Institute for the Wireless Internet of Things

at Northeastern University

Colosseum Evolutions

AI, NRDZ, Digital Twin, OTIC

Colosseum Team
Institute for the Wireless Internet of Things
Northeastern University
m.polese@northeastern.edu

Platforms for Advanced Wireless Research

MASSACHUSETTS TECHNOLOGY COLLABORATIVE

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Outline

- AI JumpStart
- NRDZs
  - Idea
  - Colosseum for NRDZs
- Digital Twin
- OTIC

AI Cluster for Colosseum

Goal: *extend* ***AI*** *capabilities of* ***Colosseum*** *and provide researchers access to unique* ***AI+wireless*** *experimental facilities*

Possible use cases:

- Efficient training of large-scale wireless datasets collected on Colosseum
- Real-time, AI-driven 5G signal processing on for PHY layer & above
- Model-free adaptation to current network conditions and requirements

Partially funded by the MassTech Collaborative AI Jumpstart program

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AI Cluster

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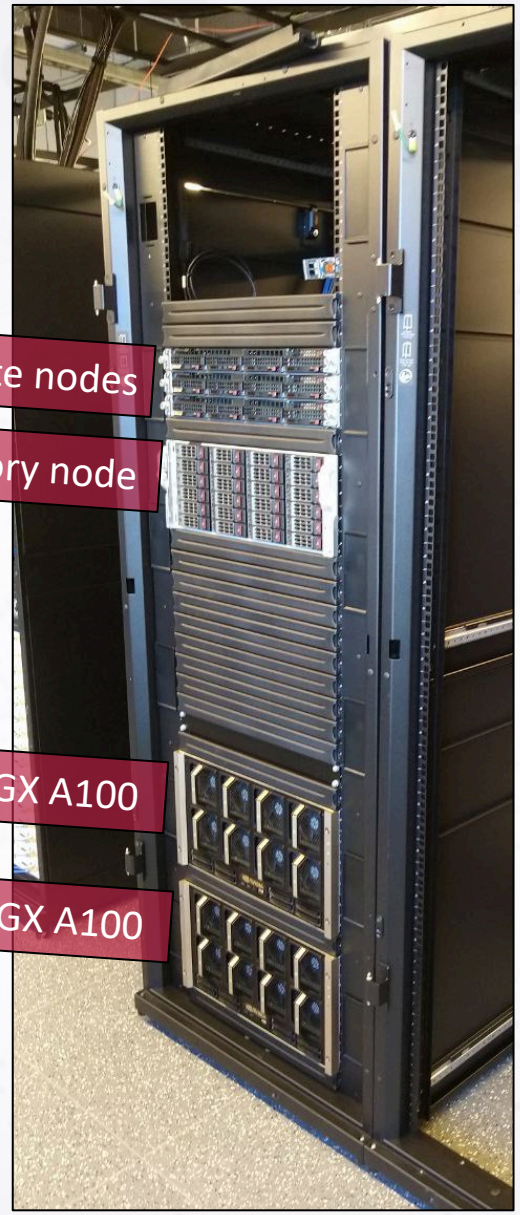
- Build GPU-accelerated software-defined, cloud-native applications for the 5G vRAN
  - 2x NVIDIA DGX A100
  - 1x Large memory node
  - 3x compute nodes
  - 1x MLX Infiniband switch

8 NVIDIA A100 GPU 40 GB

Mellanox Infiniband switch



How do we **integrate** the new rack into Colosseum?

HashiCorp Nomad

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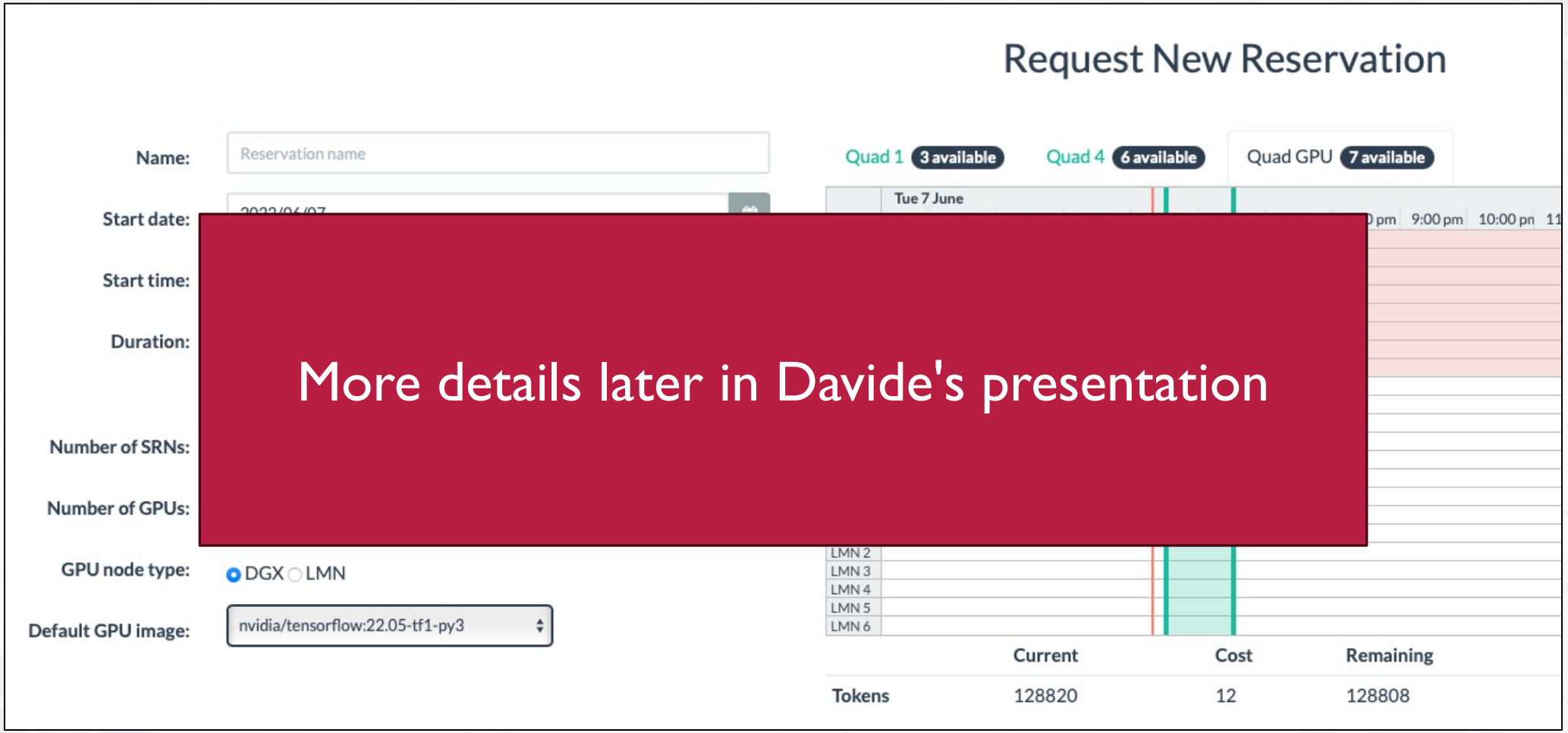
AI Jumpstart Integration in Colosseum

The system is fully integrated with Colosseum:

- Users can reserve SRNs and GPU resources
- Container orchestration based on Nomad
  - Test pilot on AI Jumpstart system to evaluate future applications to the whole Colosseum

GPUs are integrated in the reservation system



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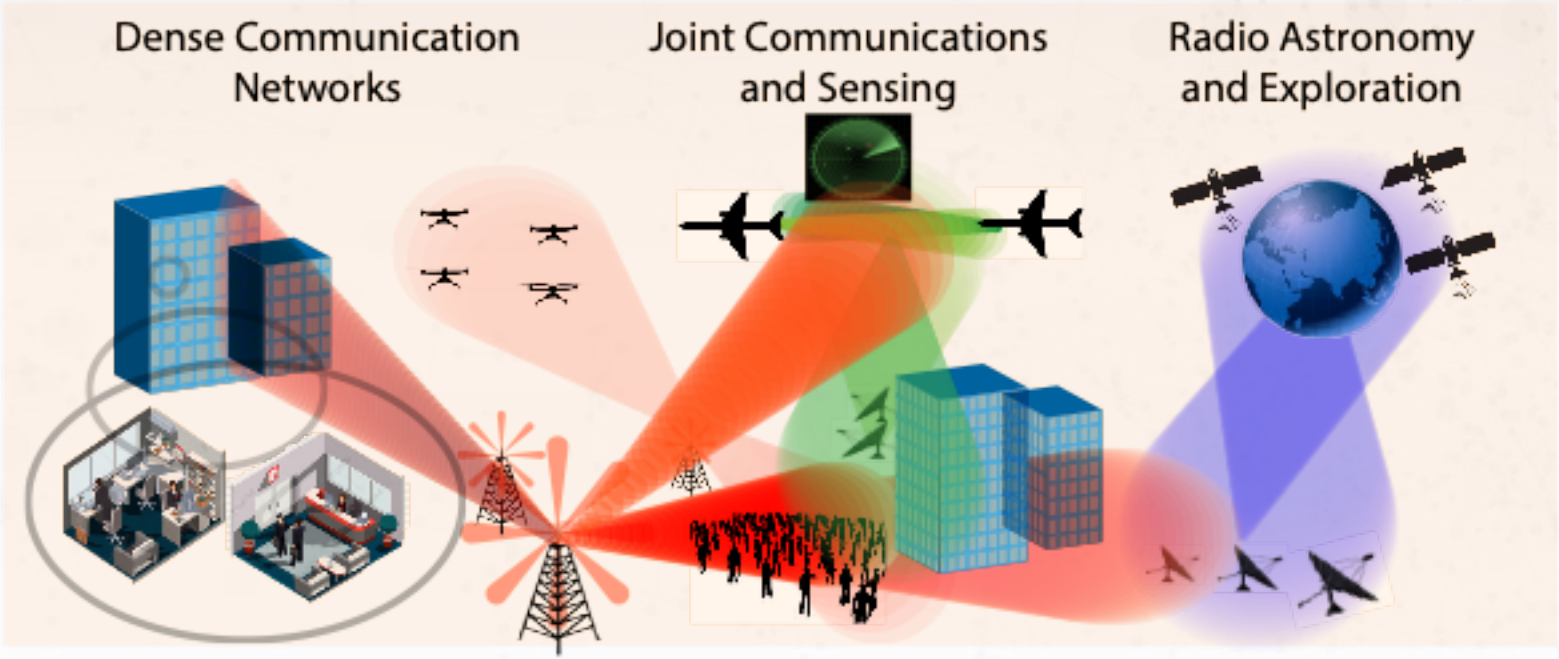
National Radio Dynamic Zones



Spectrum is a
- **limited** resource with
- many **different** uses and stakeholders

How can we improve the coexistence of different services?

M. Polese et al., Coexistence and Spectrum Sharing Above 100 GHz, in Proceedings of the IEEE (to appear)

NRDZ Goal

NRDZ is an NSF program that wants to:

- Create safe playgrounds for spectrum experiments that are not allowed under current regulations

- Bring together passive and active users to explore new uses of spectrum and spectrum sharing

NRDZ and Colosseum

How can we enable controlled, repeatable experiments for NRDZs?

- Controlled environment
- No risk of harming actual active/passive users
- Multiple RF scenarios

- Hardware-in-the-loop
- Software-based protocol stacks

Emulate NRDZs in Colosseum

1. Open RF experimental environment available to the NSF community
2. Large scale
3. Integrated with other over-the-air testbeds (PAWR)

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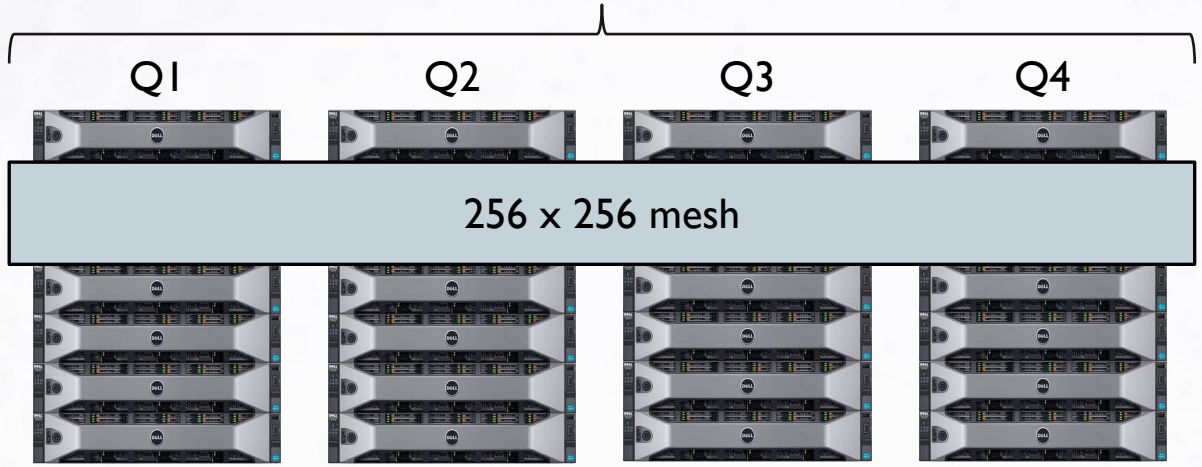
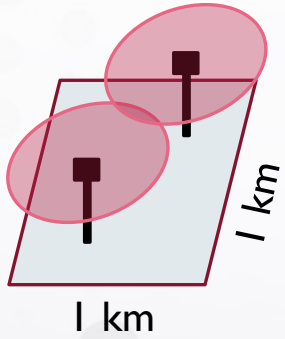
Current Colosseum and planned extensions

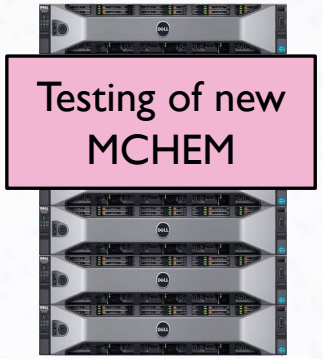
Existing Colosseum



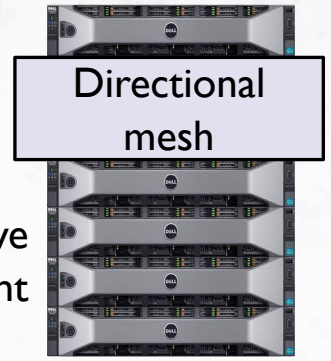


Sub-6 GHz – Omnidirectional

NRDZ extensions

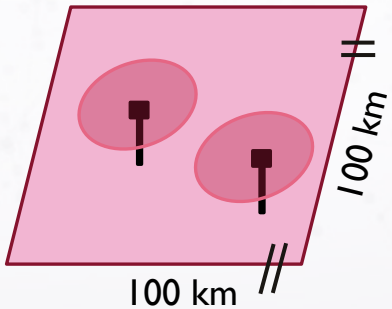


Development quadrant

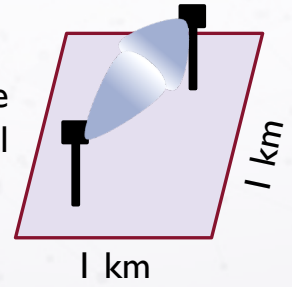


mmWave quadrant

New Wireless Emulation Capabilities



mmWave Directional



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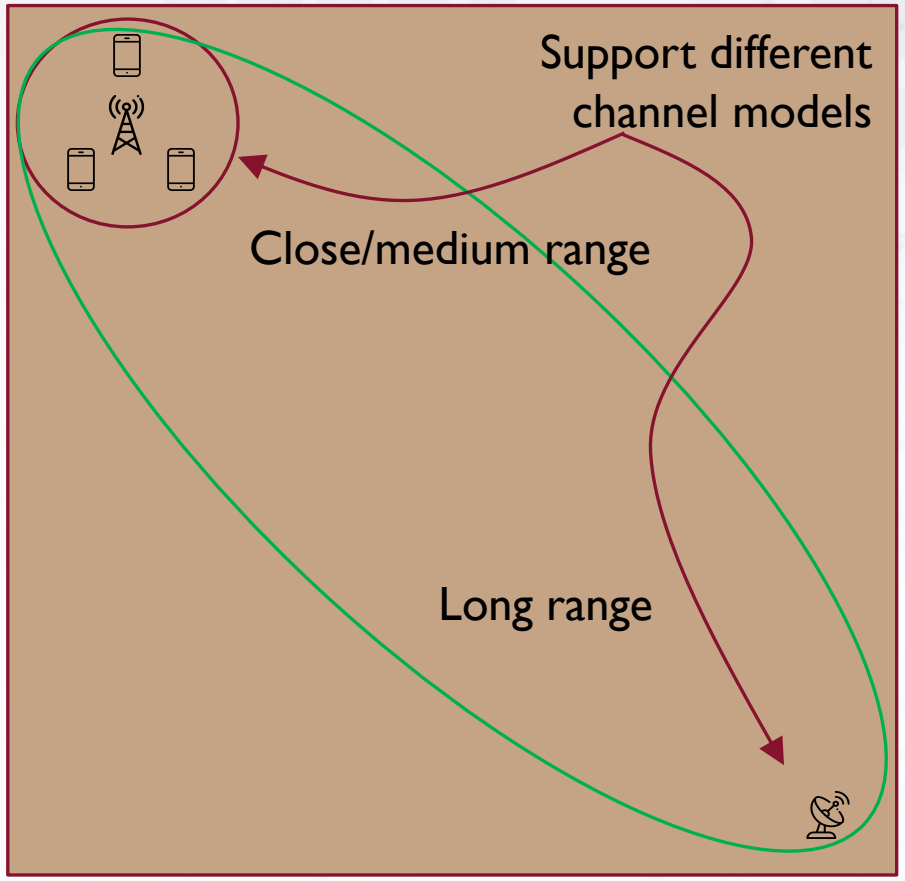
NRDZ and Colosseum



- Understand coexistence with different waveforms and receivers
- Study near-far interference issues
- Develop spectrum sharing solutions in heterogeneous environments
  - Example: CBRS radar coexistence – primary detection and secondary adaptation in a large geographical area

Coexistence issues with generic waveforms

- Colosseum is based on software-defined radios
- Generate custom waveform – or standard compliant waveforms

Study interference in different RF scenarios

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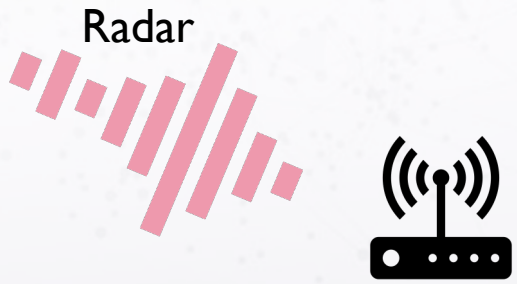
Spectrum sharing

- Develop spectrum sharing solutions in heterogeneous environments
  - Example: CBRS radar coexistence – primary detection and secondary adaptation in a large geographical area



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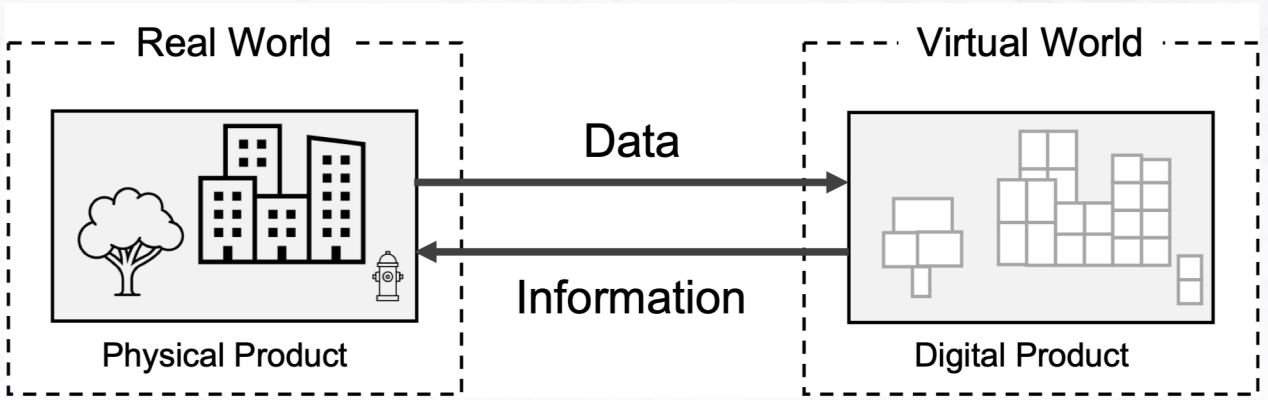
Wireless Digital Twins

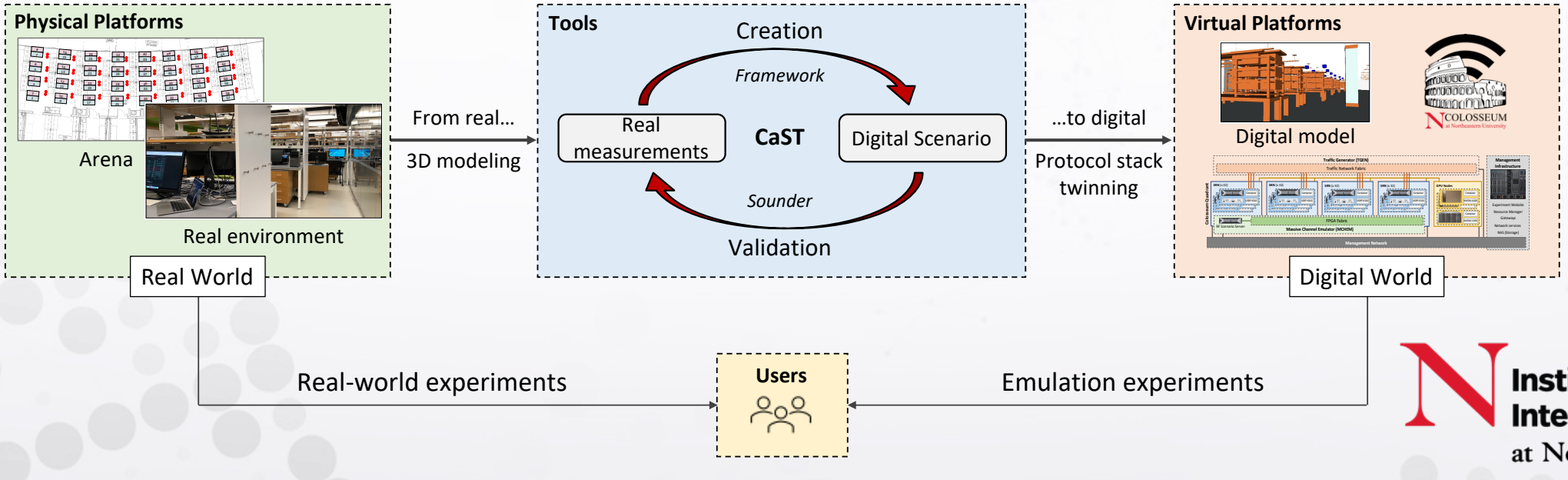
Large-scale emulators are widely used for modeling real-world environments, with **repeatability** and **lower-cost**

Reliability of emulations rely on:

- **Precision** of the underlying RF/Traffic models
- **Fidelity** of the emulation process and system

- **Goal**: Create a high-fidelity **Digital Twin** to reliably replicate experiments as close as possible to reality





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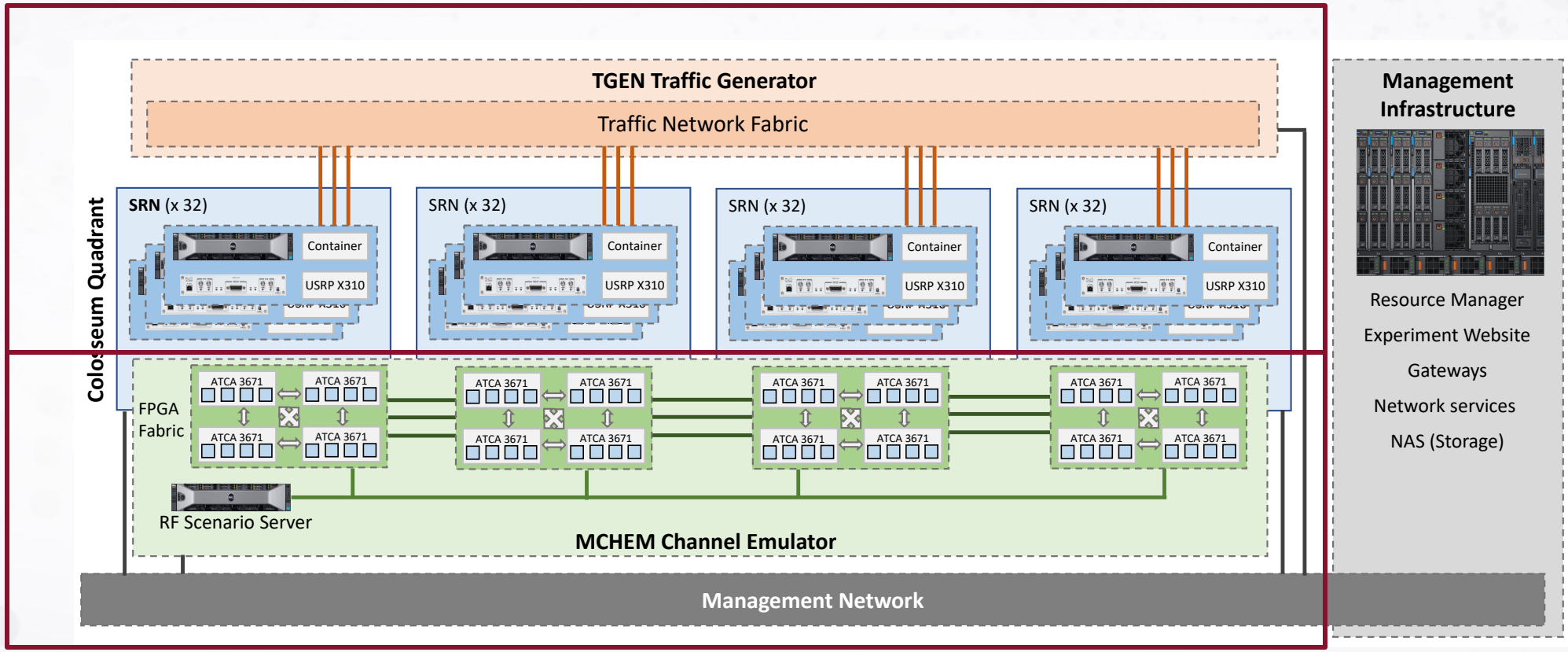
Colosseum as a Digital Twin

Protocol stack and applications twinning ⟶ CI/CD



Wireless RF scenario twinning ⟶ CaST

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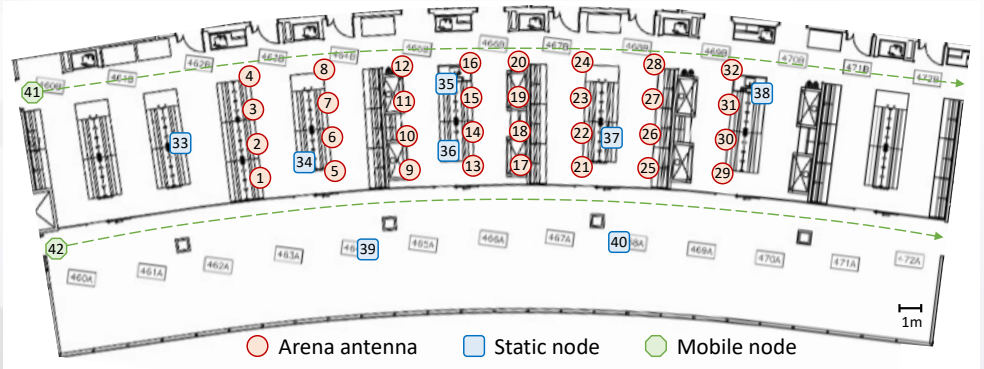
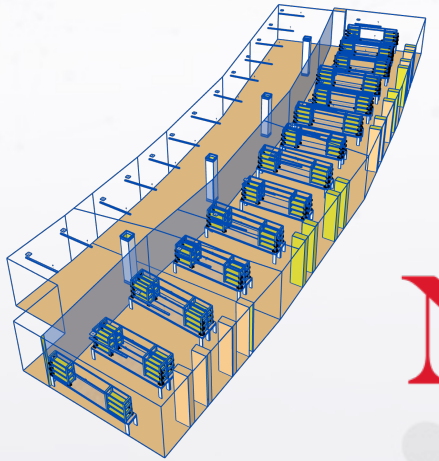
Twinning Arena and Colosseum

Arena: over-the-air testbed in indoor environment



Ray-tracing in the same environment



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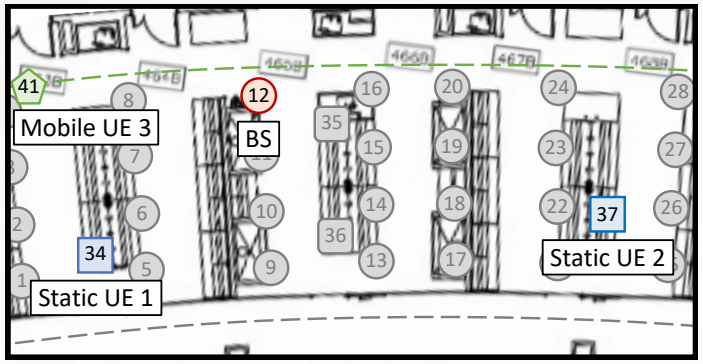
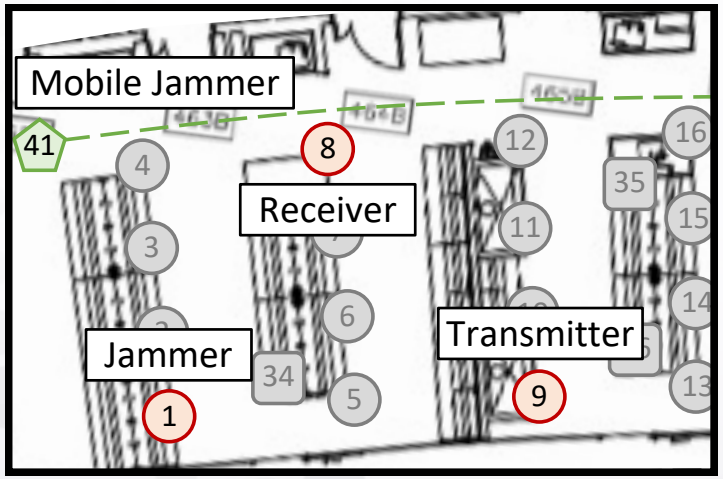
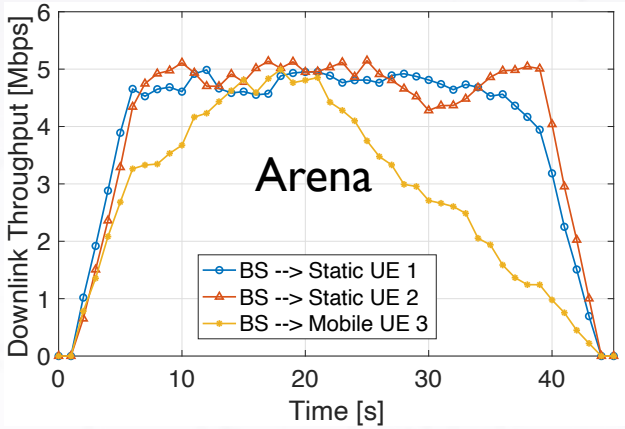
Twinning Arena and Colosseum Cellular and Jamming Experiments

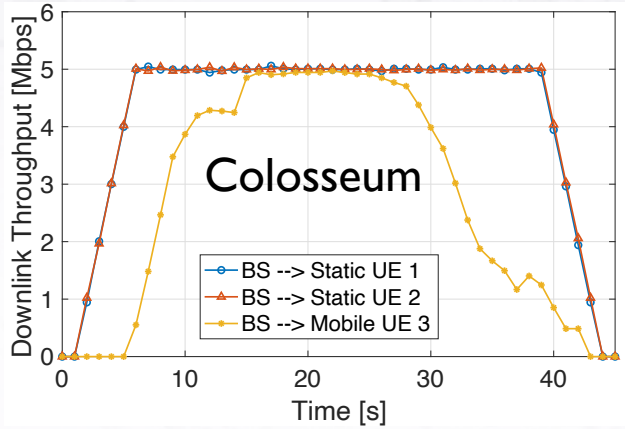


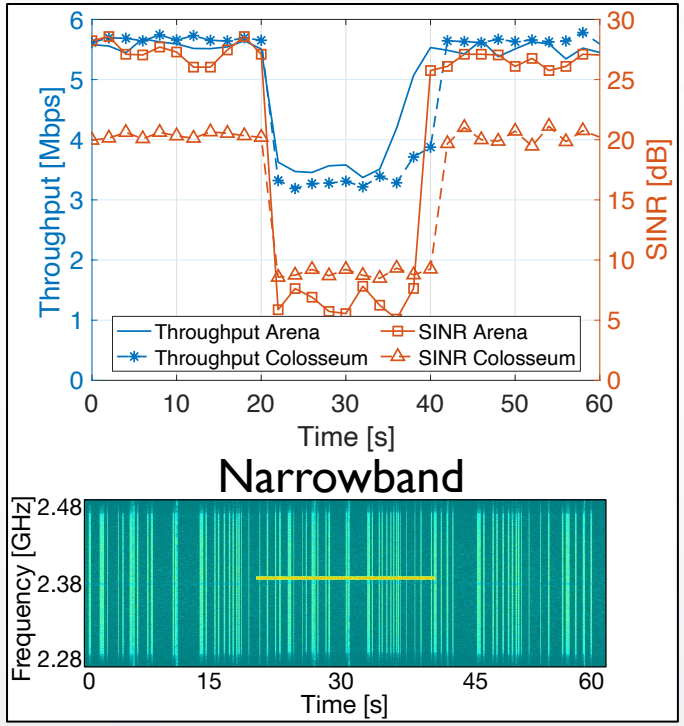
srsRAN cellular experiment nodes with 5 Mbps Downlink UDP traffic

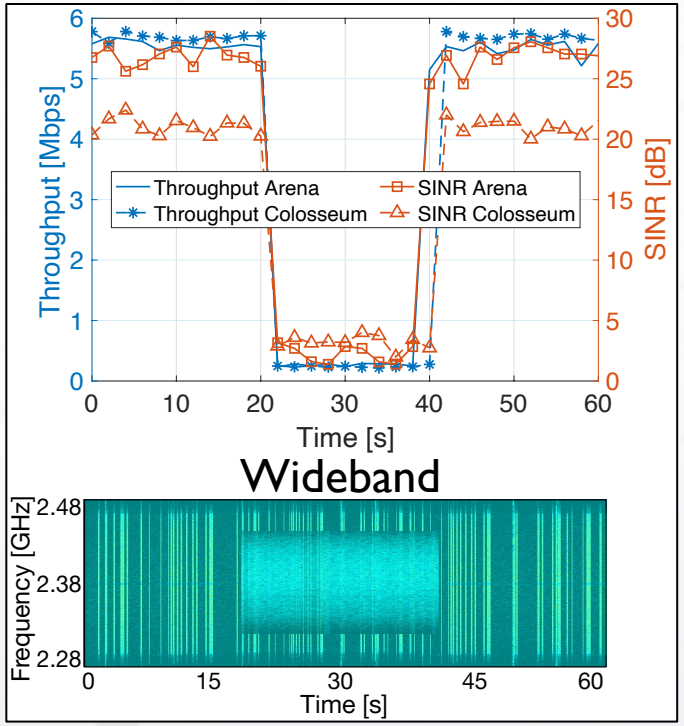


Wi-Fi jamming experiment nodes with a narrowband and a wideband jammer









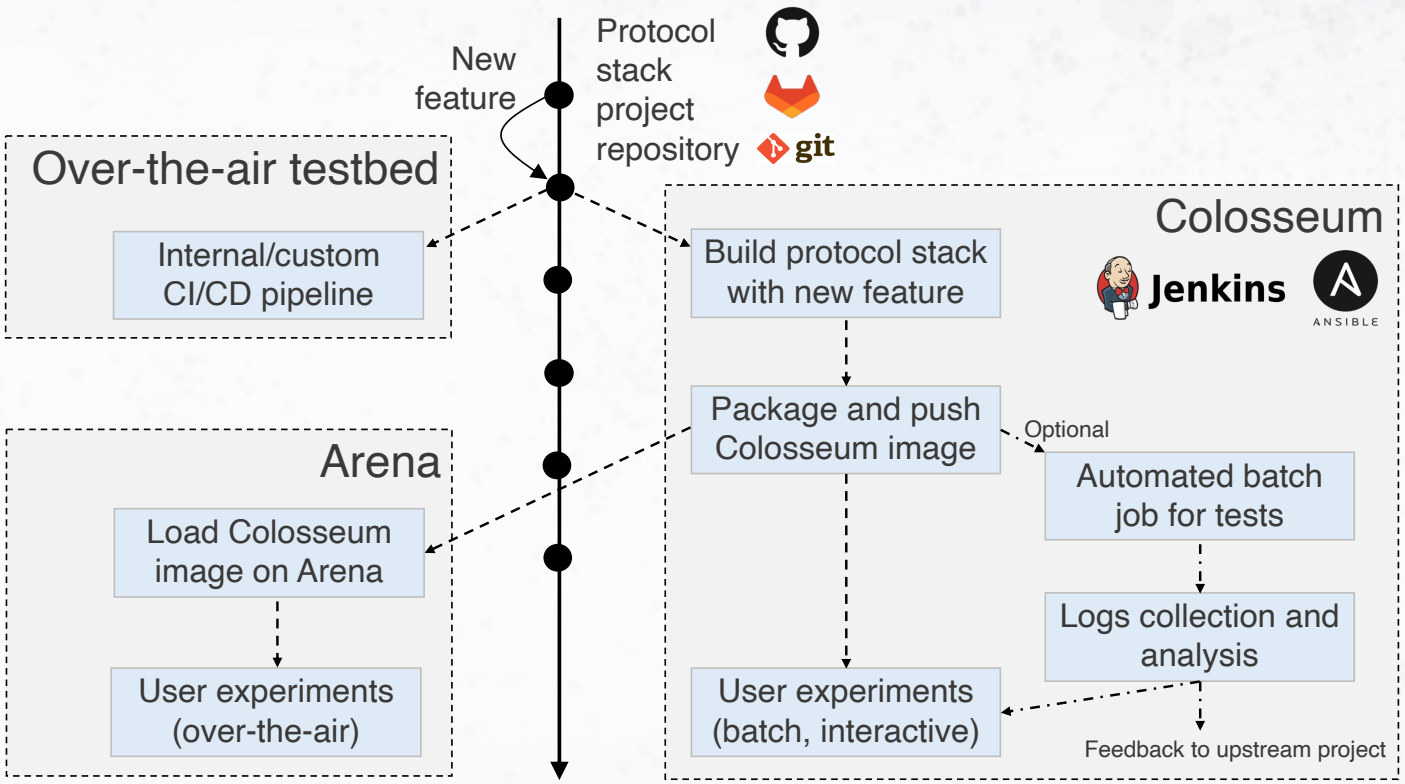
Protocol stack twinning - End-to-End CI on Colosseum

Open6G CI/CD Framework

Triggered by change to *any* component:

For every system-wide, end-to-end test case:

- ***Pulls*** and, if necessary, builds *every* component
- ***Assembles*** configured system(s)
  - LXC & Docker images, config files, etc.
  - Includes tests to execute once started
- ***Loads/generates*** Colosseum channel scenarios
- ***Submits*** Colosseum batch job
- ***Parses*** logs to determine pass/fail



This work is partially supported by the U.S. National Science Foundation under grant CNS-1925601, by the U.S. Department of Transportation, Federal Highway Administration, and by OUSD(R&E) through Army Research Laboratory Cooperative Agreement Number W911NF-19-2-0221.

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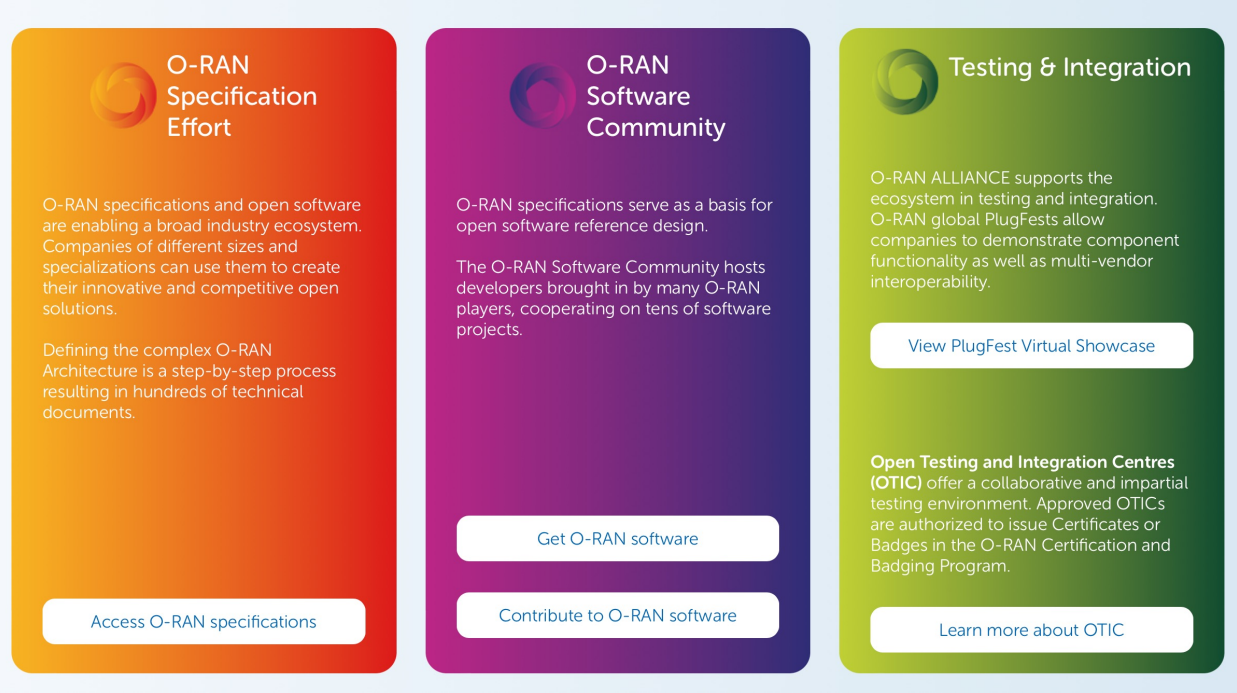
WIoT and O-RAN Alliance

WIoT contributions:

- WG3 and nGRG contributions
- Multiple O-RAN Software Community contributions
- Open6G OTIC
- OpenRAN Gym



OTIC Goals

Testing of next-generation Open RAN system with focus on end-to-end control, RICs, AI/ML

Different Radio Access Network (RAN) implementations for xApp/rApp testing

Leverage testbeds available at Northeastern (including Colosseum)

New testing equipment for RIC testing and beyond

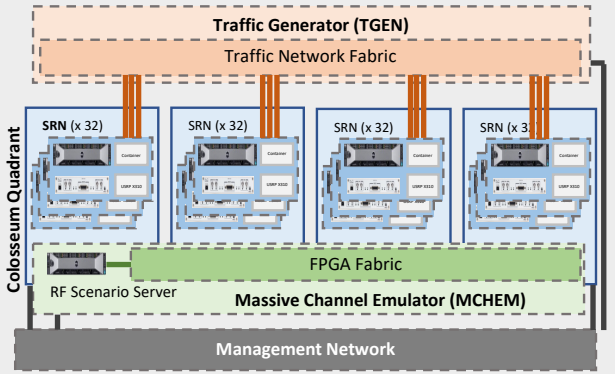
OTIC Architecture

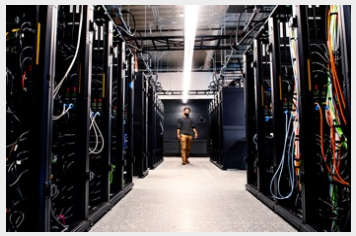
User-facing infrastructure

OTIC portal

VPN
(user, site-to-site)

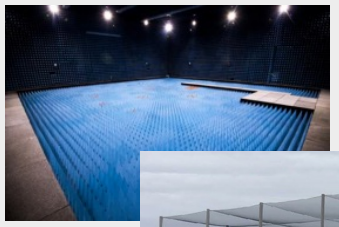
Colosseum

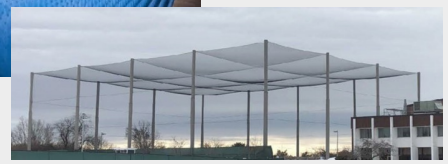




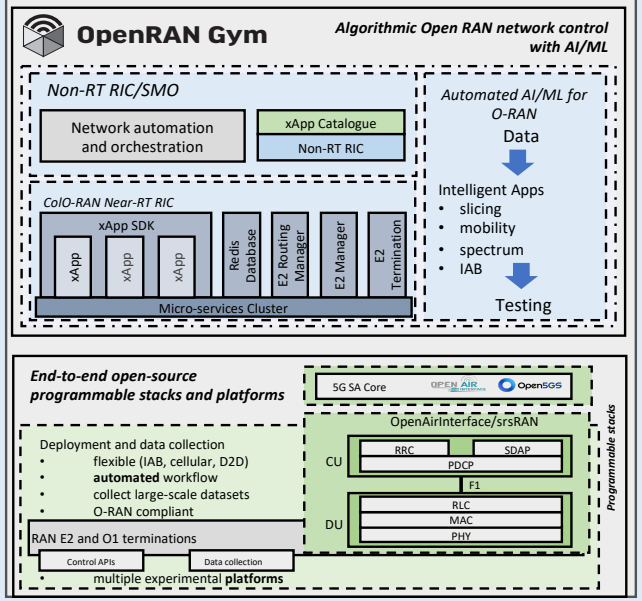
Over-the-air facilities

- Commercial RAN equipment
- SDR test bench
- UAV facility
- Anechoic chamber
- Testing equipment





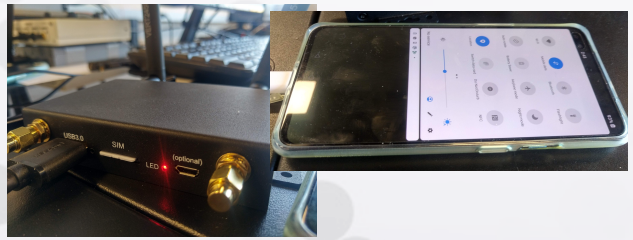
End-to-end Open6G architecture

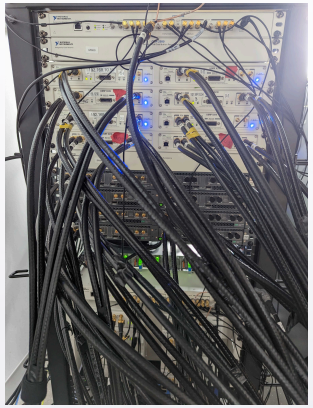


Compute, storage, network switching fabric

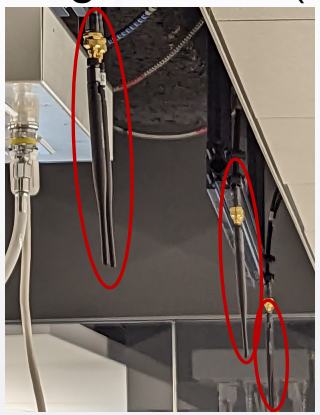
Private 5G Testbed

- Fully automated w/ AI and Red Hat's OpenShift
  - zTouch pipelines
  - Resilient to fault, and self-healing
- Virtualized, programmable O-RAN compliant network w/ OpenAirInterface
- Provides connectivity to smartphones, 5G dongles
- 5G experimental research for spectrum-sharing, security, AI-based control use cases
- Some specialized servers for GPU-based PHY layer w/ NVIDIA Aerial Research Cloud
- FCC Innovation Zone



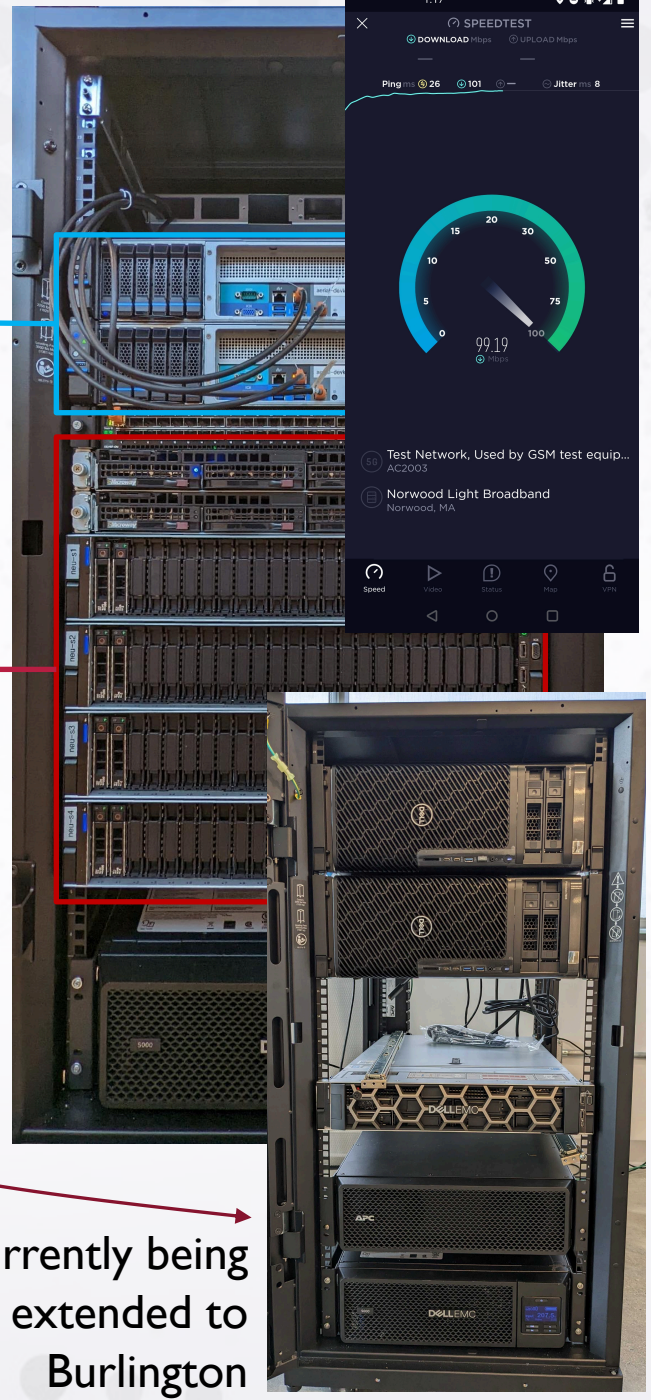


Ceiling antennas (64x)



Specialized HW for GPU-based PHY layer

OpenShift Cluster



Currently being extended to Burlington

LVX VERITAS VIRTVS

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Thank You! (Questions?)

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MITRE

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