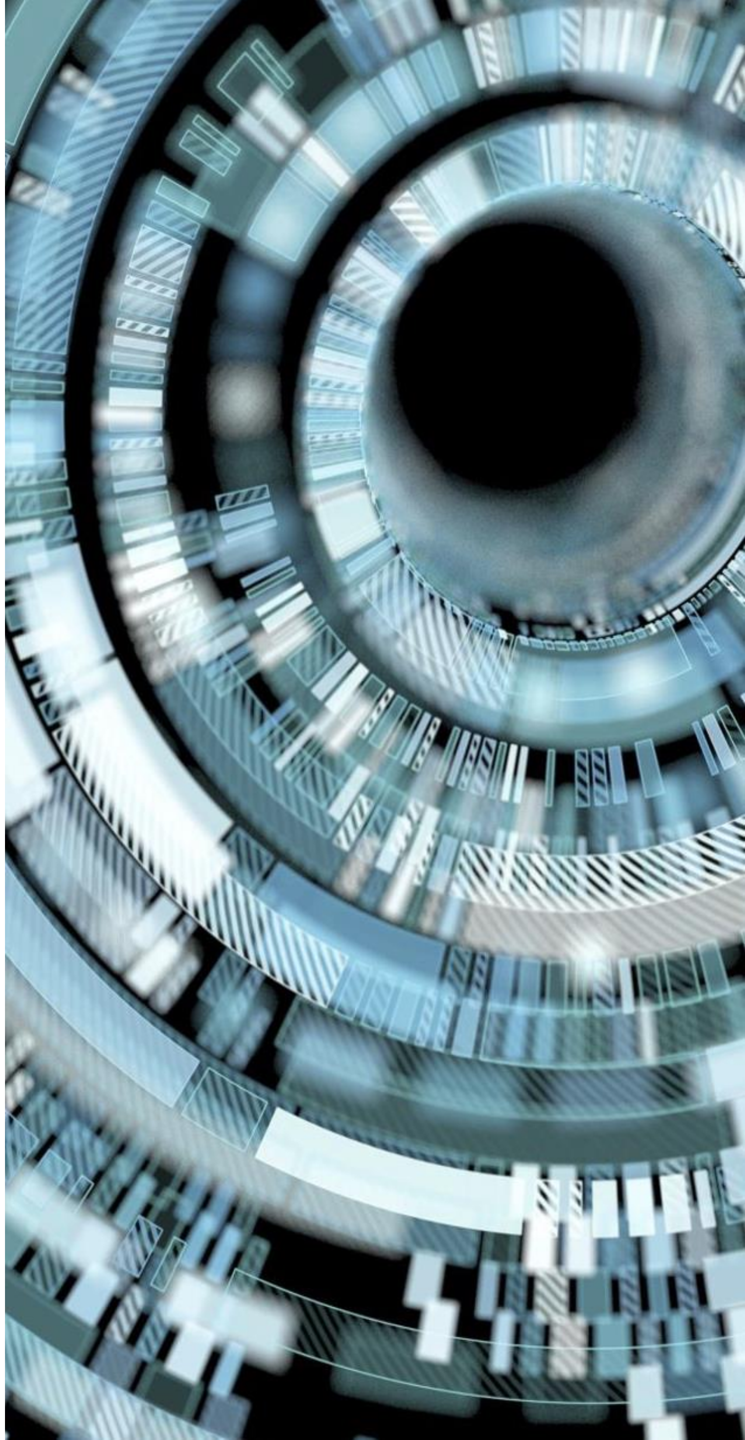
Infrastructure and Costs
Companies like AMN are providing backhaul services like 2G, 3G, LTE and Wi-Fi in rural Africa using Starlink kits as gateways.

Regulatory Challenges
Challenges include orbital coordination, spectrum management, and adherence to national and international regulations..

Starlink Kits	Hardware	Subscription
Rural Africa	$180 - $390	$28 -$53
Rural Asia	$200 - $500	$45 - $100
Rural USA	$175- $350	$85 - $120

Hybrid and Emerging Technologies

- Community Networks
- Balloons/Drones
- Li-Fi (Light Fidelity)



Community Networks

Grassroots Initiative
Community networks are built, owned and maintained by local residents using affordable, open-source technologies.

Target Areas
They serve rural, indigenous, and low-income urban areas where commercial internet providers are absent.

Technology
Mesh networks, Wi-Fi hotspots, small-scale broadband.

Funding and Budget
Community networks operate on low budgets supported by donations, grants, and community contributions.

Digital Inclusion Impact
These networks empower locals by fostering digital inclusion and promoting self-reliance. The Zenzeleni Community Network in Rural South Africa offered unlimited for R25/month ($1.50)

Challenges
Funding, technical expertise, regulatory support.

Wi-Fi Hotspot in Zenzeleni Community (South Africa) Network

Installation of equipment Community Internet Network in Indonesia. Source: Asia Pacific Network Information Centre APNIC

Balloons and Drones
High Altitude Platform Stations (HAPS)

Stratospheric Connectivity Platforms
HAPS Balloons and Drones fitted with telecom transceivers operate in the stratosphere (20-50 km altitude) well above commercial air traffic and weather disturbances. They are capable of remaining in a stable and fixed position for long durations (weeks to months) providing continuous telecommunication coverage over a wide area.

Geographic Deployment Benefits
Ideal for temporary connectivity in remote or disaster-affected regions lacking infrastructure.

Advantages
Rapid deployment and wide coverage over inaccessible regions during emergencies.

Budget, Regulatory and Other Challenges
High costs and regulatory hurdles include airspace management and spectrum licensing coordination. HAPS Alliance promoting the use of HAPS for last-mile connectivity.

Latency and Potential Uses
Moderate latency systems hold promise for emergency response and bridging connectivity gaps.

Li-Fi (Light Fidelity)

Visible Light Communication
Li-Fi uses visible light to transmit data, enabling communication where radio waves are restricted or undesirable.

Indoor Connectivity
Li-Fi is ideal for indoor spaces like offices, hospitals, and aircraft, offering secure and efficient communication.

Low Latency and Regulation
Li-Fi features extremely low latency and minimal regulatory constraints due to its use of unregulated visible light spectrum.

Cost-Effective Implementation
Leveraging existing LED infrastructures makes Li-Fi a budget-friendly option for high-speed data transmission. Potential for integration with smart lighting and IoT. Li-Fi devices expected on market by 2029. Standardization led by IEEE 802.11bb Global Light Communications Standard.

Limitations
Requires line-of-sight, affected by obstructions.

Comparative Overview of Technologies

TECHNOLOGY	GEOGRAPHY	BUDGET	REGULATION	LATENCY
FWA	Suburban/Rural	Moderate	Licensed Spectrum	Moderate
Mobile (4G/5G)	Urban/Suburban	High	Strict Licensing	Low (5G)
Wi-Fi Mesh	Urban/Community	Low	Unlicensed	Low
TVWS	Rural	Moderate	Dynamic Access	Moderate
GEO Satellite	Remote	High	International	High
LEO Satellite	Global	High	Complex	Low
Community Net	Underserved	Low	Varies	Variable
Balloons/Drones	Remote/Disaster	High	Airspace/Spectrum	Moderate
Li-Fi	Indoor	Low	Minimal	Very Low