LEGO for 6G: A modular open access end-to end-network architecture to enable B5G/6G research

September 15 2022

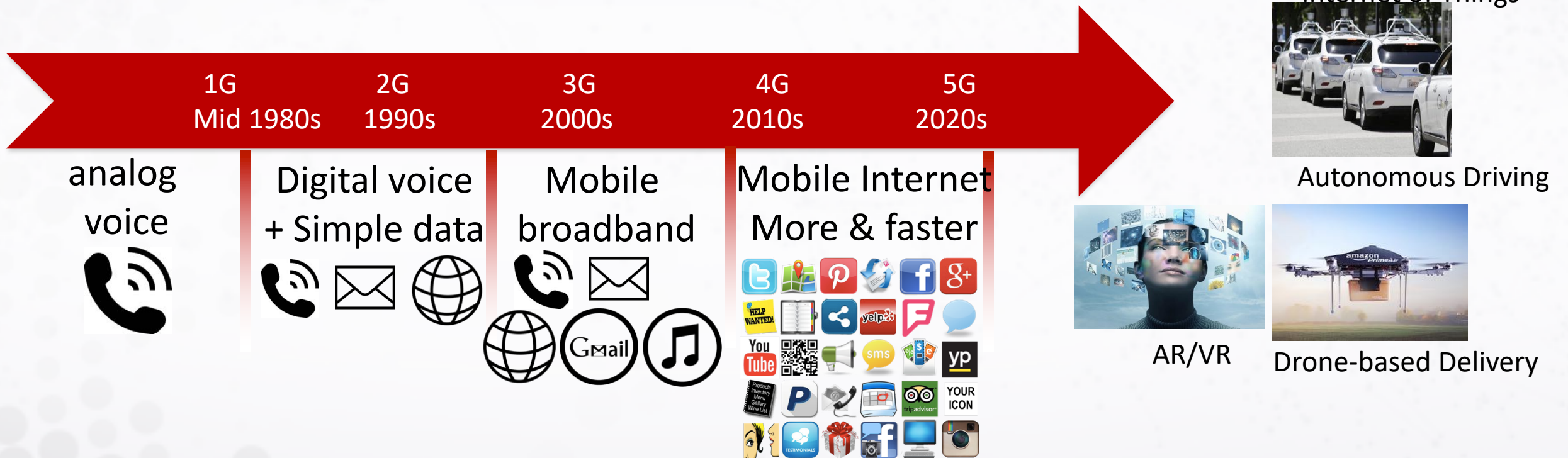*Abhimanyu Gosain*
Northeastern University
agosain@coe.neu.edu

$whoami

- Senior Director @ Institute for Wireless Internet of Things at NU
- Co-Manage NSF Platforms for Advanced Wireless Research (PAWR) Project Office
- DoD Innovate Beyond 5G Program Senior Advisor
- US FCC Technology Advisory Council 6G WG Co-Chair
- Board Appointments
  - OpenAirInterface Software Alliance Board Member
  - O-RAN Alliance Academic Research Council
  - Open Networking Foundation (ONF) Member
  - ATIS NextG Alliance
  - Magma Foundation Founding Member
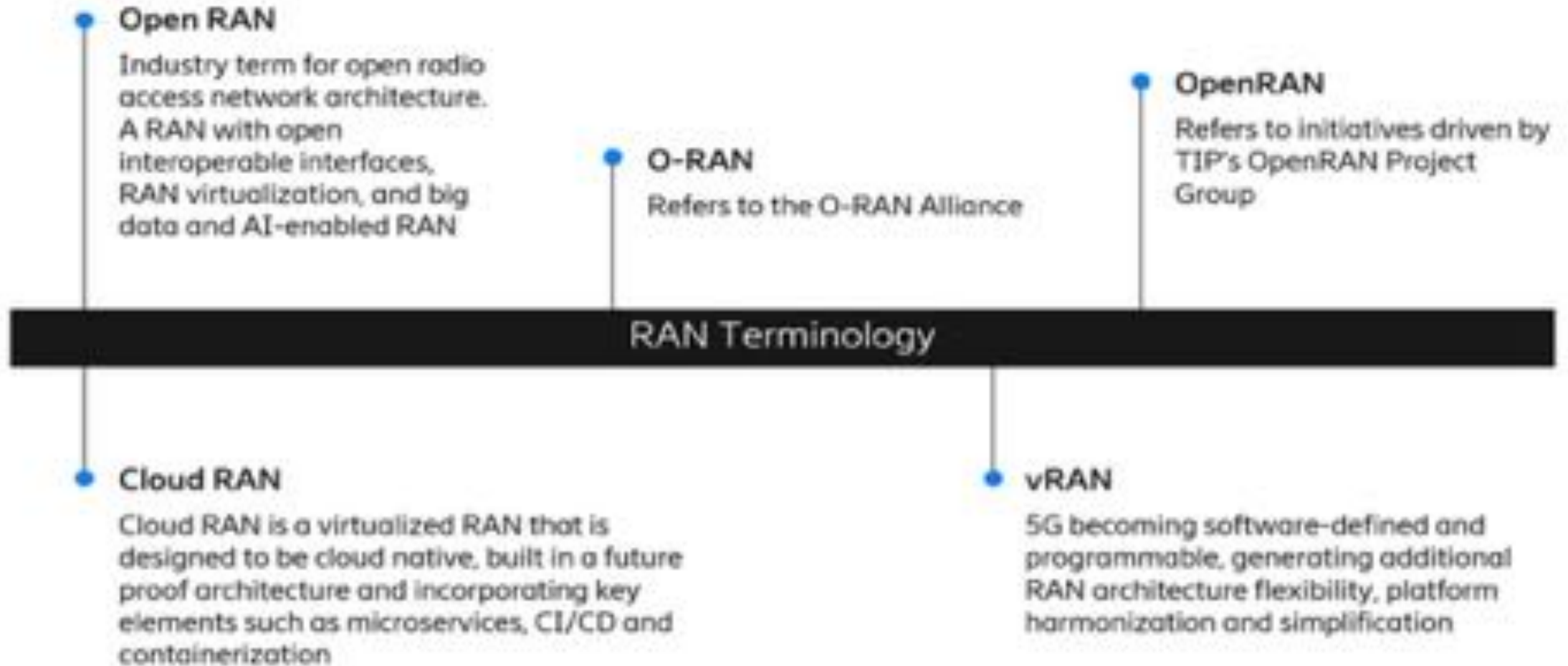- Co-Founder of 6GSymposium

What is 5G?

- Next generation mobile network

Internet of Things

Autonomous Driving

1G Mid 1980s	2G 1990s	3G 2000s	4G 2010s	5G 2020s

analog voice

Digital voice + Simple data

Mobile broadband

Mobile Internet More & faster

AR/VR

Drone-based Delivery

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Radio Access Network Terminology

Open RAN

Industry term for open radio access network architecture. A RAN with open interoperable interfaces, RAN virtualization, and big data and AI-enabled RAN

O-RAN

Refers to the O-RAN Alliance

OpenRAN

Refers to initiatives driven by TIP's OpenRAN Project Group

RAN Terminology

Cloud RAN

Cloud RAN is a virtualized RAN that is designed to be cloud native, built in a future proof architecture and incorporating key elements such as microservices, CI/CD and containerization

vRAN

5G becoming software-defined and programmable, generating additional RAN architecture flexibility, platform harmonization and simplification

Open RAN: Much More than "Horizontal Disaggregation"

Traditional "black-box"

RRC	SDAP	PDCP

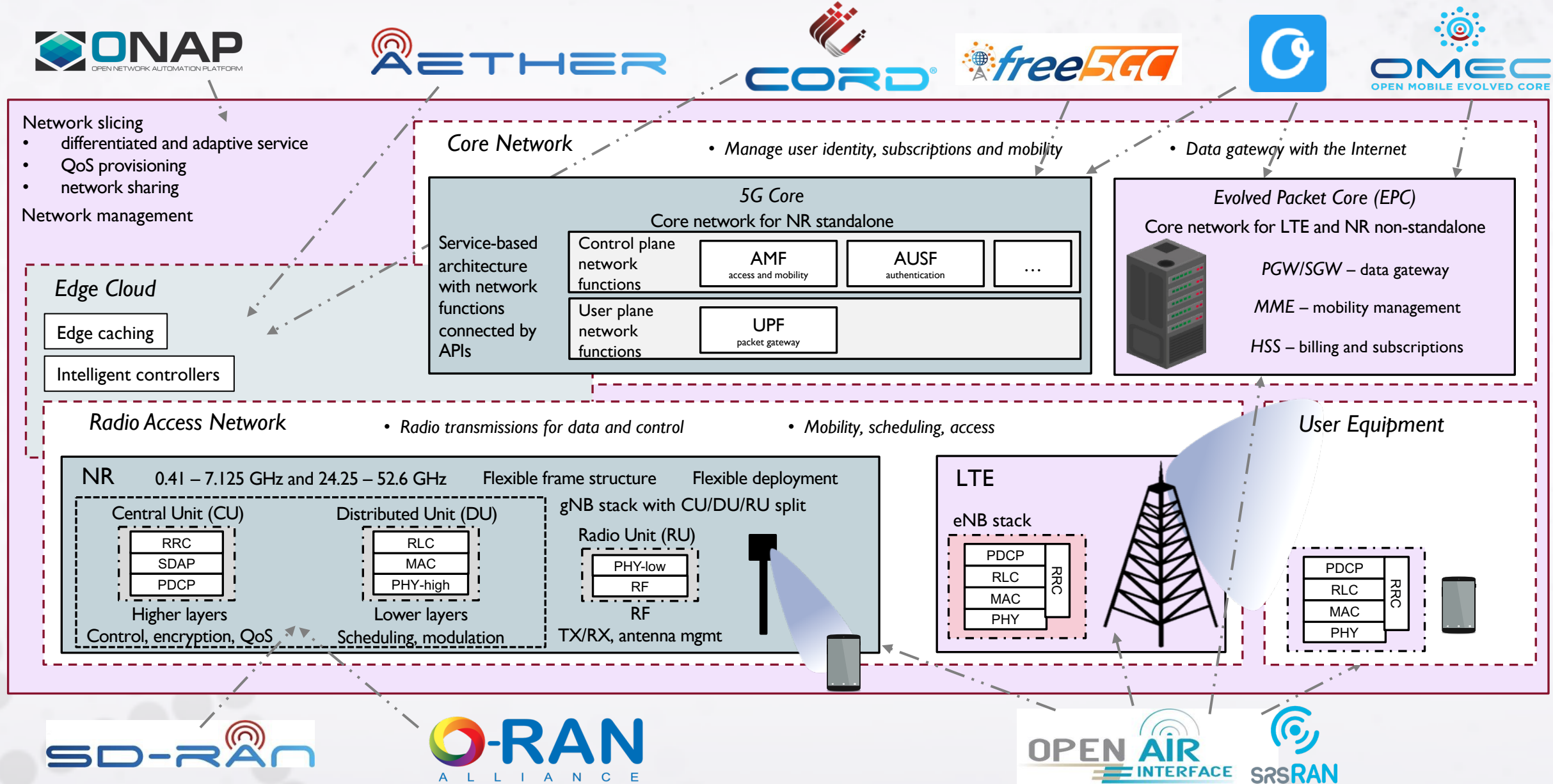| RLC	MAC	RF	PHY
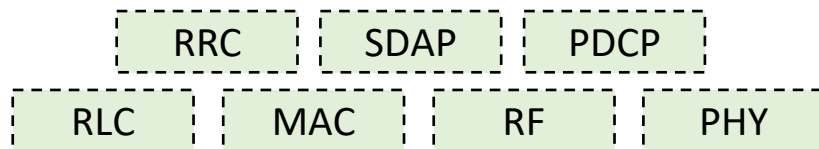
Open, programmable and virtualized
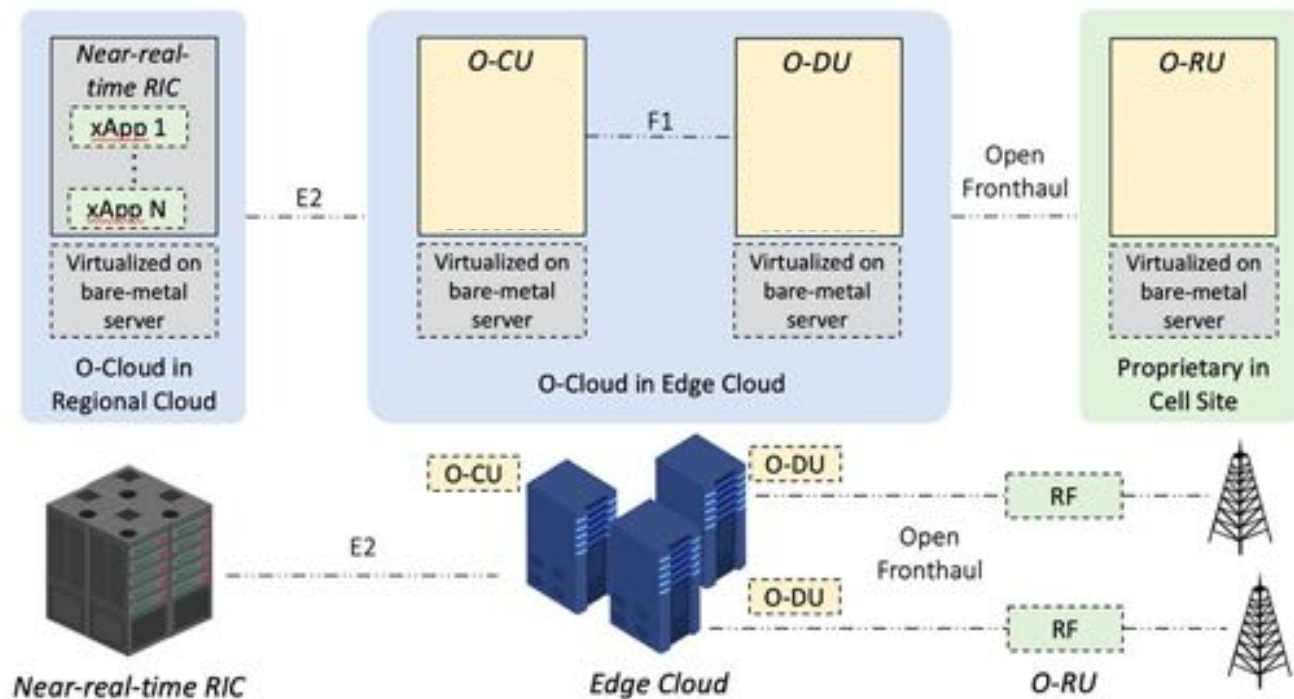
L. Bonati, M. Polese, S. D'Oro, S. Basagni, and T. Melodia, *"Open, Programmable, and Virtualized 5G Networks: State-of-the-Art and the Road Ahead,"* Computer Networks, vol. 182, Dec 2020.

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5

End to End Virtualized Programmable B5G Architecture

ONAP OPEN NETWORK AUTOMATION PLATFORM

AETHER

CORD®

free5GC

OMEC OPEN MOBILE EVOLVED CORE

Network slicing
- differentiated and adaptive service
- QoS provisioning
- network sharing

Network management

Edge Cloud

Edge caching

Intelligent controllers

Core Network
- *Manage user identity, subscriptions and mobility*
- *Data gateway with the Internet*

5G Core
Core network for NR standalone

Service-based architecture with network functions connected by APIs

Control plane network functions		
AMF access and mobility	AUSF authentication	...

User plane network functions	
UPF packet gateway	

Evolved Packet Core (EPC)
Core network for LTE and NR non-standalone

PGW/SGW – data gateway

MME – mobility management

HSS – billing and subscriptions

Radio Access Network
- *Radio transmissions for data and control*
- *Mobility, scheduling, access*

User Equipment

NR   0.41 – 7.125 GHz and 24.25 – 52.6 GHz   Flexible frame structure   Flexible deployment

gNB stack with CU/DU/RU split

Central Unit (CU)

| RRC |
| SDAP |
| PDCP |

Higher layers
Control, encryption, QoS

Distributed Unit (DU)

| RLC |
| MAC |
| PHY-high |

Lower layers
Scheduling, modulation

Radio Unit (RU)

| PHY-low |
| RF |

RF
TX/RX, antenna mgmt

LTE

eNB stack

PDCP	
RLC	RRC
MAC	
PHY	

User Equipment

PDCP	
RLC	RRC
MAC	
PHY	

SD-RAN

O-RAN ALLIANCE

OPEN AIR INTERFACE

srsRAN

PAWR program seeks to maintain U.S. leadership in advanced wireless networking innovation

PAWR is funded by the National Science Foundation and a wireless Industry consortium of 35 wireless companies and associations. The PAWR Project Office (PPO) manages the program and is co-led by US Ignite and Northeastern University.

Founded 2017

Aarna Networks | alef | American Tower | Anritsu | AT&T | atis | Black & Veatch | Carlson

CommScope | Crown Castle | ctia | Ericsson | FACEBOOK | HTC | intel | InterDigital | Johns Hopkins

Juniper | Keysight | MathWorks | National Instruments | Nokia Bell Labs | Oracle | Polaris Networks | Qualcomm | SAMSUNG

sigfox | Siradel | Sprint | T-Mobile | TIA | Vapor | verizon | VIAVI

PAWR platforms were chosen to be geographically diverse and research focus independent

POWDER

Salt Lake City, UT

Software defined networks and massive MIMO

AVAILABLE TODAY !!

COSMOS

West Harlem, NY

Millimeter wave and backhaul research

AVAILABLE TODAY !!

AERPAW

Raleigh, NC

Unmanned aerial vehicles and mobility

AVAILABLE TODAY !!

Rural Broadband Platform

Ames, IA

Colosseum – *World's largest RF emulator, located at Northeastern University in Boston*
AVAILABLE TODAY !!

Researchers use PAWR testbeds to prove out concepts in an array of disciplines

Cybersecurity Testing

Internet of Things

Millimeter Wave Performance Optimization

Open Source Hardware & Software Development

AI-Enabled Network Functions

Accelerated Virtualization of Network Architectures

Dynamic Spectrum Management

Highly Mobile Unmanned Aerial Vehicles

Interoperable/Interchangeable Modules Per Use Case

UE   gNodeB   Core

| OAI | OAI | OAI | Spectrum Sharing Coherent MIMO |

Standard Interfaces   Standard Interfaces

| OAI + IDCC | Radisys | Radisys | mmWave Antenna Array Integration |

Standard Interfaces   Standard Interfaces

| NI | Radisys | Radisys | Network Slicing Security |

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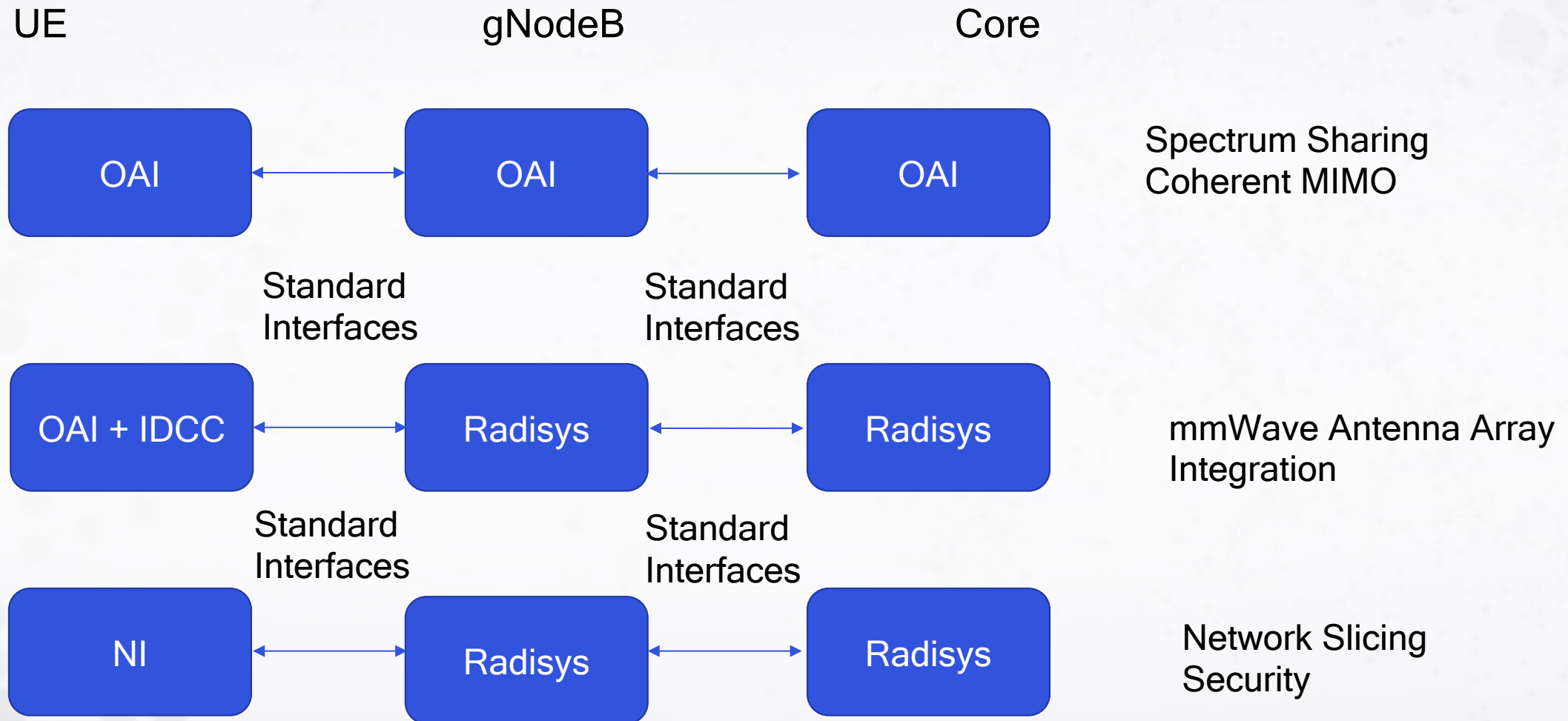
Colosseum @ Northeastern

Colosseum is the world's most powerful hardware-in-the-loop emulator

- 256 software-defined radios
- 25.6 GHz of emulated bandwidth, 52 TB/s RF data
- 21 racks of radios, 171 high-performance servers w/ CPUs, GPUs
- Massive computing capabilities (CPU, GPU, FPGA):
  - \> 900 TB of storage
  - 320 FPGAs
  - 18 10G switches
  - 19 clock distribution systems
  - 52 TB/s of digital RF data

Create and test complex 5G scenarios

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Colosseum Architecture
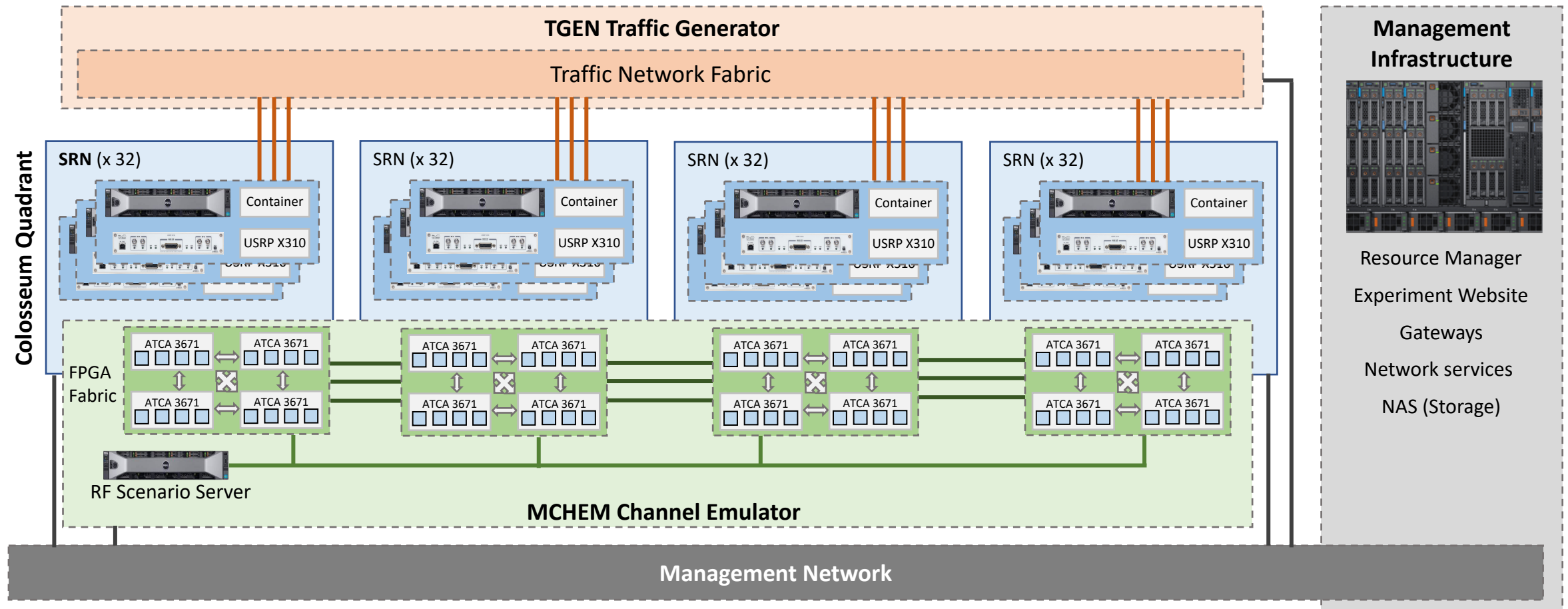
Experiment-as-a-Service Over Multiple Testbeds

One **container** to rule them all:
- Initial design and testing at-a-scale on Colosseum w/ different scenarios
- Validate on real-world indoor environment on Arena
- Experiment into the wild on PAWR city-scale platforms

Test at-a-scale on emulated scenarios

Validate in real wireless environment

Test large-scale capabilities

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Network Intelligence in 5G + O-RAN

Jamming Attack

Infrastructure Failure Mode

IAB Failure

Non Real-time RIC — Near Real-time RIC — Centralized Unit (CU) — Distributed Unit (DU) — Radio Unit (RU)

Recovery Loop 1 (<10ms)

Recovery Loop 2 (10-500ms)

Recovery Loop 3 (> 500ms)
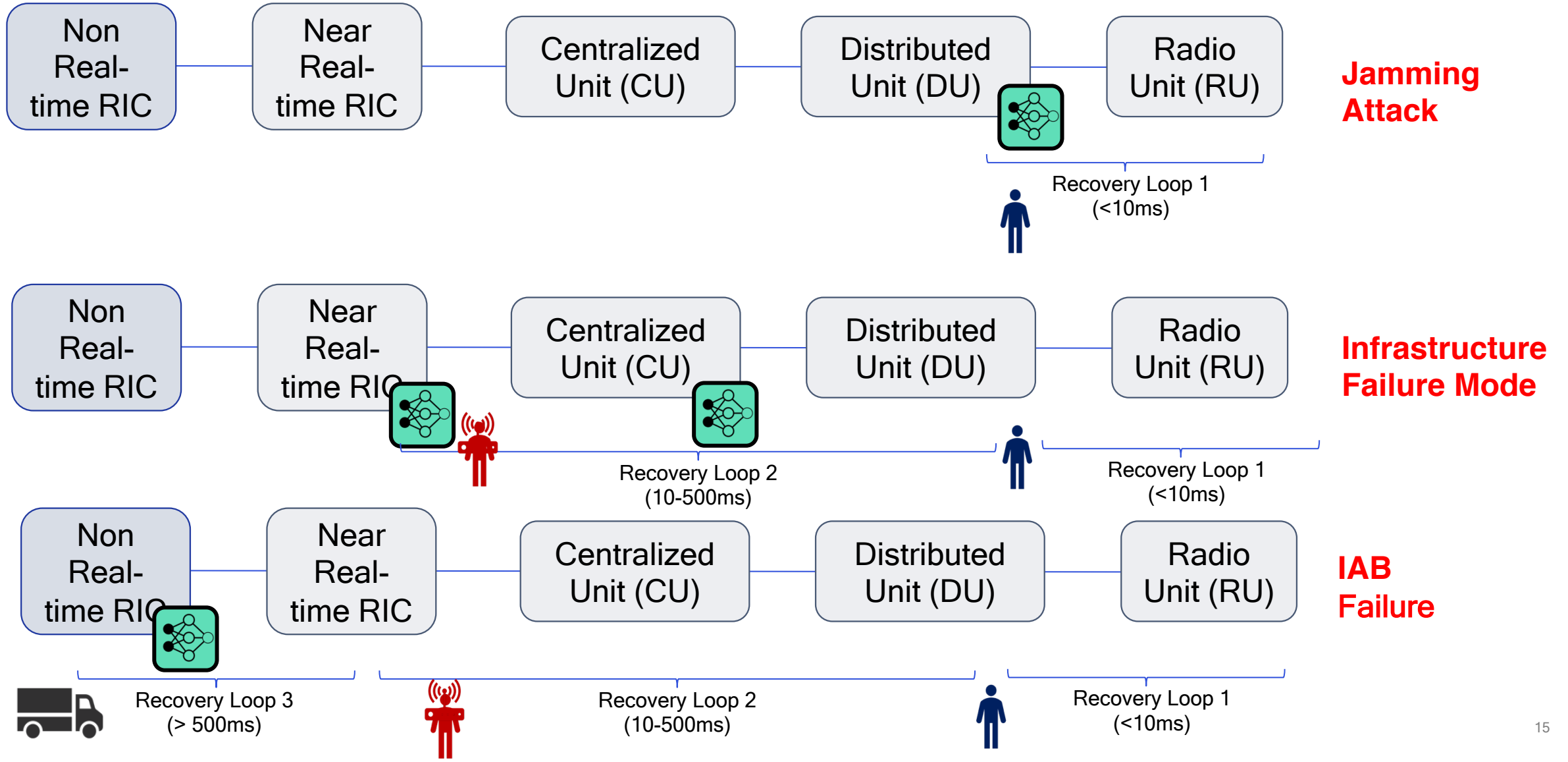
Toward End-to-end Data-Driven Control in the Open RAN

Currently supported by O-RAN

Control and learning objective	Scale	Input data	Timescale	Architecture
Policies, models, slicing	> 1000 devices	Infrastructure-level KPIs	Non real-time > 1 s	
User Session Management e.g., load balancing, handover	> 100 devices	CU-level KPIs e.g., number of sessions, PDCP traffic	Near real-time 10-1000 ms	
Medium Access Management e.g., scheduling policy, RAN slicing	> 100 devices	MAC-level KPIs e.g., PRB utilization, buffering	Near real-time 10-1000 ms	
Radio Management e.g., resource scheduling, beamforming	~10 devices	MAC/PHY-level KPIs e.g., PRB utilization, channel estimation	Real-time < 10 ms	
Device DL/UL Management e.g., modulation, interference, blockage	1 device	I/Q samples	Real-time < 1 ms	

For further study or not supported

Architecture diagram labels: Service Management and Orchestration (SMO) non real-time RIC; A1; O1; gNB; Near real-time RIC; E2; CU; F1; DU; Open FH; RU; Mobile devices

OpenRAN Gym

*An **open-source** toolbox for **xApp development** and Open RAN **experimentation***

Enables:

1. Data collection

2. AI/ML model design

3. Model training and testing

4. Model deployment on near-RT RIC as xApp

5. Runtime inference and control of a softwarized RAN

L. Bonati, M. Polese, S. D'Oro, S. Basagni, T. Melodia, *"OpenRAN Gym: An Open Toolbox for Data Collection and Experimentation with AI in O-RAN,"* Proceedings of IEEE WCNC Workshop on Open RAN Architecture for 5G Evolution and 6G, Austin, TX, USA, April 2022

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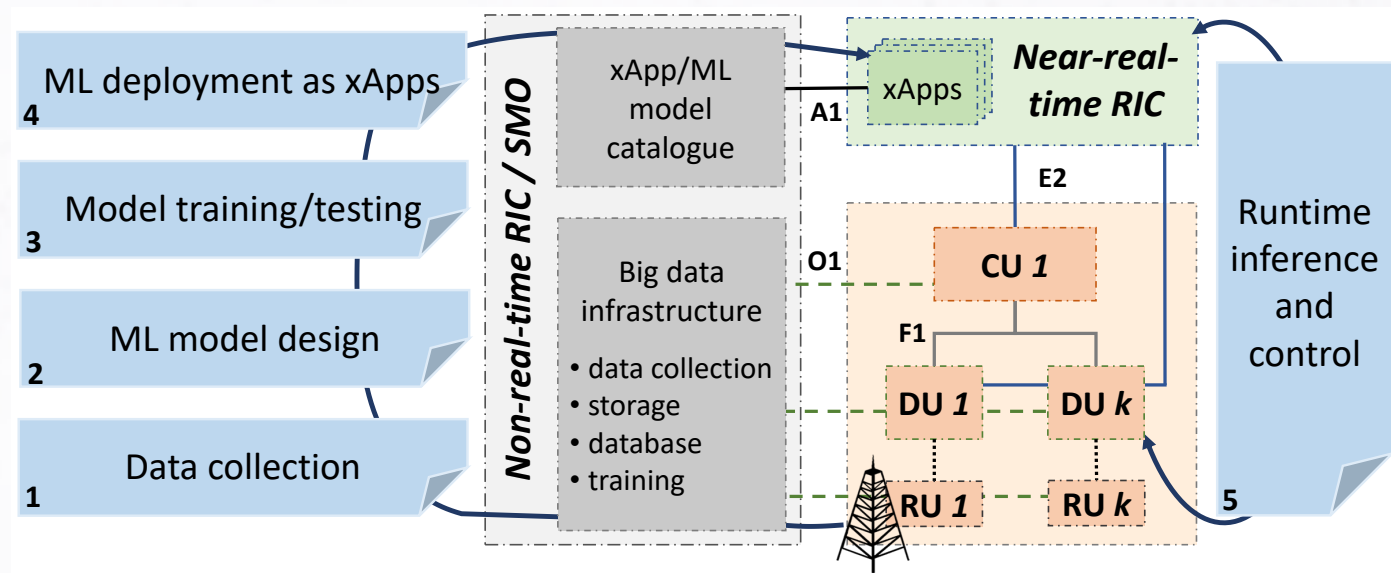
OpenRAN Gym Components

- O-RAN-compliant **near-real-time RIC** running on Colosseum (ColO-RAN)

- RAN framework for **data-collection and control** of the base stations (SCOPE)

- **Programmable** protocol stacks (based on srsRAN at this time)

- Publicly-accessible **experimental platforms** (e.g., Colosseum, Arena, PAWR platforms)

Experimental Platforms for Data Collection and Testing
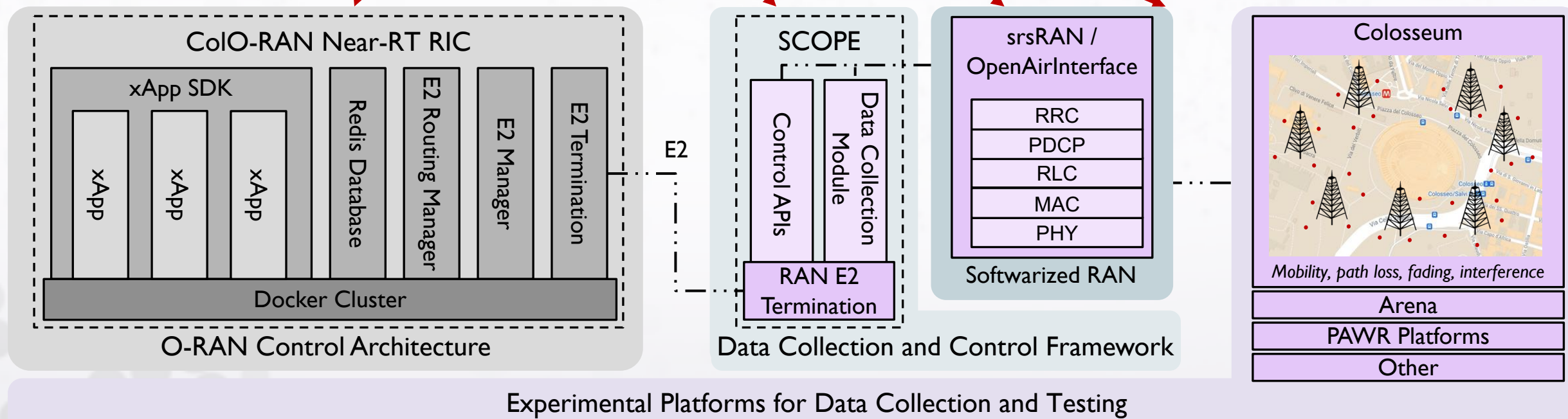
xApp Structure

Data-driven logic unit:

- Process RAN data and compute control action

SM Connector:

- Interface w/ the RIC and get data from the RAN

- Forward RAN data to data-driven logic unit

- Send computed control actions to RAN through RIC and E2 termination
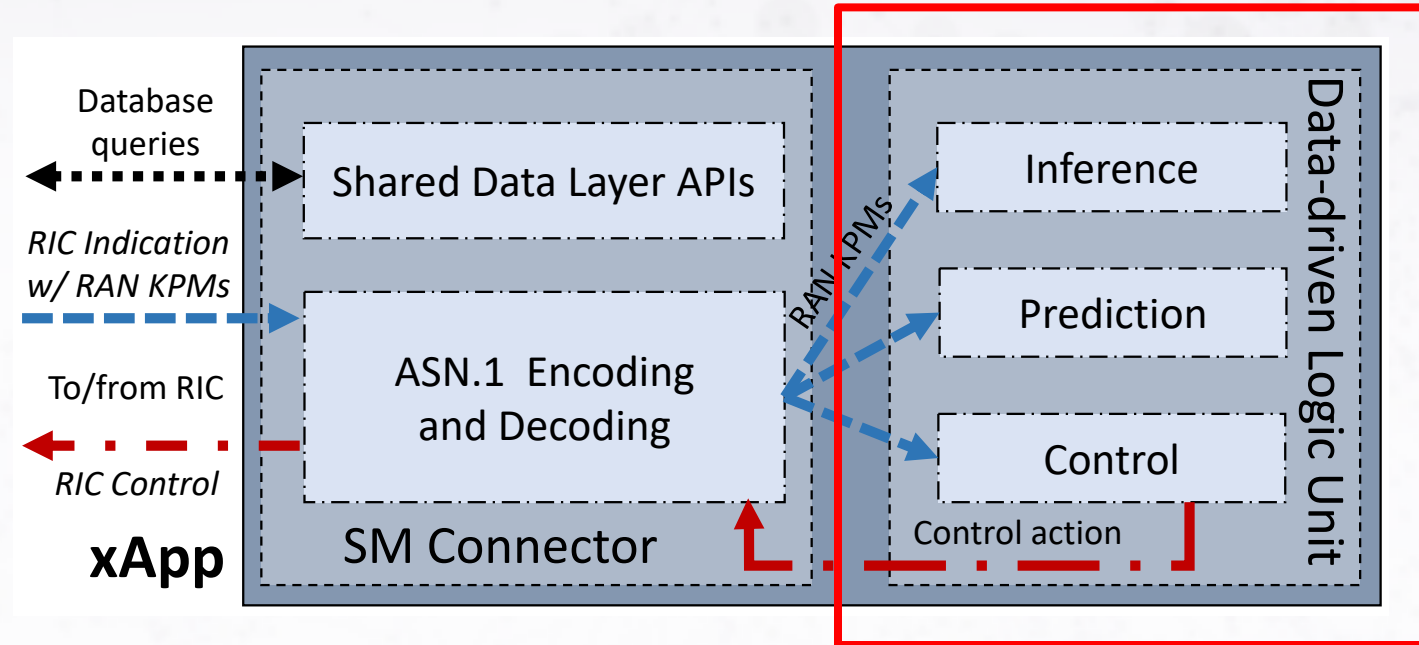
Zero-Touch AI-Driven Automation and Orchestration

Network operator's intent

> **I need to stream 4K video to 100 users in Times Square, NY from 8pm to 9pm**

Zero-touch Control

Data

Control actions

- **Intent recognition**
- **Automated** orchestration
- **Zero-touch reconfiguration**
- **Adapt** to network state and traffic demand

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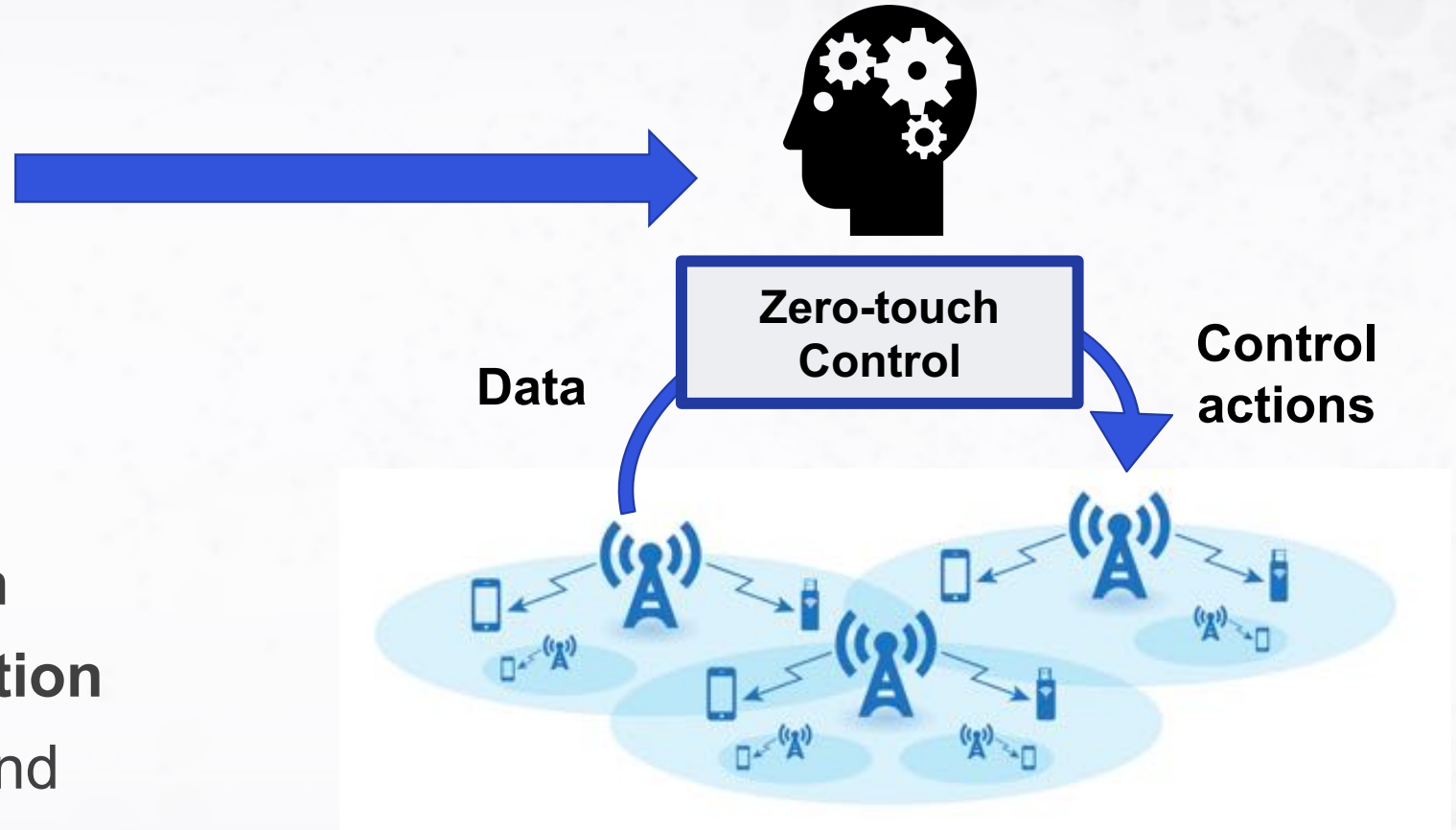
SCOPE

- Implements **base stations/UEs** with:
    - Network slicing functionalities
    - MAC-layer functionalities (e.g., custom scheduling policies)
    - PHY-layer functionalities (e.g., power-control, control of MCS)
- Automatic **data-collection** of RAN statistics
- Flexible **control APIs** to interface w/ the RAN in **real time**
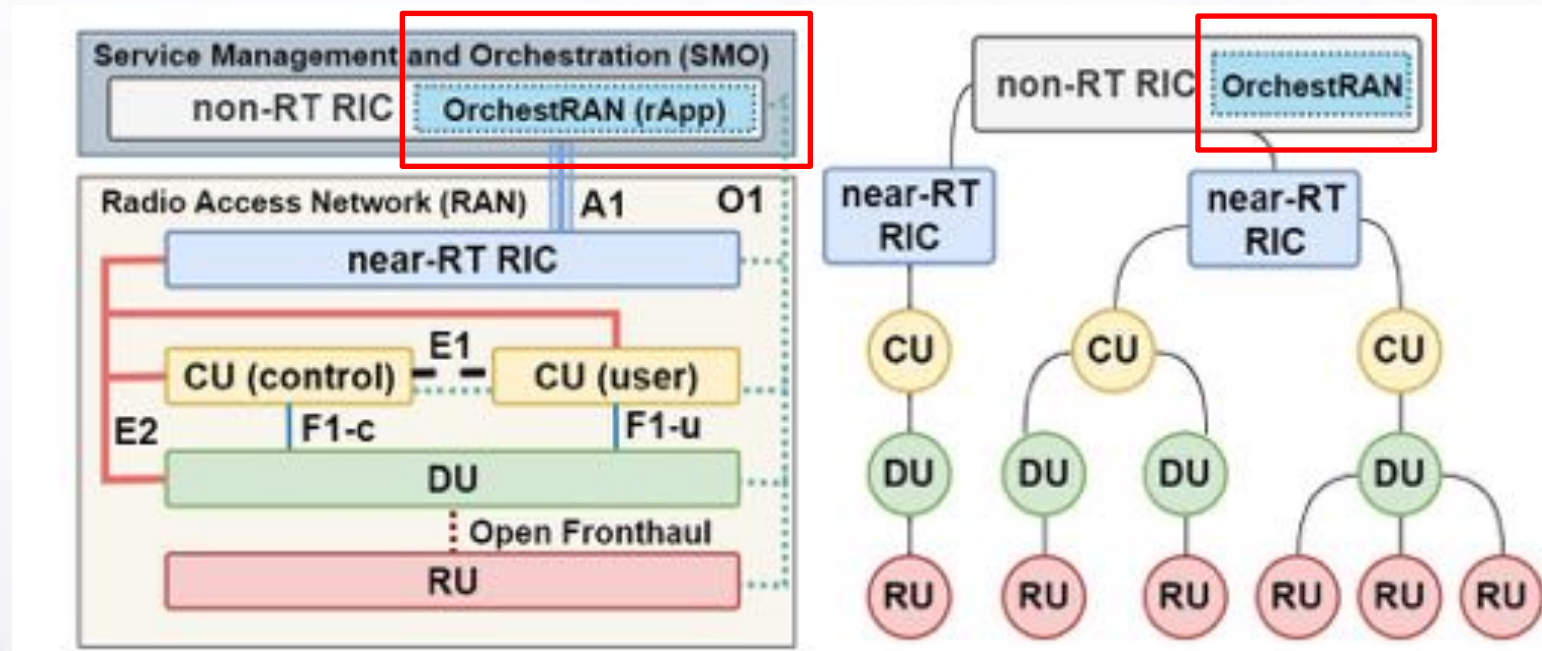- Enables to **prototype** custom control logic **at-scale**

L. Bonati, S. D'Oro, S. Basagni, and T. Melodia, "*SCOPE: An Open and Softwarized Prototyping Platform for NextG Systems,*" in Proceedings of ACM MobiSys, Virtual Conference, June 2021

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Open RAN Orchestration

Some Open Problems

2. Which models best satisfy the intent?

1. What does the intent mean?

ML/AI catalog

High-level intent

I want to change scheduling/slicing decisions in real time to broadcast 4K video in Times Square, NY

3. Where and when to deploy network intelligence?

Non-RT RIC

Near-RT RIC

CU

CU

DU DU DU

DU DU DU

RU RU RU RU

RU RU RU RU

Infrastructure

4. How to deploy, execute, manage intelligence?

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OrchestRAN: Orchestrating Intelligence in the Open RAN

Execute in the non-RT RIC

- **Intent recognition**

- Compute **intelligence placement**

- **Automate** deployment/execution/management of intelligence

 S. D'Oro, L. Bonati, M. Polese, T. Melodia, "OrchestRAN: Network Automation through Orchestrated Intelligence in the Open RAN," in Proceedings of IEEE INFOCOM, May 2022

OrchestRAN Step-by-step

(II) Collect requests

(III) Compute orchestration policy
- Which model
- Where and when

(I) Submit request
- Functionalities
- Locations
- Time-scale
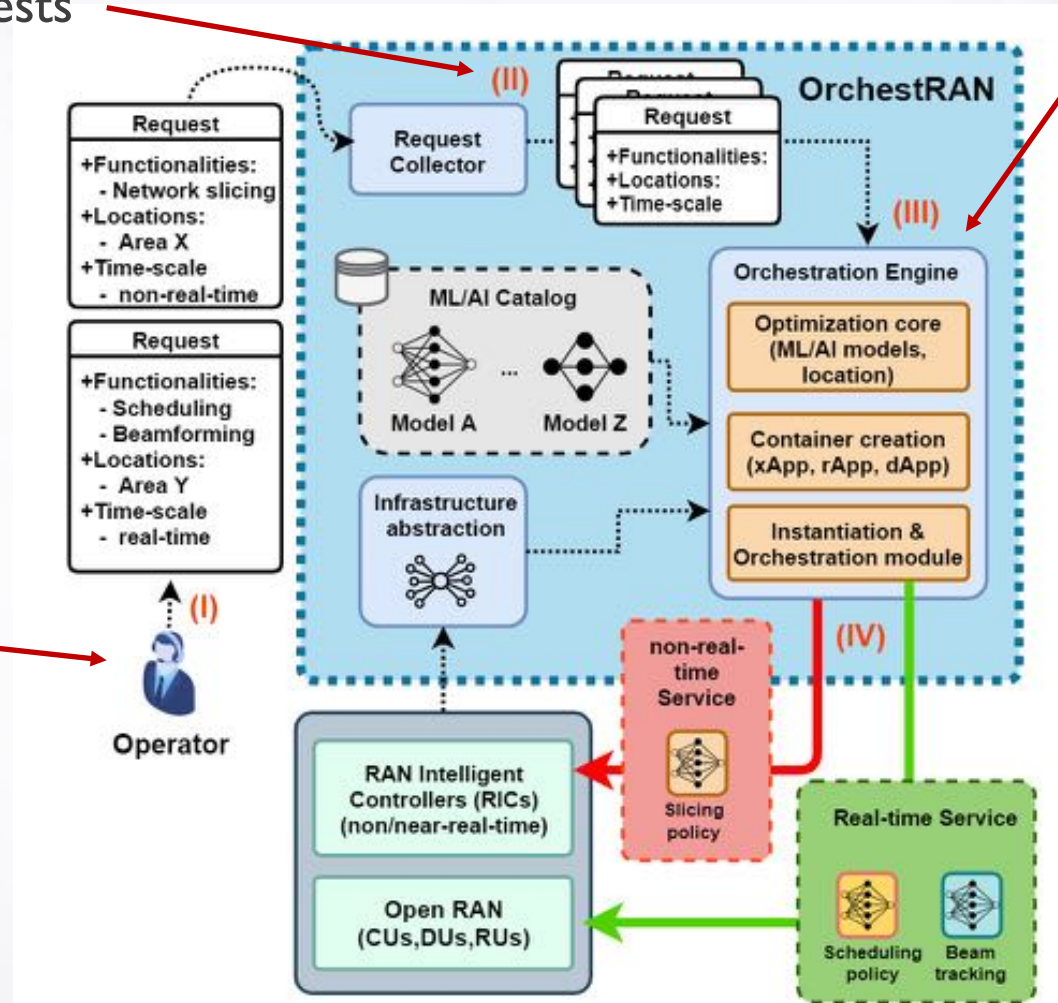
(IV) Deploy intelligence
- xApp on near-RT RIC
- dApp on CU/DU

Deployed on OpenShift

- Enterprise-level Platform-as-a-Service based on Kubernetes

- Large-scale infrastructure manager w/ control primitives

- Improved security

- Robustness

- Failure tolerance

- Automated application deployment and scalability
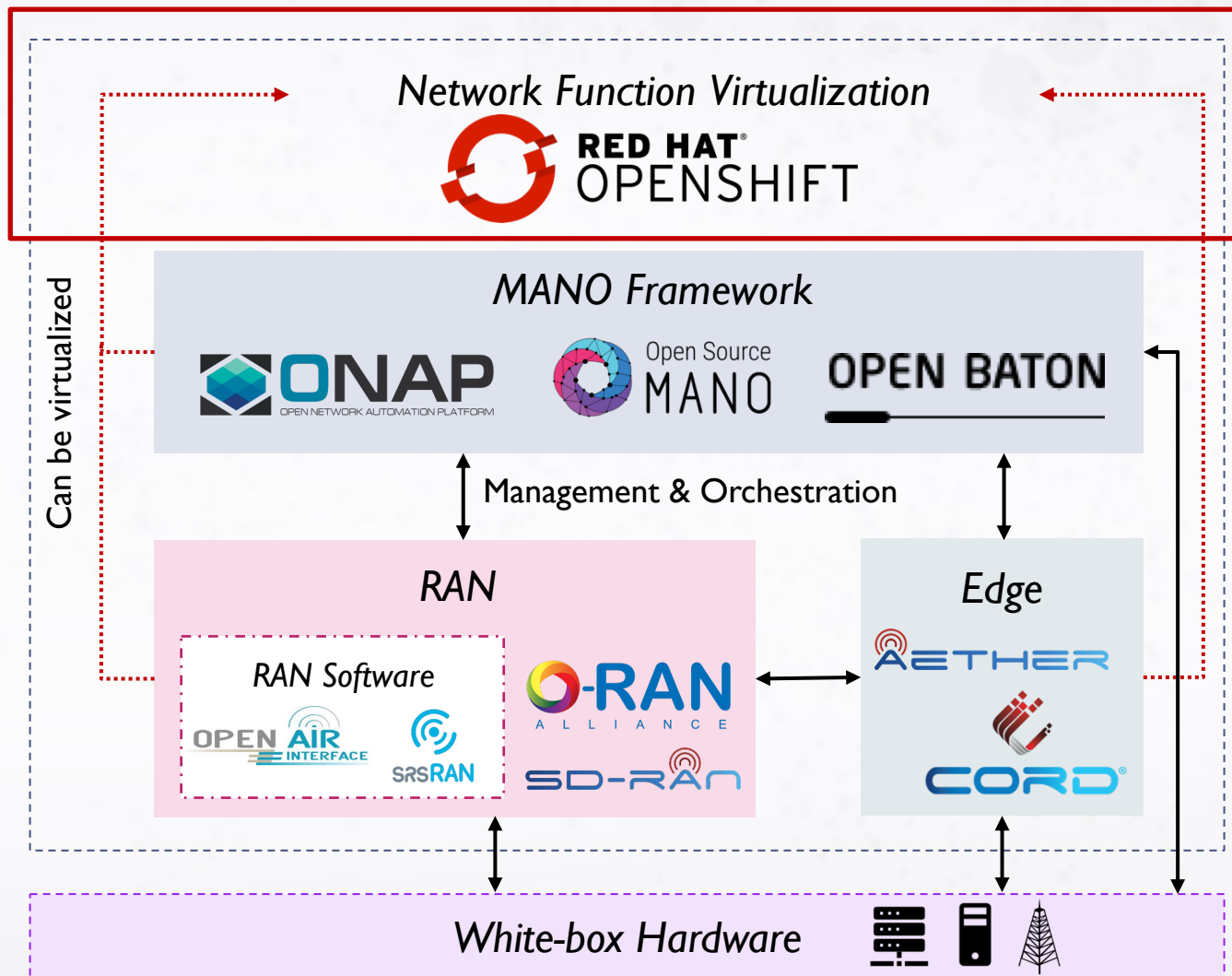
RAN Function Orchestration

Interface with OpenShift APIs to

- **Orchestrate** RAN functions **on demand** (e.g., base station placement)
- **Orchestrate intelligence** based on intent (e.g., xApps, dApps)
- Query status of services and **redeploy/adjust allocations** if necessary
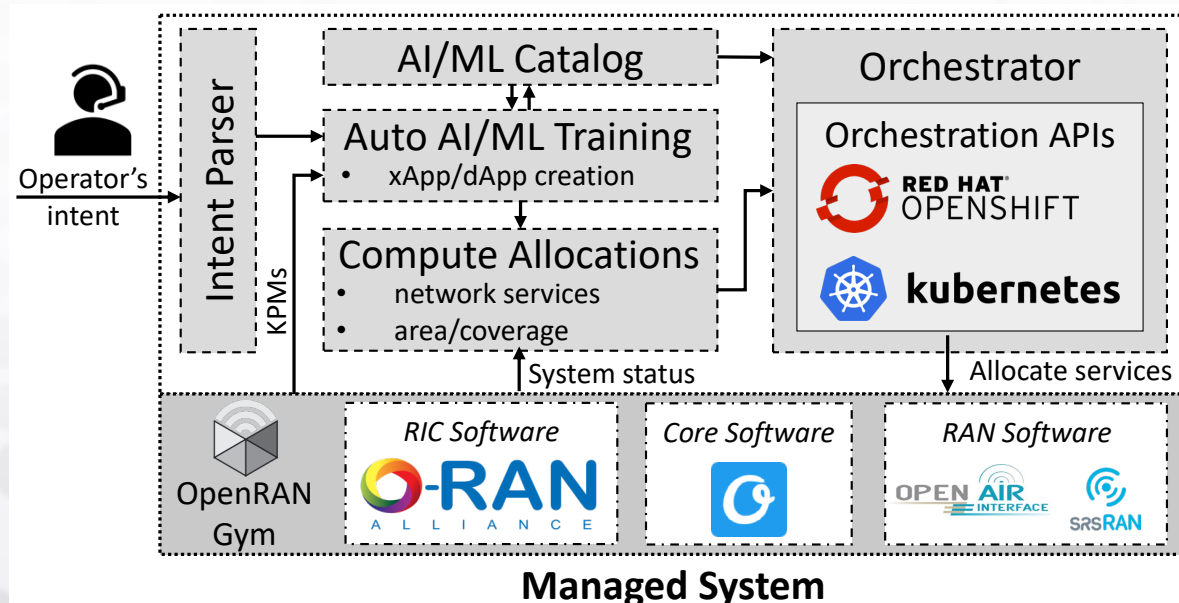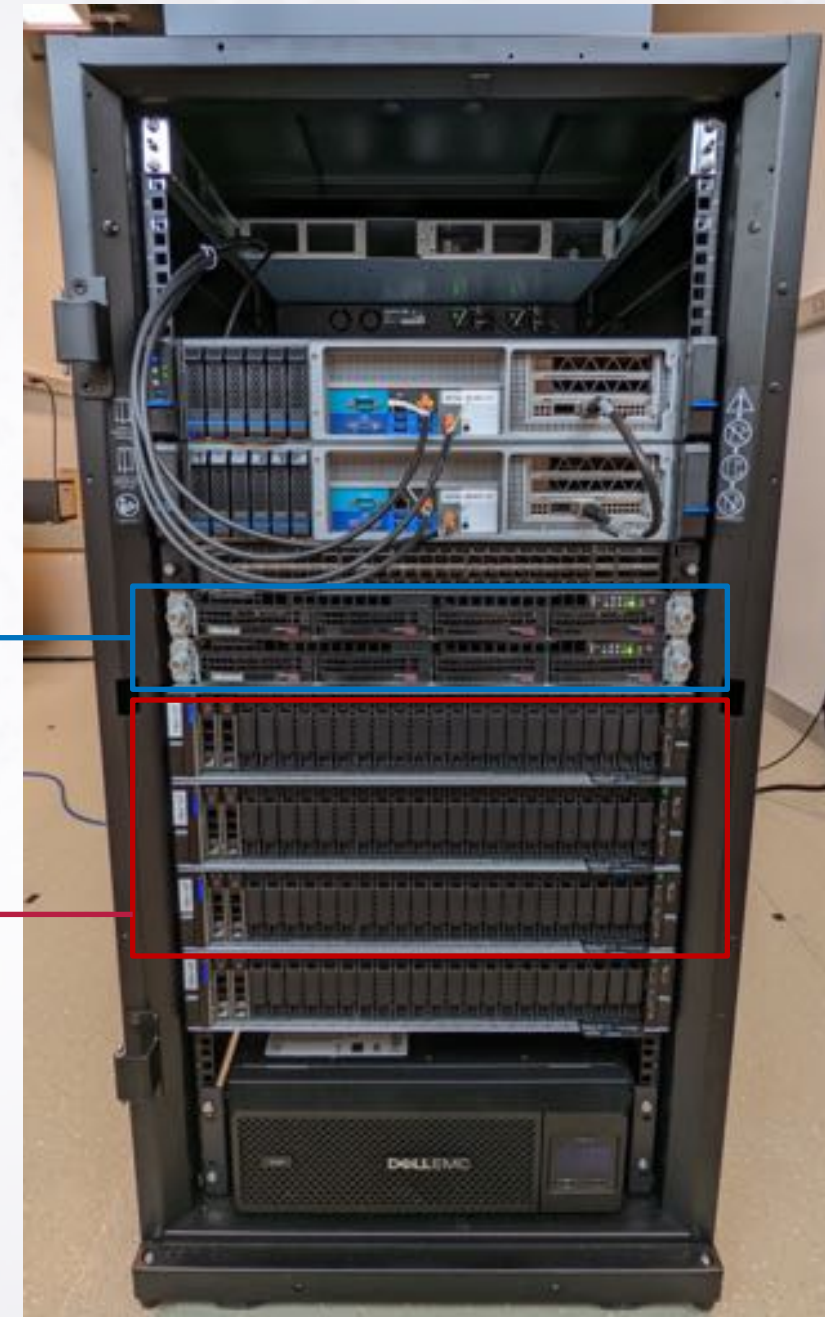
OpenShift-based Neutral Host Infrastructure

- Tenants **submit intent** to SMO
- SMO **converts intent** and communicates it to edge datacenters with near-RT RIC
- Edge datacenter leverages OpenShift to **orchestrate intelligence based on intent** (e.g., xApps, dApps) and **deploy services** at cell sites
- Query status of services and **redeploy/adjust allocations** if necessary
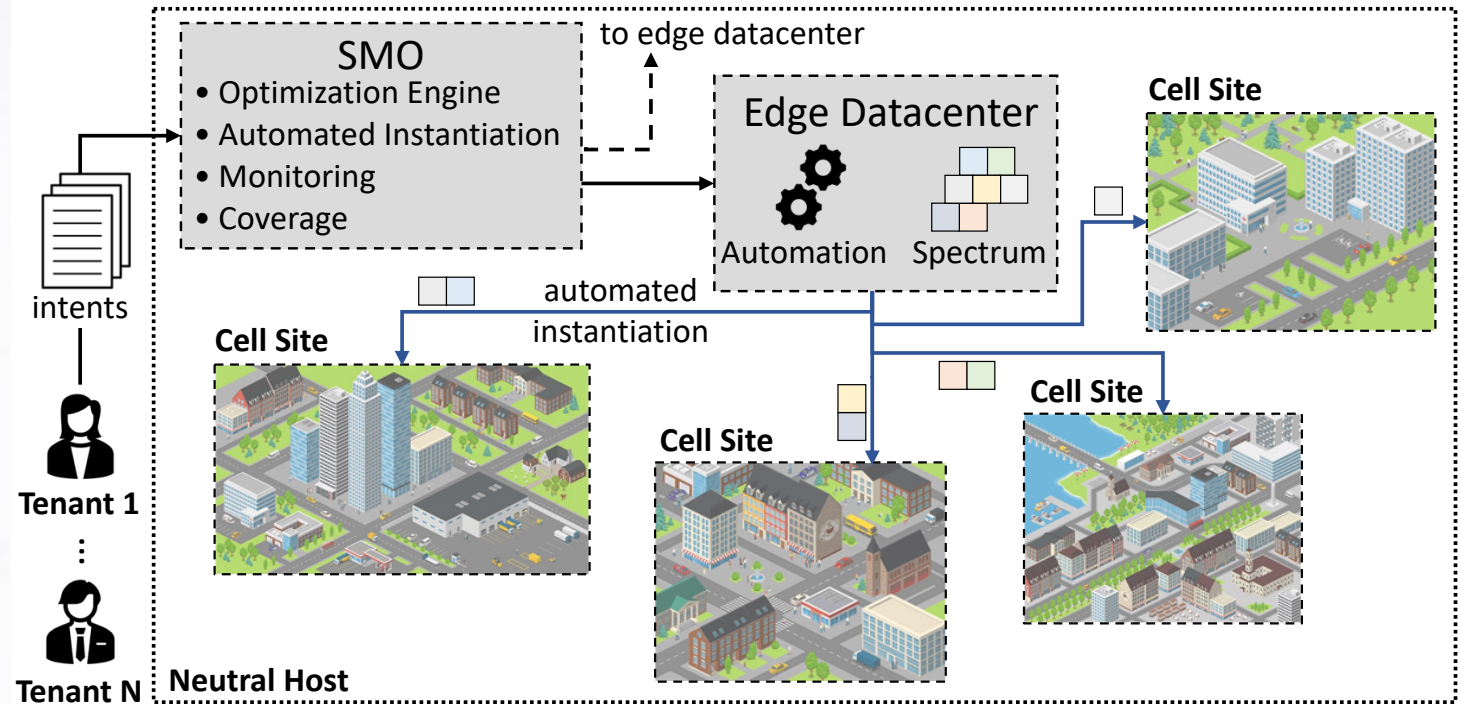
Deployed as Microservices Interfaced w/ Arena Grid

An open-access wireless testing platform based on an indoor 64-antenna ceiling grid connected to programmable SDRs for sub-6 GHz 5G spectrum research.
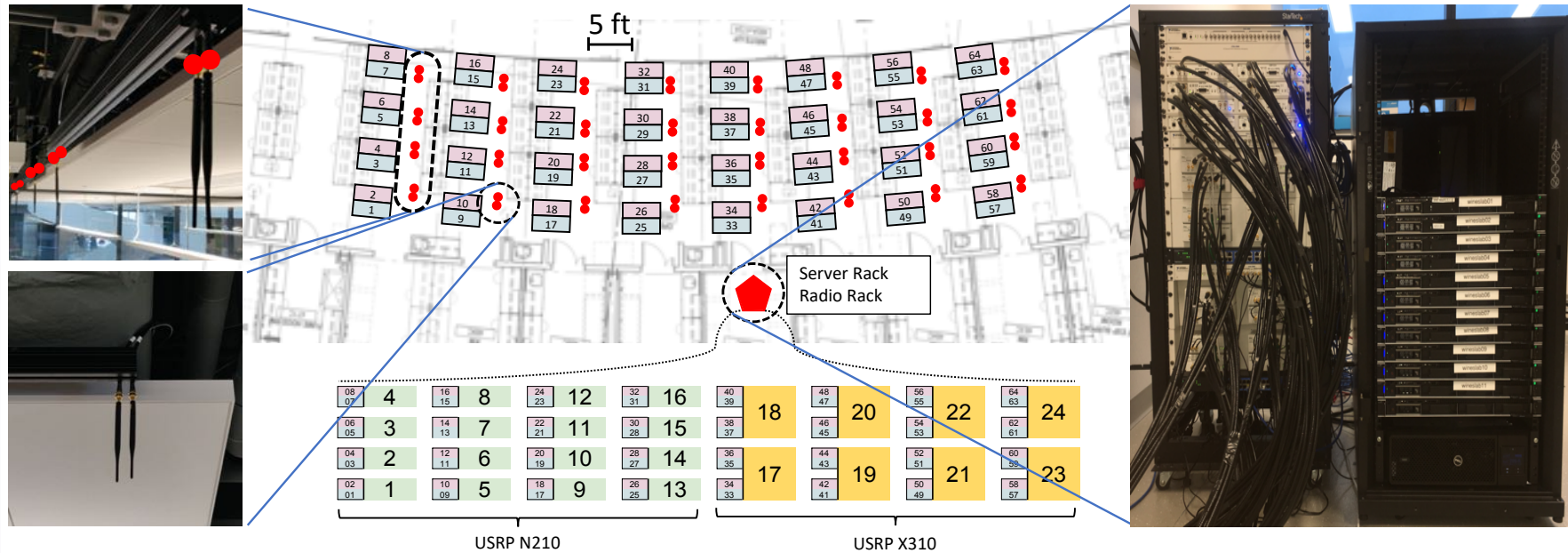
- Real-time real-channel evaluation platform
- Fully-synchronized testbed
- Repeatable, flexible, and scalable high-fi indoor experiments

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Learn More…
http://advancedwireless.org
http://colosseum.net