Communication in Distributed Systems

3 Backhaul Technologies

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HTTP over UDP: an Experimental Investigation of QUIC

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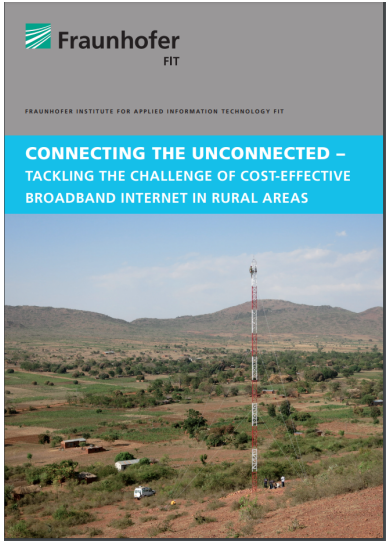
Talking Points:

- What is the goal of this paper?
- What is SPDY and what is the main drawback?
- QUIC implements retransmissions and congestion control at the application layer. Why?
- What is a CID in the context of QUIC?
- At the Experiment with L = 0%. Why are there lost packets?
- Explain the result in Figure 5d.

Backhaul Technologies

Further Material

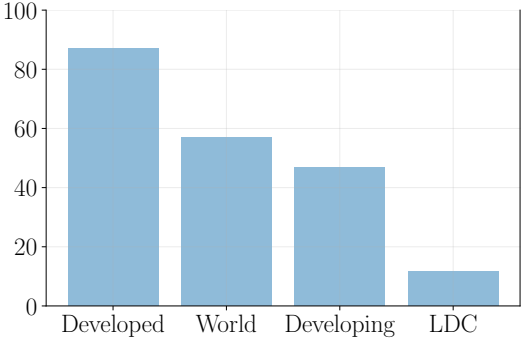


The following is based on [4], a sponsored study where I participated.

Motivation: Internet in Rural Areas

1. Motivation: Internet in rural areas

Only **57%** of people on the **globe** and only **11.8%** of people in **least developed countries** live in a household with Internet (2019) [1].

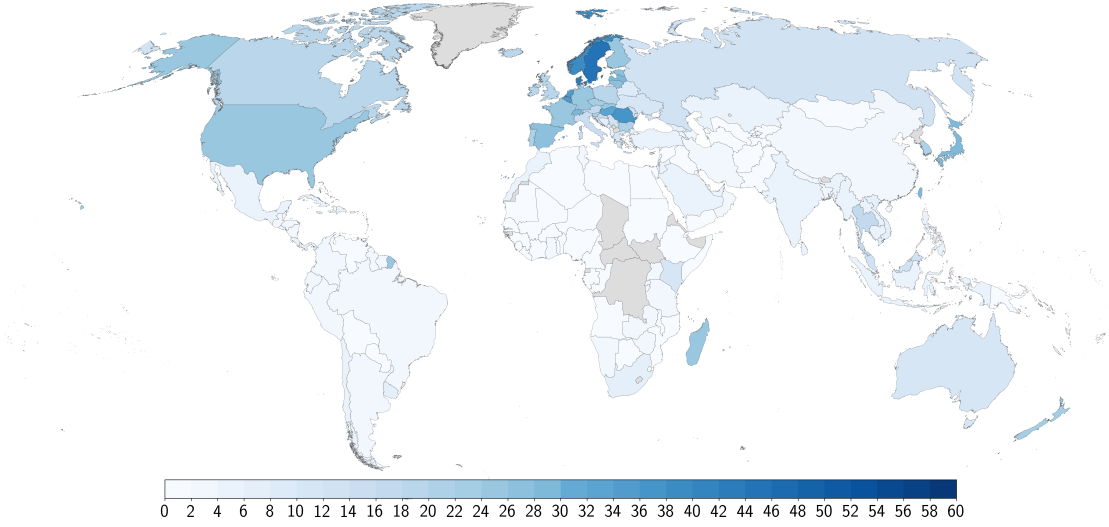


ITU-T Measuring digital development (2019) [1]

Three barriers for Internet adoption:

- **Affordability**: **Profitability gap for Internet Service Providers (ISPs) (civil engineering)**
- **Appetite**: The lack of relevant online content and missing populations awareness
- **Ability**: The lack of local Information and Communication Technologie (ICT)-Skills

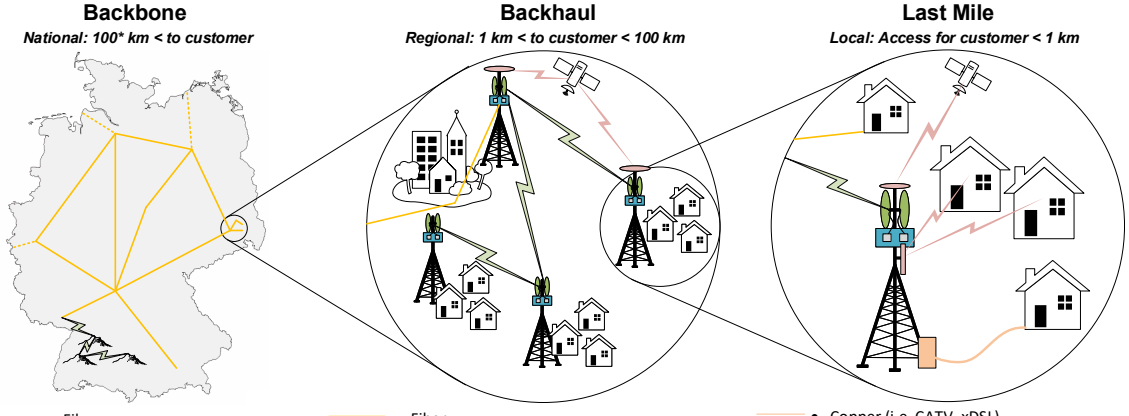
1. Motivation: Internet in rural areas



Average Internet connection speed in Mbps (2017)

Overall Network architecture

Network architecture



- Backbone — National Backbone Networks (high speed, redundant)
- **Backhaul — Distribution Networks connecting Points of Presence to the Backbone**
- Last Mile — Access Networks connecting homes

Network architecture - General remarks

- **Stable, redundant Backbone networks are crucial**
- There are no (longer-term) alternatives to either Fiber or, in some cases, MicroWave.

- The longer the distance between two points, the lower the throughput.
- Wireless domain: trade-off between capacity and overall costs.
  - Longer range connections require less infrastructure on the ground.

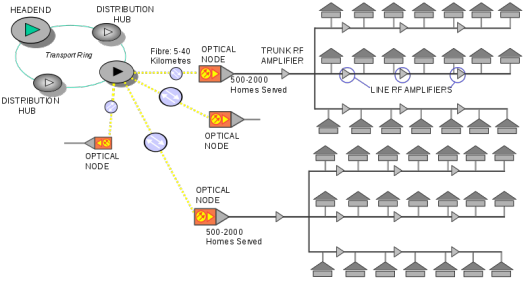
- **Point To Point (P2P) architectures provide higher capacity but require more equipment**.
- **Point To Multipoint (P2MP) architectures imply lower per-user costs as well as capacity since multiple users share the medium (air or cable)**.

- Common criteria for each possible network segment (**qualitative!**):
  - Technology Readiness Level (TRL) (−− − ± + ++)
  - Quality of Experience (QoE) (−− − ± + ++)
  - Costs — CAPEX and OPEX on a per-user basis ($ $-$$ $$ $$-$$$ $$$)
- **Top-down approach from common to innovative solutions based on [4]**

Cable Television (CATV) and Digital Subscriber Line (DSL)

Cable Television (CATV) and Digital Subscriber Line (DSL)

- **DSL and CATV are by far the most common broadband access technologies**
- When cable-based provisioning has not yet begun, investments in copper or coaxial is unlikely to be considered!



https://de.wikipedia.org/wiki/Hybrid_Fiber_Coax

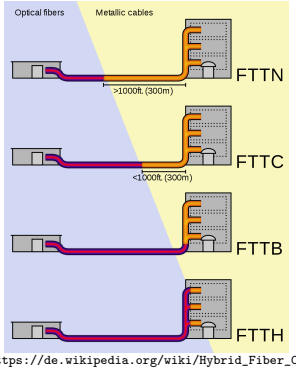
- DSL technologies use copper wires
  - Main challenge: Signal attenuation at longer distances (about >2km)
- CATV technologies use coaxial cables
  - Main challenge: P2MP technology where the users share the capacity of the cable

Segment	Favored	QoE	Costs	Supplement	TRL	Remarks
Backhaul	✗	−−	$-$$	Fiber	++	
Last Mile	✓	+	$	✗	++	CPE, Consider only if present

Fiber

Fiber

- Symmetric transmission rates of up to hundreds of GBit/s even on long distances.
- **The deployment of fiber as close to the customer as possible is the best solution for a future-proof network and alternatives should only be considered where a pure fiber solution (Backbone, Backhaul and Last Mile) is not economically feasible.**
- Fiber-To-The-X (FTTX):
  - Fiber-To-The-Node (FTTN)
  - Fiber-To-The-Curb (FTTC)
  - Fiber-To-The-Building (FTTB)
  - Fiber-To-The-Home (FTTH)



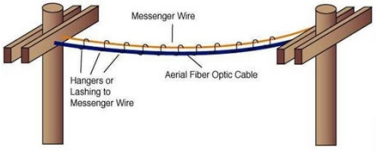
https://de.wikipedia.org/wiki/Hybrid_Fiber_Coax

Segment	Favored	QoE	Costs	Supplement	TRL	Remarks
Backbone	✓	++	$$-$$$	(MiroWave)	++	Mandatory mid-term
Backhaul	✓	++	$$-$$$	Directional Wireless	++	Mandatory long-term
Last Mile	✓	++	$$$	Copper, Cellular, WiFi Mesh	++	CPE, Often too costly

Fiber - Cost reductions

- **The costs of the optical fiber itself is relatively low.**
- The main cost driver in rural areas are the required civil engineering **(up to 90%)** and scarce qualified staff for splicing the interconnections.
- **Goal is to minimize digging.**

Aerial fiber:



http://www.unitekfiber.com/fiber-optic/aerial-fiber-optic-cable/

DigOnce:

https://primex.com/four-policies-that-can-speed-up-fiber-adoption/

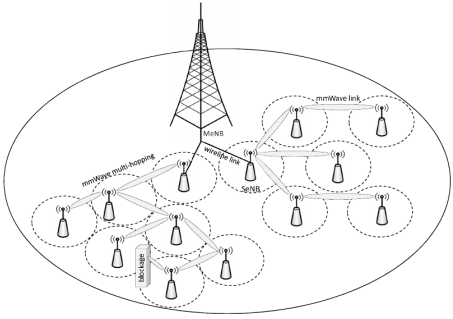
Micro-Trenching:

https://www.yesrus.com/fiber-optic-solutions-blog/microtrenching-the-low-impact-buried-plant-method

Cellular

Cellular / Mobile Networks (2G/3G/4G/5G)

- P2MP architecture where each cell is served by one base station.
- Base station requirements to be effective:
  - Exposed location
  - Stable electricity
  - **High-speed interconnection to the Backbone**



Millimeter-Wave Multi-Hop Wireless Backhauling for 5G Cellular Networks [6].

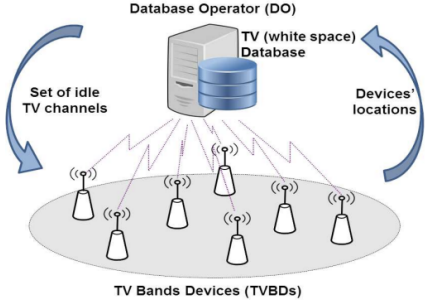
- Urban Areas: Last Mile Access network
- Rural Areas: Macro-cells of up to 30km range or **self-backhauling** to avoid the need for a Backhaul infrastructure.
- **5G promises a radical increase in the peak rates. However, current research efforts (i.e. mmWave) and standardization are focused on high density urban scenarios [2].**

Segment	Favored	QoE	Costs	Supplement	TRL	Remarks
Backhaul	✗	–	$$-$$$	Directional Wireless, Fiber	++	Macrocell
Last Mile	✓	+	$$	WiFi Mesh/HotSpot	++	Smallcell

TV White Spaces

TV White Spaces

- The term **White Space** refers to frequencies typically allocated to TV broadcasting services which are not or no longer in use at certain locations.
- Although many of those frequencies are not being used, typical regulatory regimes prohibit their use for alternative purposes such as *rural broadband*.



http://doi.org/10.1109/TVT.2016.2597866.

- Idea: Dynamic Spectrum Management with Cognitive Radio Networks.
- Allow secondary user to utilize the frequency when not needed locally:
  - Establish a nationwide **database** with *White Spaces*
  - Establish **spectrum sensing** of the User Equipment (UE).

Segment	Favored	QoE	Costs	Supplement	TRL	Remarks
Backhaul	✗	—	$	Directional Wireless, Fiber	—	CPE, Macrocell

Directional Wireless

Directional Wireless (Licensed and License-exempt)

- P2P links.
- Cost-effective wire-like alternative in the Backhaul to connect Last Mile technologies to the Backbone.
- Different bands (licensed or license-exempt):
  - 5 GHz (i.e WiFi)
  - 24 GHz (MicroWave)
  - 60 GHz (mmWave)
- The advantage of, often costly, **licensed** spectrum is that the license holder has exclusive usage rights.
- Multiple users might compete for the same resource in the **license-exempt** case which may affect the predictability of the channel and therefore crucial parameters such as capacity and latency.

www.commsmea.com/15067-comba-telecom-launches-4g-lte-base-station-antennas

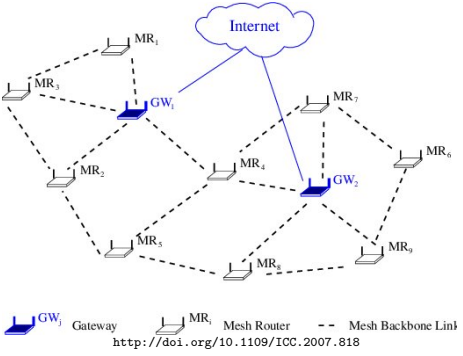
- **Mobile base stations are often provisioned via P2P wireless links.**

Segment	Favored	QoE	Costs	Supplement	TRL	Remarks
Backbone	✗	–	$$	Fiber	++	
Backhaul	✓	+	$$	Fiber	++	
Last Mile	✗	+	$$$	✗	+	CPE

Wi-Fi Mesh

Wi-Fi Mesh / HotSpot

- Wireless Mesh Networks (WMNs) operate in license-exempt bands using off-the-shelf WiFi routers which greatly reduce the overall costs.
- Decentralized protocol design
- **Depending on the number of uplink connections to the Internet, important links in a WMN can quickly become a bottleneck**
- **Single Radio vs. Dual Radio vs. Multi-Radio**
  - Performance vs. Complexity



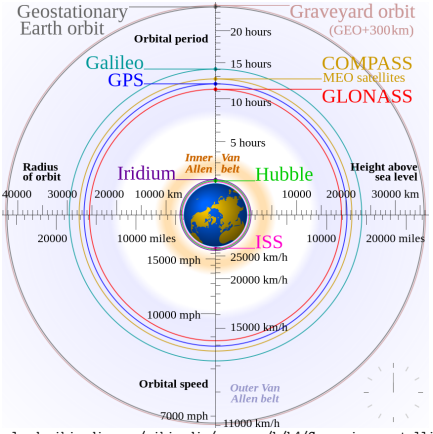
- **Properly designed, WMN are suitable for community networks where users become the operators of their own infrastructure (i.e. Freifunk).**

Segment	Favored	QoE	Costs	Supplement	TRL	Remarks
Backhaul	✗	–	$$-$$$	Directional	±	Multi-Radio nodes possible
Last Mile	✓	±	$-$$		+	Maybe CPE for in-door coverage

GEO Satellites

Satellites - Geosynchronous Earth Orbit (GEO)

- Geosynchronous Earth Orbit (GEO) satellite systems (orbit at 35700 km) have been in use for decades.
- **New Idea:** use higher frequencies (27 to 40 GHz) and multiple but relatively small spot beams to achieve high aggregated capacities.
- The main issues with GEO satellite communication is the typical RTT more than 500 ms seconds:
  - **Less suitable for voice or real-time data.**
  - **Even web surfing feels sluggish.**



https://upload.wikimedia.org/wikipedia/commons/b/b4/Comparison_satellite_navigation_orbits.svg

Segment	Favored	QoE	Costs	Supplement	TRL	Remarks
Backbone & Backhaul	✗	−−	$$-$$$	Cellular, WiFi	++	
Last Mile	✗	−−	$$	✗	++	CPE

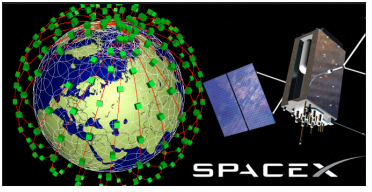
Alternative Networks

Alternative Networks: Overview

- "Alternative Networks" are currently evaluated [7]
- Global players aiming to attract the untapped markets
- Viable technical information vs. immense media coverage

Google Project Loon

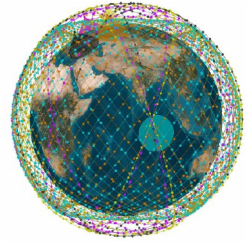
Facebooks "Aquila"



OneWeb, SpaceX

Satellites - Medium Earth Orbit (MEO) and Low Earth Orbit (LEO)

- MEO or LEO systems operate in lower orbit (between 160 km and 2000 km) - significantly reduce the RTT.
- Medium Earth Orbit (MEO) or Low Earth Orbit (LEO) actors such as OneWeb (and similarly also SpaceX or O3b) claim to be closing the *digital divide* by launching constellations of numerous satellites that could provide continuous Internet service to almost all areas of the earth.

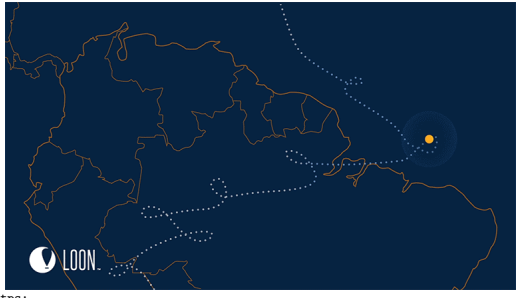


http://doi.org/10.1016/j.actaastro.2019.03.040

- **Challenges**:
  - Questionable Business Cases (for example OneWeb):
    - Rural population density of Sub-Saharan Africa: 26 people per km^2, Beam-width per satellite 1 Million km^2, capacity of 7.2 Gbps, overbooking-factor 200 = **55.4 kbs per person**
  - The handover of ground stations, inter-satellite communication as well as signaling to the ground at high speeds while maintaining a high throughput.
  - Market-dominating power of single satellite ISPs
  - Space debris in the lower earth orbit

HAPs - Drones and Balloons

- The altitude is much lower (20 km) and the cell size is therefore smaller (5000 km^2) compared to Low Earth Orbit (LEO).
- 4G cell from the sky.
- Balloons: prone to dynamic drag while in the air.
- To maintain a quasi-stationary position: drones need to circle above the coverage area which requires energy.
- To completely cover the area of Sub-Saharan Africa, more than 5000 High-Altitude Platforms (HAPs) would be needed assuming that HAPs could permanently maintain their current position.



https://medium.com/loon-for-all/1-million-hours-of-stratospheric-flight-f7af7ae728ac

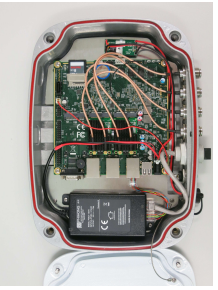
Alternative Networks: WiFi-Based Long-Distance Networks

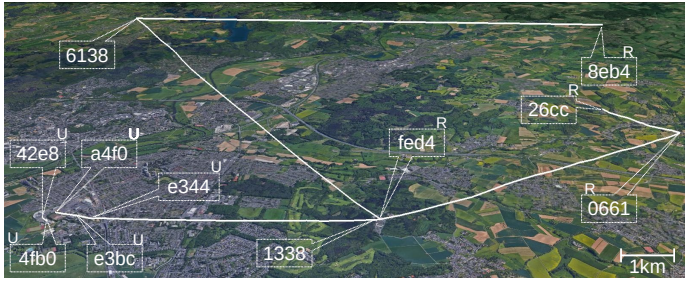
WiFi transmitter and directional antennas ...

- Inexpensive (low CAPEX)
- Unlicensed bands (low OPEX)
- Low energy consumption (Wind and Solar)

... used in a Coordinated Wireless Backhaul Network (WBN) [5].

$\approx$ 2000 networks in the US [3]





Reading for next week

Reading for next week

Alternative Networks: Toward Global Access to the Internet for All

Jose Saldana, Andrés Arcia-Moret, Arjuna Sathiaseelan, Bart Braem, Ermanno Pietrosemoli, Marco Zennaro, Javier Simó-Reigadas, Ioannis Komnios, and Carlos Rey-Moreno

Abstract: It is often said that the Internet is ubiquitous in our daily lives, but this holds true only for those who can easily access it. In fact, billions of people are still digitally disconnected, as bringing connectivity to certain zones does not make a good business case. The only solution for these unsatisfied potential users is to directly undertake the building of the infrastructure required to obtaining access to the Internet, typically forming groups in order to share the corresponding cost. This article presents a global classification and a summary of the main characteristics of different Alternative Network deployments that have arisen in recent years with an aim to provide Internet services in places where mainstream network deployments do not exist or are not adequate solutions.[7]

Video to watch:

Using ground relays with Starlink

`https://www.youtube.com/watch?v=m05abdGSOxY`

Thank you for your attention.
Are there any questions left?

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References I

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The Essential Role of Fixed Wireless in Universal Broadband Coverage, October 2015.

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Connecting the Unconnected Technical options and constraints for economically feasible broadband connections in rural areas.
Tech. rep., Fraunhofer-Institut für Angewandte Informationstechnik FIT, Sankt Augustin, 2019.

[5] Mannweiler, C.
Context-Enabled Optimization of Energy-Autarkic Networks for Carrier-Grade Wireless Backhauling.
phdthesis, TU Kaiserslautern, 2015.

[6] Sahoo, B., Yao, C.-H., and Wei, H.-y.
Millimeter-wave multi-hop wireless backhauling for 5g cellular networks.

References II

[7] Saldana, J., Arcia-Moret, A., Sathiaseelan, A., Braem, B., Pietrosemoli, E., Zennaro, M., Simo-Reigadas, J., Komnios, I., and Rey-Moreno, C.
Alternative Networks: Toward a Global Access to the Internet for All.
IEEE Commun. Mag. (2017), 2–8.