Building Flexible, Low-Cost Wireless Access Networks with Magma

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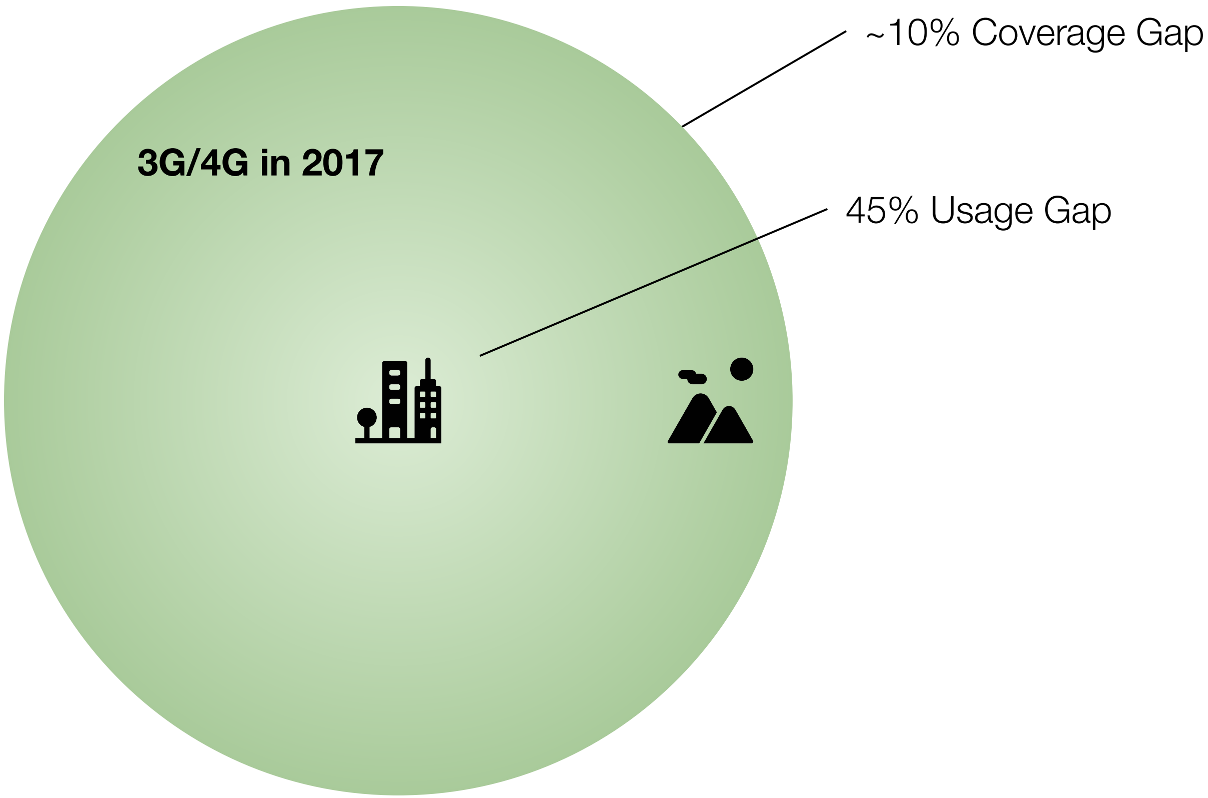
Thanks!

Meta Connectivity, FreedomFi, AccessParks, Linux Foundation, Telefonica, Kroton Peru, BRCK, MuralNet, and the entire Magma developer and user community!

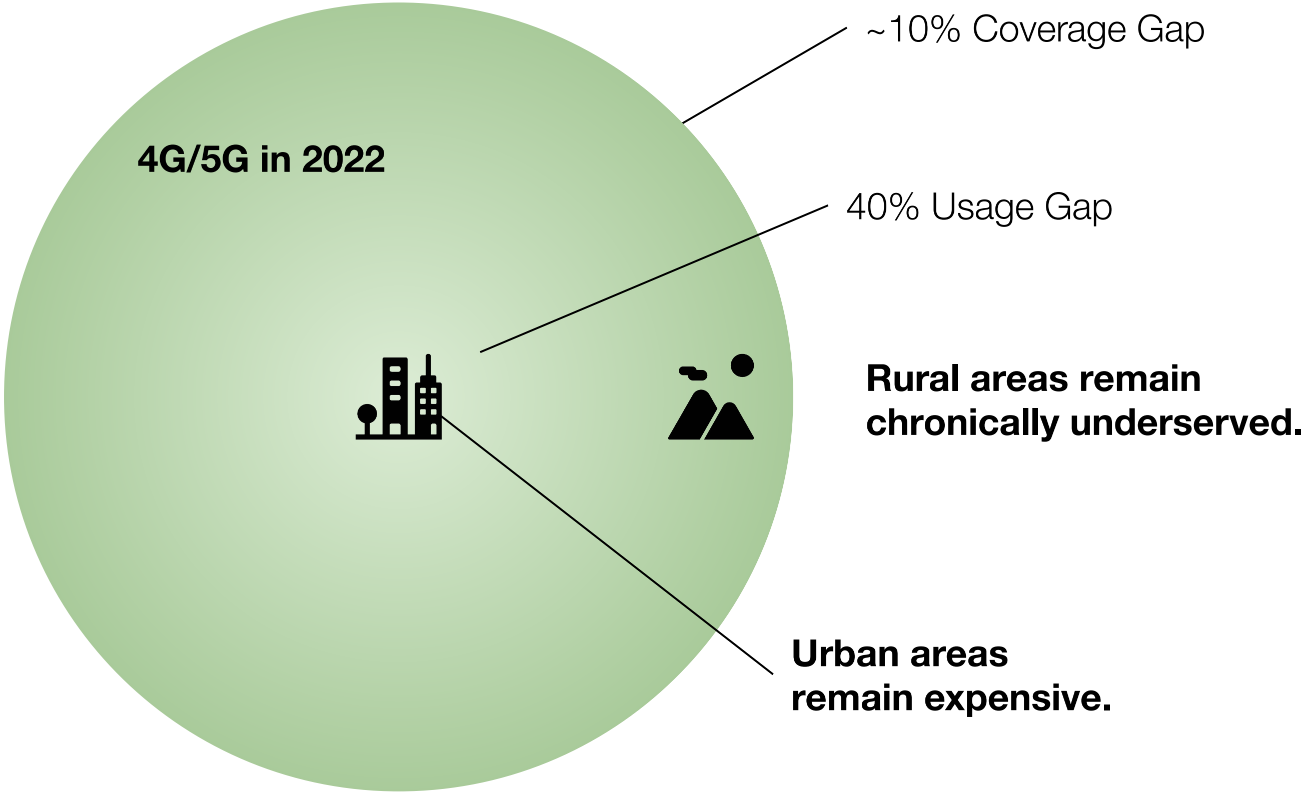
Extra thanks to co-authors Amar Padmanabhan and Bruce Davie for some of the slides/figures in this talk.

Cellular: the most successful **real networks**?

- Cellular networks cover **>97%** of world population
- **5+ billion** people and **20+ billion** devices on cellular networks
- **100 exabytes** transferred on cellular networks… per month!
- The **primary** way most humans connect to the Internet



Source: GSMA, “The State of Mobile Internet Connectivity 2022”



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Why is this the case?

Rural areas remain chronically underserved

- Lack of backhaul to cellular towers
- Lower population density
- Lack of reliable electricity
- Lower overall return on investment

Urban areas remain expensive

- Increasing demand requires densification
- Infrastructure upgrades are costly
- Network updates are difficult
- Barriers to entry reduce competition

How can we **reduce costs**, **enable competition**, and **improve reliability and scalability**?

Going beyond the cellular edge: An example from Peru

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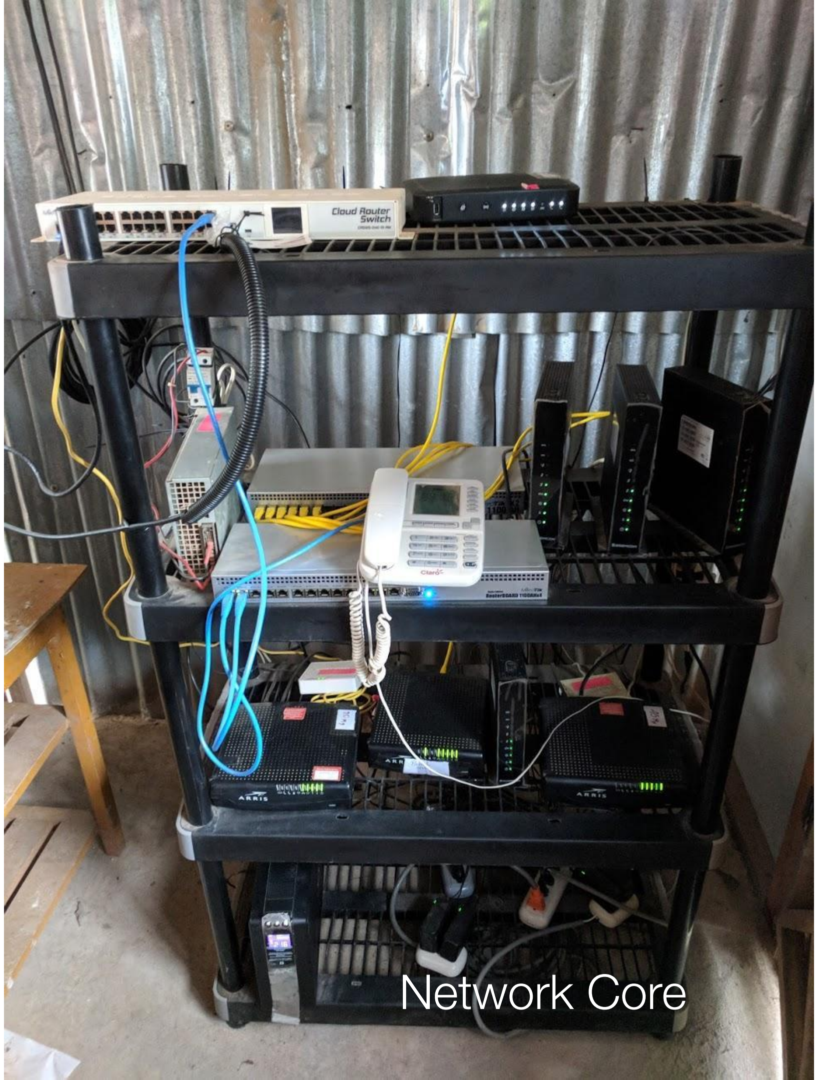
Going beyond the cellular edge: An example from Peru

Pucallpa, Ucayali, Peru

Wireless ISP Tower


Air1 Central Office
Outskirts of Pucallpa


Power Backup



Network Core


Microwave Relay (~40km)

Puerto Bermudez, Pasco, Peru (~200km)


Power Backup


WiFi Last Mile

Why does Air1 use WiFi instead of cellular?

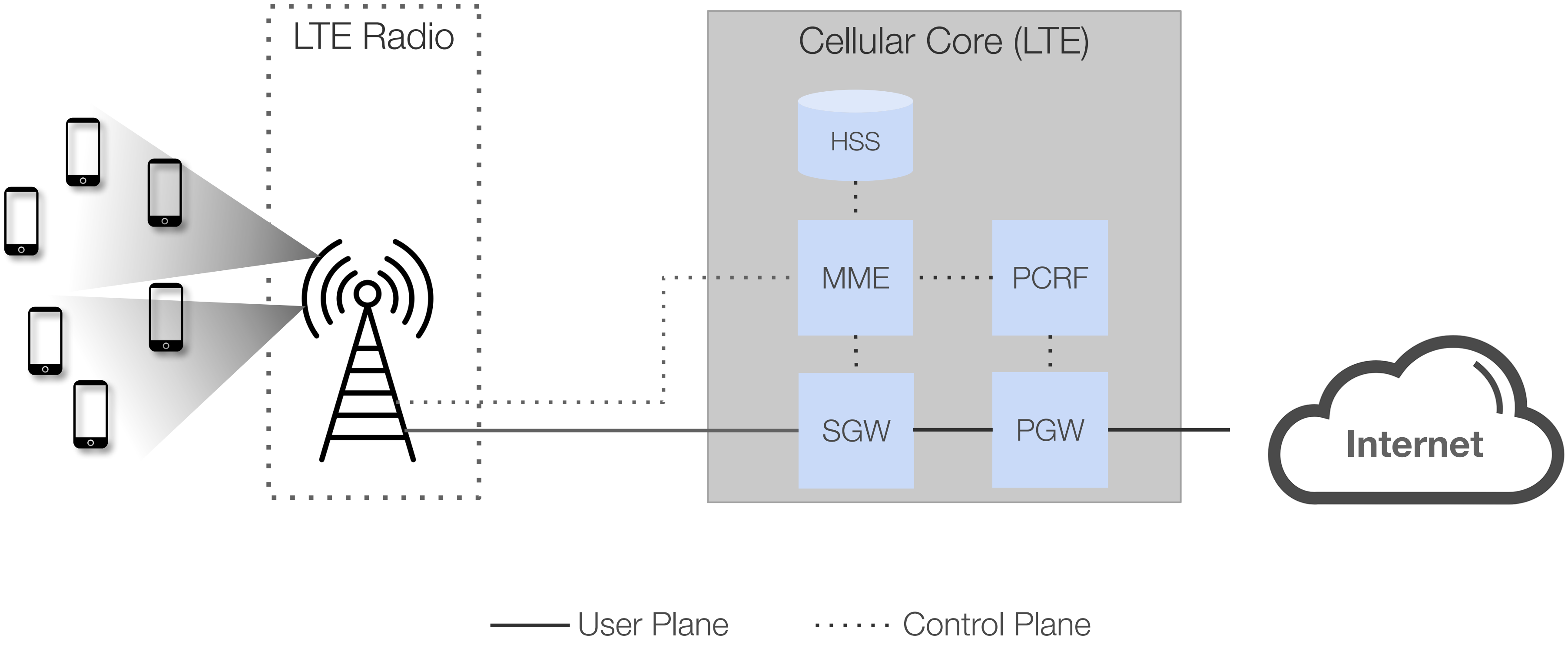
	WiFi	Cellular
Last mile coverage	Low: 10-100m per AP	High: 1-10km+
Scalability	Low: intended for local networks	High: commonly used to build nation-scale networks
Richness of policy support	Low: best-effort access	High: complex QoS policies
Barrier to entry	Minimal: home networks, rural ISPs	High: requires packet core!

This high barrier to entry manifests in many ways…

- Difficult to get started: cellular cores are complicated!
- Expensive to get started: cellular cores are expensive!
- Locked into the 3GPP world: a completely new vocabulary than the Internet
- **Stuck with a network architecture intended for large, nation-scale network operators!**

The choice of **radio technology** should not define an operator’s **network architecture.**

Traditional cellular relies on **centralized** core networks



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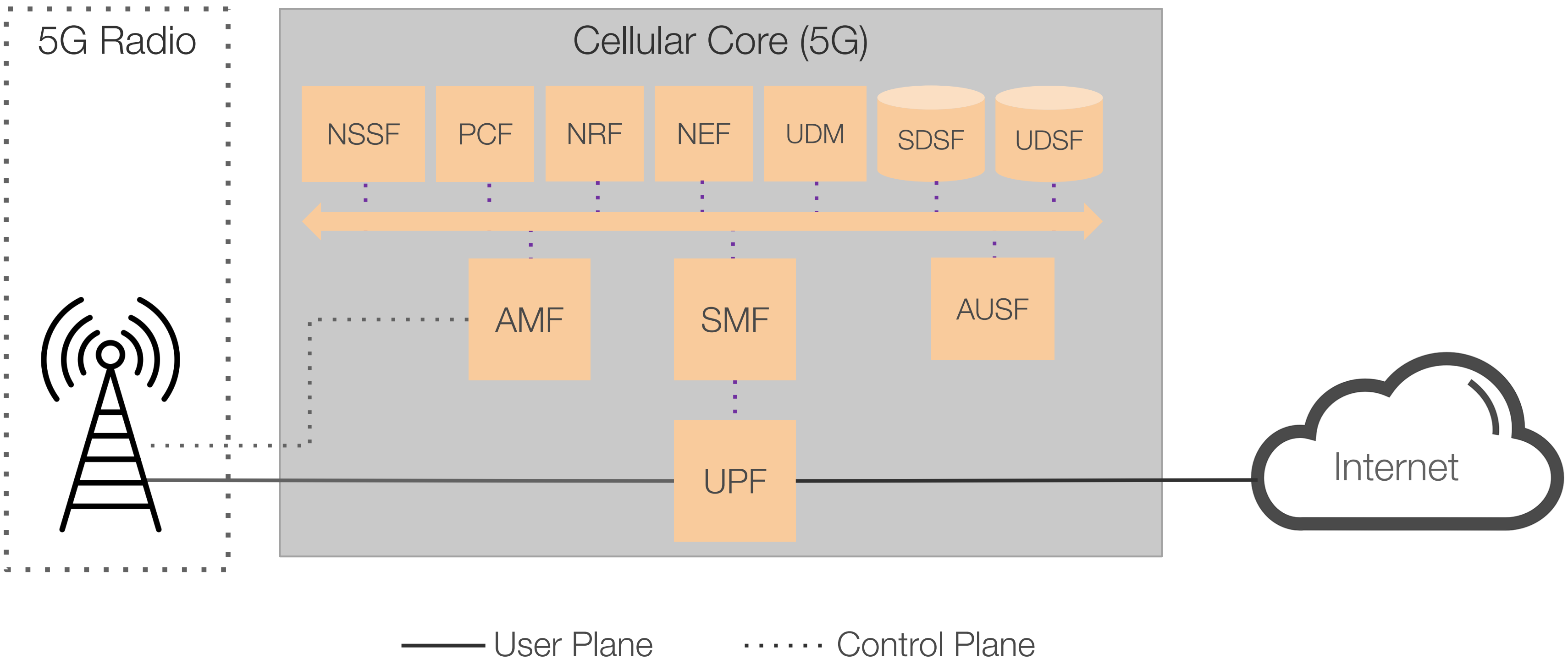
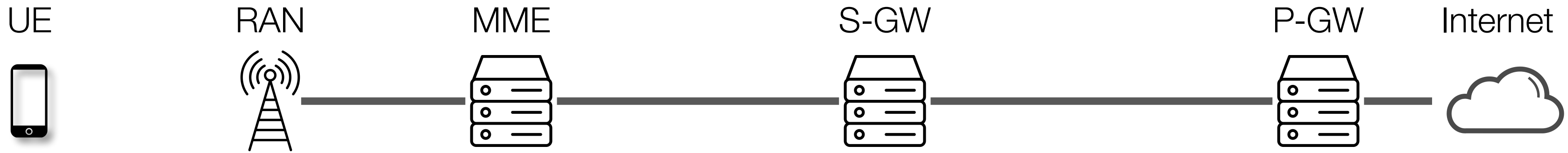


Traditional cellular cores **leak state** across elements



NAS State

UE Identifiers

APN Profiles

Auth vectors

Bearer state

Idle state buffering

UE IP Address

Policy enforcement

Bearer state

“I am connected to this network”

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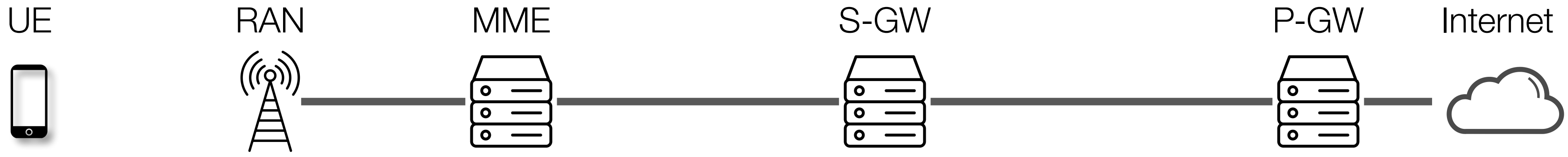
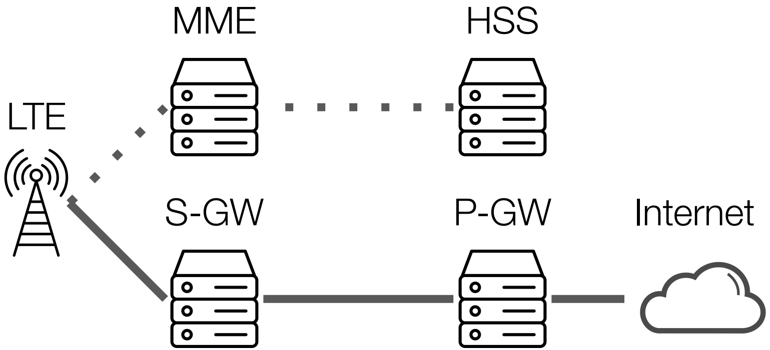


"I am connected to this network"

NAS State	Bearer state	UE IP Address
UE Identifiers	Idle state buffering	Policy enforcement
APN Profiles		Bearer state
Auth vectors		

- State replicated across elements for **each** UE
- State in each element must stay synchronized

Traditional cellular **leaks the radio** into the core



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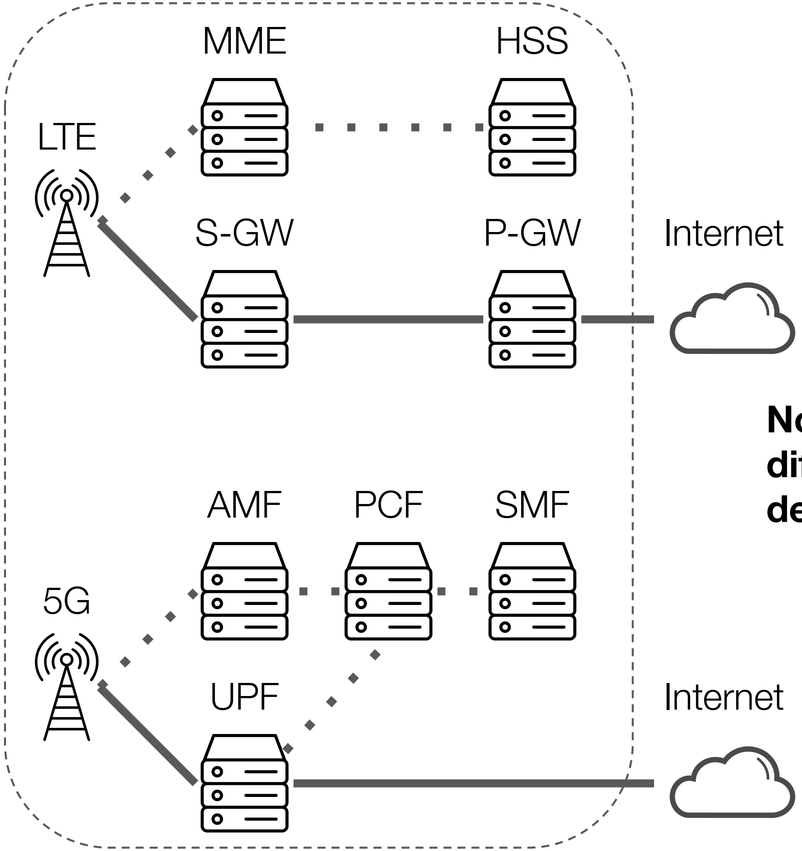
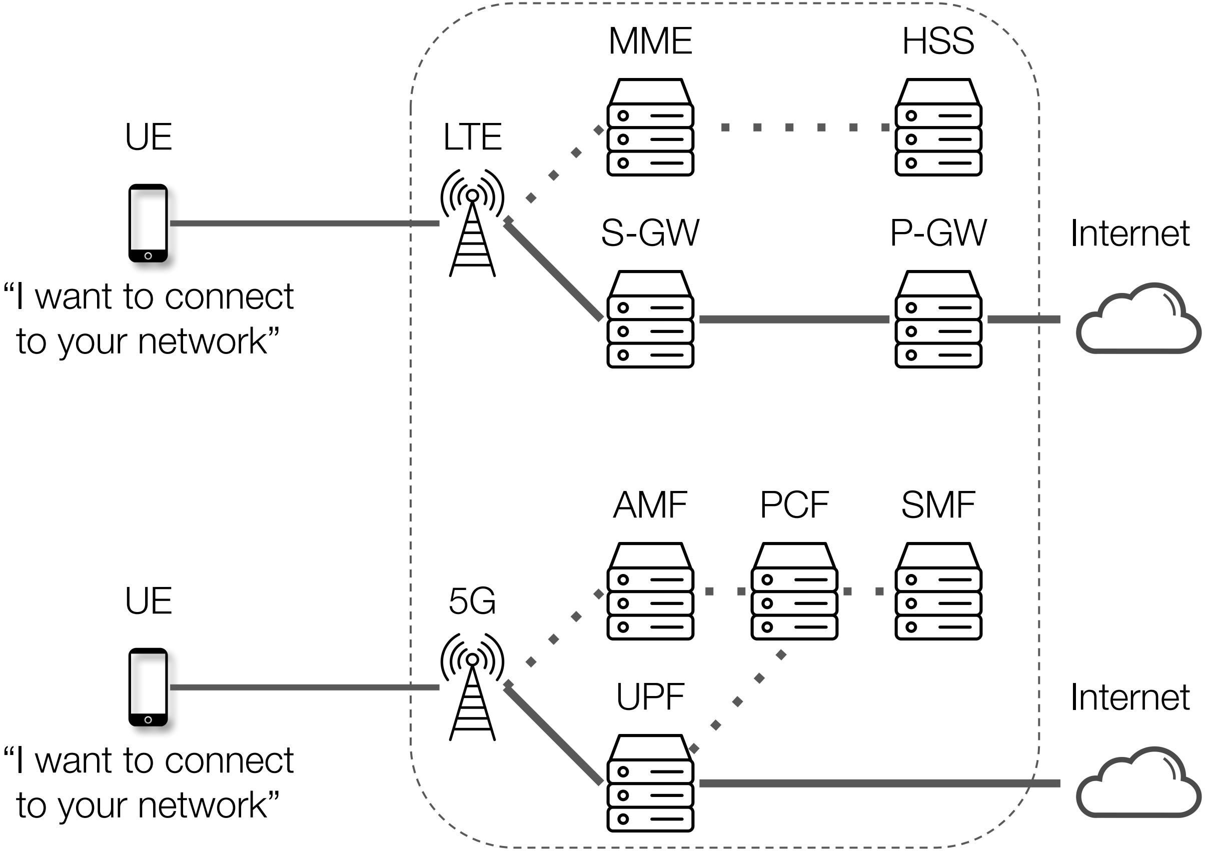


No commonality between different network generations, despite filling similar roles!

Traditional cellular **leaks the radio** into the core



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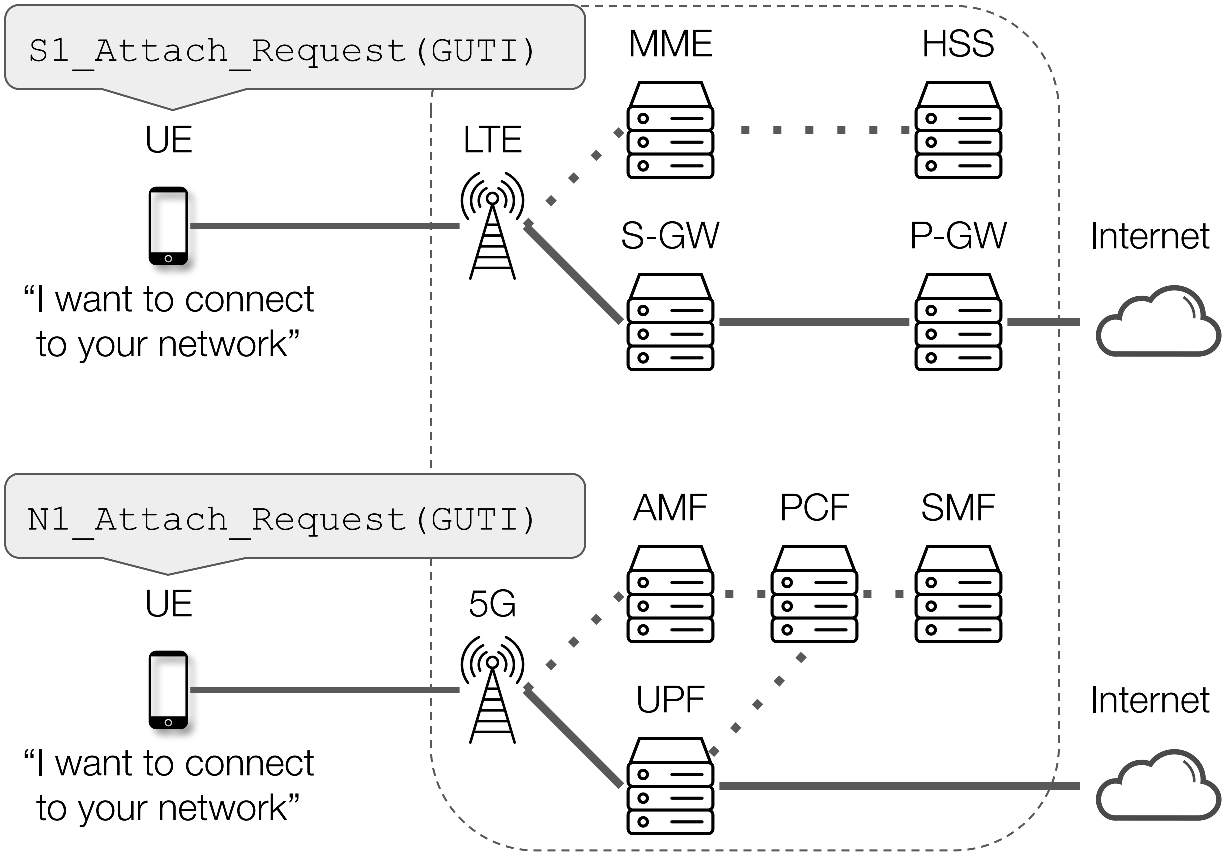
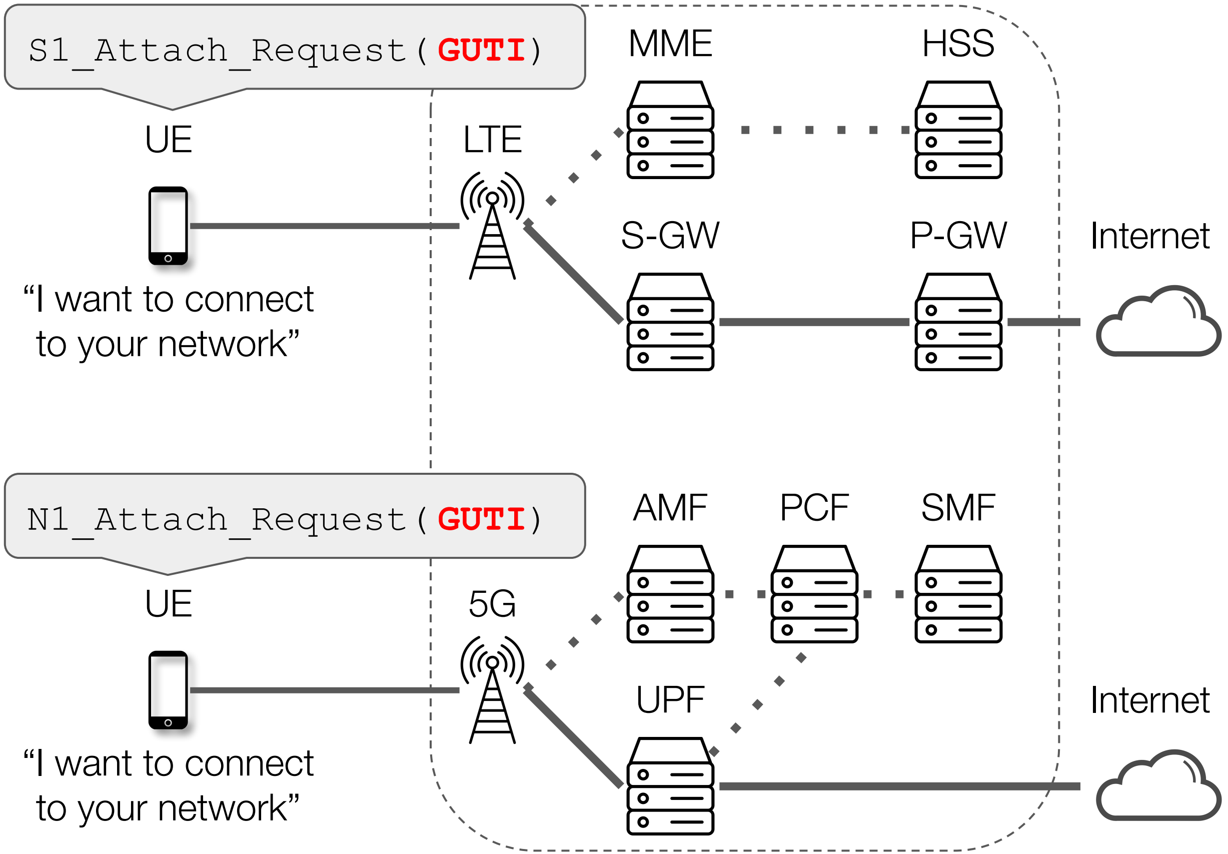


Different interfaces and messages for functionally equivalent procedures, exposed to the core network!

Traditional cellular **leaks the radio** into the core



Different interfaces and messages for functionally equivalent procedures, exposed to the core network!

And these identifiers aren't even the same, despite the name!

Why do operators put up with this?

They want to use **cellular radios!**

They want to support **rich policies** in their access networks:

- Fine-grained authentication
- Charging for service
- Quality of service guarantees
- Many other policies **to ensure these network operators can bill users for service.**

They also care about **mobility**, which is easier with a central point to anchor your IP address.

- We'll come back to this!

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The Design Philosophy of the DARPA Internet Protocols (Clark)

1. Internet communication must continue despite loss of networks or gateways.
2. The Internet must support multiple types of communications service.
3. The Internet architecture must accommodate a variety of networks.
4. The Internet architecture must permit distributed management of its resources.
5. The Internet architecture must be cost effective.
6. The Internet architecture must permit host attachment with a low level of effort.
7. The resources used in the internet architecture must be accountable.

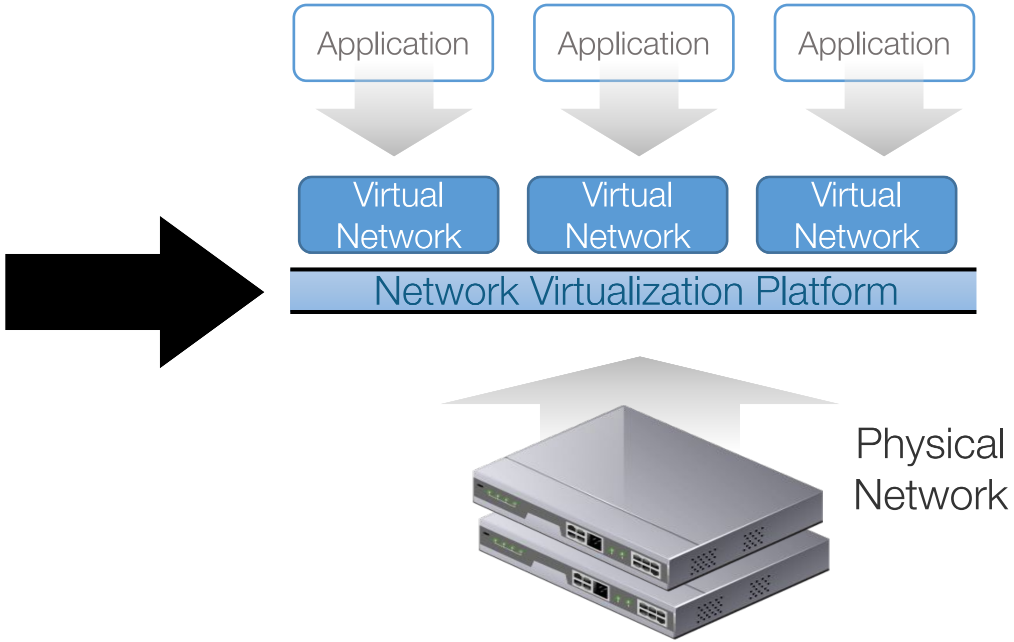
The Bad Old Days, before SDN

- Each middlebox has state associated with each workload
- State needs to be synchronized across middleboxes
- Each middlebox independently solves scale and reliability
- We implement policy by arranging on-path devices

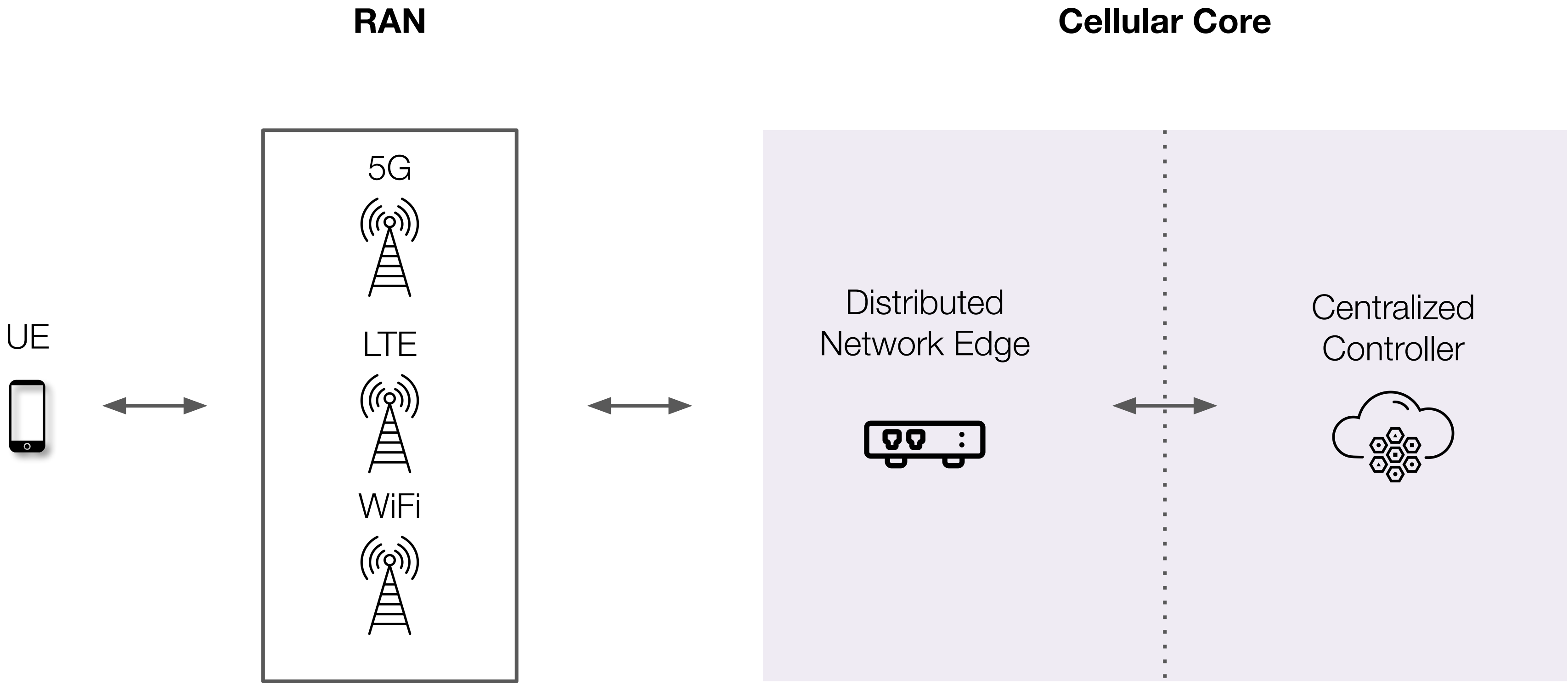
This is the reality today for traditional cellular networks!

We’ve solved these problems in the data center…

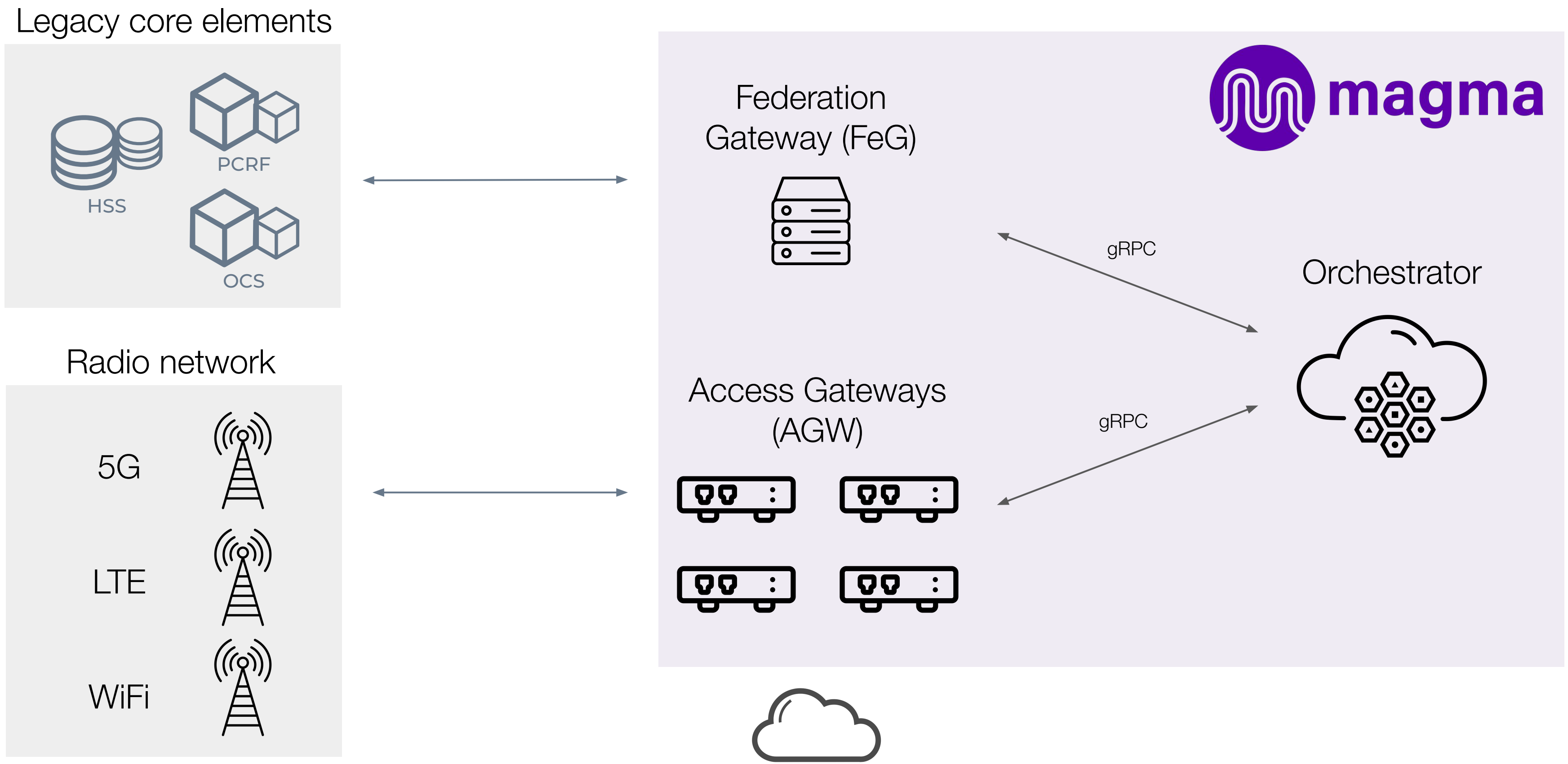
- Separation of **policy-rich**, **software** edge from fast, simple **fabric**
- Manageability via a **logically centralized control plane**



Distribute the **network edge**, maintain **central control**



Magma: An open, distributed cellular core



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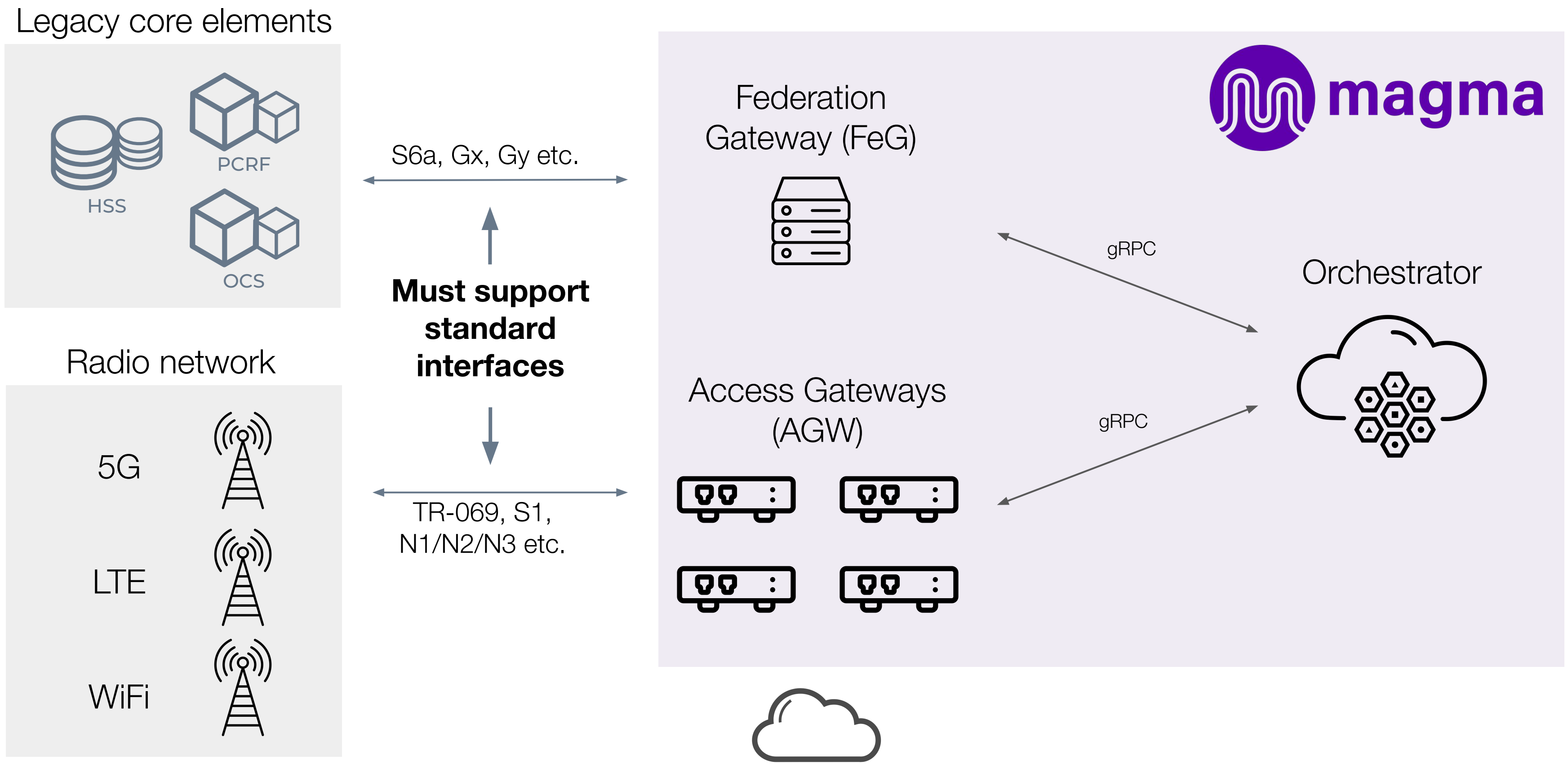

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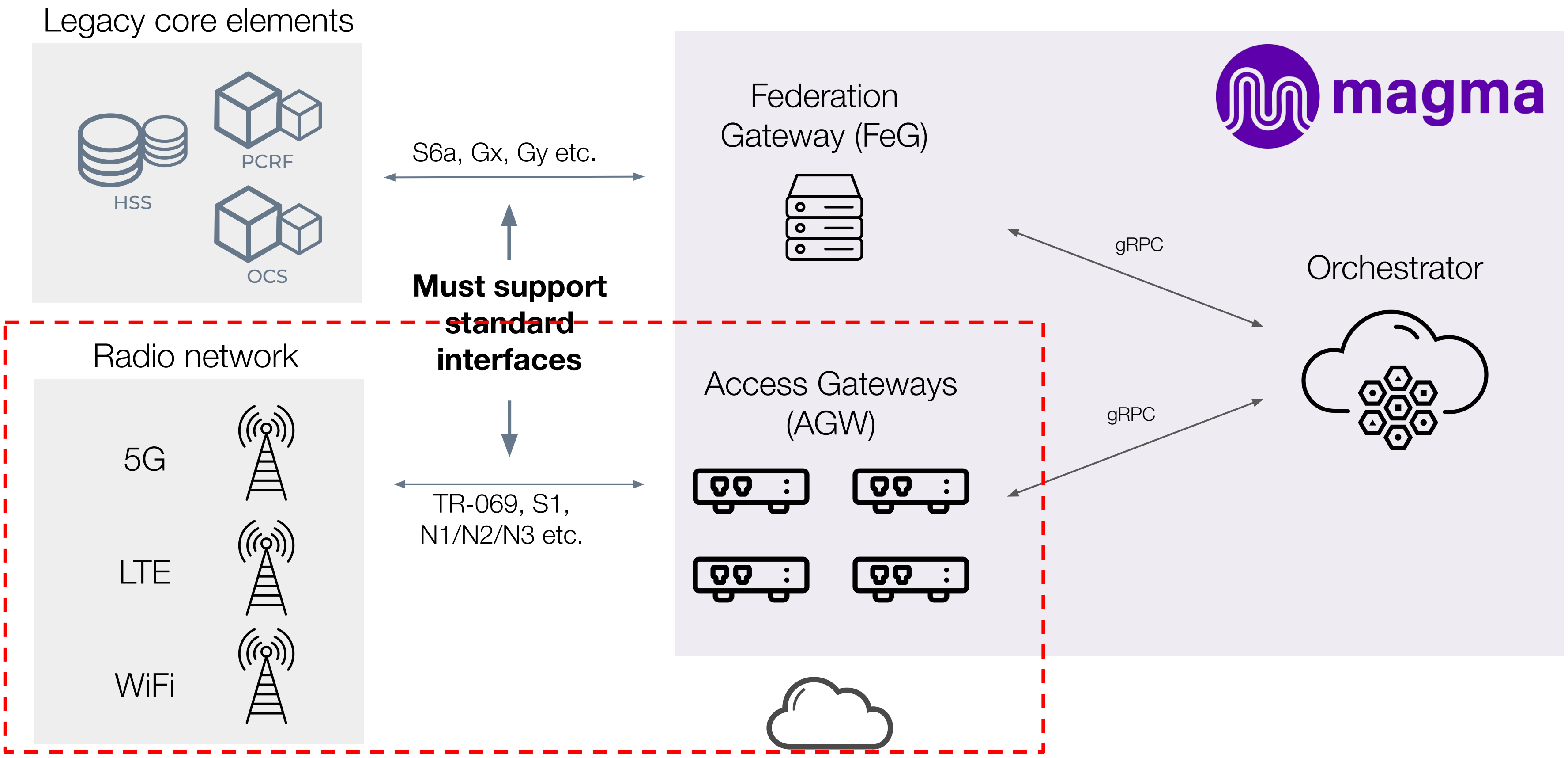
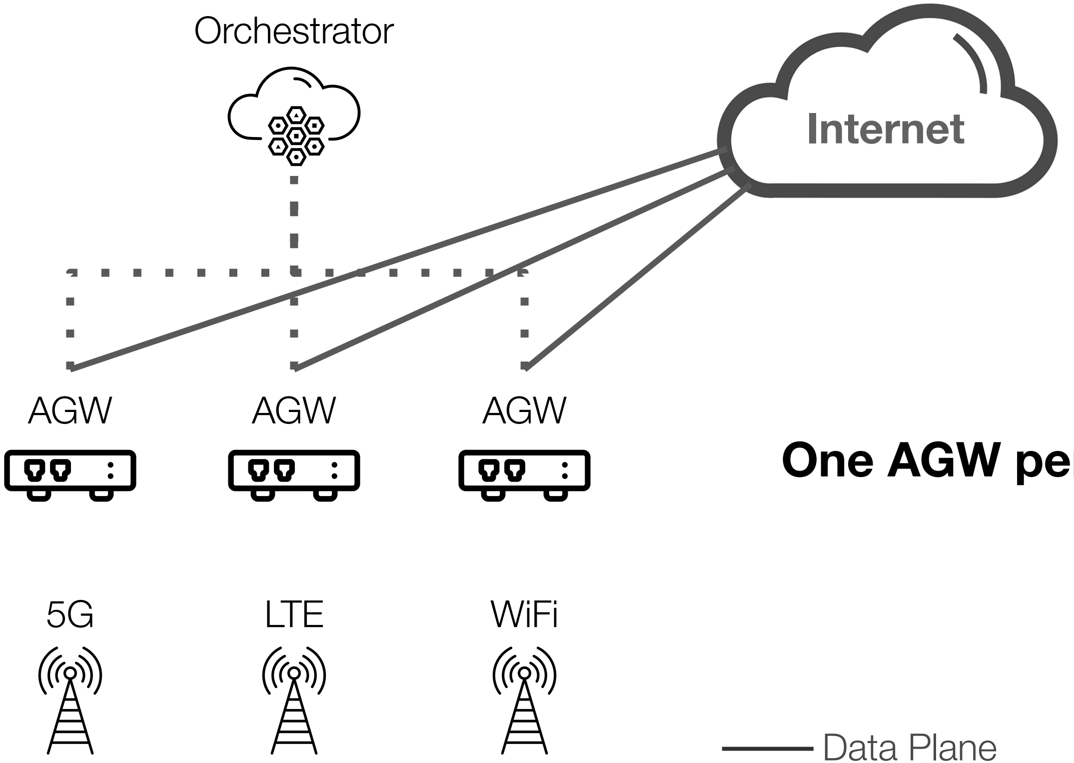


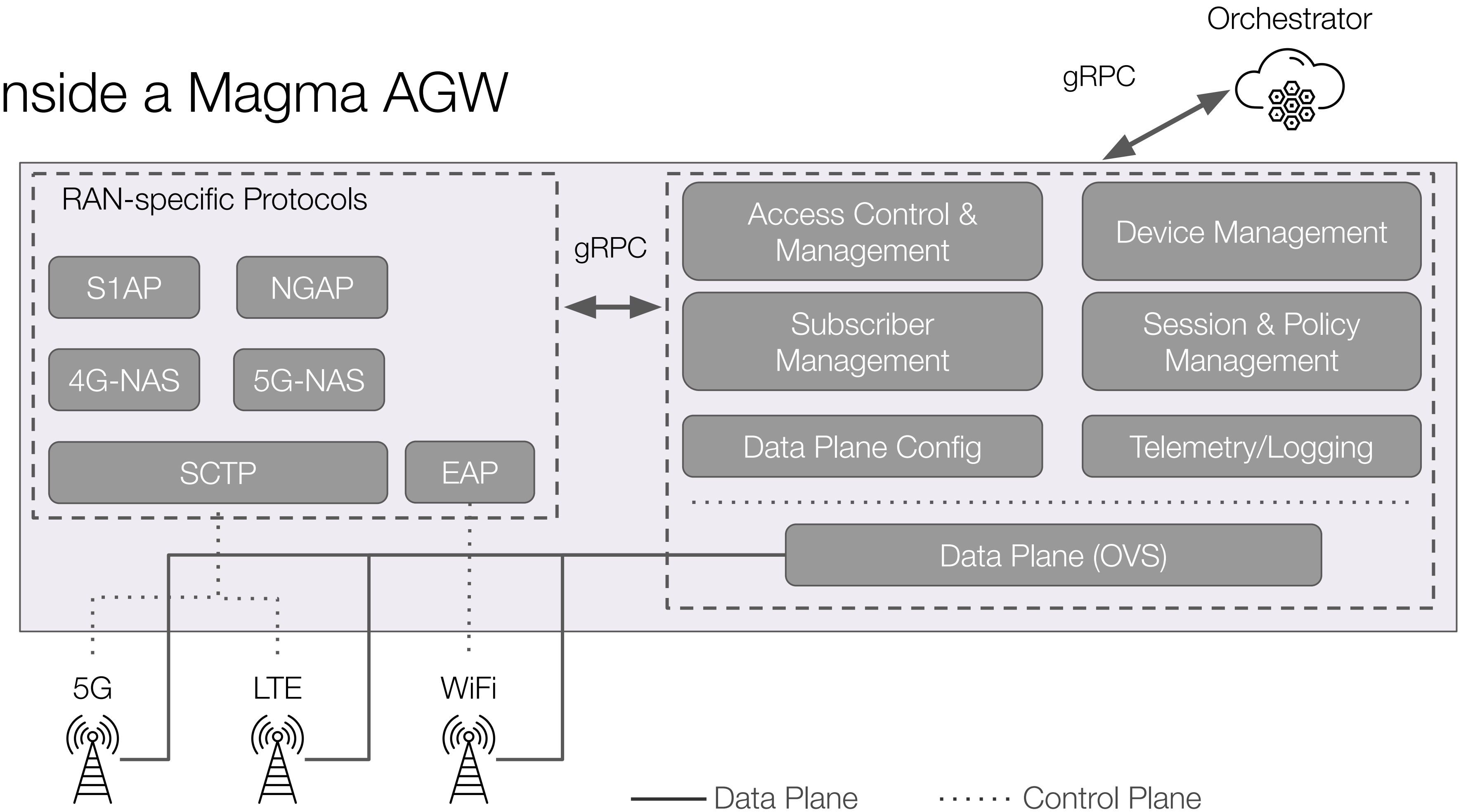
Magma’s distributed network edge



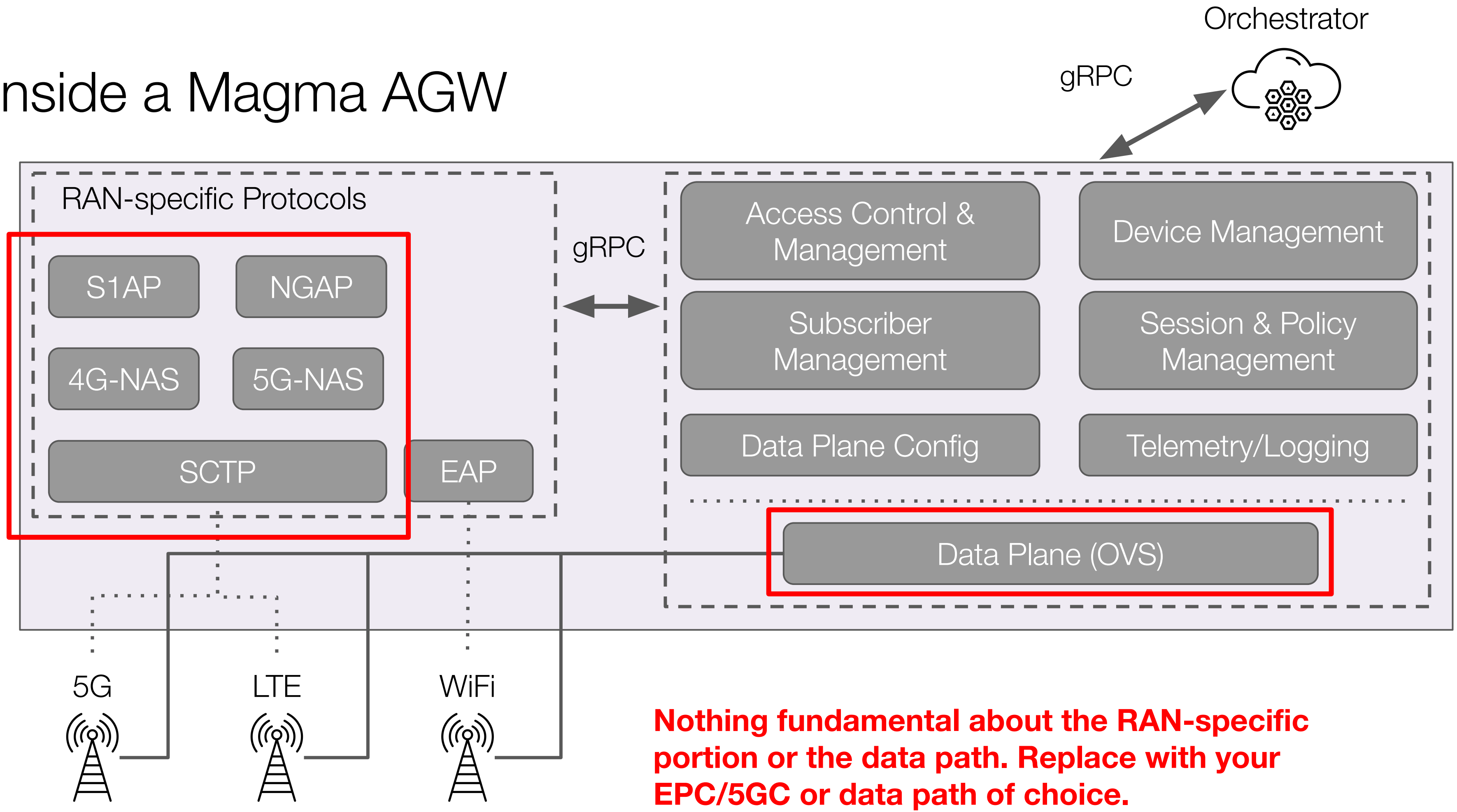
One AGW per cell site

Data Plane
Control Plane

Inside a Magma AGW



Inside a Magma AGW



Nothing fundamental about the RAN-specific portion or the data path. Replace with your EPC/5GC or data path of choice.

Dealing with distribution

Two key challenges from the distributed approach Magma takes:

- How do we manage state in this distributed environment?
- How do we design the control plane?

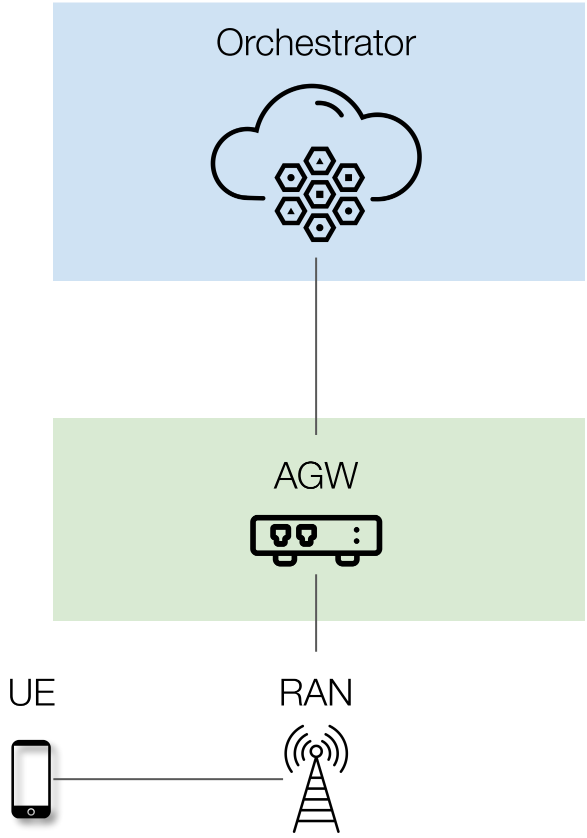
Hierarchical control planes in Magma

Configuration State: Changes on **human** timescales

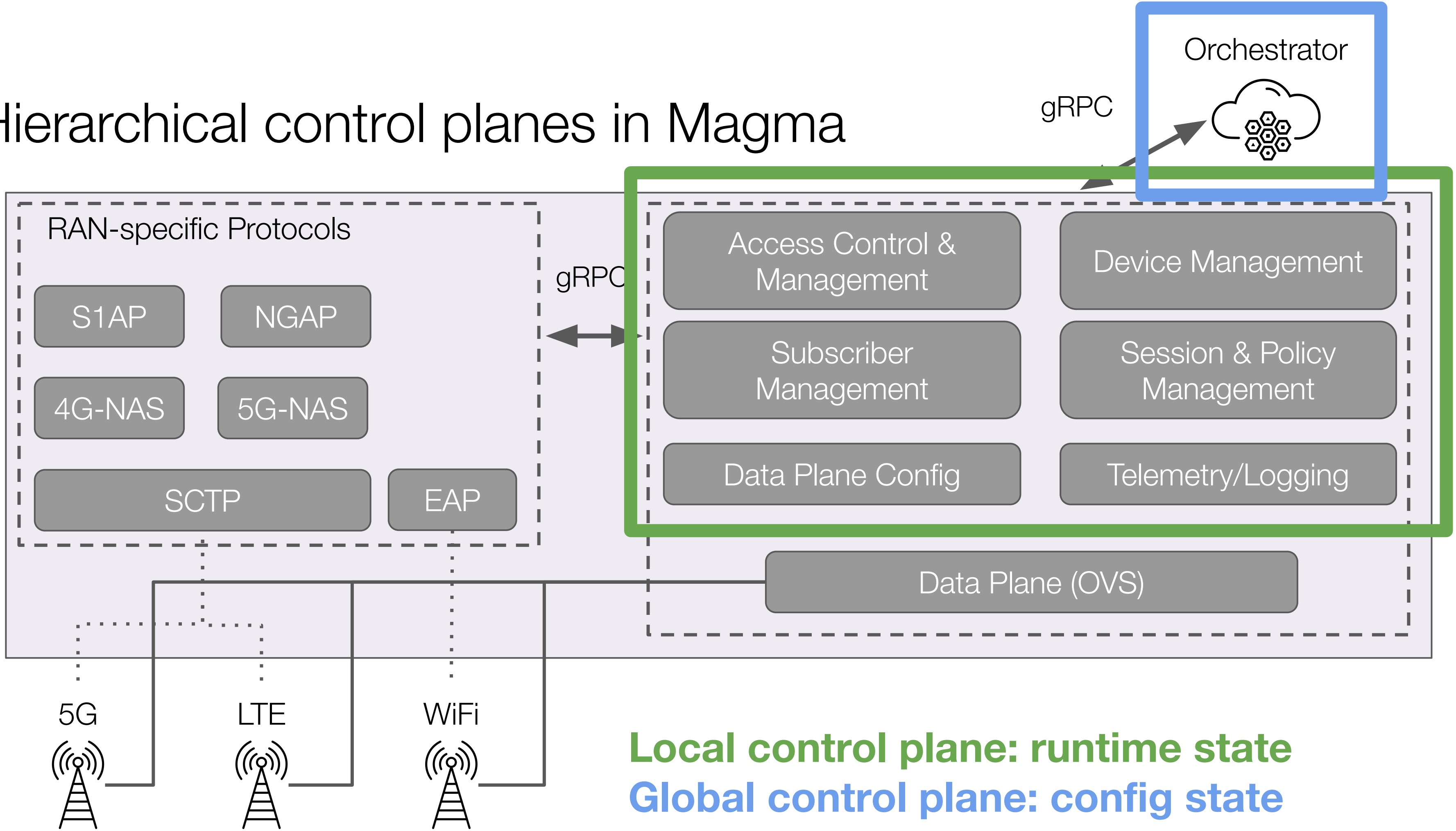
- “This user is allowed to connect to the network”
- “Apply this rate policy to this user’s traffic”
- Managed by **global** control plane: stored in the **Orchestrator** and modified by operator via REST APIs

Runtime State: Changes on **network** timescales

- “This is the NAS state of this UE”
- “This users has consumed 75% of their data quota”
- Managed by **local** control plane: ephemeral, recoverable, and stored in the **AGW**



Hierarchical control planes in Magma



Local control plane: runtime state

Global control plane: config state

Implications of this approach

- Abstract the radio access network: no more state leakage
- Modularize the network edge: simplified core, no choke-point devices
- Scale-out core means a scale-*down* core: low barrier to entry
- Central control: easier network administration
- **Isolated fault domains: simpler recovery semantics**

Nation-scale outages happen regularly in traditional cores

O2 4G data network restored after day-long outage

7 December 2018 | Comments

June T-Mobile U.S. Network Outage Disrupted More Than 250 Million Calls: FCC

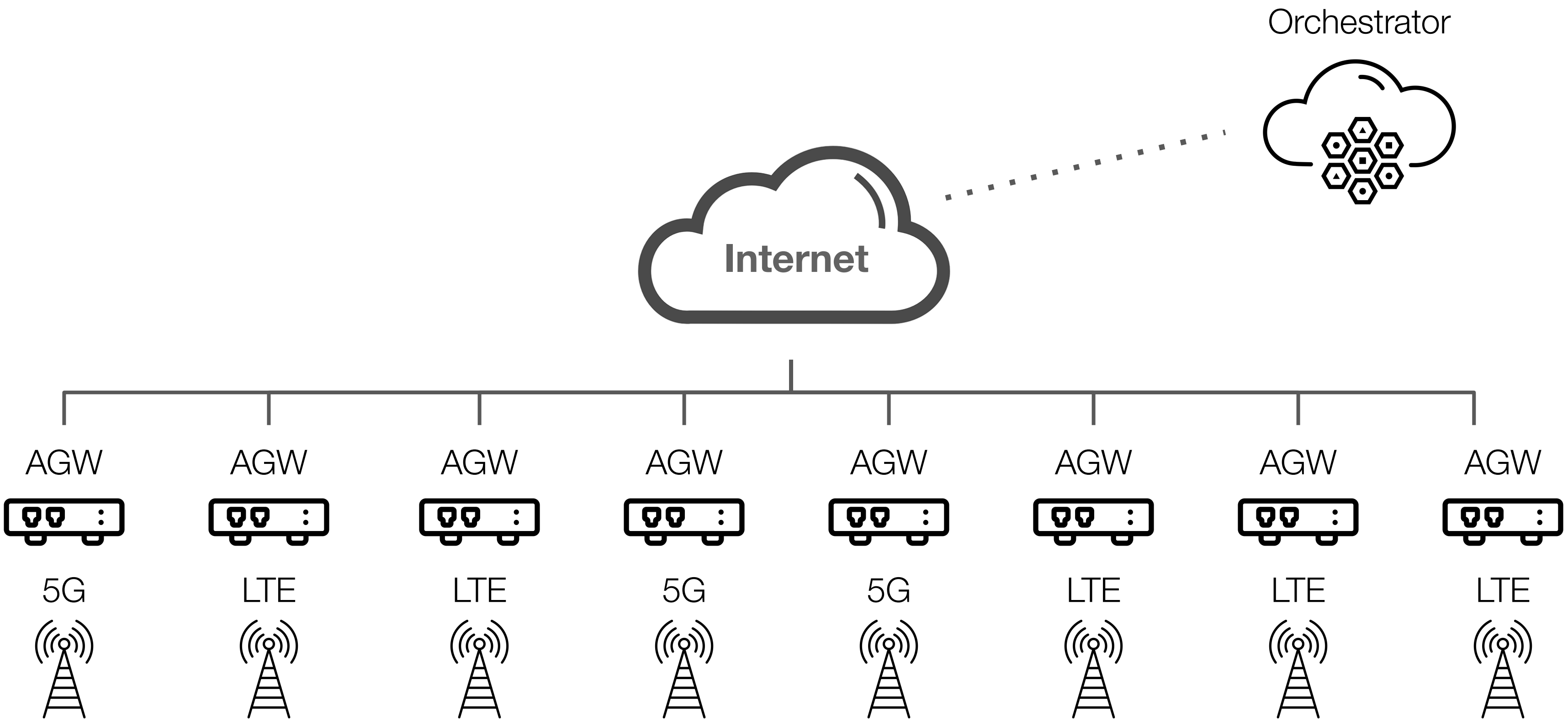
By Reuters | Oct. 22, 2020, at 11:23 a.m.

FINANCE • CONSUMER •

2:01pm, Apr 9, 2021 Updated: 2:28pm, Apr 9

‘Fully panicked’: Nationwide outage hits Vodafone

Constraining the failure domain



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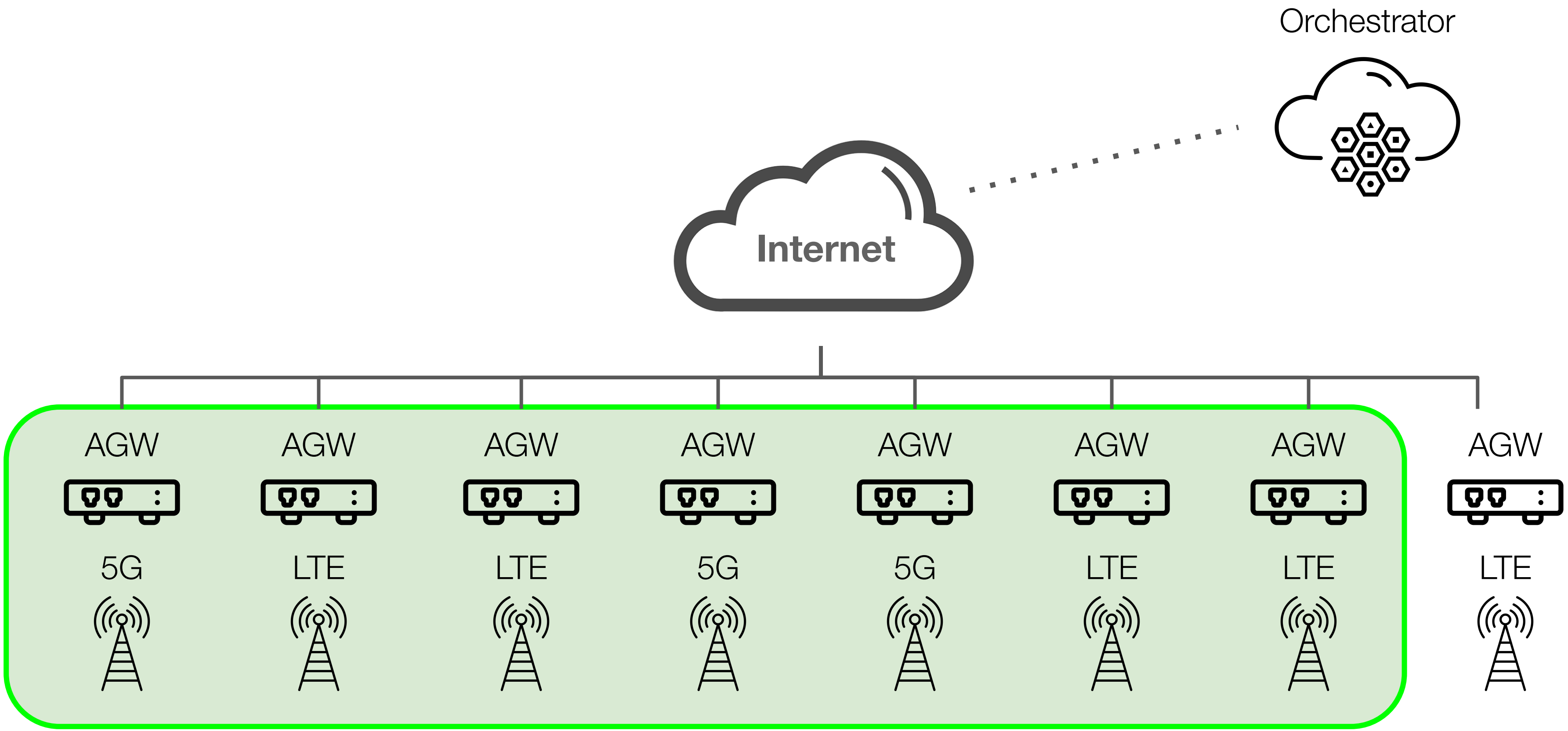
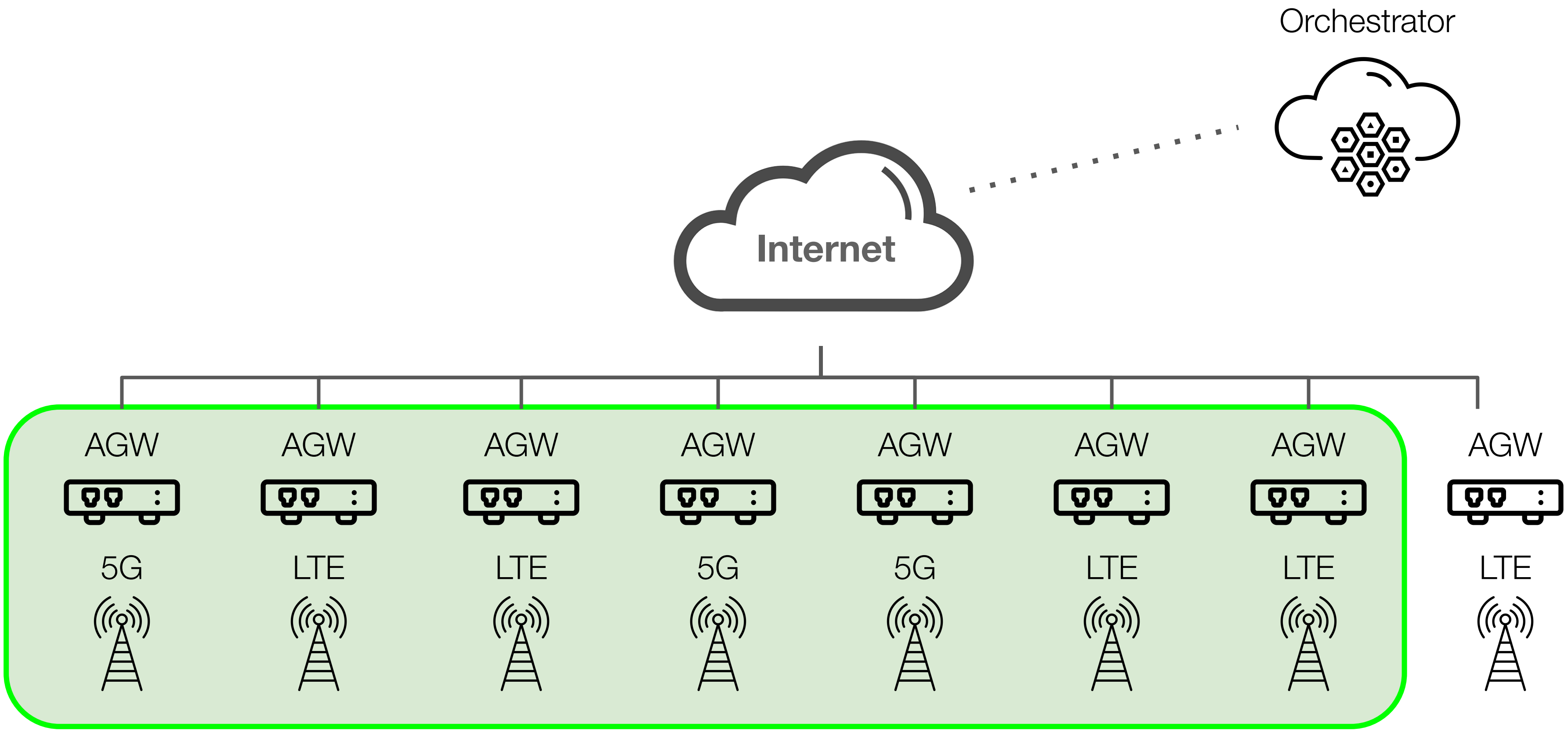


Data plane is not impacted by control plane failure



Evaluation

Magma’s first deployment, 2017
Photo: E. Makeev

Key questions

- Does Magma handle realistic workloads?
- Does Magma reduce costs of deploying wireless access networks?
- Can Magma support large-scale production deployments?

Emulation Testbed

Spirent Landslide

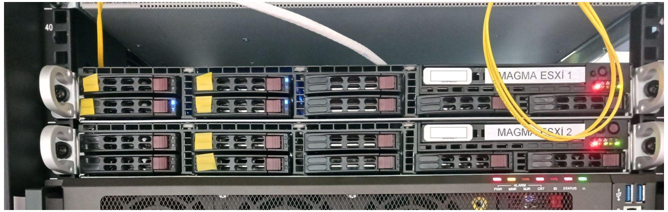
- Commercial core network test device
- Emulates many hundreds of eNodeBs and UEs
- Max capacity: 2.5Gbps offered load

Virtual AGW

- Intel Xeon 6126 2.60GHz, 8GB of RAM, and 2x10G Mellanox ConnectX-3 NICs
- Varying number of cores, depending on experiments

Bare Metal AGW: typical hardware used for real deployments

- Bare Metal Intel J3160 quad-core 1.6GHz CPU, 8GB RAM four Intel I210 1Gbps NICs
- $369 on Amazon this morning, with free delivery!

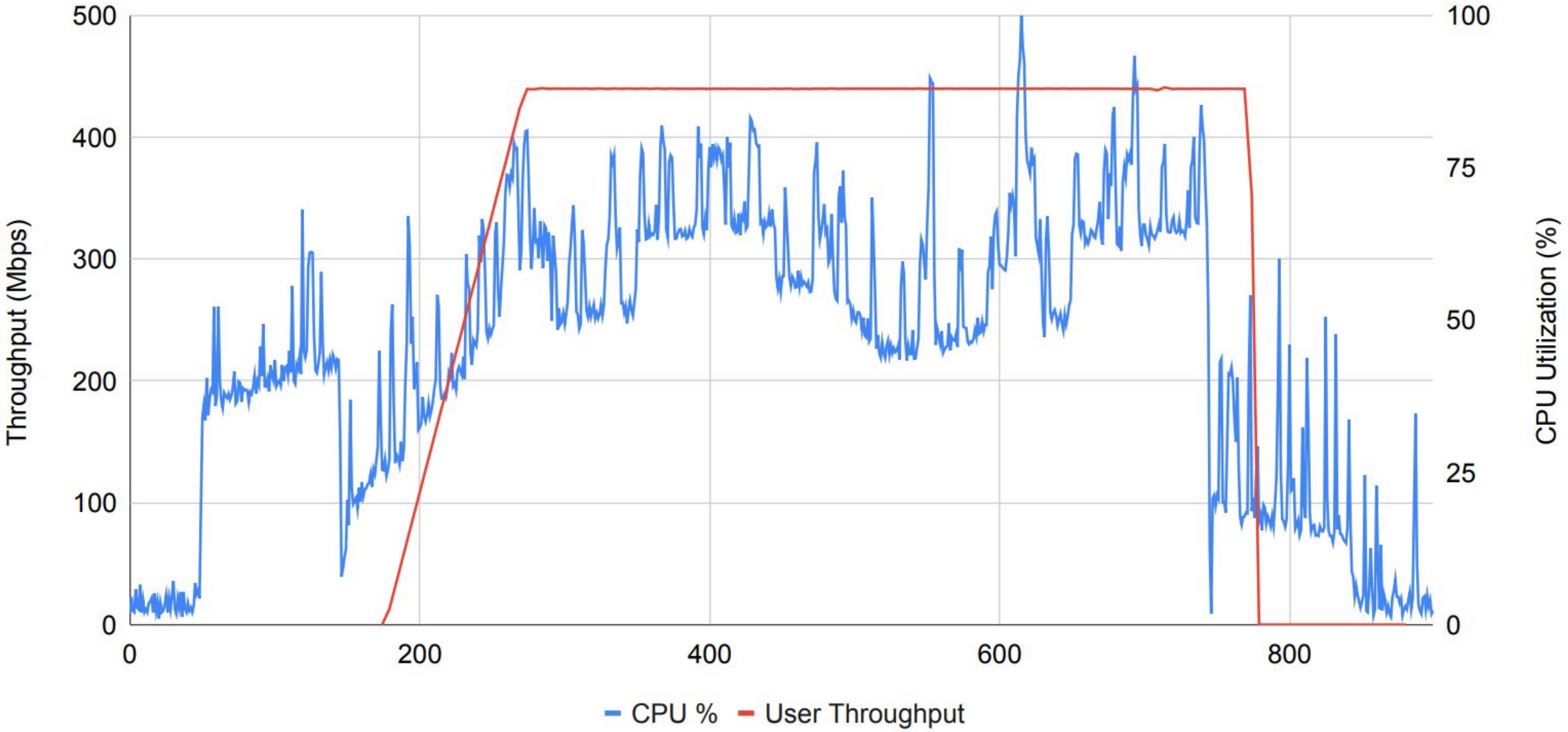


The RAN is the capacity bottleneck for an AGW

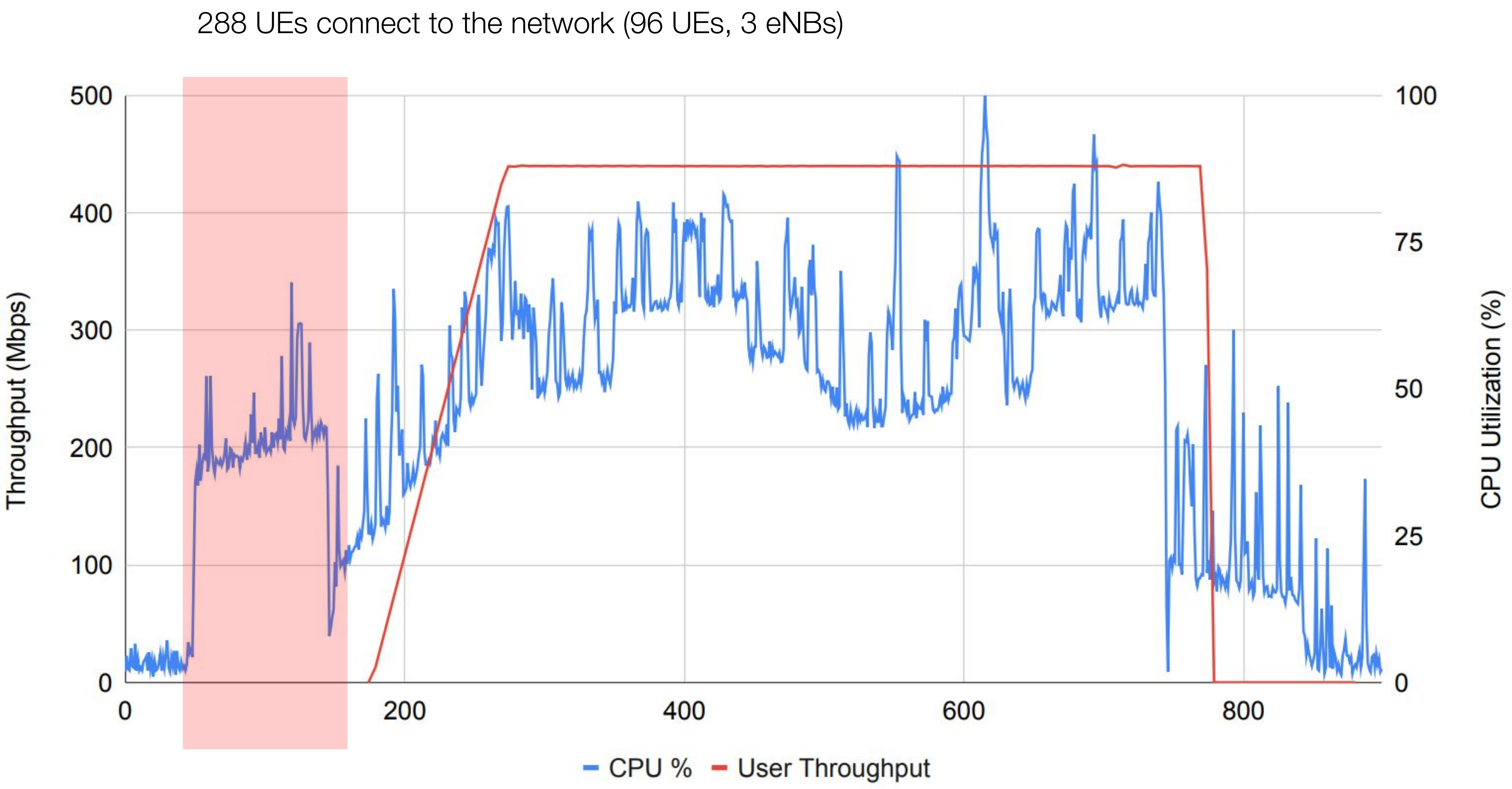
- Standard deployment is one AGW per cell site
- A cell site typically consists of 1-3 eNodeBs
- A typical eNodeB supports **~100 active users** and **~150Mbps**
  - Assuming 20MHz channels

Using a bigger RAN (e.g., C-RAN)? Just use a bigger AGW (details in the paper)

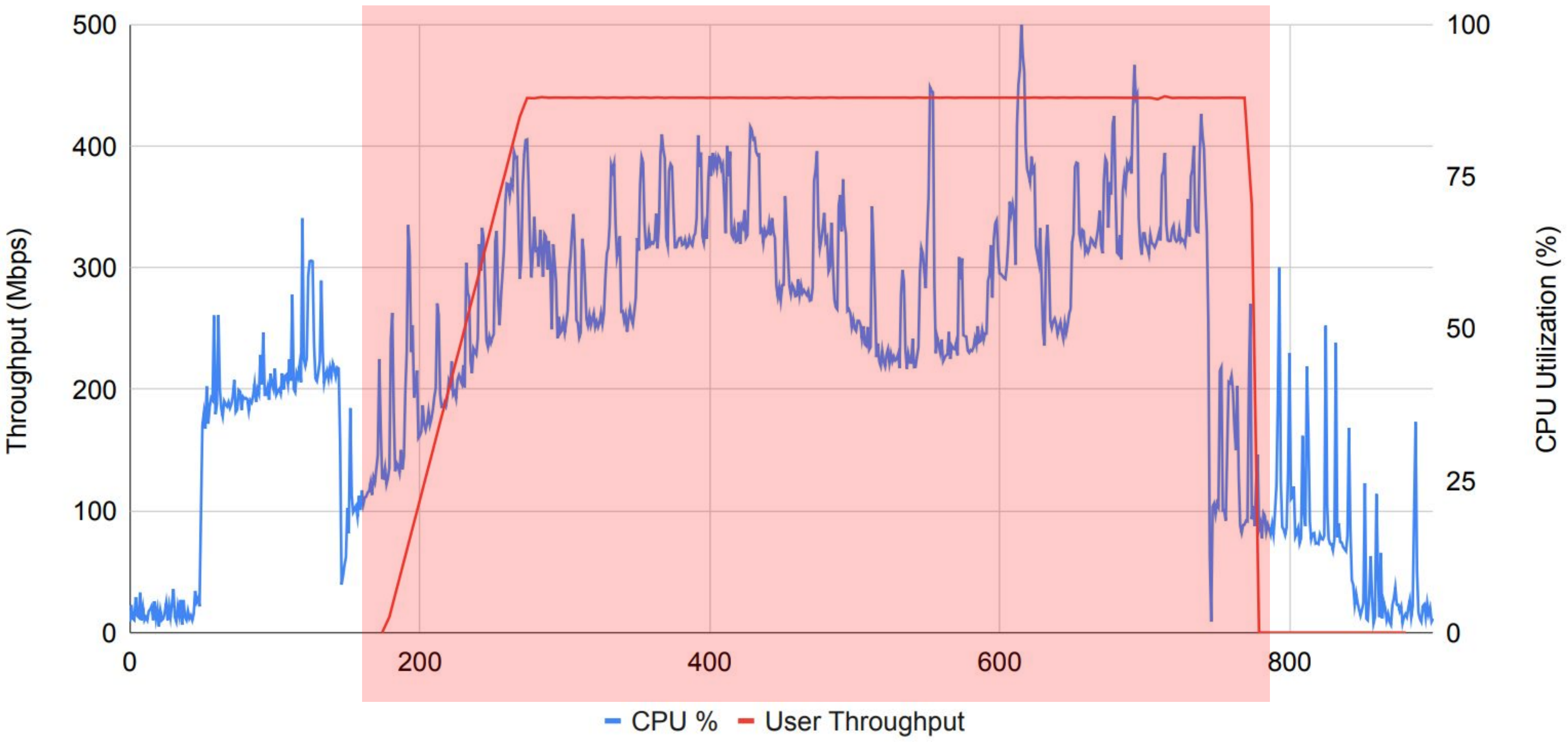
Magma in Puerto Bermudez, PE



Throughput (Mbps)
CPU Utilization (%)
500
400
300
200
100
0
100
75
50
25
0
0
200
400
600
800
CPU %
User Throughput

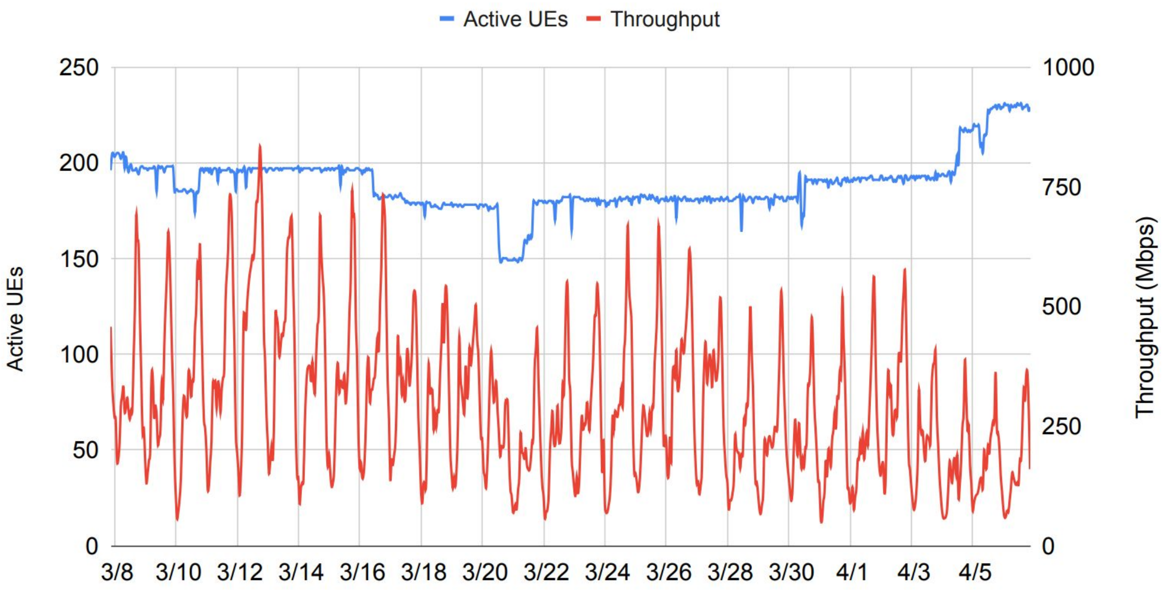

288 UEs connect to the network (96 UEs, 3 eNBs)
Throughput (Mbps)
500
400
300
200
100
0
100
75
50
25
0
CPU Utilization (%)
0
200
400
600
800
CPU %
User Throughput

UEs each perform an HTTP download, maxing out eNB capacity
(432Mbps offered load)



Magma in production: AccessParks

- CBRS LTE network
- Fixed wireless service to WiFi hotspots
- 14 sites, 200 hotspots



Magma reduced AccessParks costs by 43%

AccessParks

- CBRS LTE network
- Fixed wireless service to WiFi hotspots
- 14 sites, 200 hotspots

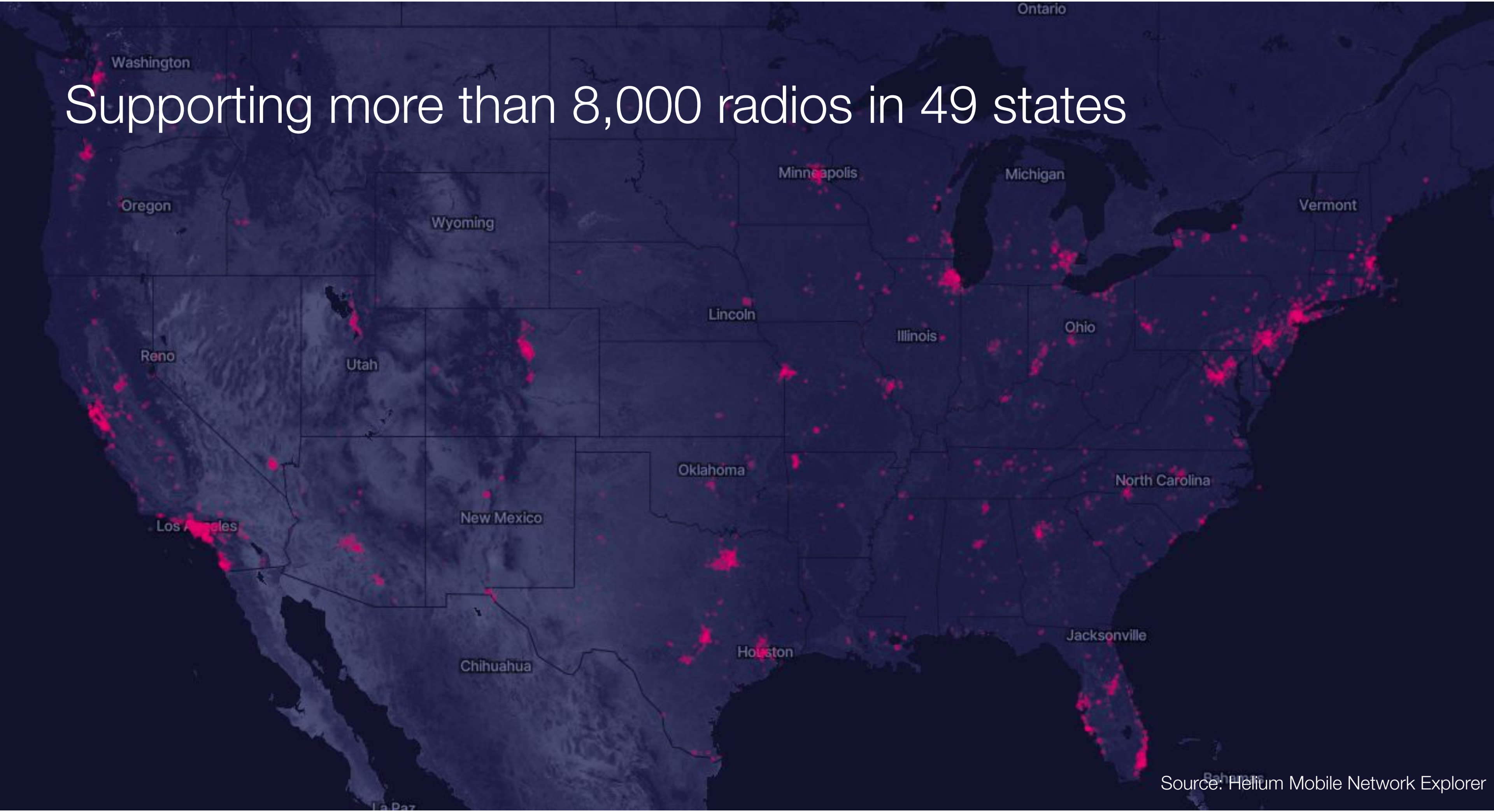
Item	**Traditional**	**Magma**	**Difference (%)**	**Notes**
RAN	$7,950	$7,950	-	Identical RAN and backup power.
Core HW	$1,200	$300	-$900 (-75%)	
Core SW	$2,000	$600	-$1,400 (-70%)	Licenses/support.
Field Eng.	$200	$200	-	Installation.
LTE Eng.	$5,000	$330	-$4,670 (-93%)	Planning, core config.
Cost/Site	$16,350	$9,380	-$6,970 (-43%)	

Magma in production: FreedomFi (Helium 5G)

FREEDOMFI

- “DeWi” Cellular Network
- Neutral host – supports roaming customers from other MNOs
- Over 5k AGWs deployed in <5 months
- Adding 150 per week (as of April 2022)
- Orchestrator costs: ~$4,000/mo

Supporting more than 8,000 radios in 49 states



Source: Helium Mobile Network Explorer

Current challenges in Magma

- Poor (3GPP) Control Plane performance
  - Maximum of 3UE/s attach rate on low-end AGW
  - Solved with larger AGWs, but mostly an engineering artifact
- Lack of wide-area mobility support
  - Currently, mobility is only supported **within** a single AGW
  - Surprisingly, many cellular use cases don’t need mobility!
  - Perhaps end hosts handle mobility better than the network? [CellBricks, SIGCOMM’19]
- Certification: Interoperability testing with an operator’s traditional core is hard
  - **1+ year process** to complete testing with most operators
  - No incentive for incumbent vendors to make testing with alternative core networks easy!

Magma: an open, distributed core network

- The **choice of radio technology** should not define an operator’s **network architecture**
- Separation of **policy-rich**, **software** edge from fast, simple **fabric**
- Manageability via a **logically centralized control plane**
- Runs on inexpensive hardware and supports small networks, minimizing **barrier to entry** for new operators at the edge
- Deployed in both **small networks** and **at scale** in dozens of commercial deployments worldwide

https://github.com/magma

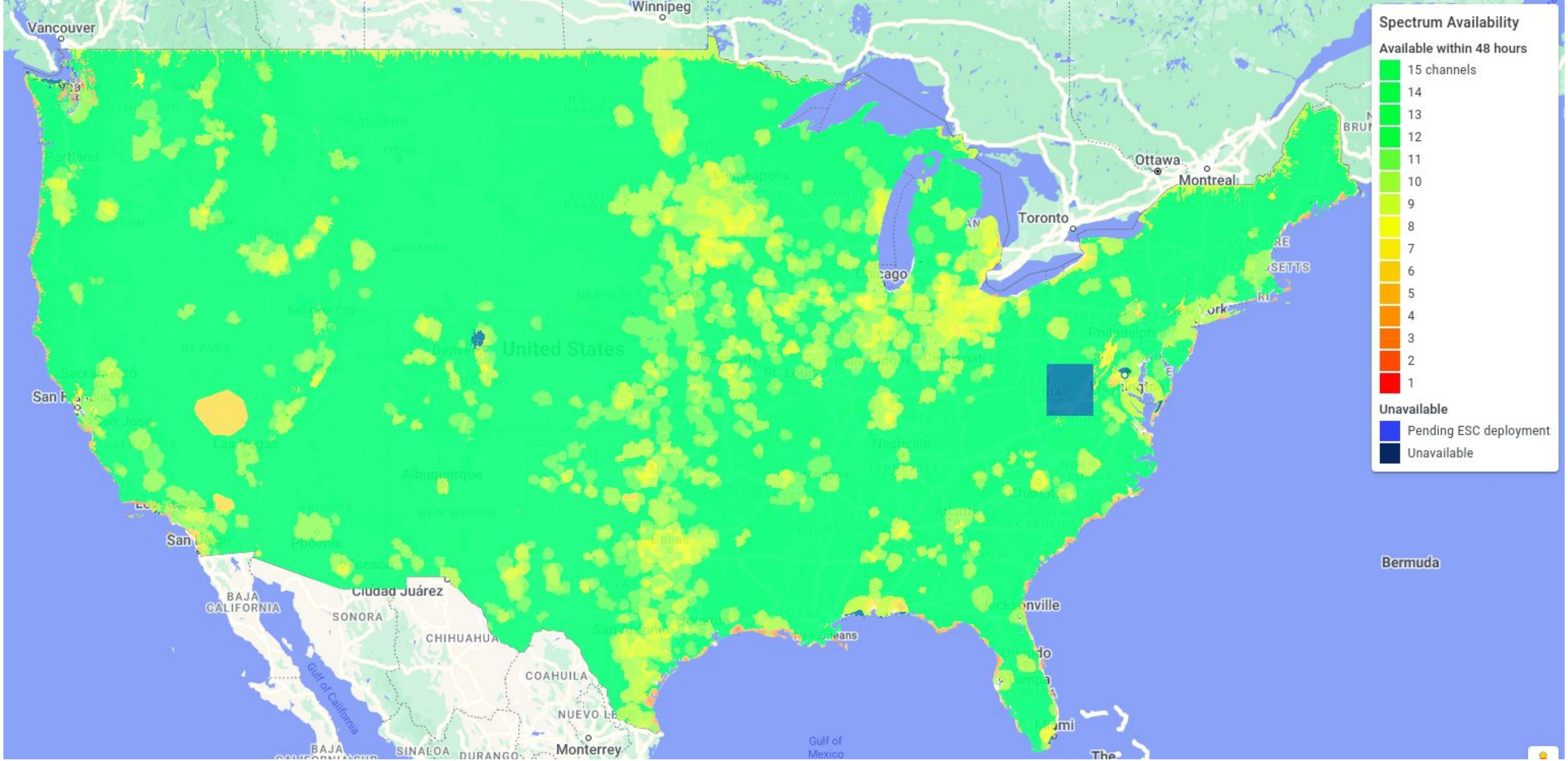
https://magmacore.org

Thanks!

Shaddi Hasan
shaddi@vt.edu
@shaddih

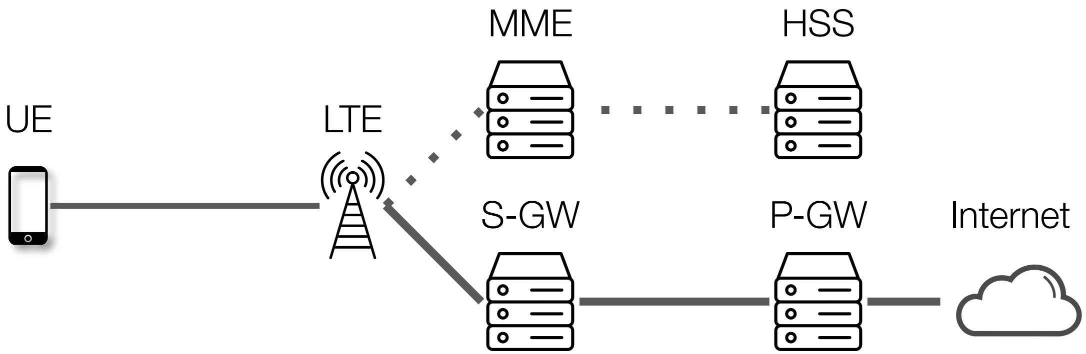
Learn more: magmacore.org

Backup



CBRS spectrum availability this week in the US (Google SAS)

What breaks with a core element fails?



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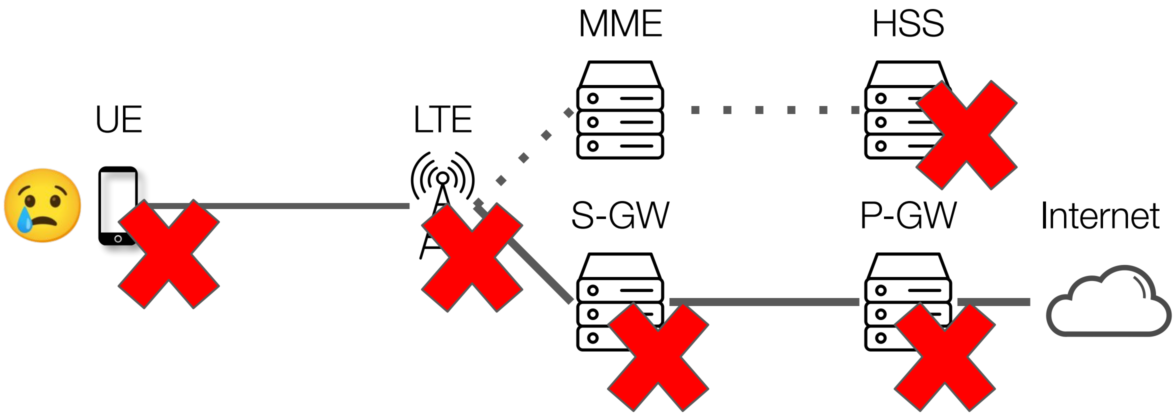

The entire network is unusable