Institute for the Wireless Internet of Things at Northeastern University

FutureG Research Platforms
Open6GRIT
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$whoami

- Senior Director @ Institute for Wireless Internet of Things at NU
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- DoD FutureG Program Senior Advisor
- US FCC Technology Advisory Council 6G WG Co-Chair
- Board Appointments
  - OpenAirInterface Software Alliance Board Member
  - ATIS NextG Alliance
  - Magma Foundation Founding Member
  - B5GPC Japan Advisory Board Member
- Co-Founder of 6GSymposium

Institute for the Wireless Internet of Things

Air Force Research Laboratory

Office of Naval Research

MassTech Collaborative

National Science Foundation

NASA

10

Sponsoring Agencies

DARPA

AFOSR

Department of Homeland Security

Army Research Office

IARPA

National Leadership
~$36M in new grants in 2023

+

Industry Consortium

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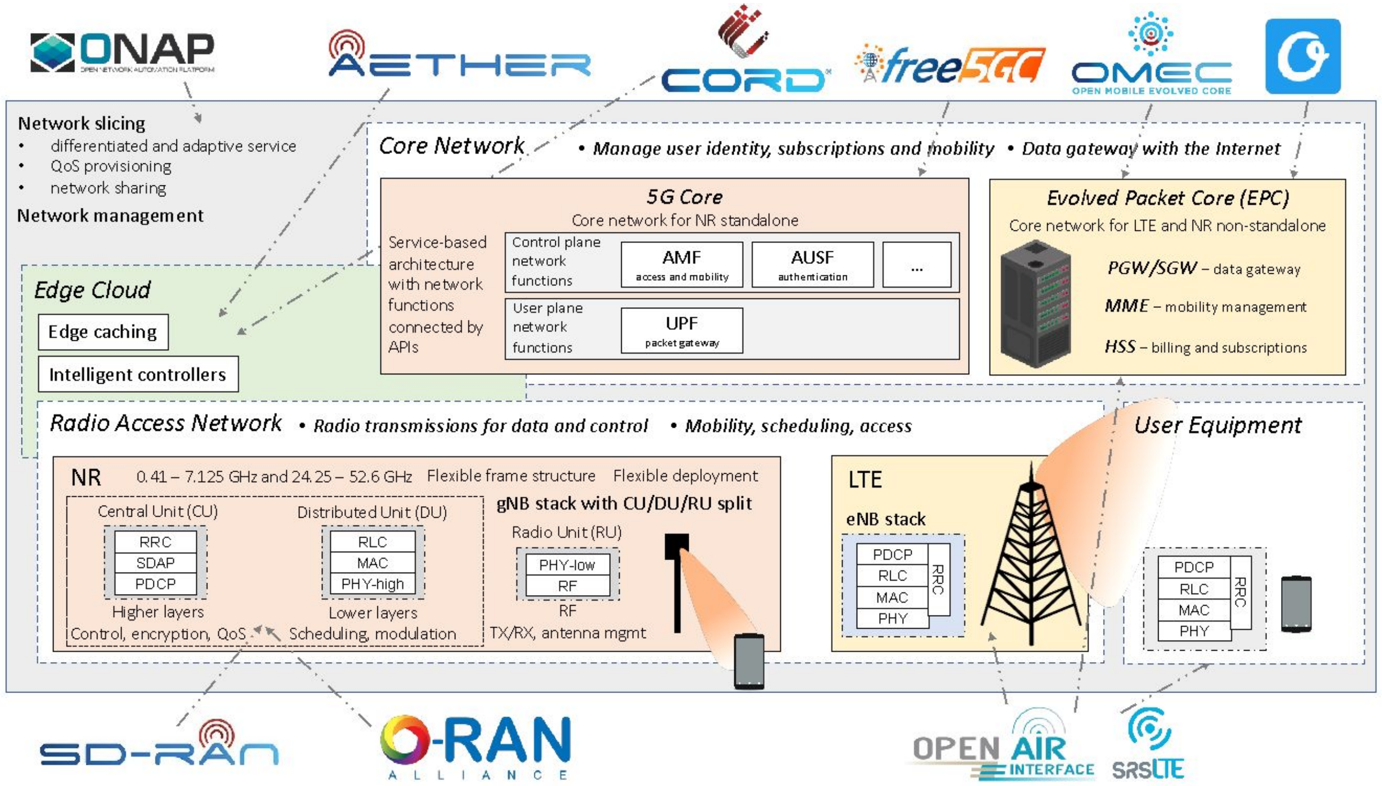
A Roadmap Toward 6G

1. Conquering the Spectrum
2. Open, Programmable, Virtualized
3. AI-Native Processing and Control
4. Flexible Spectrum Exploitation
5. Connecting the Metaverse

NEXTG PROGRAMMABLE AND VIRTUALIZED NETWORKS

- **Program** network functionalities in **software**
- **Optimize** network performance through AI/ML applications (e.g., xApps, rApps)

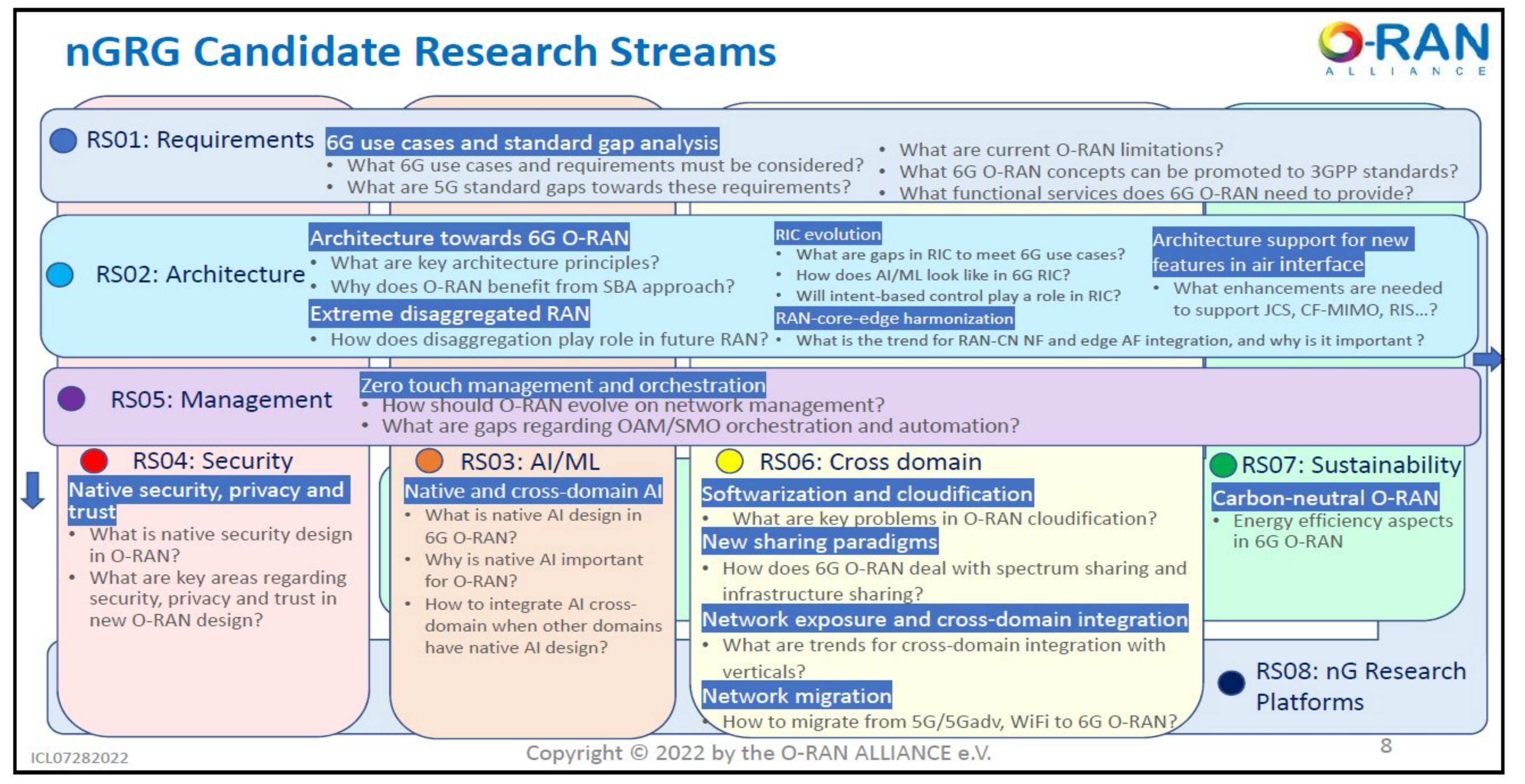


L. Bonati, M. Polese, S. D'Oro, S. Basagni, and T. Melodia, *"Open, Programmable, and Virtualized 5G Networks: State-of-the-Art and the Road Ahead,"* Computer Networks, vol. 182, Dec 2020.

Need for:

- Open research tools to **prototype** NextG solutions in **controlled environments**
- **Large-scale datasets** to design/train AI/ML solutions

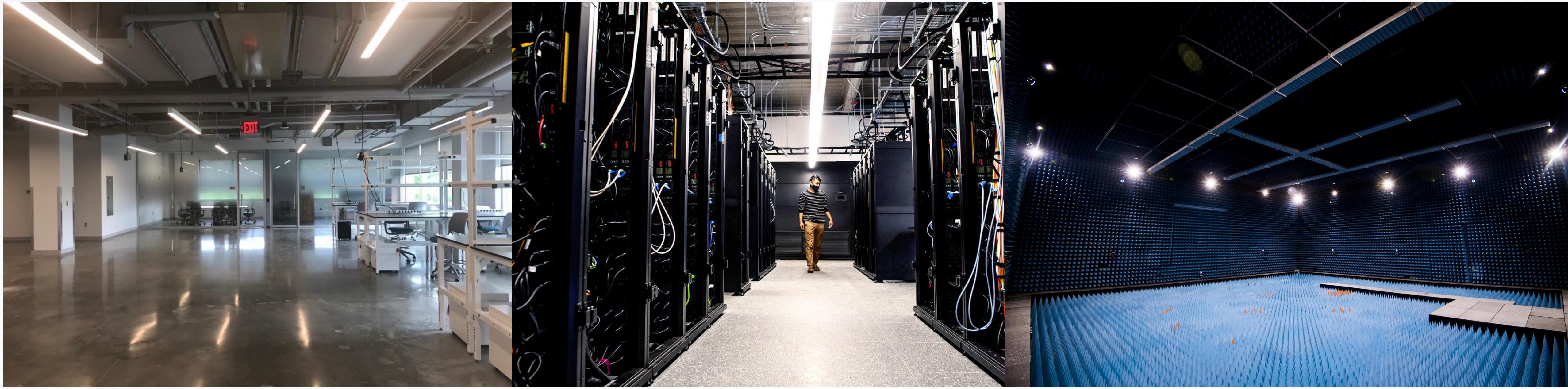
Open Radio Access Networks (Open RAN)



O-RAN Alliance NextG Research Group

Open6G Research and Development Center

Industry-University Cooperative Center



~4600 sq feet of prime space in Burlington, MA
Co-located with Colosseum, massive AI computing, anechoic chamber

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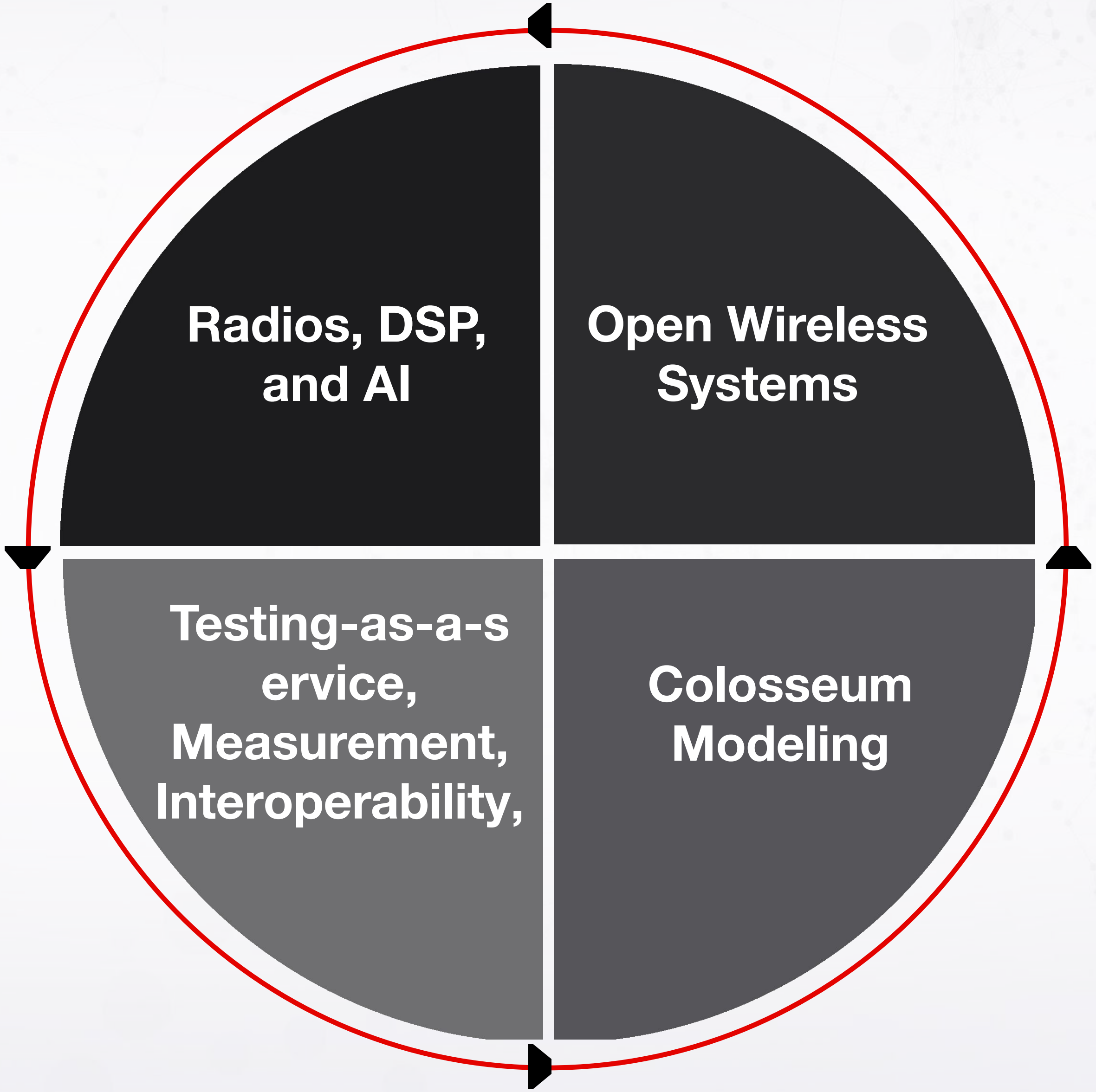
6G R&D Examples

- Machine Learning in Wireless
- Software Defined Radios
- mmWave, teraHertz

- ORAN
- Spectrum
- EM Compliance



- Development of protocol stacks
- Virtualization Environments
- RIC Algorithms
- Machine Learning

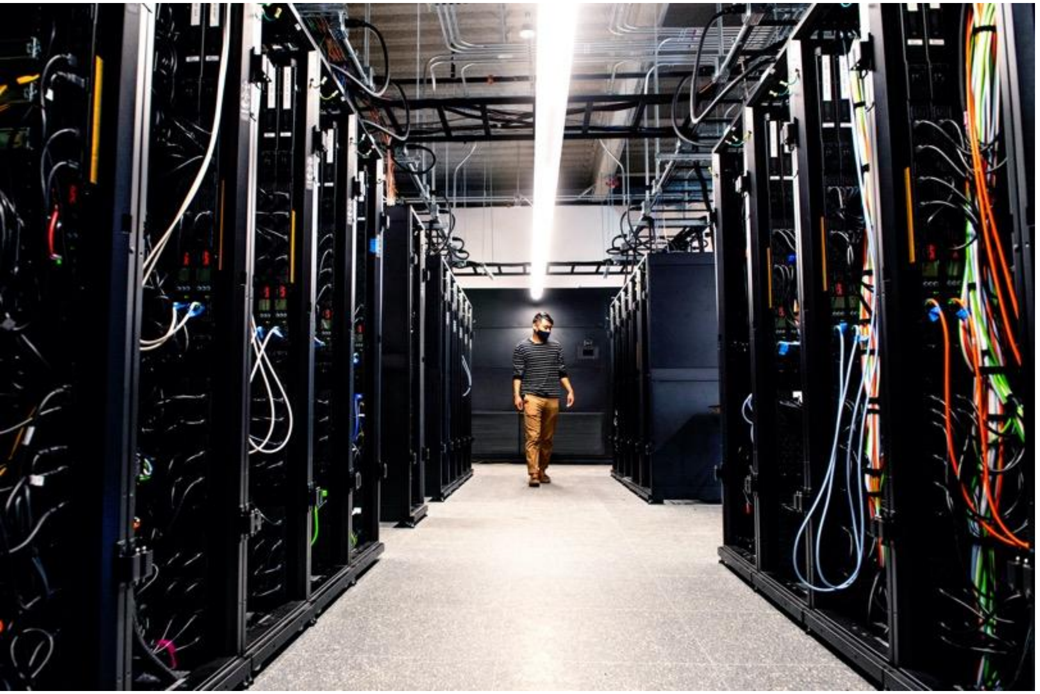
- Design of Scenarios
- Algorithmic Development
- Leveraging tens of libraries

Goals of Open6G

- Industry/University **cooperative research, development, testing**
- Develop reference 5G/6G reference software; SRS-RAN and OAI
- Testbed-as-a-service (Colosseum, Arena, PAWR)
- Modeling, Simulation as a Service
- Digital Twins
- Algorithm development, Dataset Creation
- Open Ran Interoperability Testing and Validation
- xApp/rApp Development
- Unmanned aerial systems experiments
- Over-the-air-testing over FCC Innovation Zone
- Spectrum sharing measurements/developments

Facilities and Resources

COLOSSEUM: THE WORLD'S LARGEST EMULATOR OF VIRTUALIZED WIRELESS SYSTEMS



- Unique instrument for Spectrum Sharing, AI in Wireless
- 5G, O-RAN, AI, Spectrum, IoT, drones
- mmWave work in progress
- $30M Investment
  - 256 x 256 100 MHz RF channel emulation, 128 Programmable Radio Nodes
  - Massive computing resources (CPU, GPU, FPGA)
  - Access control and scheduling infrastructure

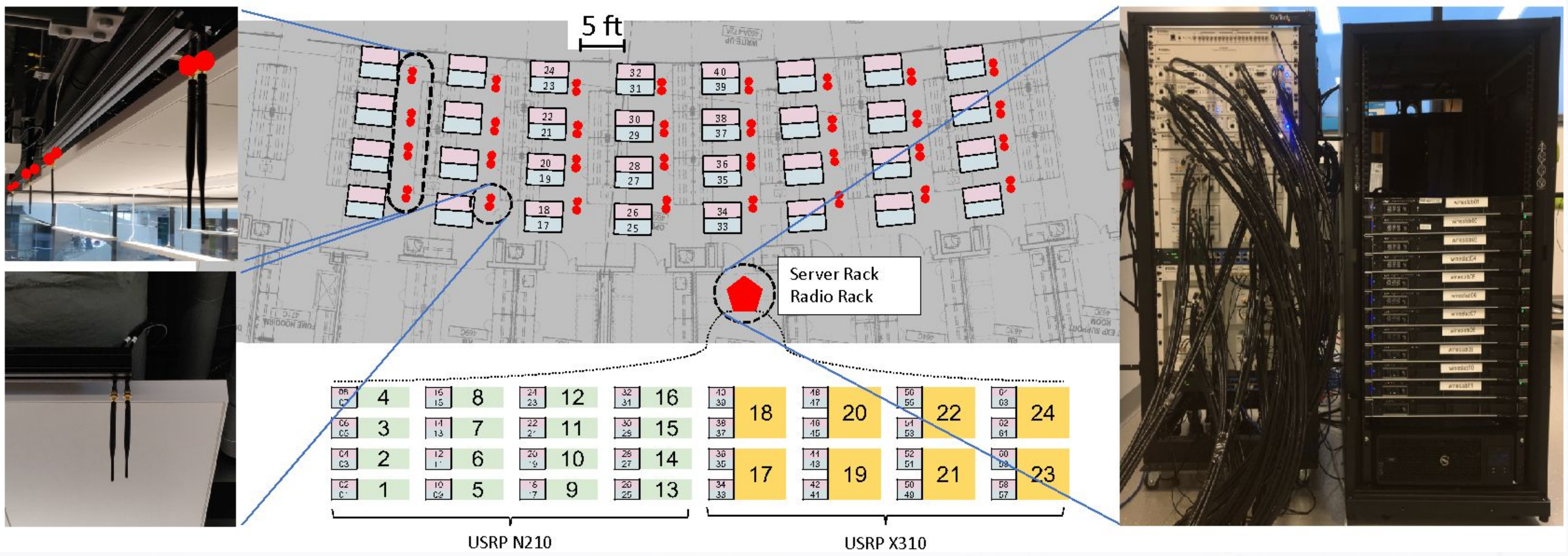
COLOSSEUM at Northeastern University

Platforms for Advanced Wireless Research

LVX VERITAS VIRTVS

ARENA: Large Scale Virtualized Wireless Indoor Testing

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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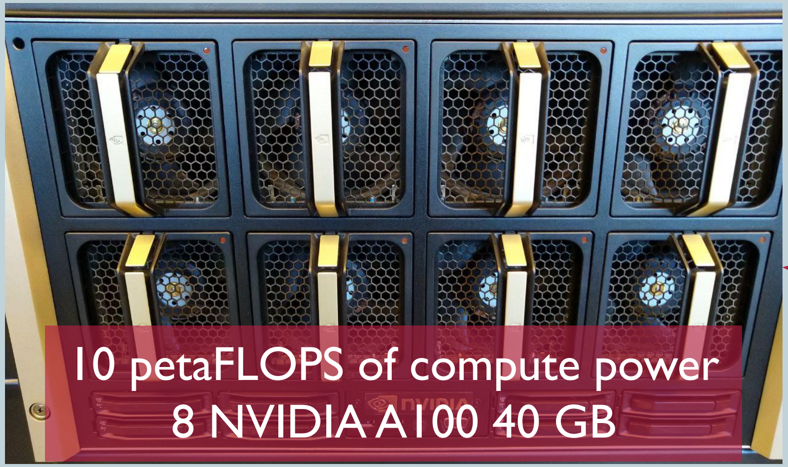
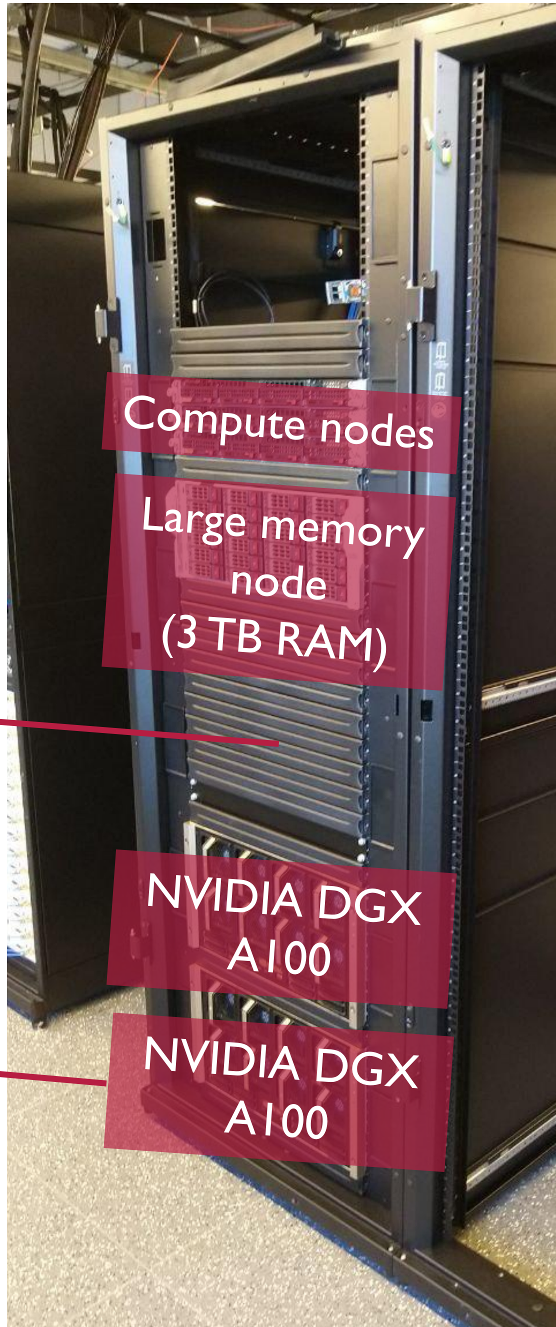
AI Jumpstart Rack on Colosseum

***Goal:** extend **AI** capabilities of **Colosseum** with unique **AI+wireless** experimental facilities*

Use cases:

- Large-scale training of RF datasets collected on Colosseum
- Real-time, AI-driven signal processing
- Model-free adaptation and network control





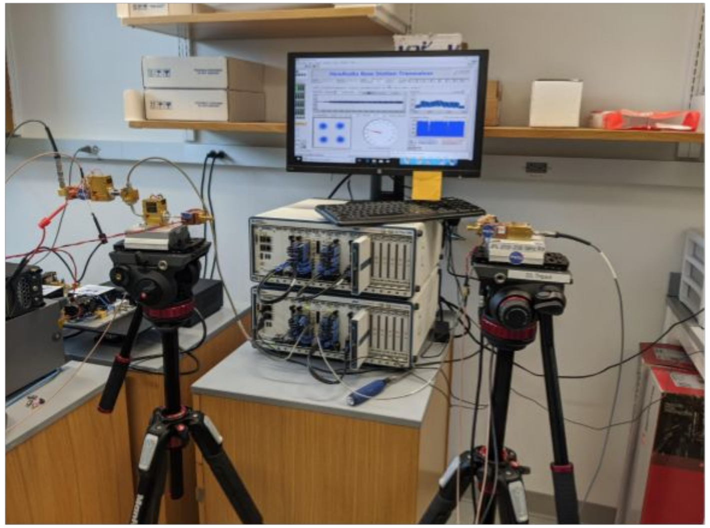
Soon available to Colosseum

mmWave and Terahertz Testbed

Largest mmWave testbed available in the nation

World's only multi-band THz communication system, able to cover 120 GHz, 240 GHz, and 1.1 THz

First data-transmissions above 1 THz (or true terahertz)



Leadership in NSF Platforms for Advanced Wireless Research

Industry Consortium

Cash, equipment & services, engineering, marketing, & R&D support

Platforms for Advanced Wireless Research

NSF and Research Community

Grants, experimental spectrum licenses, research agenda

PAWR Project Office

$100M Program, public-private partnership

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PAWR PLATFORMS WERE CHOSEN TO BE GEOGRAPHICALLY DIVERSE AND RESEARCH FOCUS INDEPENDENT

POWDER

Salt Lake City, UT

Software defined networks and massive MIMO

COSMOS

West Harlem, NY

Millimeter wave and backhaul research

AERPAW

Raleigh, NC

Unmanned aerial vehicles and mobility

ARA

Ames, IA

Rural Broadband and Agtech

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

Anechoic Chamber and Drone Test Range

Outdoor UAS Test Range

- Outdoor 150’x200’x60’ netted enclosure for GPS enabled flight testing
- Equipped with enhanced kinematic GPS for extremely precise centimeter positioning
- Steady state/gust wind test capability for small drones for performance characterization
- Interconnected flight path between outdoor and indoor test ranges for seamless transition
- 60’ observation deck in adjacent building for flight test viewing

Anechoic Chamber UAS Test Range

- Large-scale Faraday cage/Anechoic Chamber (50’x50’x22’)
- 64 antenna/SDR array for jamming, interference, spoofing, communications testing, and Global Navigation Satellite System (GNSS) Simulator
- EMP test capability (RS105)
- Networking for autonomy, swarms and massive MIMO
- Able to test large drones up to 1300+ lbs
- RF testing from 300MHz to 18+GHz
- 24 camera HD optical tracking system for precise positioning

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

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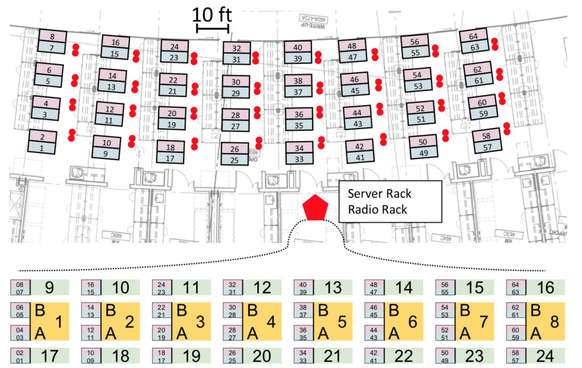
Validate in real wireless environment



Test large-scale capabilities

Platforms for Advanced Wireless Research

COSMOS

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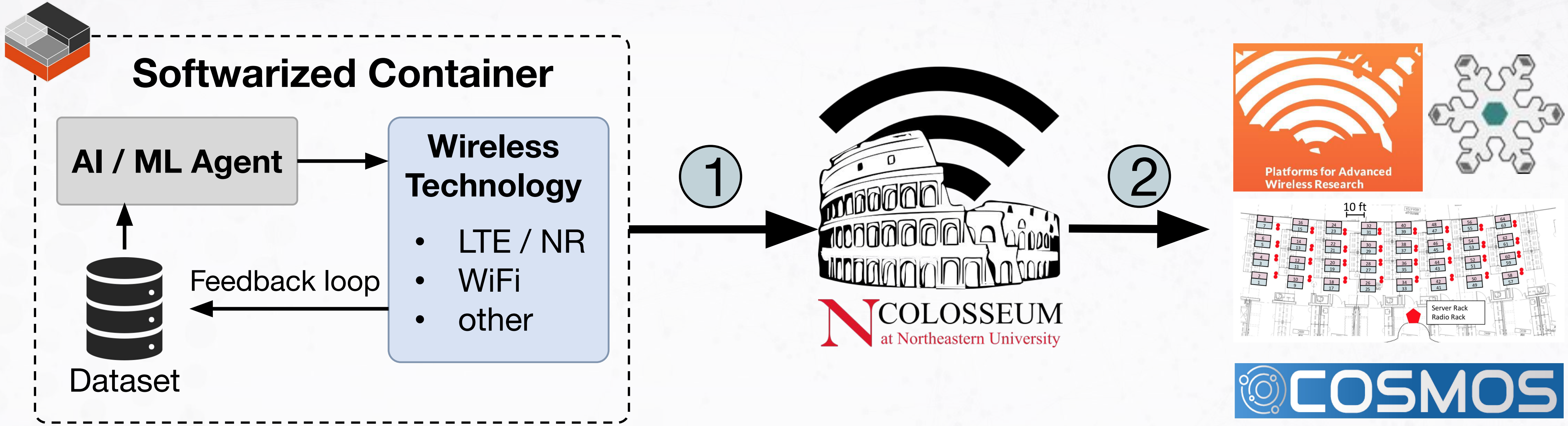
AI/ML Pipelines on Colosseum/PAWR



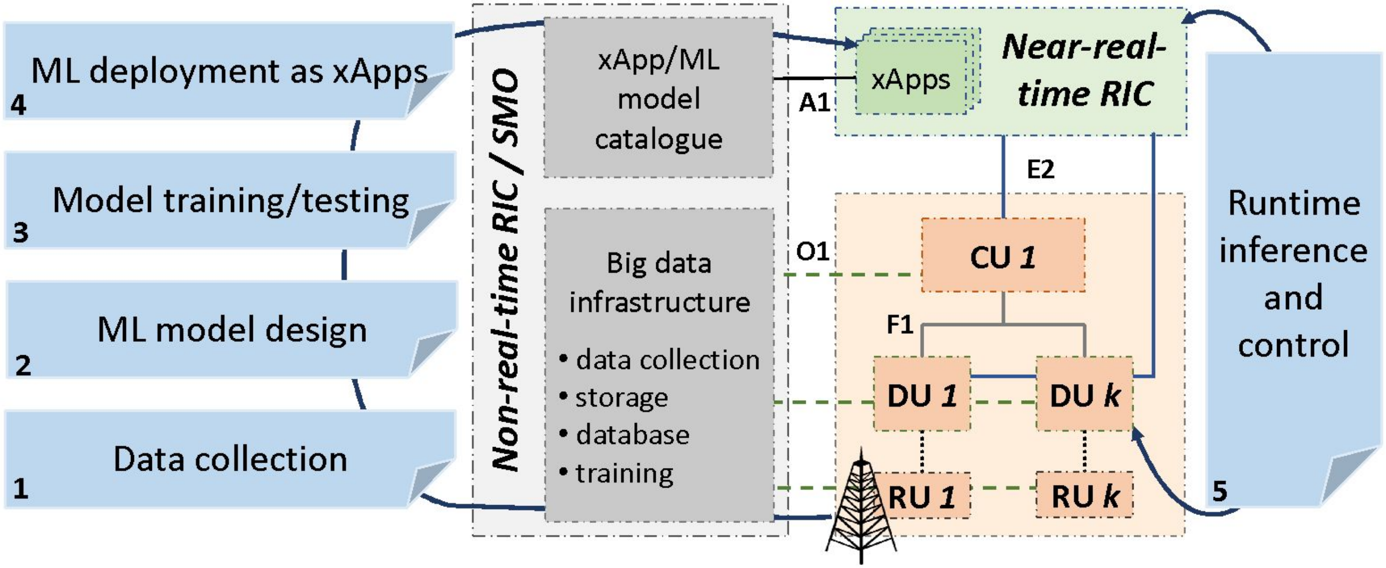
1. Prototype AI / ML solutions at-a-scale on emulated RF and traffic scenarios
2. Validate in real-world wireless environment

OPENRANGYM

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

Enables:

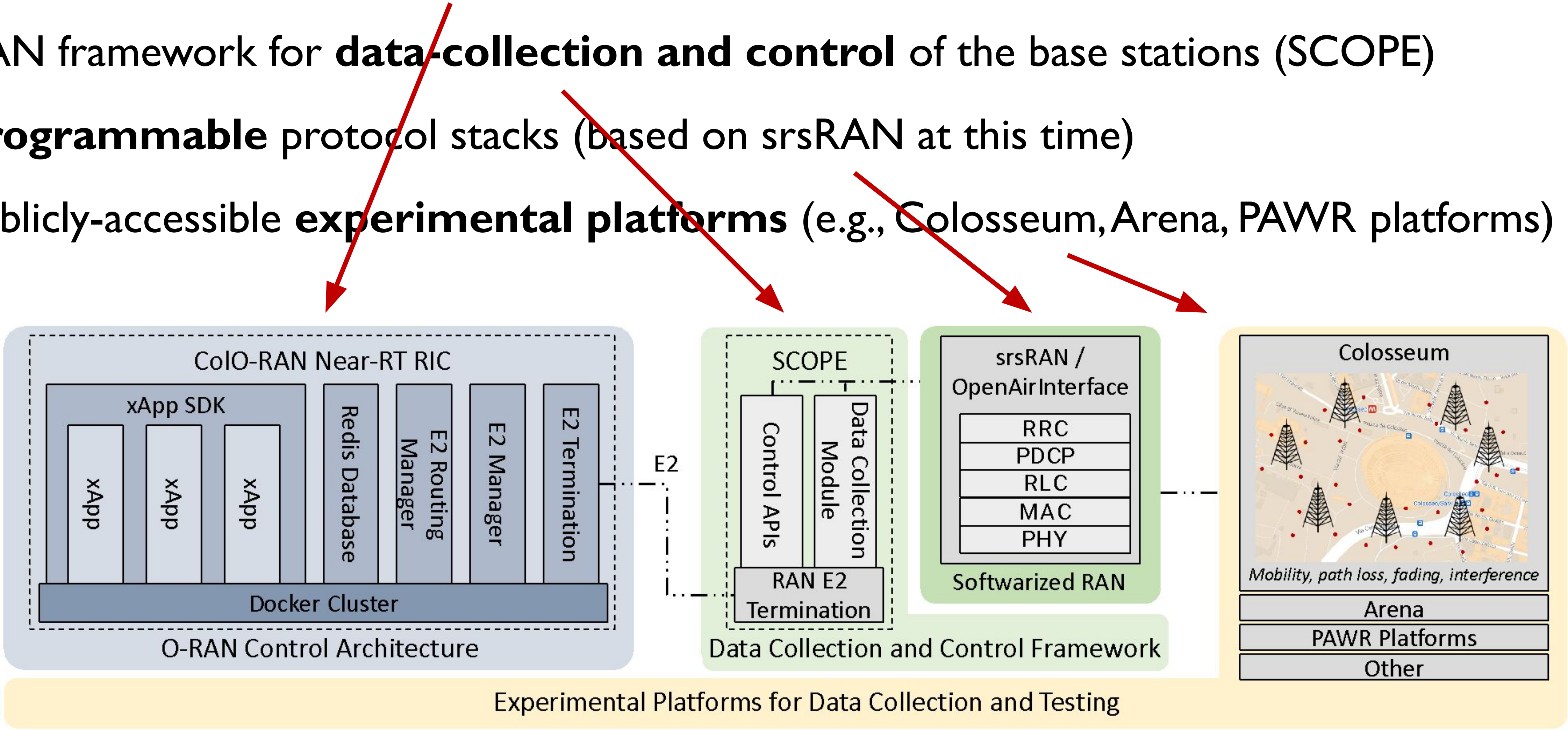
1. Data collection
2. AI/ML model design
3. Model training and testing
4. Model deployment on near-RT RIC as xApp
5. Runtime inference and control of a softwarized RAN



M. Polese, L. Bonati, S. D'Oro, S. Basagni, T. Melodia, *"ColO-RAN: Developing Machine Learning-based xApps for Open RAN Closed-loop Control on Programmable Experimental Platforms"*, arXiv:2112.09559 [cs.NI]

OPENRANGYM 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)



Real-time Adaptation with dApps A Reference Implementation for Spectrum Sharing

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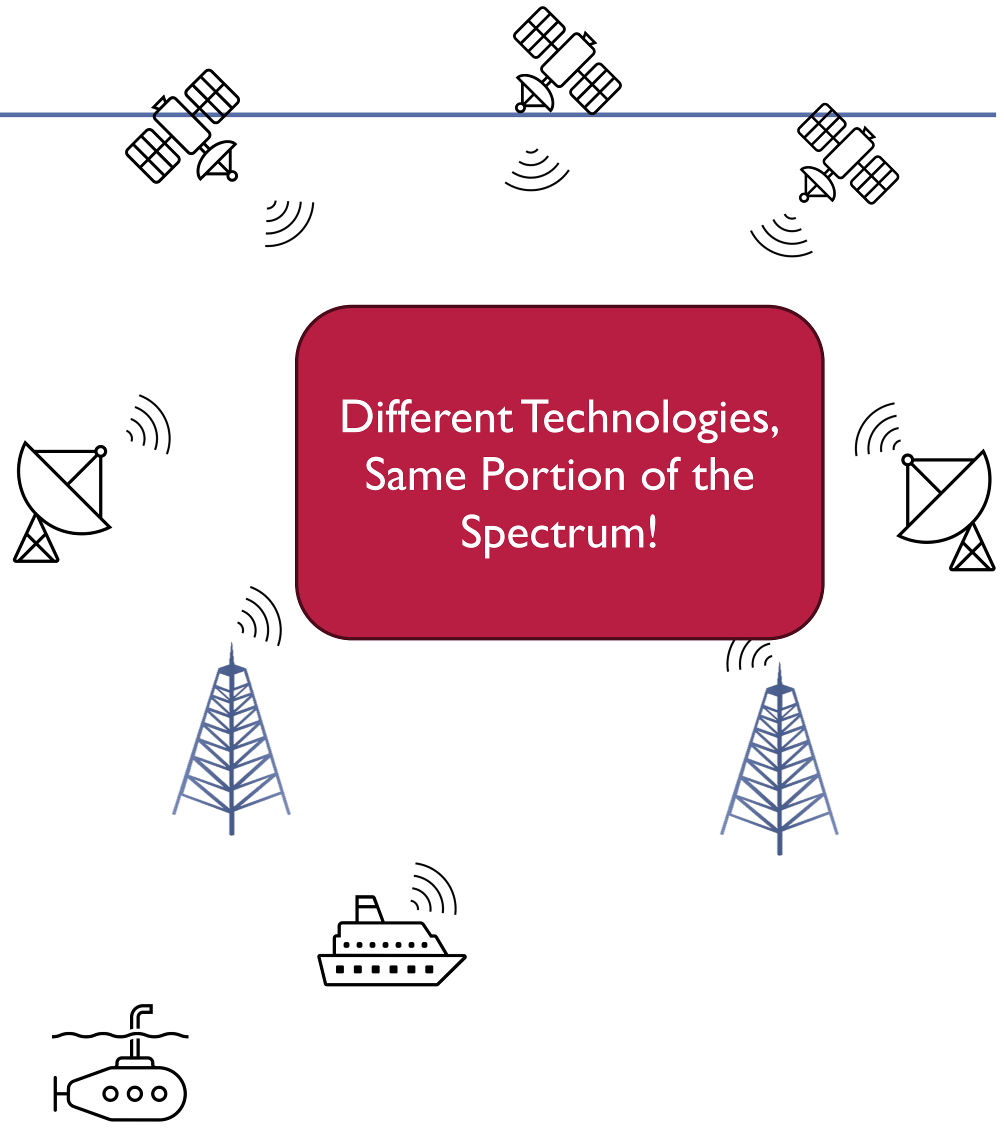
SUMMARY OF CONSIDERATIONS BEYOND ADDING SPECTRUM FOR TERRESTRIAL IMT

- Elements which all contribute to arguments for better use of existing spectrum:
  1. challenges of re-allocation or re-farming;
  2. the wide variation in real-time occupation of licensed spectrum over geography and over time (low utilization); and
  3. the state of the art of spatial multiplexing
- Flexible Access to Unused Spectrum
  - require or incentivize licensees to cede use of spectrum when it is not in use or is under-utilized. (This can also be one avenue to address one facet of the rural digital divide.)
- Spectrum Sharing among different services (e.g., federal radiolocation and commercial mobile or satellite communication), and among same services (e.g., terrestrial and non-terrestrial, including satellite)
- Increased Cell Density
  - Consider the advantages and disadvantages of increased cell-density.
- Spatial Multiplexing Technologies
  - Higher-order MIMO and beam-forming have become ubiquitous in C-band 5G systems. This approach to increase bps/Hz/km2 ensures spatial allocation of a user's signal (RF flux density) is constrained to the user's physical location.

DAPP FOR AGILE SPECTRUM, INFRASTRUCTURE, AND AI MANAGEMENT

- Spectrum is limited and used by different applications
- Citizens Broadband Radio Service (CBRS) (e.g., 3.55-3.7 GHz):
  - Licensed 5G applications (new);
    - They can use the spectrum when available;
  - U.S. Navy Radar Systems (legacy);
    - Incumbent entities with top priority on the use of the spectrum;
- Need for a combination of Spectrum Access Systems (SASs) and Environmental Sensing Capability (ESC) systems



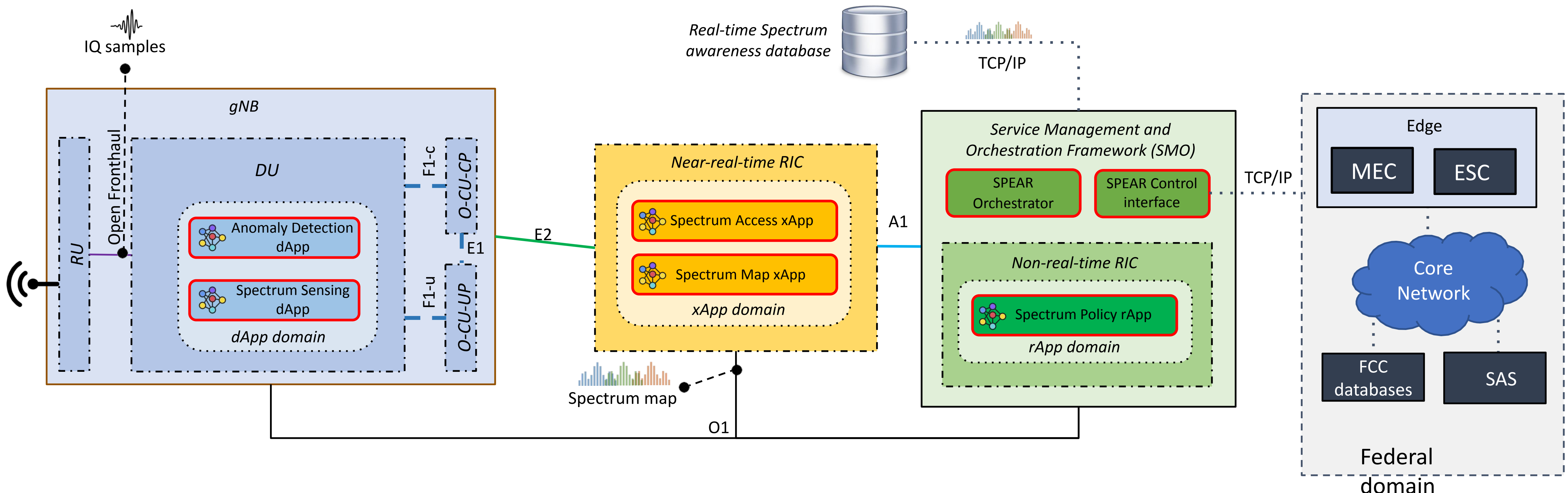
Issue: SASs are slow!

- Channel evacuation time: 240 seconds
- Incumbent detection time: 60 seconds

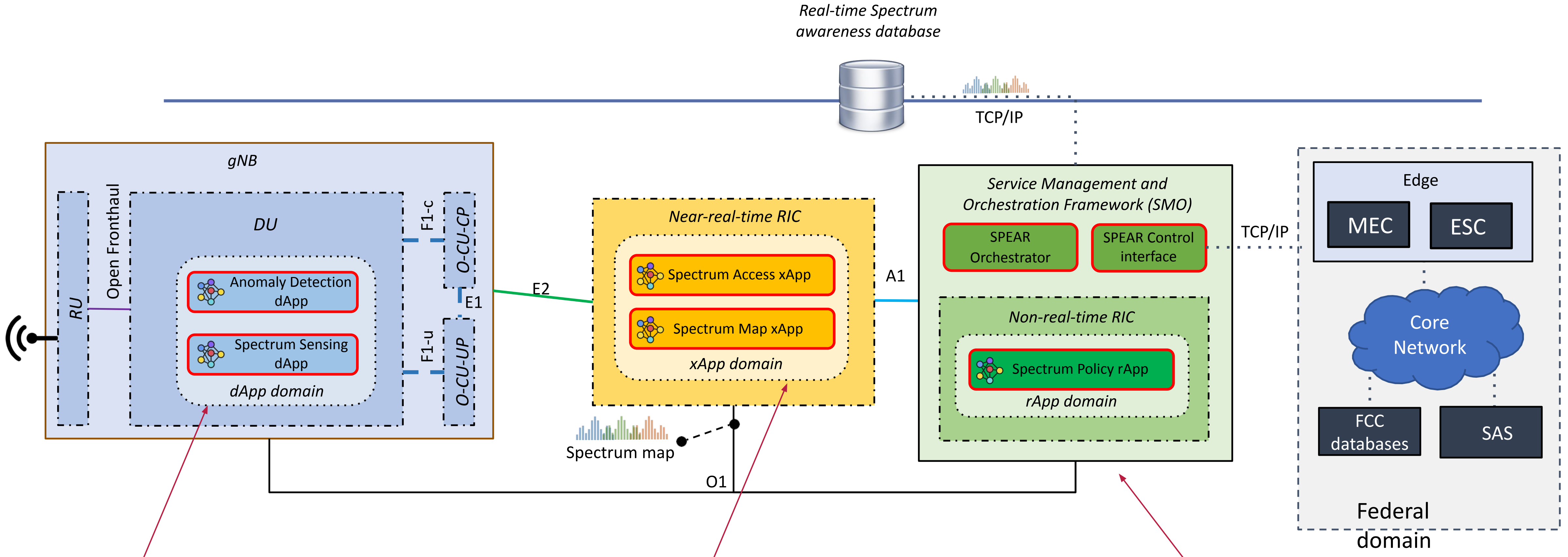
BUILDING THE NEXT-GENERATION OF INTELLIGENT SPECTRUM SHARING SYSTEMS

Automated Real-time Spectrum Management

Automation framework with O-RAN	*xApp and rApps for spectrum management*	*dApps for real-time spectrum sensing*	*High-level orchestration and control*



OVERVIEW



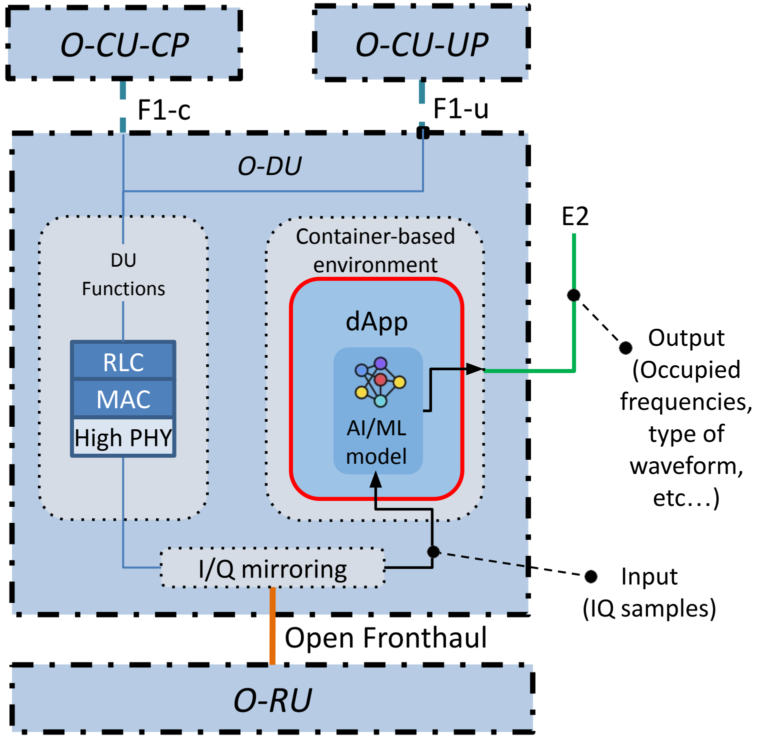
- IQ-based real-time spectrum sensing (8 ms)
- Anomaly detection
- Spectrum usage report:
    - Incumbent
    - Hole
    - Anomaly detection

- Spectrum map aggregation
- Local spectrum access policies
- Spectrum slicing
- Fast channel evacuation (<5 s)

- System interface
- Global spectrum orchestration
- Bi-directional spectrum usage / policy exchange
- Real-time spectrum awareness database

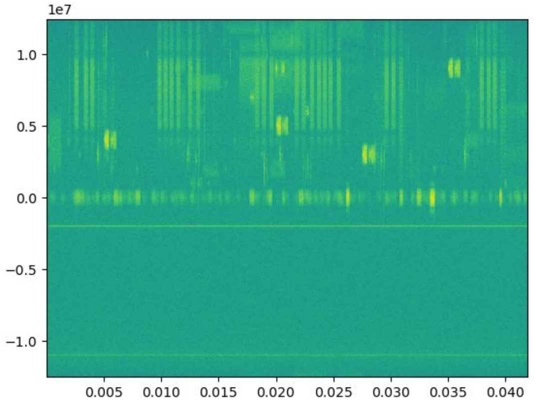
SENSING SPECTRUM + ANOMALY DETECTION VIA DAPPS AT GNBS

- Integrate (or even replace) ESC capabilities with deep learning
- High resolution local spectrum awareness
- **Parallel** data decoding + spectrum sensing via **IQ mirroring**

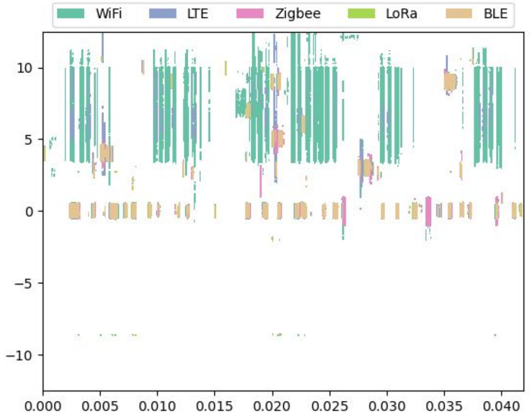


- **Input:** array of 1024 IQs in frequency domain
- **Inference time:**
  - CPU: 15 ms
  - GPU: 8 ms
  - Can be pipelined
- **Tunable** sampling frequency
- **Output**:
  - Incumbents
  - Anomalies
  - Technologies

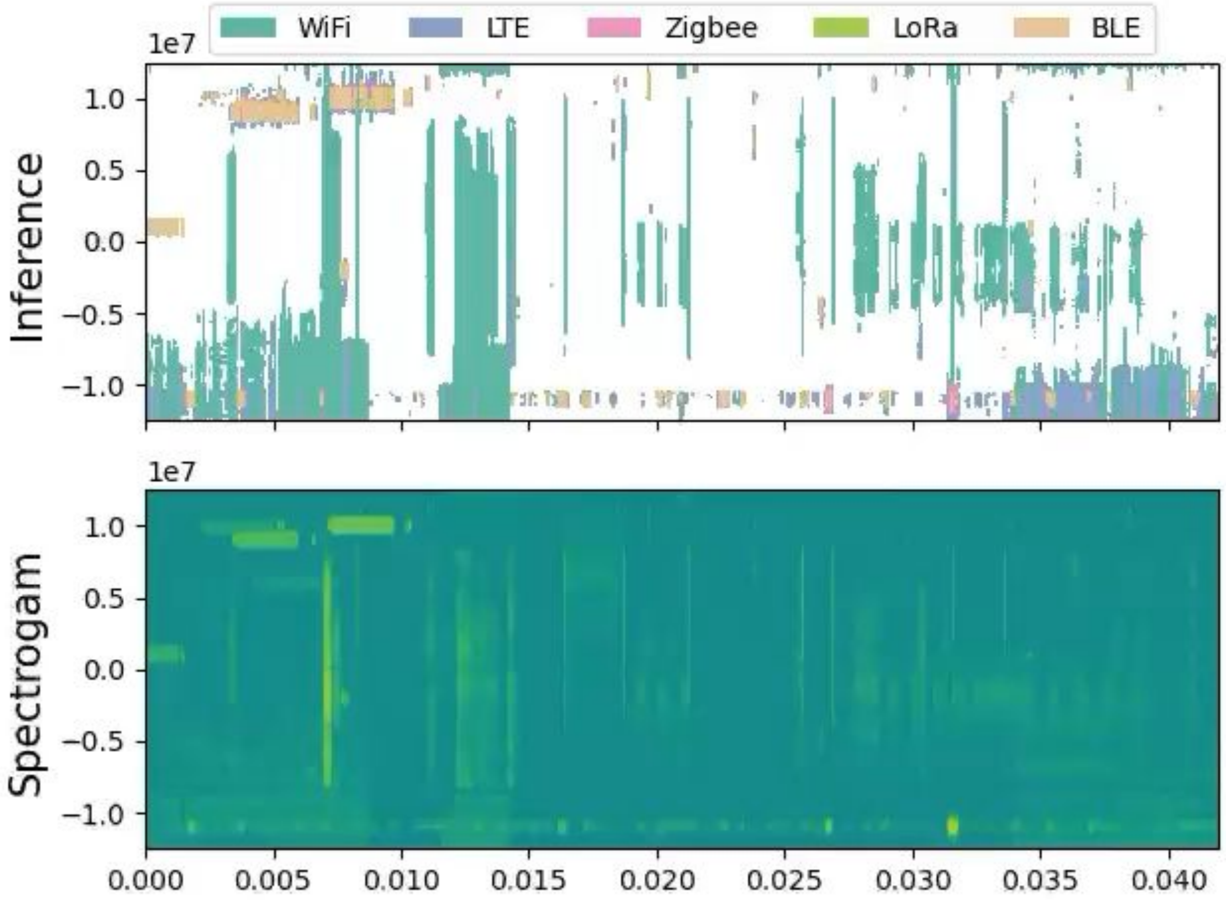
Spectrum measurements



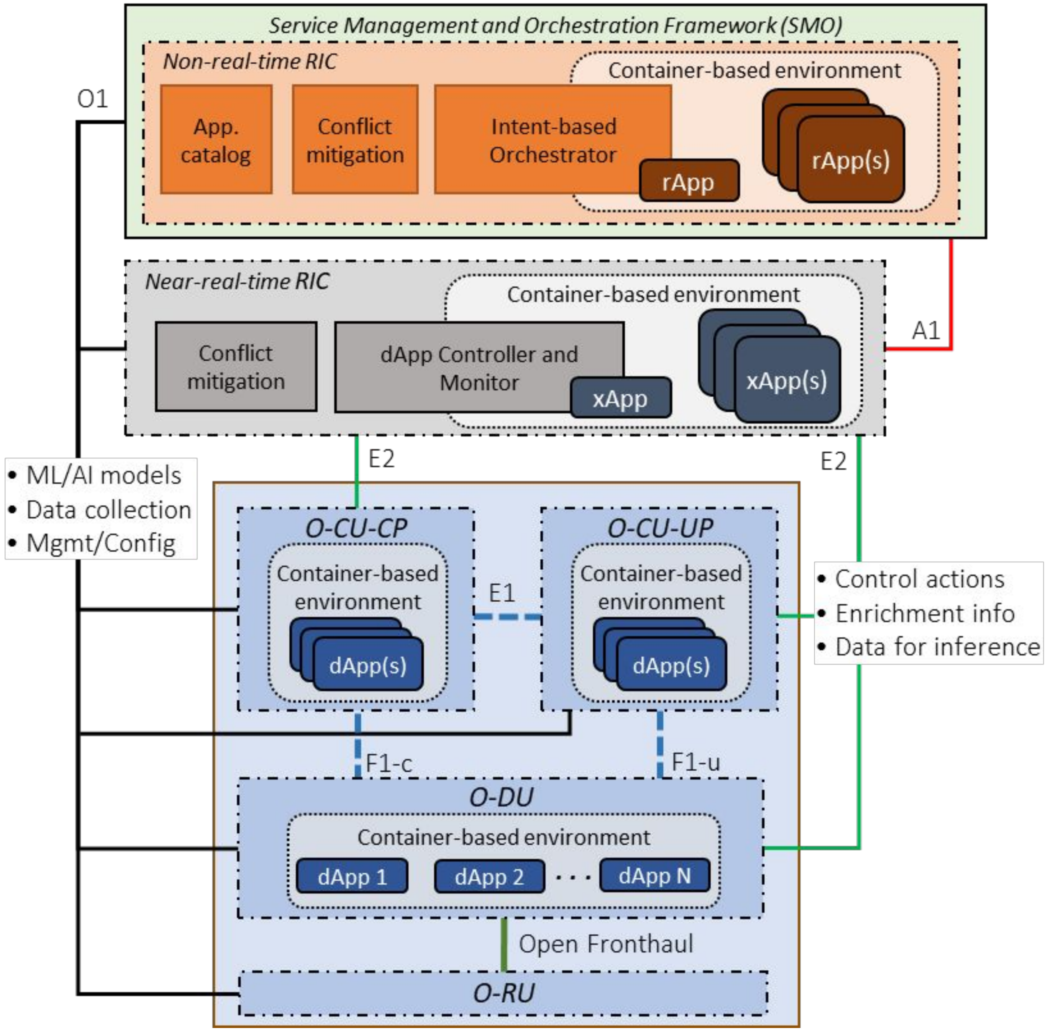
Local spectrum report (gNB)



DAPPS-BASED SPECTRUM SENSING AND CLASSIFICATION



REAL-TIME CONTROL WITH DAPPS – A REFERENCE IMPLEMENTATION



- **Transition** the dApp architecture and use cases to the first reference implementation
- **Integrate** and **implement** the dApp architectural framework on open-source programmable stacks (e.g., OAI)
  - Modular plug-and-play design to dynamically launch and stop new dApps at runtime
  - Include components for task coordination and conflict mitigation with xApps

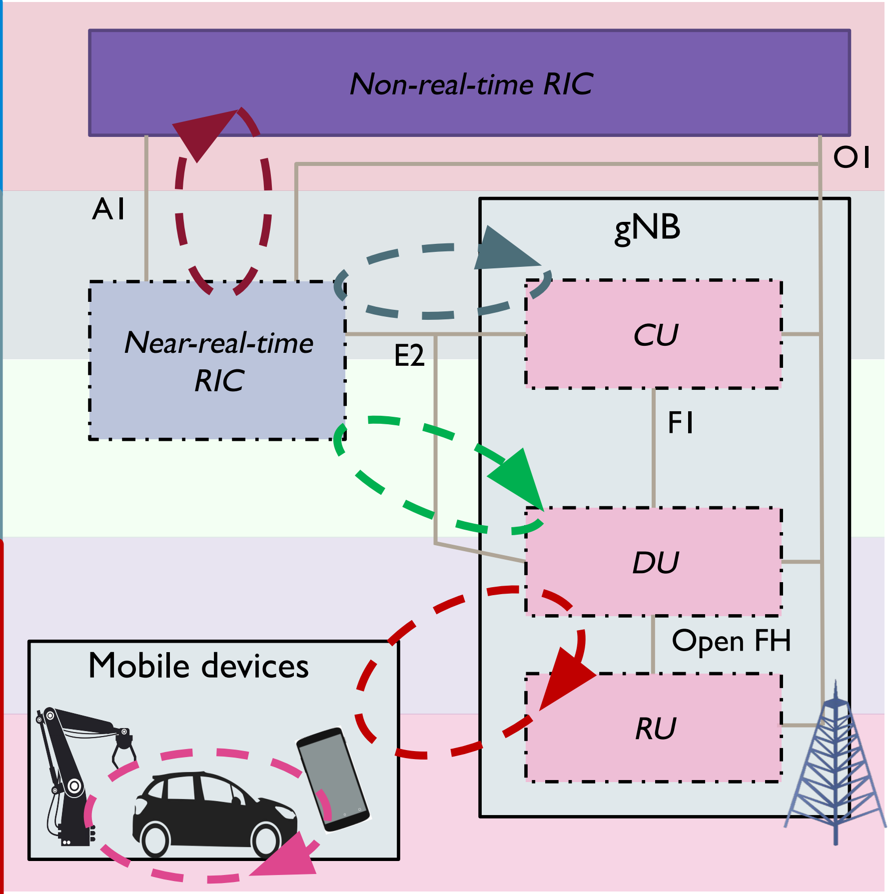
Robust framework that combines the end-to-end Open6G architecture with practical, customizable real-time control

INTELLIGENT CONTROL LOOPS IN O-RAN

O-RAN ALLIANCE

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

Architecture



Not yet standardized by O-RAN (Northeastern proposal to O-RAN nGRG) *

* D'Oro, S., Polese, M., Bonati, L., Cheng, H., & Melodia, T. (2022). dApps: Distributed Applications for Real-time Inference and Control in O-RAN. IEEE Communications Magazine, 2022.

YOU NEED TESTBEDS, DATA, AND CROSS-PLATFORM VALIDATION

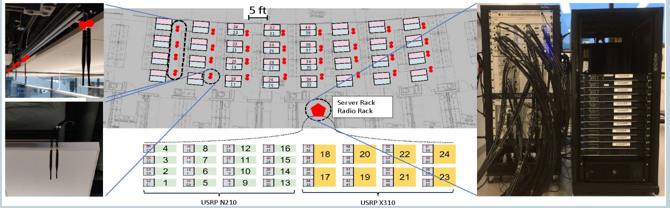
Design

Data

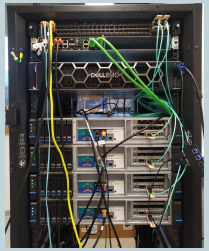
Evaluation and validation

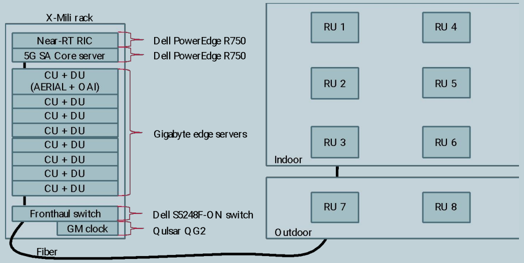
Colosseum

Arena + PAWR



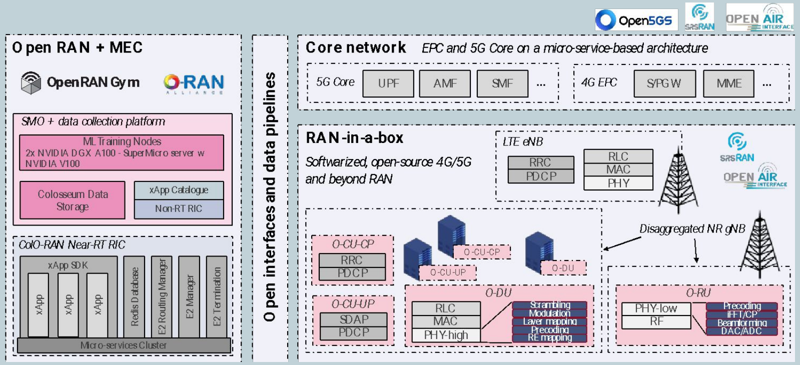
X-Mili





OpenRAN Gym

End-to-end programmable cellular



FCC Innovation Zones

Production 5G+AI automation