PURDUE UNIVERSITY

PURDUE RESEARCH FOUNDATION

NextG Developments @ Purdue University

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(along with our amazing students and collaborators at ONF and Intel Labs)

Purdue is a Hub for NextG R&D

Research

Mobile Traffic Analysis, Modeling, and Generation

Faculty: Y. Charlie Hu, Chunyi Peng, Saurabh Bagchi, Mung Chiang and …

Mobile Systems Design, Characterization, and Optimizations

Faculty: Muhammad Shahbaz, Sonia Fahmy, Christopher G. Brinton, and …

Development

5G Edge Cloud at Purdue hosting multiple tenants:
- ONF Pronto Edge Site
- NSF 5G Convergence Edge Site

Purdue Lab-to-Life 6G R&D Infrastructure:
- Smart City, Agriculture, Self-Driving Cars

Characterizing and Modeling Control-Plane Traffic for Mobile Core Network

Characterizing and Modeling Mobile Control-Plane Traffic

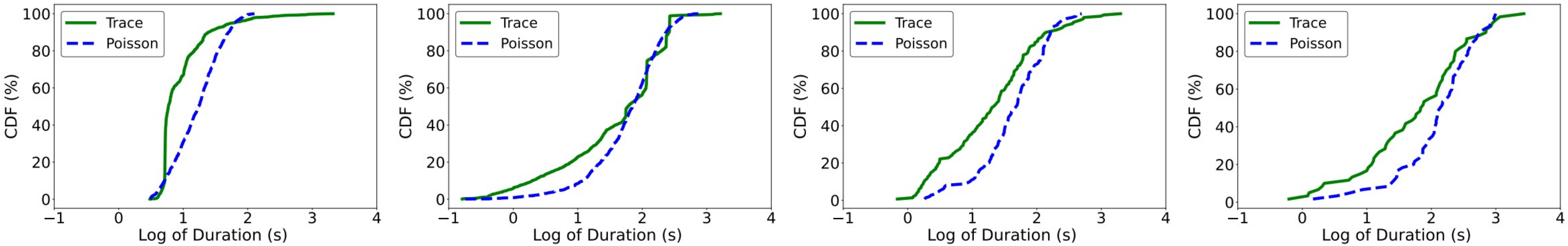
- Motivation
  - As 5G deployment gains momentum, control-plane traffic volume is escalating, control-plane performance becomes increasingly important
  - Accurate, scalable and versatile control traffic generators enable profiling and debugging mobile core performance for 4G/5G and beyond
- Main finding
  - Poisson processes cannot model inter-arrival/sojourn time for control events
- Our contribution
  - A two-level hierarchical state-machine-based traffic model that accurately captures traffic diversity among UEs and event dependence within each UE
- Traffic generator will be made available
  - As part of Aether gnbsim

Poisson Processes Fail to Model Control-Plane Traffic

- Goal: Model inter-arrival/sojourn time of control events per UE
- Poisson dist. fitting tests: Kolmogorov-Smirnov and Anderson-Darling tests
- Acquired a week-long raw trace at MMEs from a large mobile operator (~40K UEs)
- Characterize the traffic for single UE
  - Per-UE traffic varies over different time-of-day → model traffic per hour
  - Per-UE traffic varies over different device types → model traffic per device type
    - Phones, connected cars, and IoT devices
  - Extract inter-arrival/sojourn time per UE for <event type, hour, device type> → Not enough data to model per UE
- Aggregate per-UE inter-arrival/sojourn time for <event type, hour, device type> over all UEs → 0% of <event type, hour, device type> pass the tests
- Cluster UEs into different groups based on <# of events, variance of inter-arrival time> (for dominant events) → < 5.0% of <event type, hour, device type> pass the tests

Why do Poisson Models Fail?

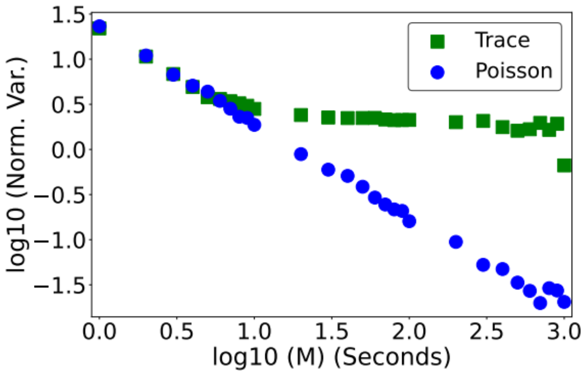
- Compare CDFs of sojourn (1^{st}, 2^{nd}) / inter-arrival (3^{rd}, 4^{th}) time of raw trace and best-fitted Poisson models (MLE) for a <event type, hour, device type>



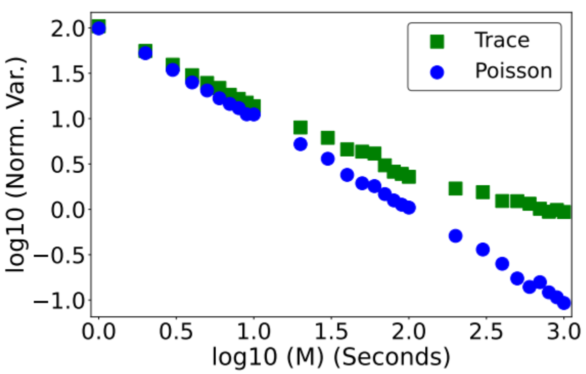
(a) CONNECTED (b) IDLE (c) HO (d) TAU

Why do Poisson Models Fail? (cont'd)

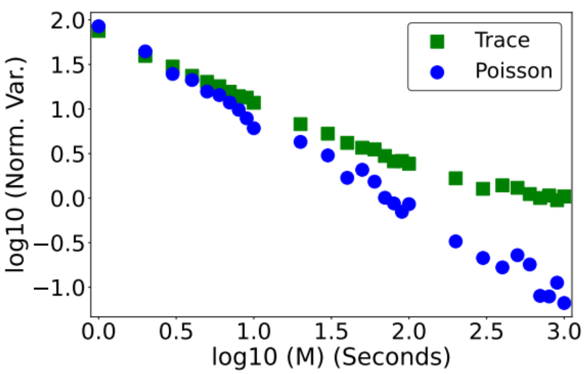
- Characterize burstiness of sojourn (1st, 2nd) / inter-arrival (3rd, 4th) time using variance-time plot [Paxson and Floyd, 1994]



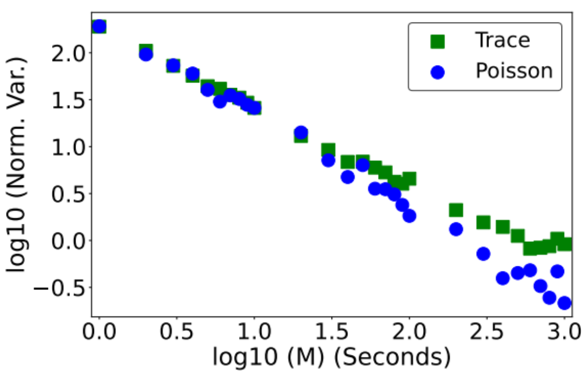
(a) CONNECTED



(b) IDLE



(c) HO



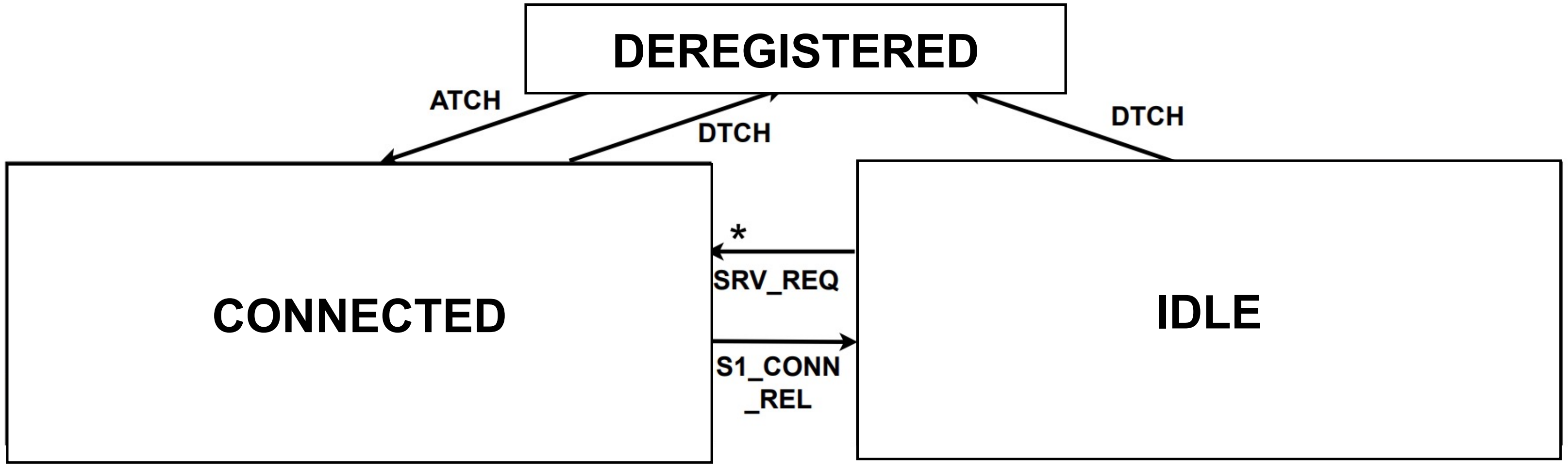
(d) TAU

How to Model Control-Plane Traffic?

- Two limitations of Poisson model

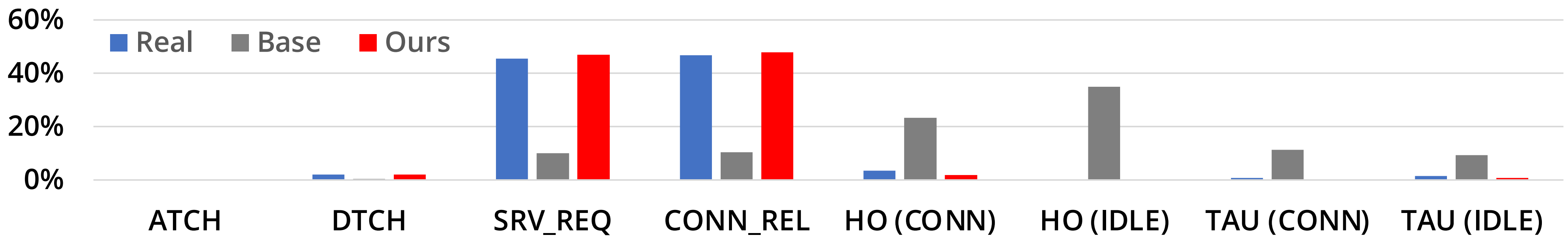
  (1) cannot fit per-event traffic; (2) cannot model dependence among events

- Our approach:
  - Use a finite state machine to model event dependence
  - 3GPP-specified state machines (merged below) only cover 4 events
  - Define new sub-states inside CONNECTED/IDLE to model rest events
  - Model probability for each state transition and dist. of sojourn time in each state
  - Generate model for each <event type, hour, device type>

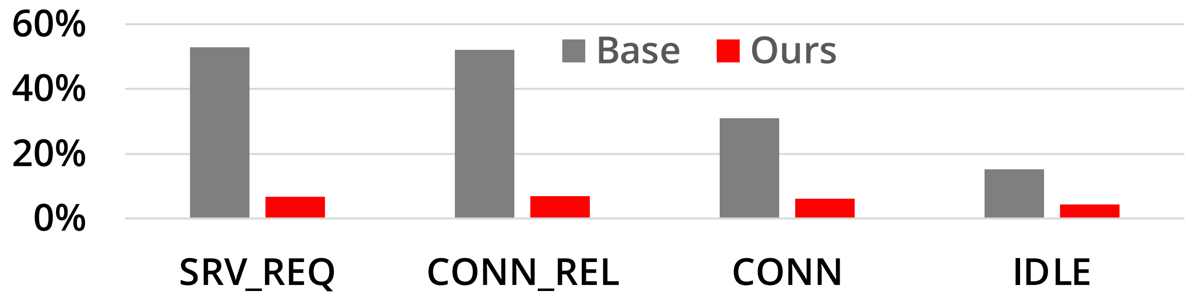


Accuracy of Our Control Traffic Model

- Methodology
  - Compare with a baseline method that uses the best-fitted Poisson distributions
  - In generating traffic for 380K UEs for 1 hour
- Macroscopic analysis: Breakdown of events for phones (230K UEs)



- Microscopic analysis: Dist. of num of events and sojourn time per UE
  - Calculate max y-distance between CDFs of real and synthesized traces



Performance Analysis and Scaling of 5G Mobile Core (using Aether)

Expectations from NextG Mobile Cores

- Massive Internet-of-Things
  - devices with ultra-low energy (10+ years of battery life), ultra-low complexity (10s of bits-per-second), and ultra-high density (1 million nodes per square kilometer).
- Mission-Critical Control
  - ultra-high availability (greater than 99.999% or “five nines”), ultra-low latency (as low as 1 ms), and extreme mobility (up to 100 km/h).
- Enhanced Mobile Broadband
  - extreme data rates (multi-Gbps peak, 100+ Mbps sustained) and extreme capacity (10 Tbps of aggregate throughput per square kilometer).

Expectations from NextG Mobile Cores

Performant

Meet both throughput and latency constraints

Scalable

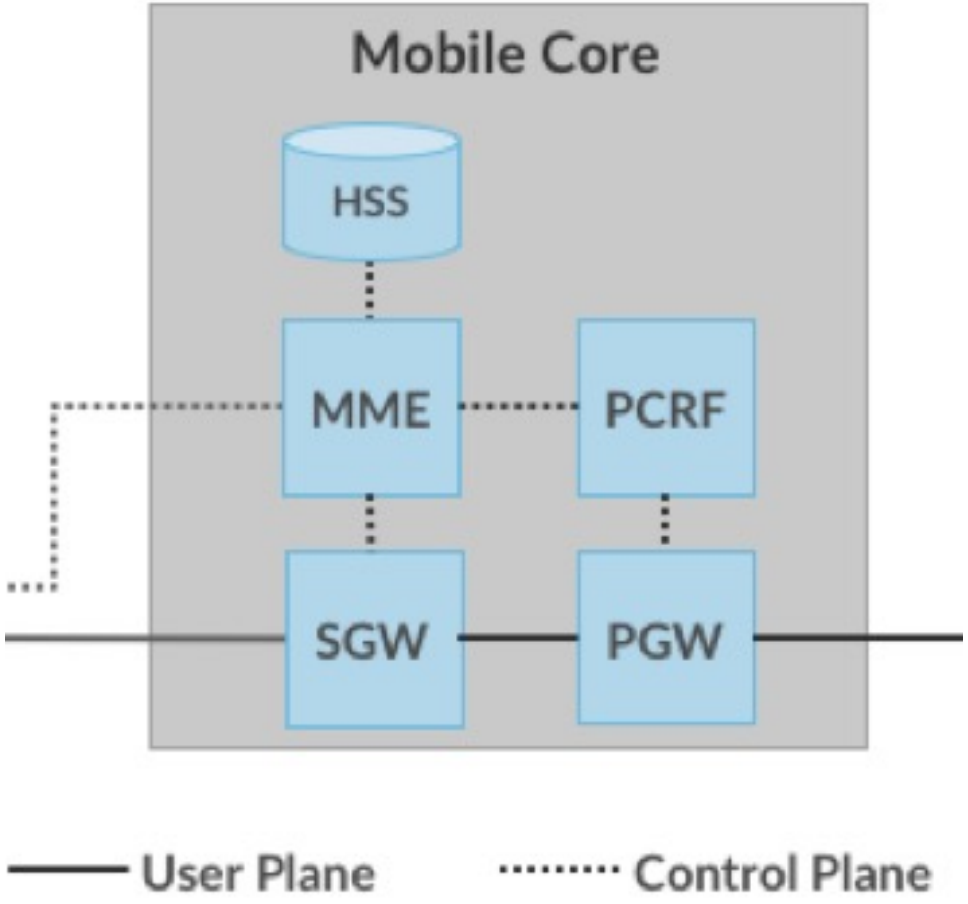
Support large number of users and devices

Flexible

Easy to modify and upgrade to support new use cases

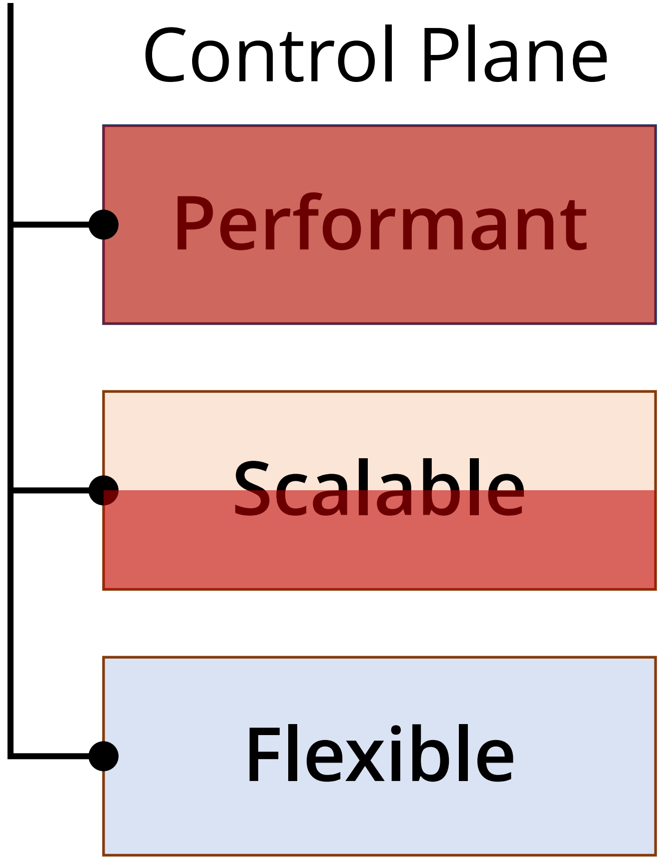
Vertically-Integrated 4G EPC in LTE

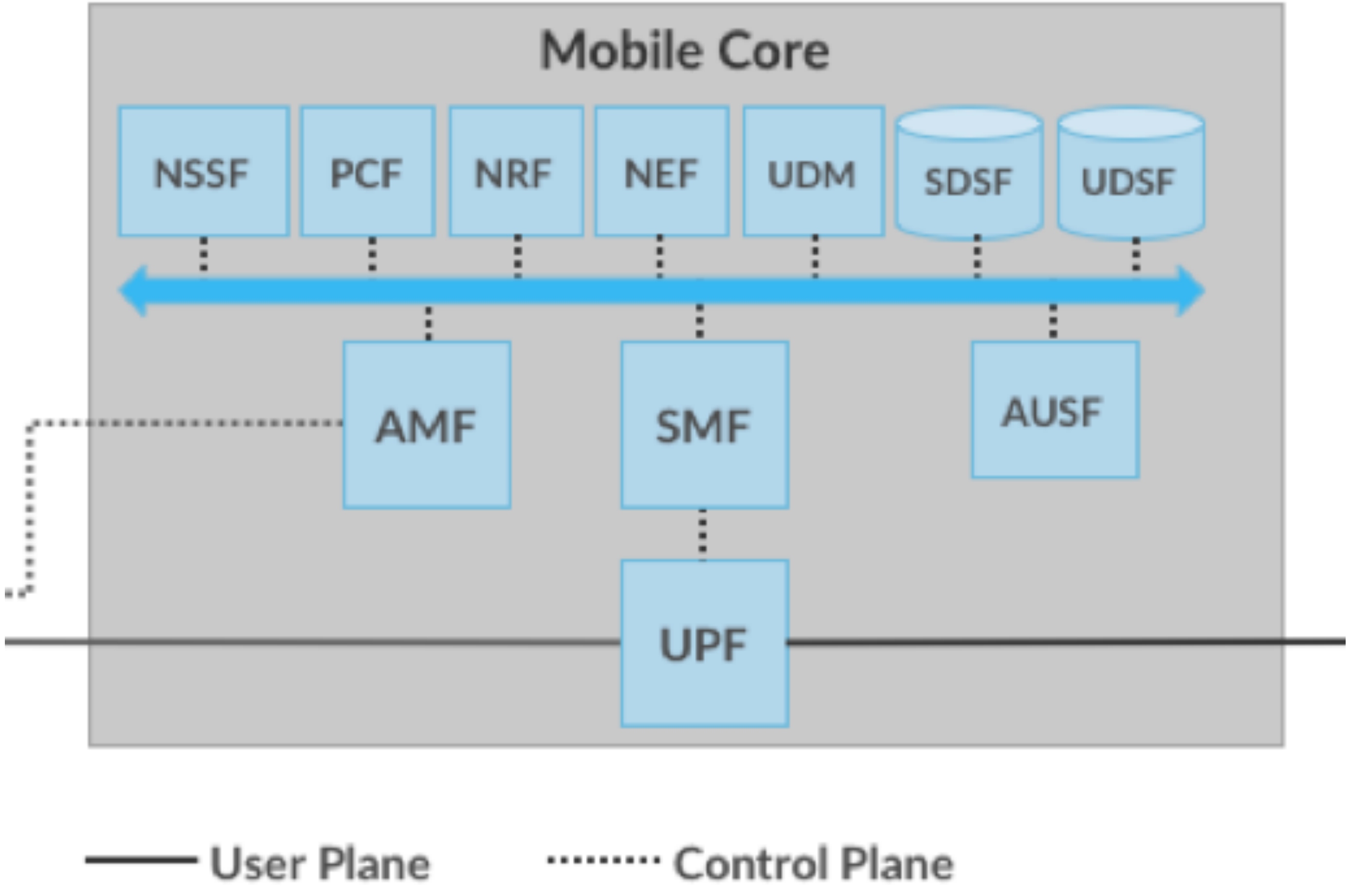
- Performant
- Scalable
- Flexible



Picture Credit: https://5g.systemsapproach.org/

Horizontally-disaggregated 5G Core

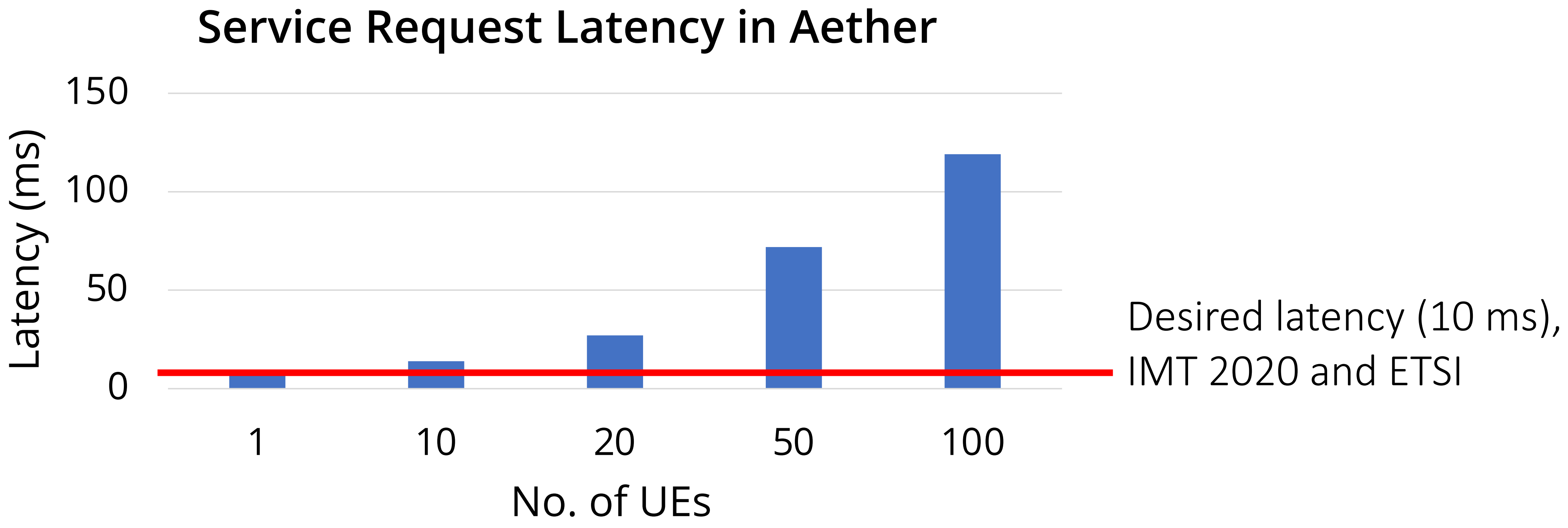




Picture Credit: https://5g.systemsapproach.org/

Poor Performance of 5GC Control Plane

- High control event latency even when bypassing UPF.



Performance Analysis and Insights using Aether

- Adding more server resources doesn’t help
  - Overall low utilization of CPU and memory
- Primary bottlenecks
  - Serialization/Deserialization
    - NGAP encoding/decoding
    - JSON to Golang struct mapping
  - Golang scheduler
    - Not designed for latency-critical 5GC traffic
  - Contention for common resources via.
    - Locks and channels

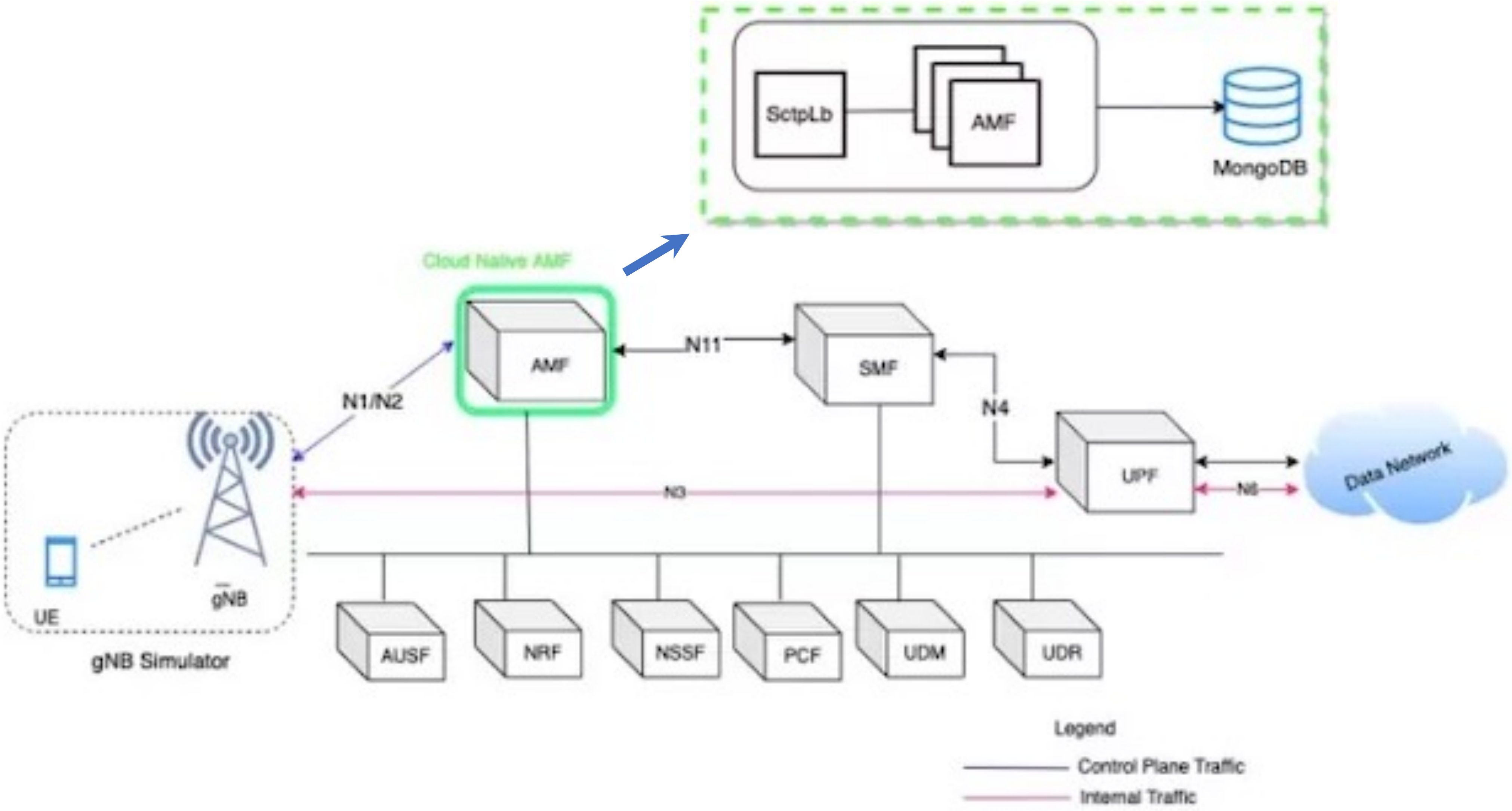
Way Forward

- Single-instance stateful service functions to
  → multi-instance stateless service functions

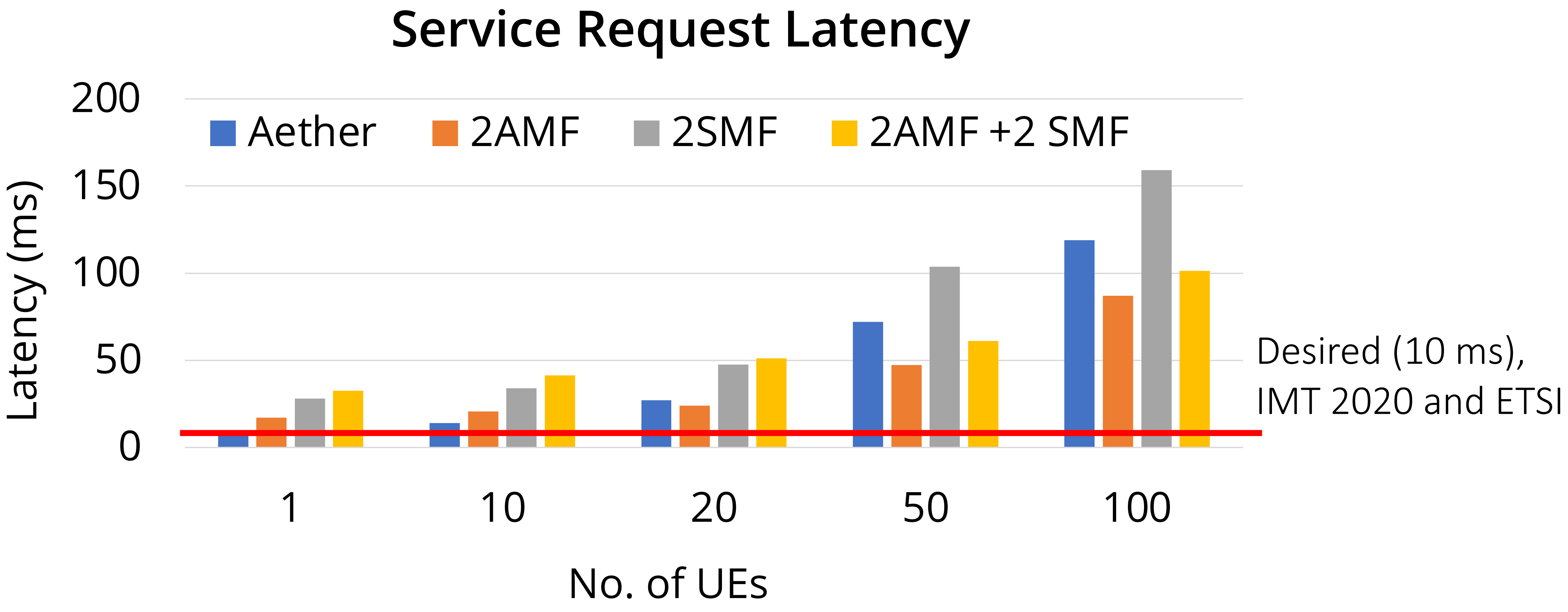
- Vertical scaling using programmable data planes (SmartNICs)
  - e.g., accelerating serialization and deserialization

- 5G-optimized microservice scheduling
- and …

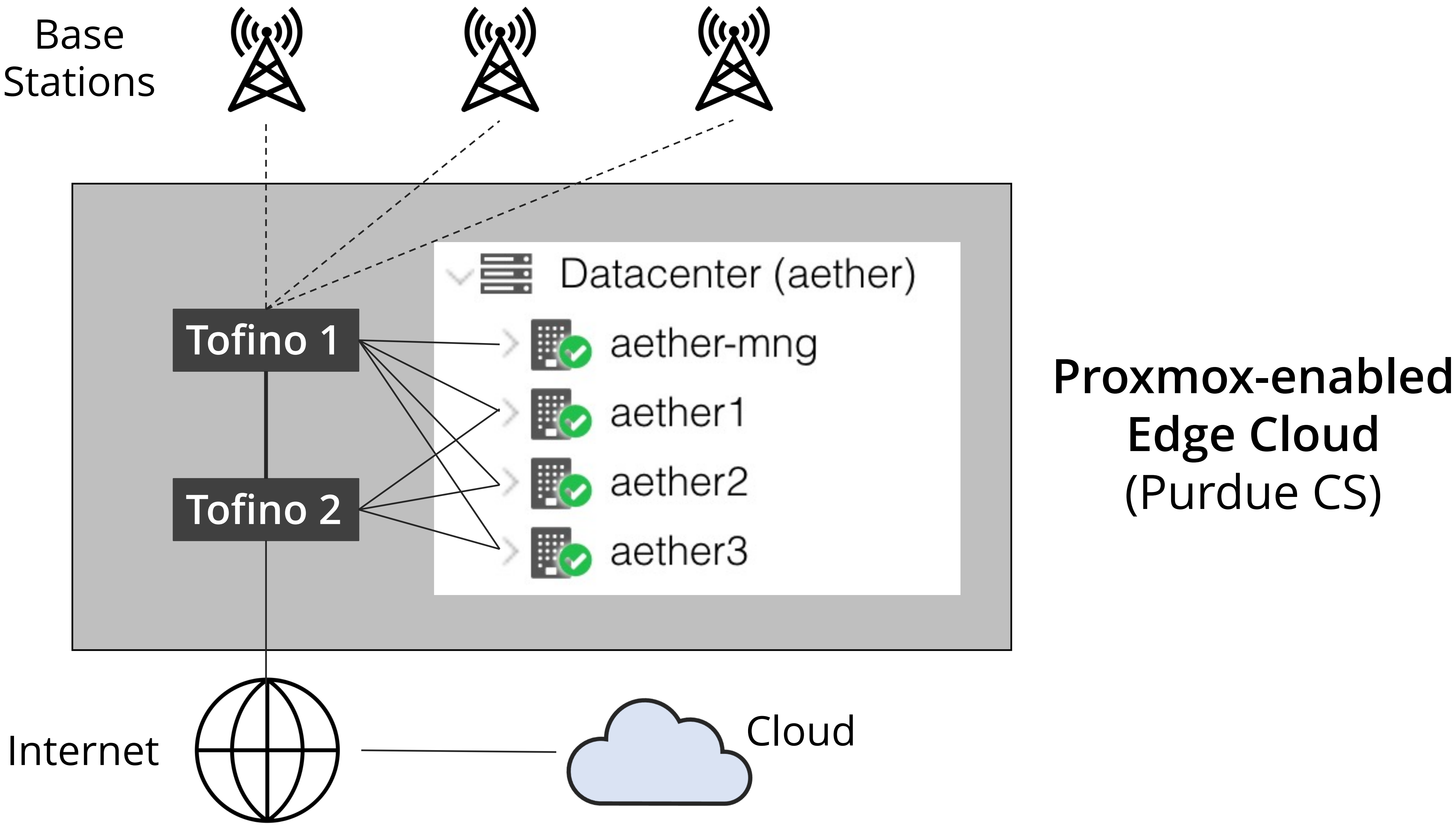
Multi-Instance Stateless 5GC Core: Aether+



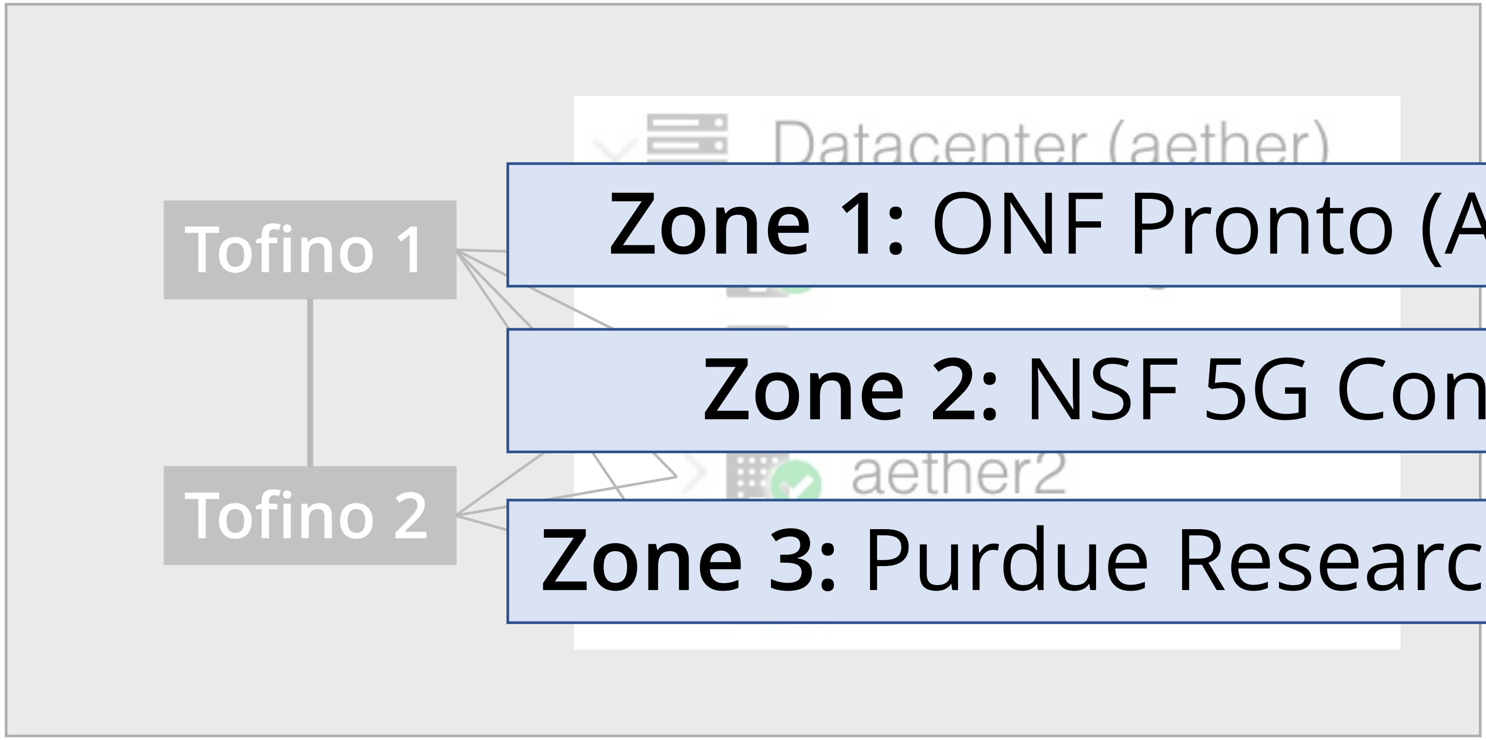
Aether vs. Aether+



5G Multi-Tenant Edge Cloud at Purdue University


Base
Stations
Tofino 1
Tofino 2
Datacenter (aether)
aether-mng
aether1
aether2
aether3
Proxmox-enabled
Edge Cloud
(Purdue CS)
Internet
Cloud

Security Zones for Multiple Tenants

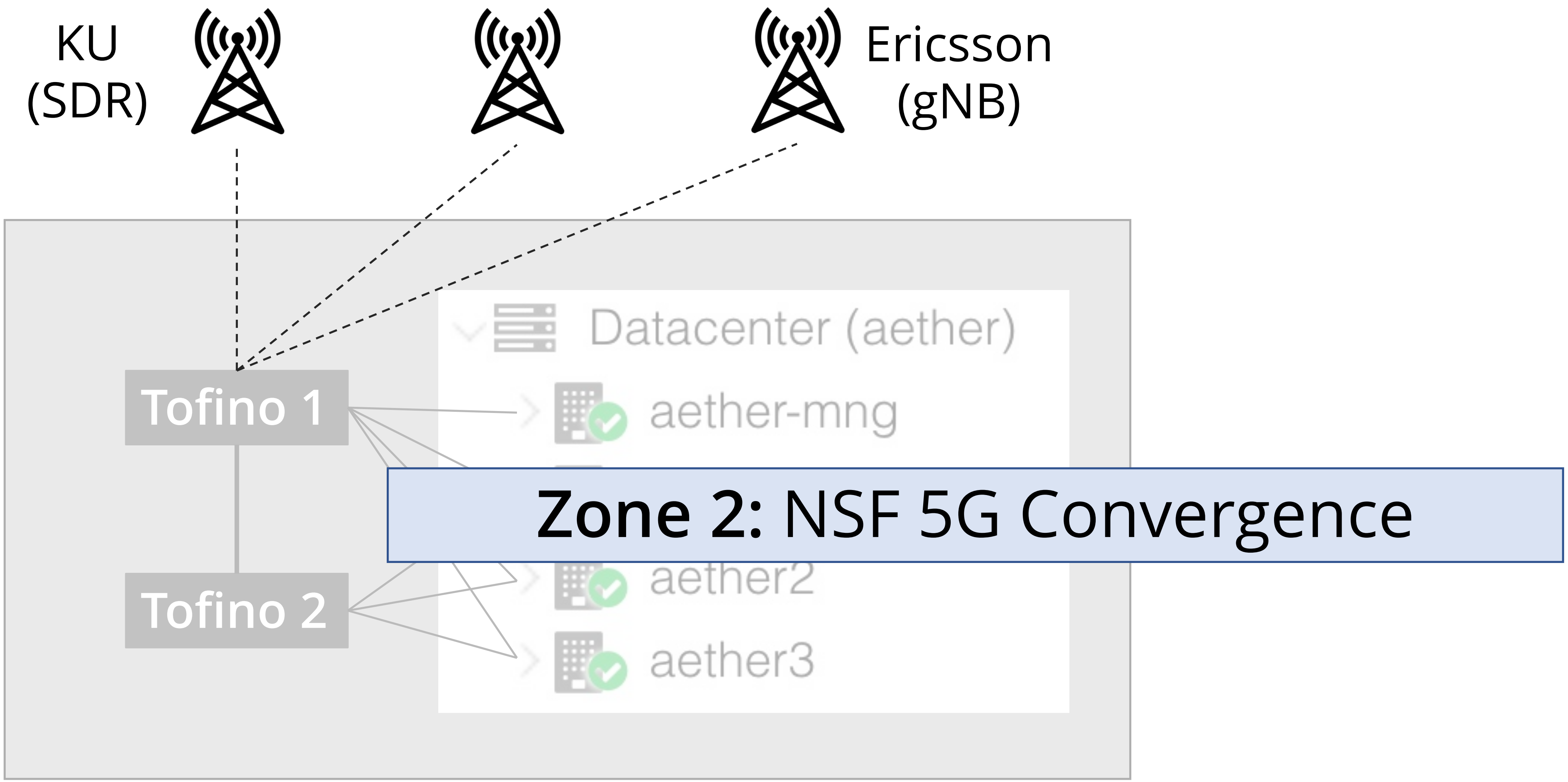


Zone 1: ONF Pronto (Aether) Core

Zone 2: NSF 5G Convergence

Zone 3: Purdue Research Foundation

Zone 2: NSF 5G Convergence



Zone 2 runs NSF 5G Convergence Site’s 5G Mobile Core (Aether) that connects to multiple institutions, serving as base stations.

5G/6G Lab-to-Life R&D Infrastructure at Purdue Research Foundation

PURDUE
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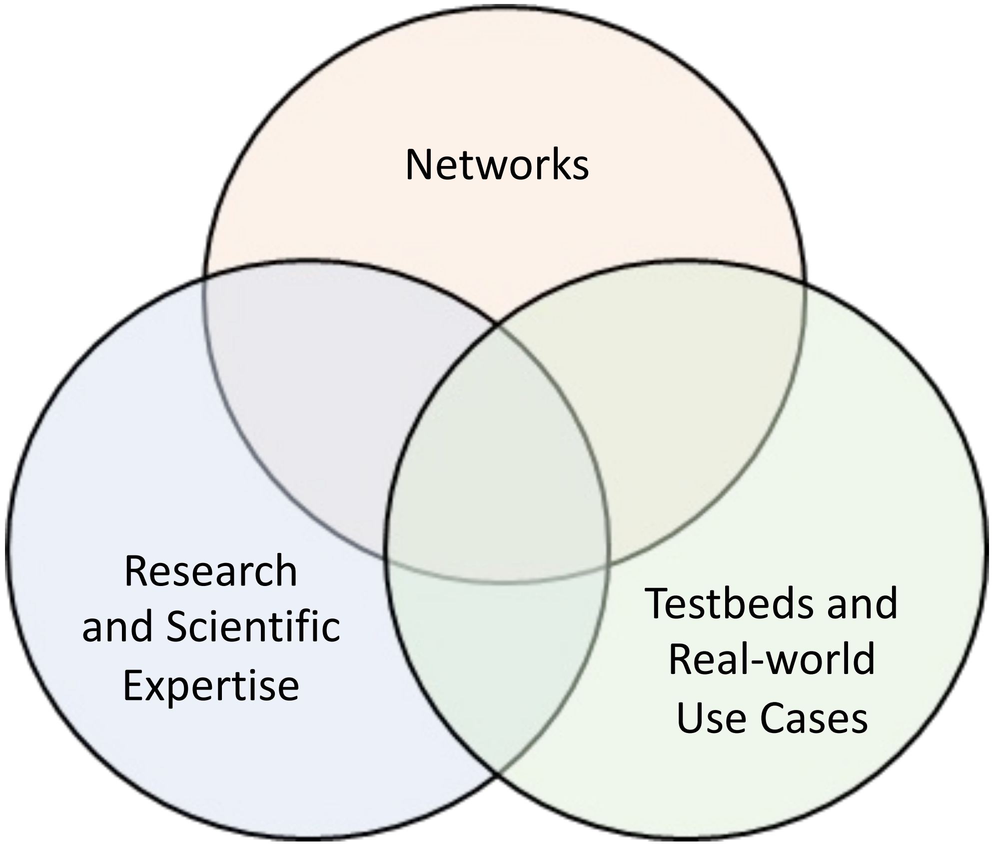
Lab-to-Life
A Research and Development Platform at Purdue University

PRF Team: Troy D. Hege, David Broecker, Mung Chiang, Kwang Taik Kim, and more

Purdue’s Lab-to-Life Platform



Lab-to-Life – Real world Test Beds

- **PPU ACRE** (Agriculture) – 1,134-acre farm facility
- **PU IN-MaC** (Manufacturing) – 62,000 sqft manufacturing facility
- **PU Airport** (Transportation / Mobility) – 2nd busiest airport in Indiana (no commercial traffic).
- **Discovery Park District** (Smart City) – 400 acre live, work, play curated urban community.
- **State Street Mobility Infrastructure** (Smart City and Autonomous vehicles) – one mile of congested roadway.
- **John Wright Forestry Center** – 477 acres, proposed site for the UAV Test Range for UTM/ATM Research

Purdue’s Lab-to-Life Expertise

- Land grant university founded in 1869; Total enrollment 50,880
- Engineering (26% of enrollment, ranked 4th nationally) and Sciences (17% of enrollment)
- Electrical and Computer Engineering (ECE) – Over 120 faculty
- Computer Science (CS) – Over 80 faculty
- Institute for Control, Optimization and Networks (ICON) – over 75 affiliated faculty
- Center for Education & Research & Information Assurance & Security (CERIAS) – over 100 affiliated faculty
- Purdue UAS Research and Test Facility (PURT)
- Herrick Laboratory (smart building infrastructure)
- Joint Transportation Research Center (JPRT)
- Indiana Next Generation Manufacturing and Competitiveness Center (IN-MaC)
- Agronomy Center for Research and Education (ACRE)
- Purdue Policy Research Institute (PPRI)
- Data Mine (data visualization and analytics)
- Birck Nanotechnology Center

Purdue's Lab-to-Life - Networks

Deployed: Neutral Host Communications Platform in Partnership with Tilson
Common, shared fiber network and edge data center (3 ISPs)

CBRS LTE Network at Discovery Park District (upgrade to 5G in fall of 2023)
Celona Core and RAN; commercially operated by SBA Communications
PAL and GAA channels available for research and development

Deploying: CBRS 5G Private Network at Purdue University Airport
Ericsson Core and RAN; PRF operated
PAL and GAA channels available for research and development

In Discussions: **Licensed spectrum**, 5G Private Network at IN-Mac operated by Commercial Carrier
Channels available for research and development
Target Summer 2023

CBRS 5G **Open-architecture private network** at ACRE
PAL and GAA channels available for research and development
Target Fall of 2023

mmWave network for State Street autonomous corridor
Evaluating options for 28Ghz, 39Ghz, and 60Ghzhz
Target Spring of 2024

CBRS 5G **Open-architecture private network** at Forestry Center for ATM/UTM/UAV
PAL and GAA channels available for research and development
Target Summer of 2024

Lab-to-Life – Supporting Purdue Research Proposals

- NSF 22-637 Mid Scale Research Infrastructure (Mid scale RI-1)
  - Up to 10 awards, up to $20 million
  - Creating an open-air drone facility for un-manned air traffic management and security research
- NSF 18-513 Major Research Instrumentation Program (MRI)
  - Up to 100 awards across three funding level categories, up to $4M
  - Autonomous vehicle and smart roadway infrastructure
- NSF 22-529 Smart and Connected Communities (SCC)
  - Up to 15 awards, up to $2.5M
  - Enhancing public safety through emergency drone-based intelligence and network priority use cases
- NSF 22-572 Pathways to Enable Open-Source Ecosystems (POSE) – In Submission
  - Up to 10 awards up to $1.5M
  - Fostering open-source eco-system in support of open-source network development

Thank you! 🙏

Follow us

- PurNET Lab - https://purnet-lab.gitlab.io/
- Purdue Research Foundation - https://prf.org/

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