Institute for the Wireless Internet of Things

at Northeastern University

Colosseum: A Large-Scale Programmable Wireless Emulator for the Research Community

Platforms for Advanced Wireless Research

COLOSSEUM

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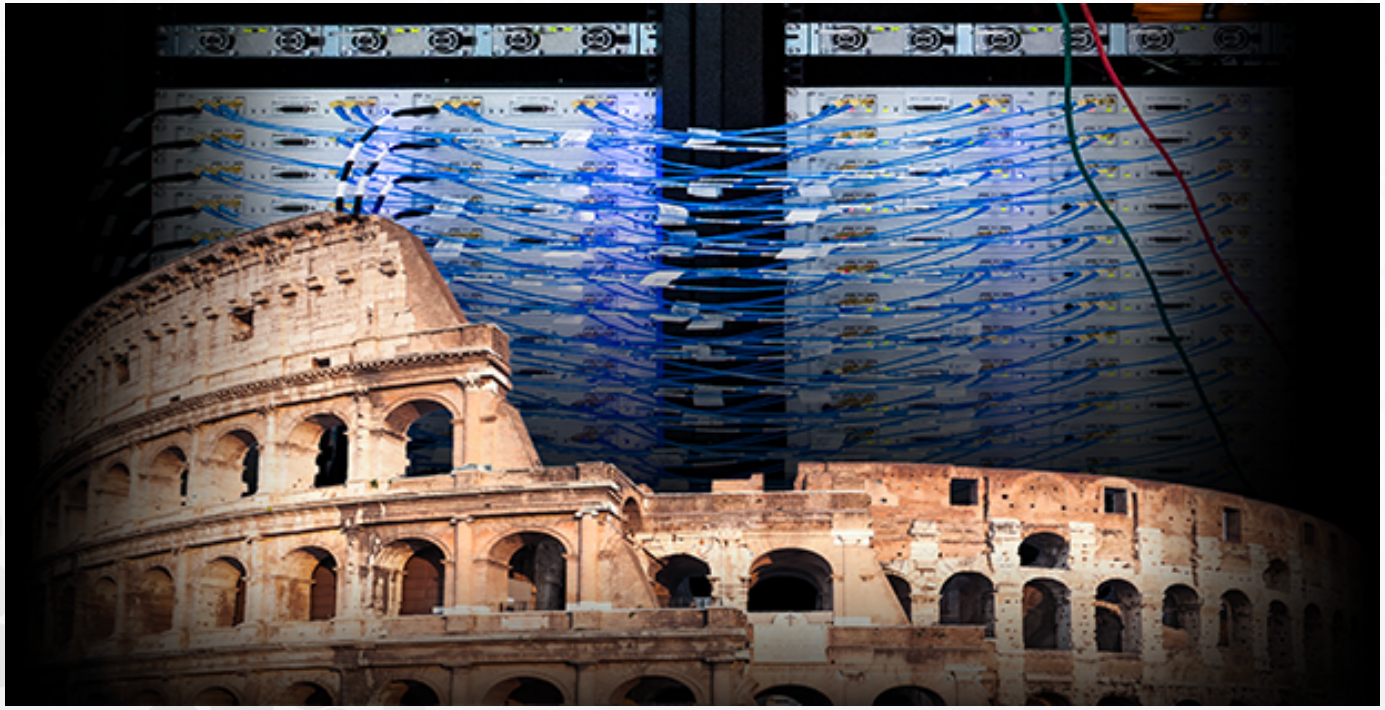
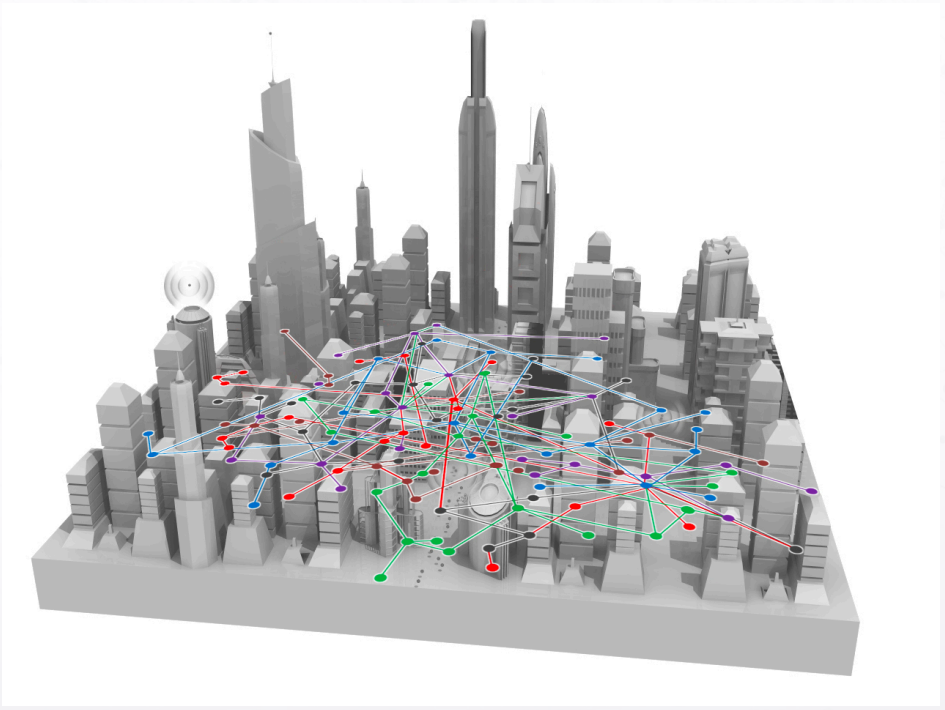
NEW NATIONAL RESOURCE FOR WIRELESS SYSTEMS RESEARCH

- Colosseum, a massive $20M wireless systems testbed developed by DARPA, has already been transferred to Northeastern University and is currently up, operational, and open to the NSF community
- Transfer to Northeastern funded by NSF CCRI grant
  - 256 x 256 100 MHz RF channel emulation, 128 Programmable Radio Nodes
  - Computing resources (CPU, GPU, FPGA)
  - Access control and scheduling infrastructure
- Supports remote shared access
  - Spectrum Sharing
  - AI + Wireless
  - 5G (softwarization, slicing, security)
  - IoT

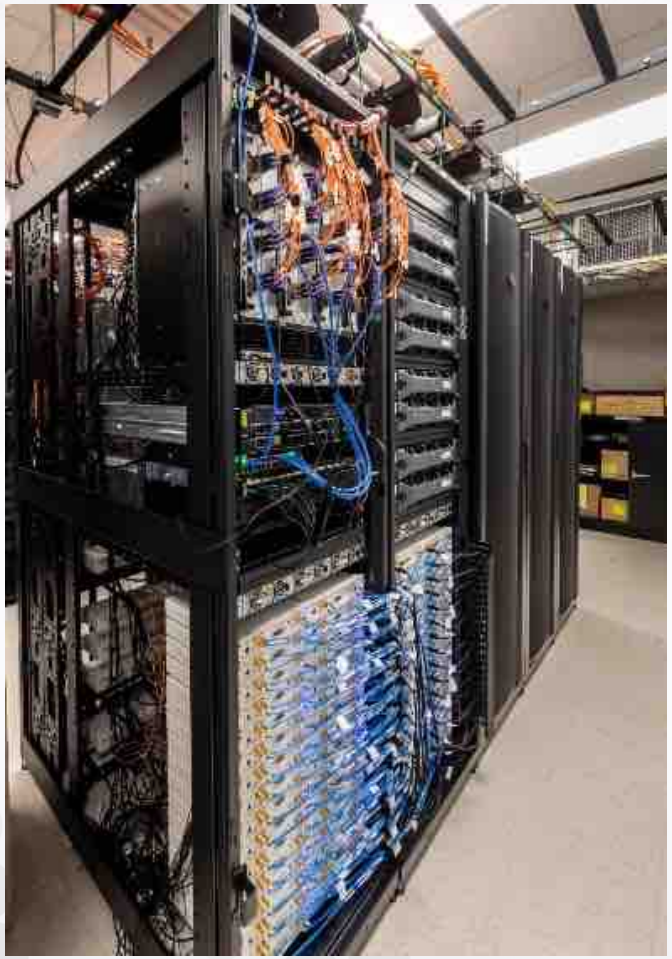
COLOSSEUM: The World's Largest Wireless Emulator

- 256 software defined radios (fully programmable)
- Fabric of field programmable gate arrays - > 65k channels emulated in real time
- 128 servers w/ hardware in the loop, remotely available for user experiments
- Diversified scenarios for better generalization of ML / AI models
- Large-scale experimentation of wireless RF systems with spectrum in the loop



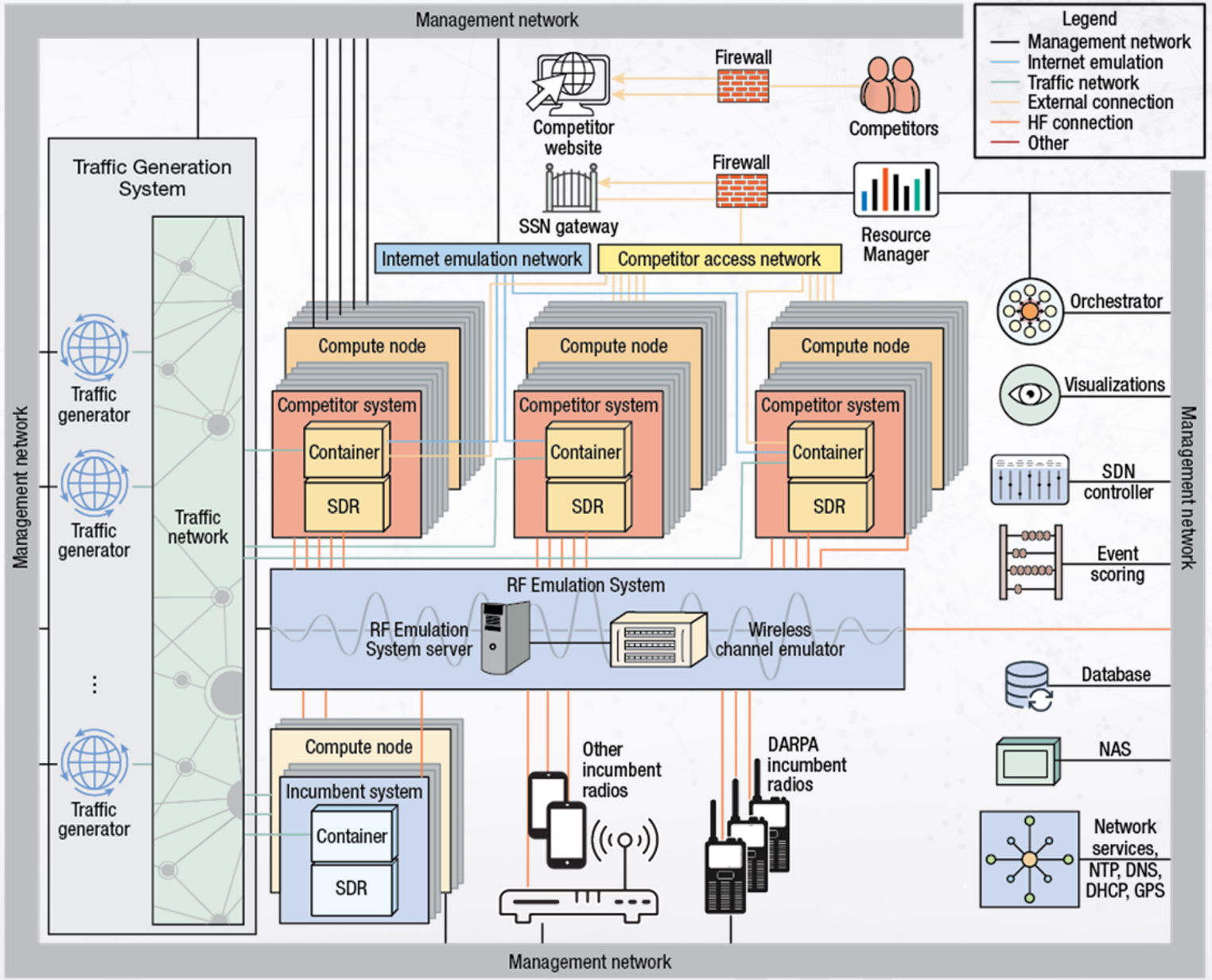


COLOSSEUM: The World's Largest Network Emulator



- 256 USRP X310s → 128 as communications devices, 128 as part of Colosseum Massive Channel Emulator (MCHEM)
- 65,536 100 MHz emulated RF channels → 25.6 GHz bandwidth, 52 TB/s RF data
- 21 racks of radios, 171 high-performance servers w/ CPUs / GPUs
- Full-mesh networking capability
- Massive Computing and support resources: (CPU, GPU, FPGA)
    - 900 TB of Network Attached Storage (NAS)
    - 320 FPGAs
    - 18 10G switches
    - 19 clock distribution systems
    - 52 TB/s of digital RF data

COLOSSEUM Architecture



COLOSSEUM: Much More Than a Supercomputer

- Colosseum has RF hardware in the loop
- Not only a simulation environment: real-time emulation with real wireless signals and emulated channels
- Combines in a SINGLE instrument
  - Fidelity of hardware channel emulators
  - Flexibility of a virtualized data center,
  - Scale of a network simulator
- Fully programmable
- $20M+ investment by DARPA
- $6M investment by NSF
- $2M investment by Northeastern

COLOSSEUM: Much More Than a Supercomputer

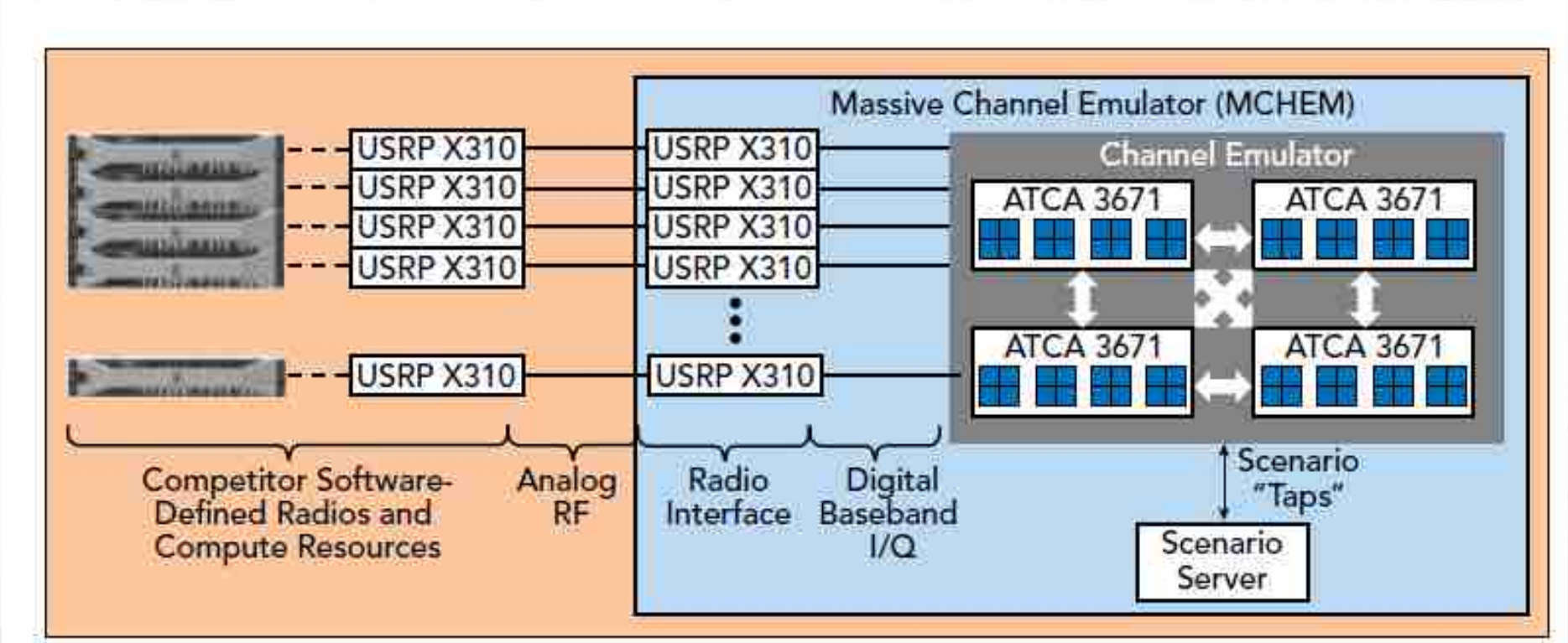
- Colosseum differs from existing supercomputers in that it combines massive RF hardware, and programmable hardware to emulate in real time and with high fidelity complex RF scenarios, including spectrum sharing, radar, etc.

- The complex realistic modeling with RF hardware in the loop enabled by Colosseum is not possible with any of the existing simulation models available on supercomputers

- In Colosseum, RF transmissions are generated by real programmable RF hardware, and RF channels are emulated through a unique fabric of programmable field programmable gate arrays, able to emulate 65k channels between each individual radio pair in real time.

Massive Channel Emulator (MCHEM)

- Emulates in real time channels between 256 independent transmitters (65k channels)
- 512-tap channel model (sparse, 4 nonzero)
- Scenarios



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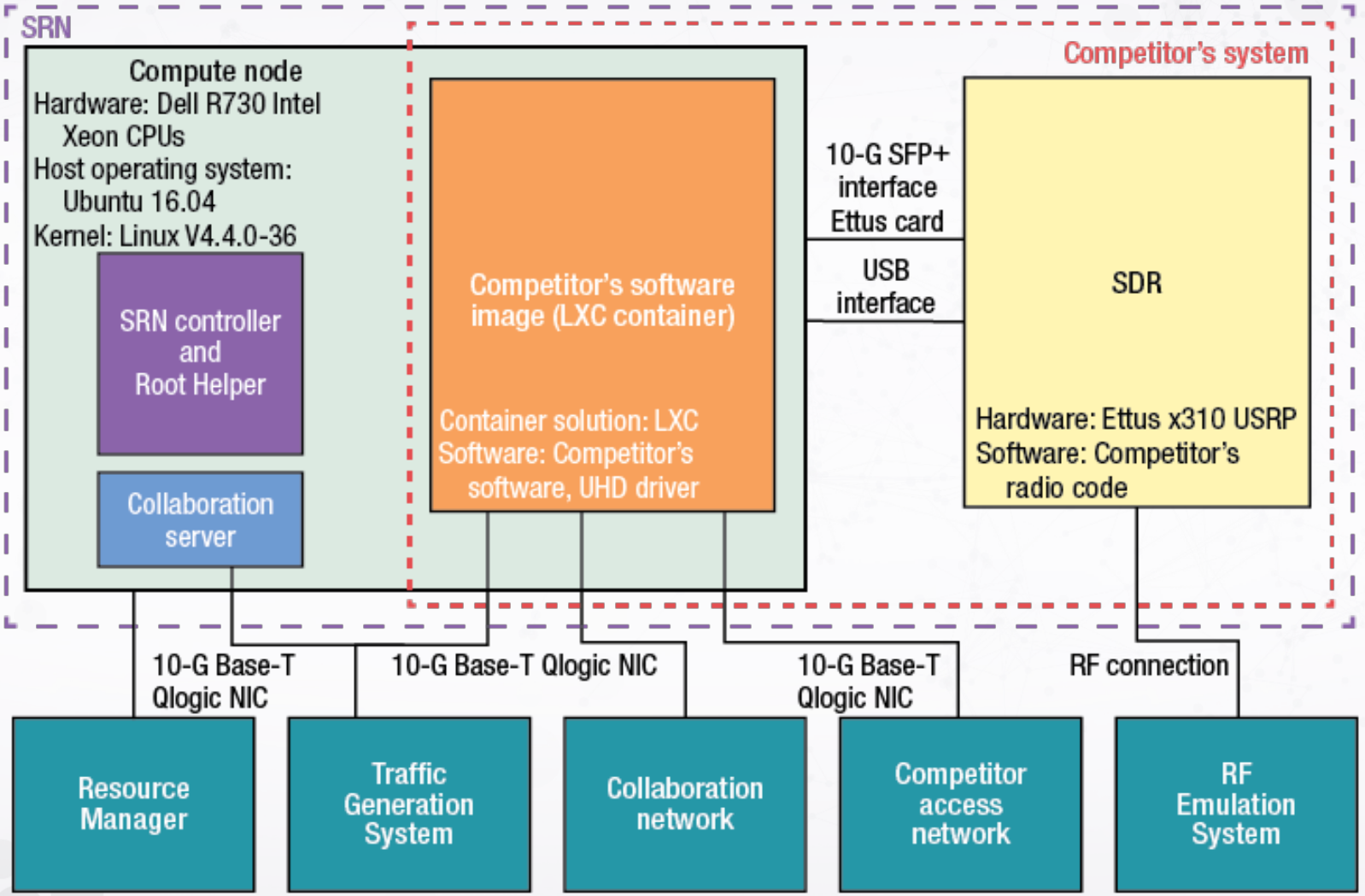
Standard Radio Node (SRN)



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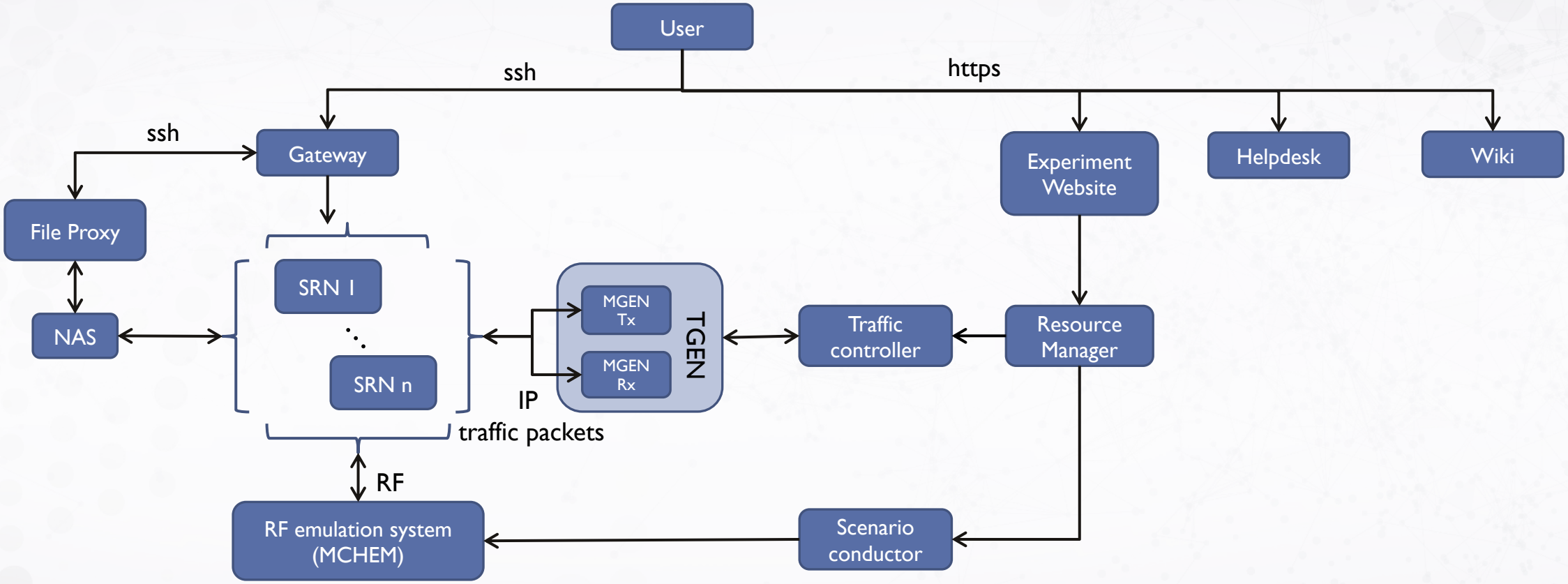
Basic Components of Colosseum's Architecture



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Traffic Generator (TGEN)

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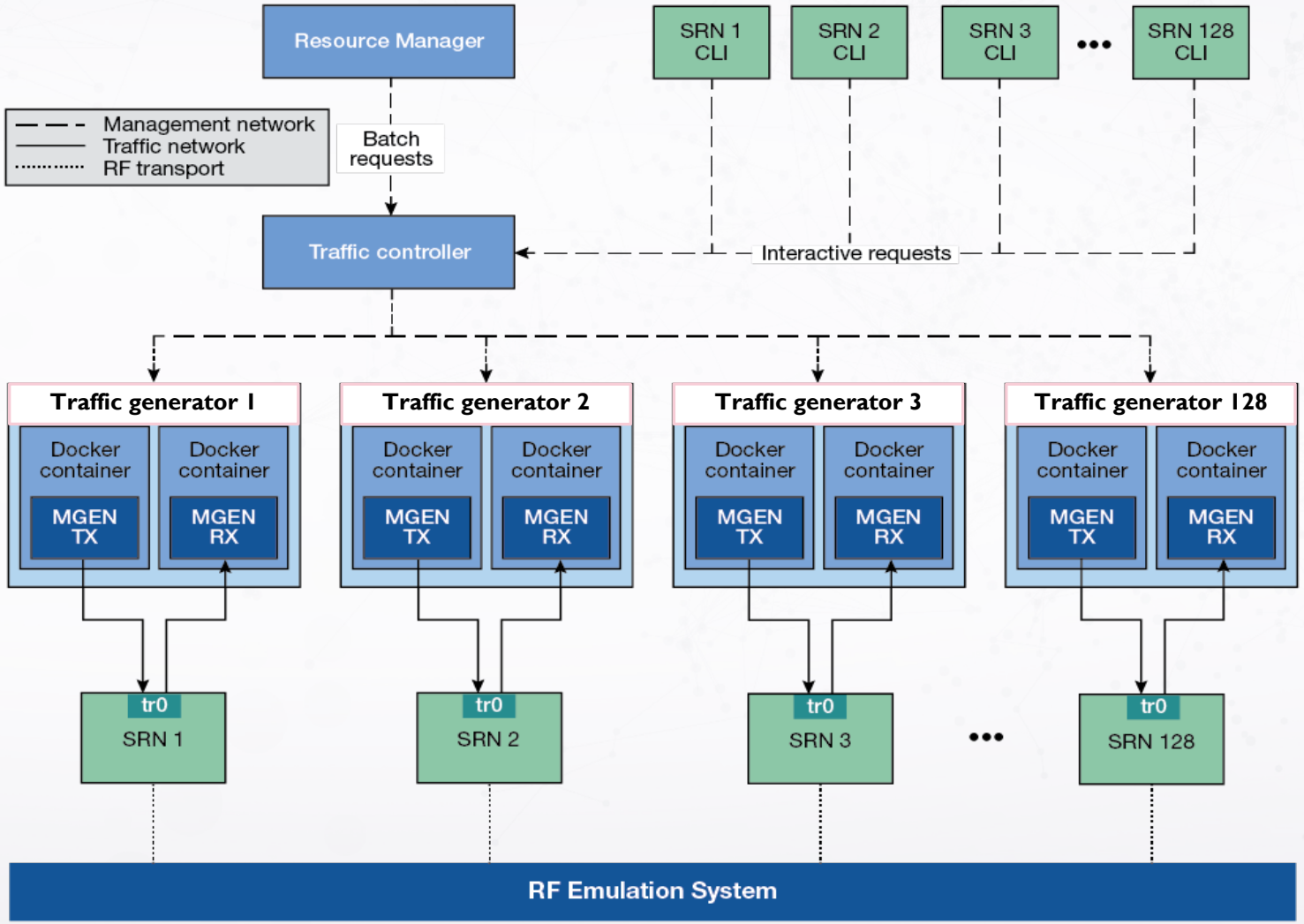
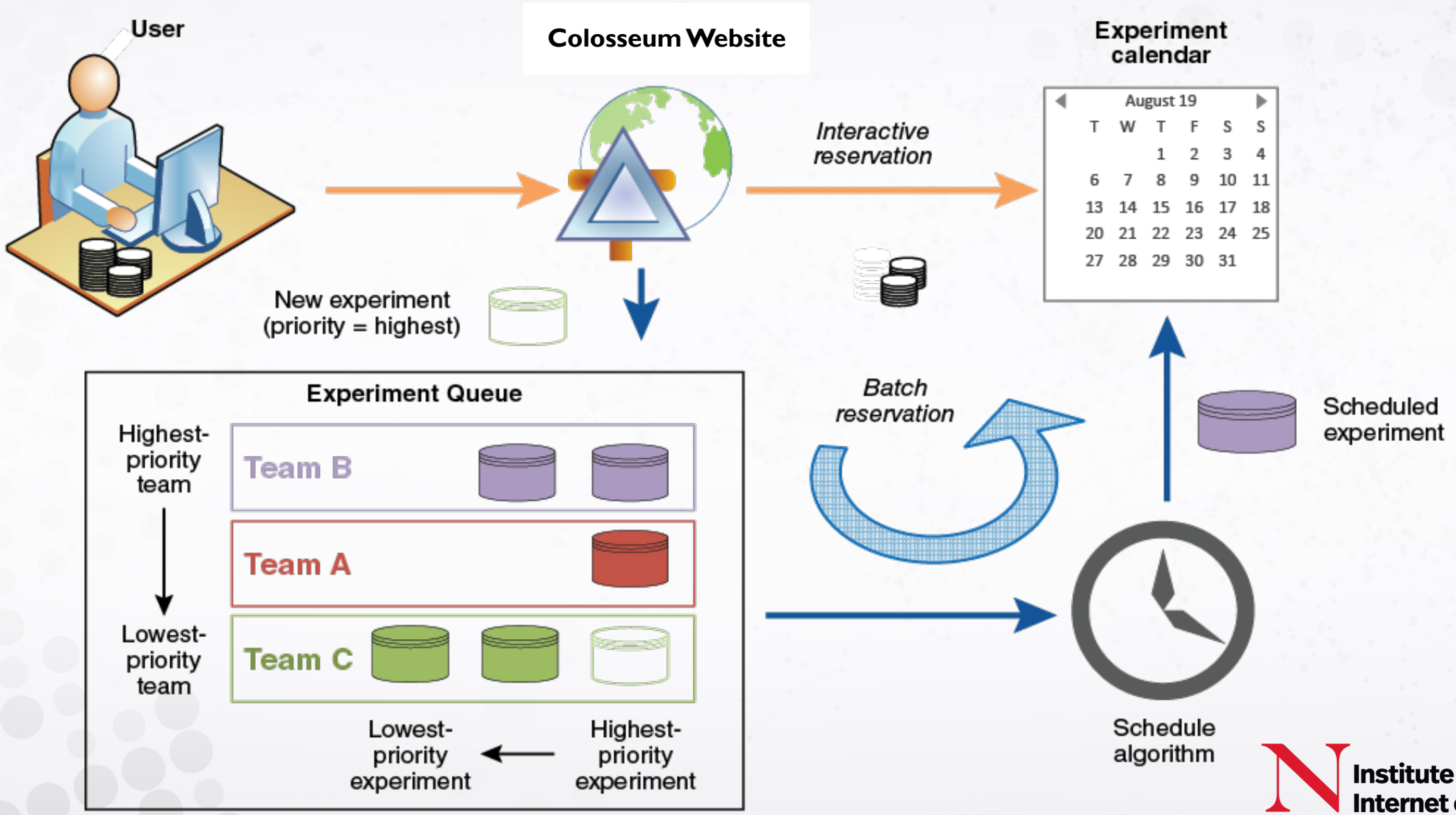
Creates UDP traffic flows between SRNs through Multi-Generator (MGEN) [1]



[1] U.S. Naval Research Laboratory, "Multi-Generator (MGEN)." https://www.nrl.navy.mil/itd/ncs/products/mgen

Experiment Workflow



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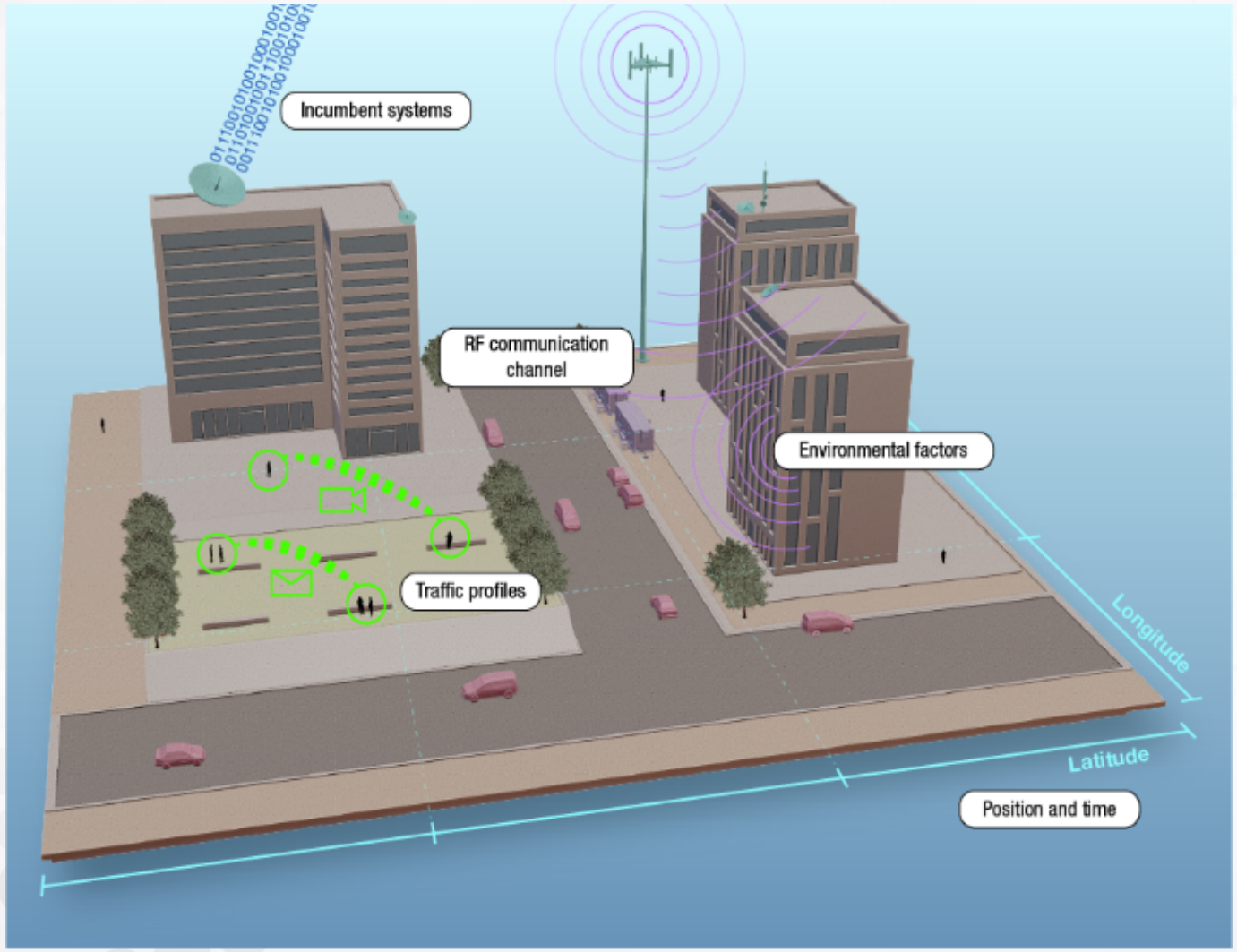
Example Scenario (Alleys of Austin)



- A platoon from the Texas Army National Guard at Camp Mabry is practicing urban maneuvers and communications in Austin.
  - The platoon is split into five squads consisting of 9 squad members and one UAV.
  - The scenario is designed to run for 930 seconds, with 300 seconds per stage for 900 seconds of competitive time and 15 seconds appended on either end. The scenario

DARPA produced scenario video:
https://youtu.be/0p-b6TZP6DI

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Example Scenario

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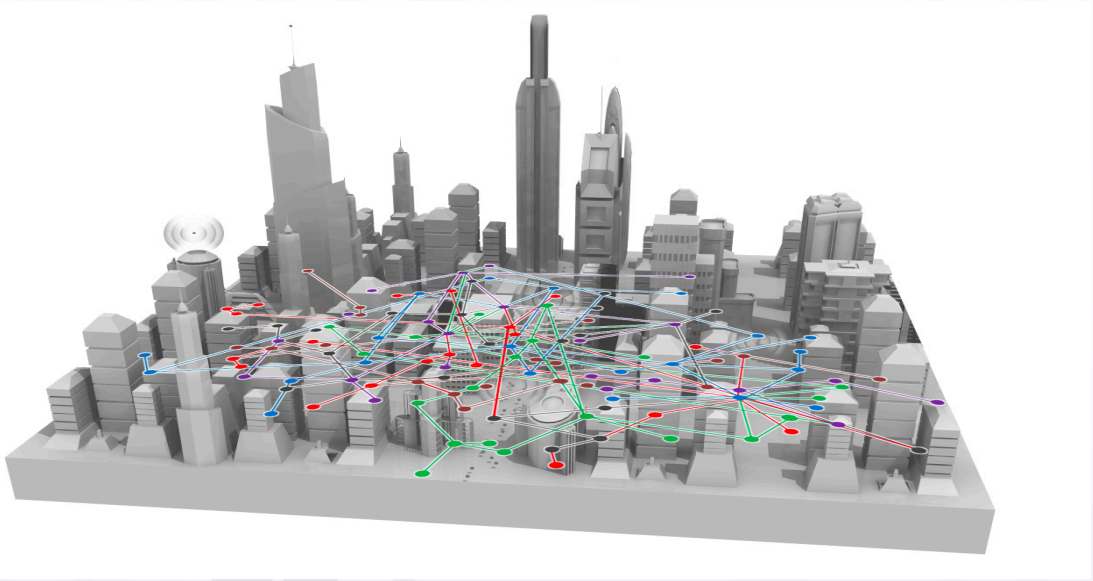
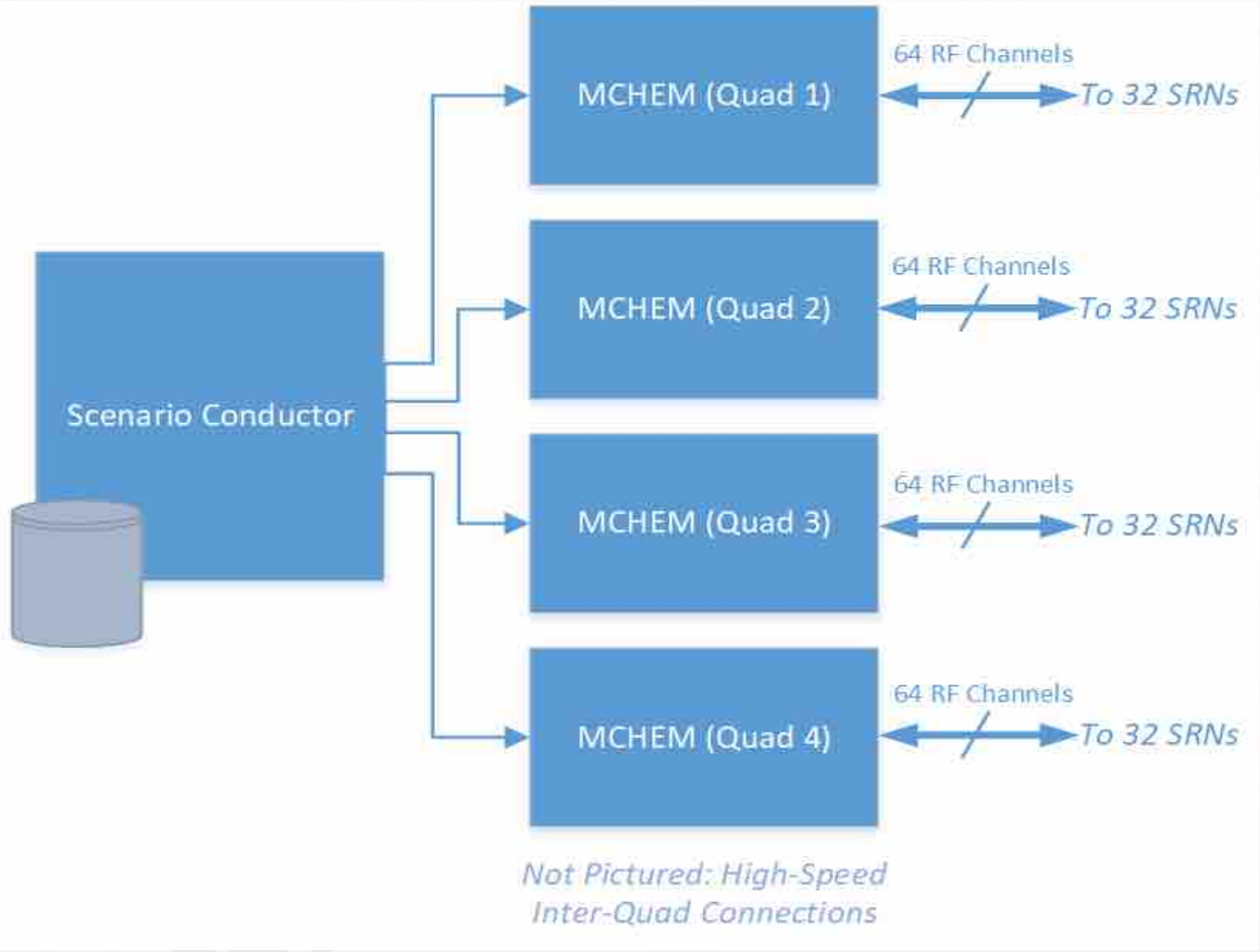
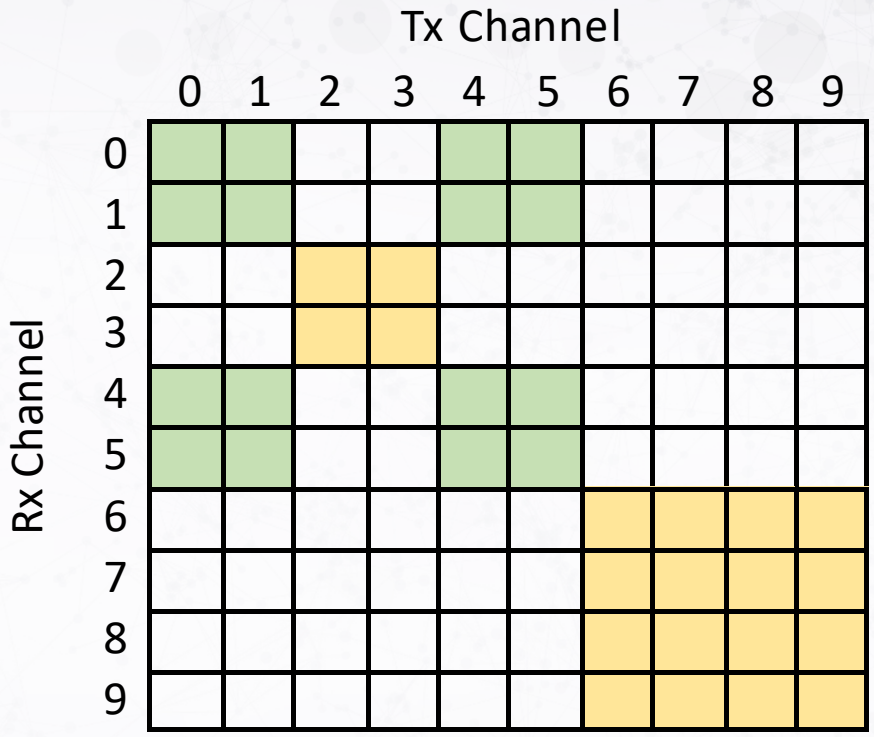
Label	Value
RF Description	Single tap; large scale
Scenario BW (MHz)	20
Traffic Description	VOIP; BFT; Imagery; UAV Video; UAV CC; Body Cam Video
Center Frequency	1000 MHz
Competitor nodes	50



Traffic Type	TOS	Delay (Sec)	Throughput (Kbs)	Goal Set	Hold Period(s)
VOIP	0x60	0.37	36.504	Voice	60
Body_cam_video	0x20	3	843.696	Video	60
Imagery_Stage	0x40	N/A	N/A	Static Images	60
UAV_CC	0x80	0.12	12.48	C2	60
UAV_video	0x20	3	843.696	Video	60
BFT	0x20	1	0.26	C2	60
UAV_telemetry	0x00	1	0.26	C2	60

Scenario Conductor





Legend

- Reservation A - Channels 0,1,4,5
- Reservation B - Channels 2,3,6,7,8,9
- Connectivity Disabled

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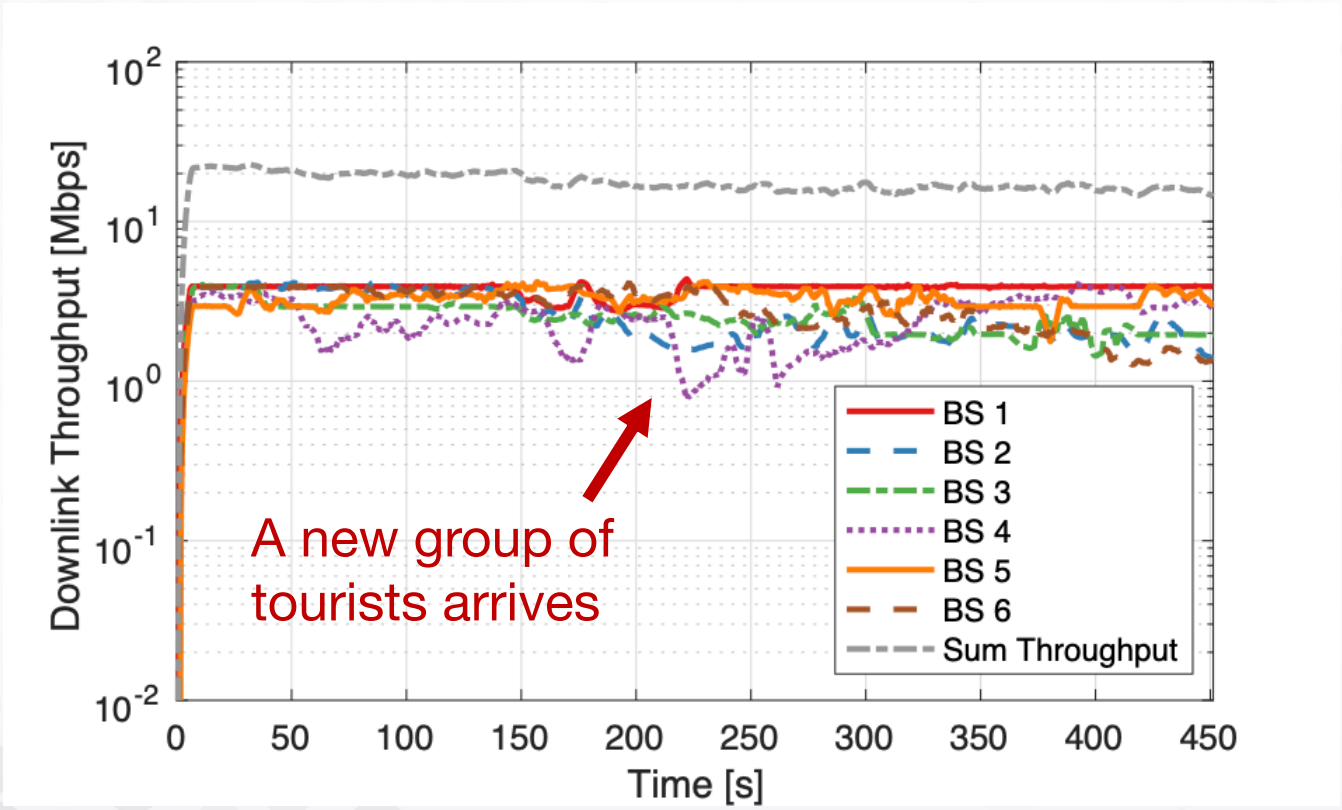
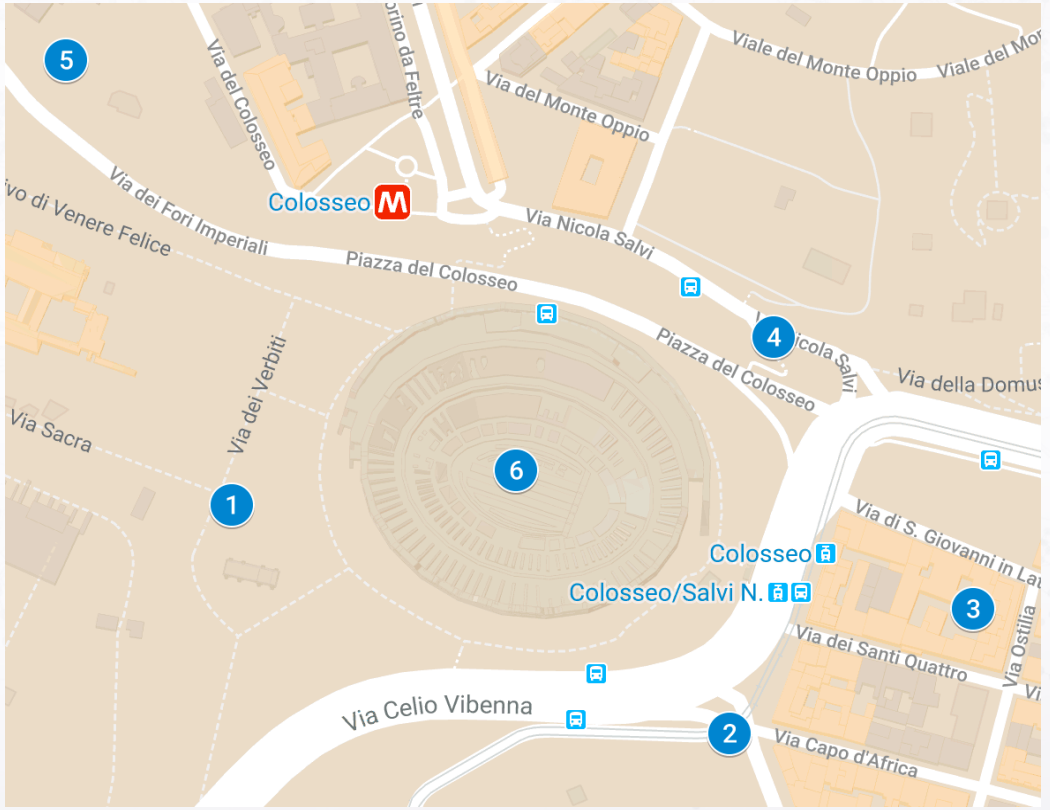
Colosseum 5G Capabilities

- Cellular network w/ srsLTE: 6 interfering base stations w/ 24 users
- Downlink video streaming
- Pedestrian user mobility
- Real-world scenario with base station locations in Rome, Italy (next to the actual Colosseum)

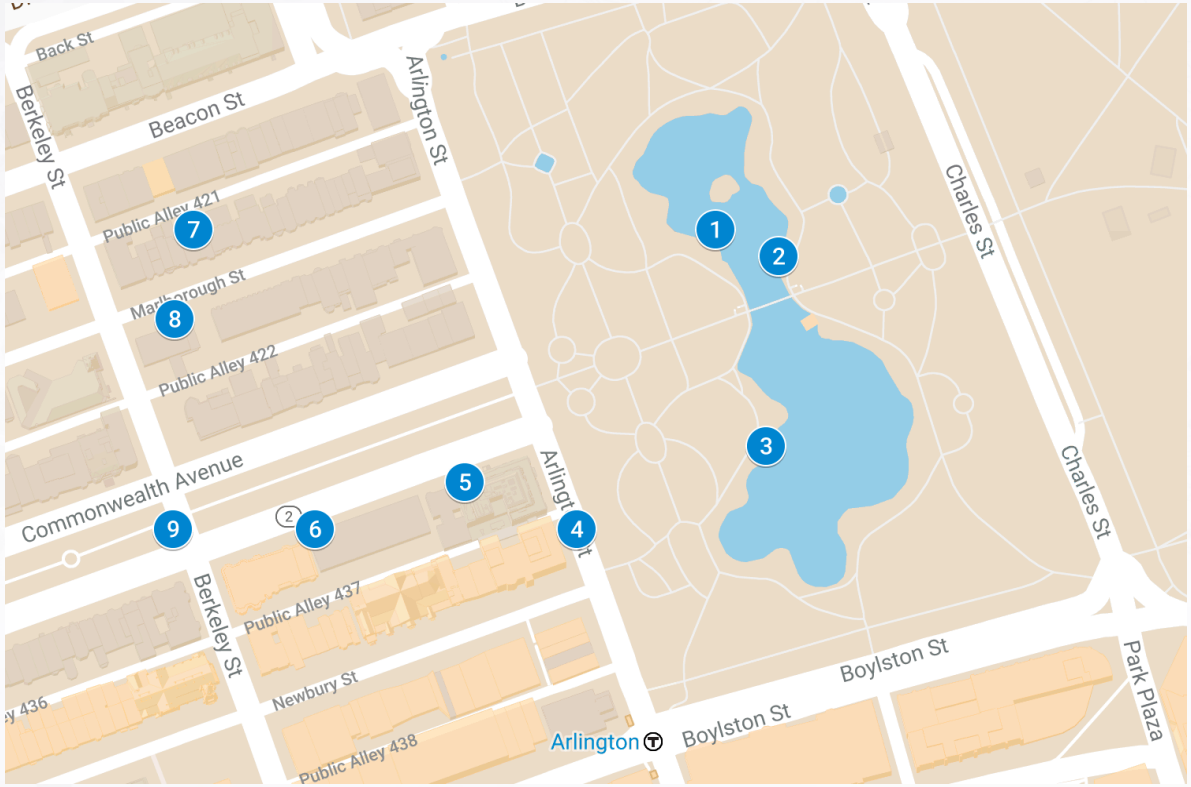


Downlink throughput

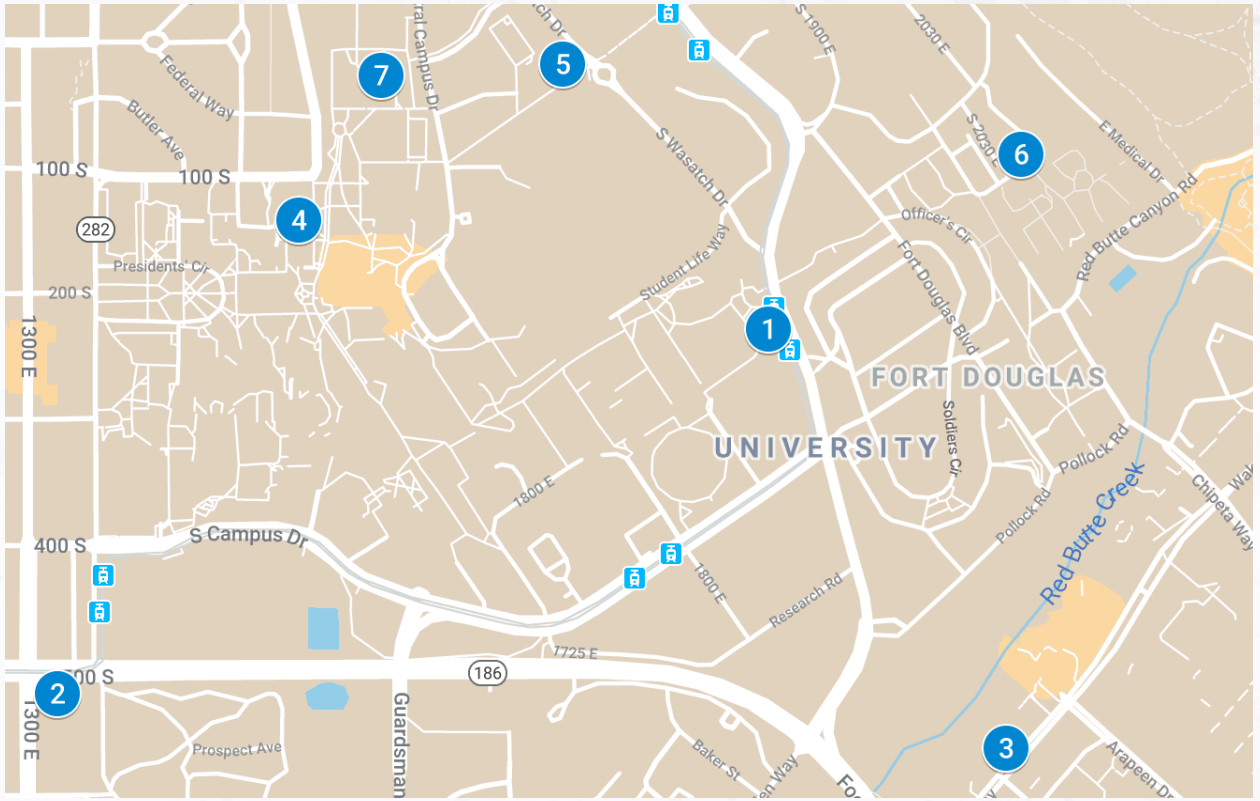


Base station locations

Additional Colosseum 5G Scenarios



Boston Public Garden, Boston, MA



POWDER PAWR – University of Utah Campus, Salt Lake City, UT

* Blue circles represent the base station locations

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A Container's Journey

- 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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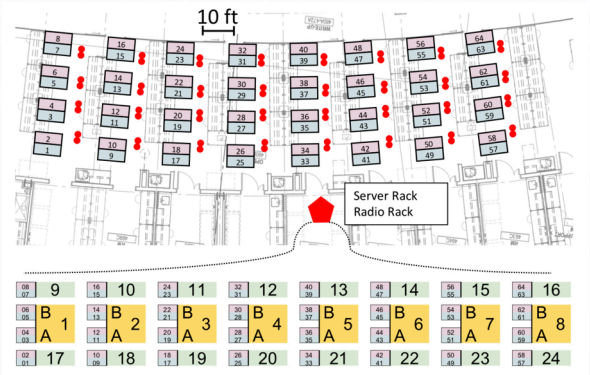
Validate in real wireless environment



Test large-scale capabilities

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COLOSSEUM: Serving Diverse Communities

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Who Can Use Colosseum?

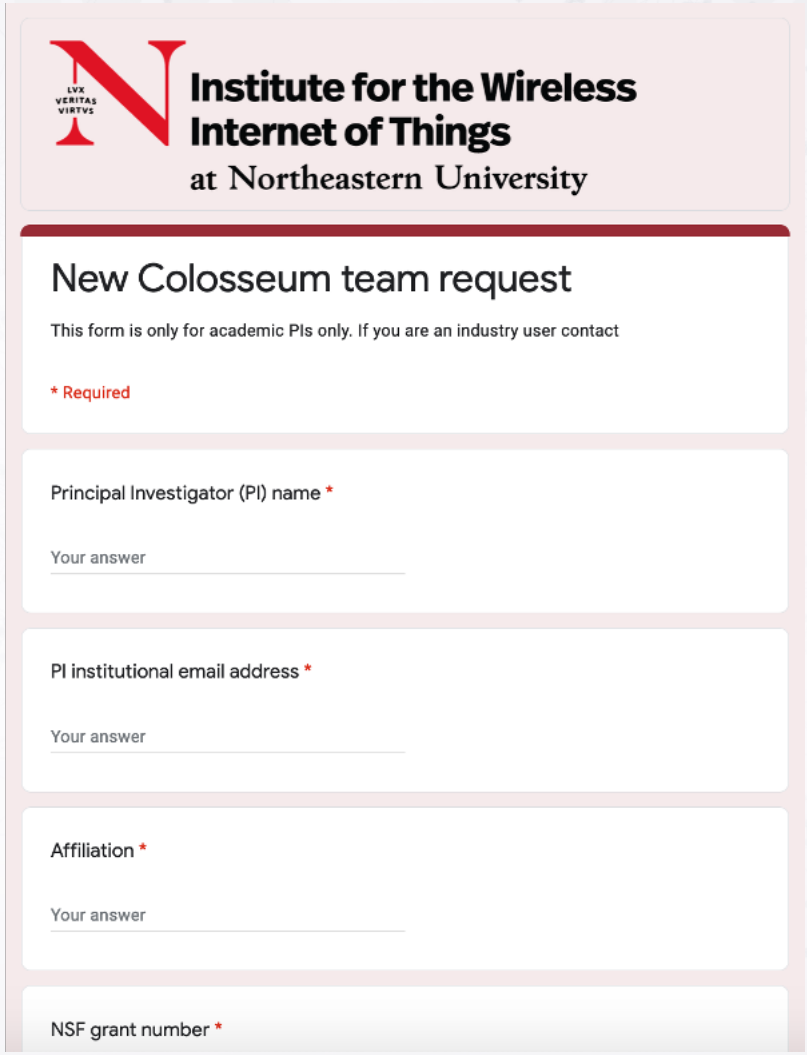
- **NSF-supported researchers** can access Colosseum free of charge
- We provide basic support and documentation, scenario creation on a best effort basis
  - Tell us what you are trying to accomplish, and we will direct you to an existing scenario, or we will try to work with you to develop a new one (resources permitting)

- **DoD researchers (i.e, ARL, AFRL, NRL)** can access Colosseum for free for two years

- Industry and other researchers: talk to us (colosseum@northeastern.edu), we are developing a fee structure for use by communities that are not currently contributing to Colosseum

Getting Started with Colosseum

- PIs can submit new team requests at:
  - Colosseum.net → under useful links
- PIs need to be either supported by NSF or a DoD researcher
- Useful links:
  - Colosseum website: colosseum.net
  - Knowledge base: colosseumneu.freshdesk.com/support/solutions
  - Help desk: https://colosseumneu.freshdesk.com/support/tickets



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New Colosseum team request

This form is only for academic PIs only. If you are an industry user contact

* Required

Principal Investigator (PI) name *

Your answer

PI institutional email address *

Your answer

Affiliation *

Your answer

NSF grant number *

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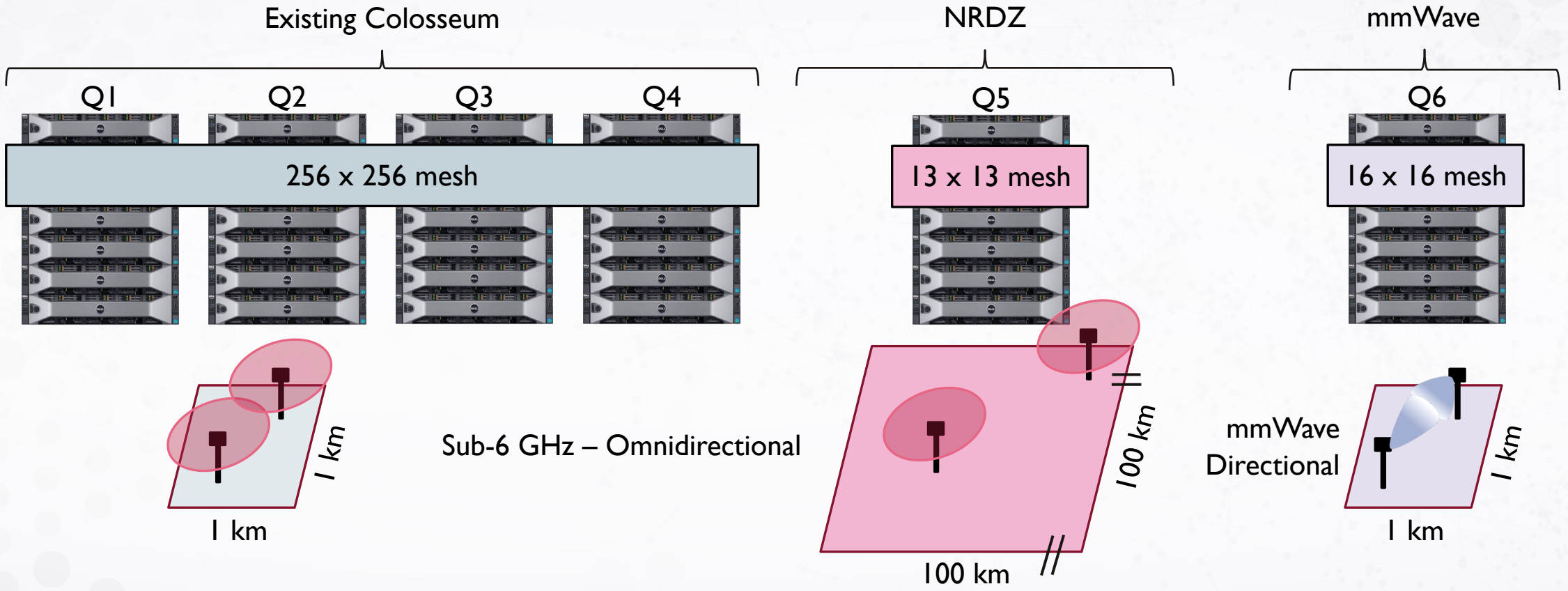
Evolution of Colosseum



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Team (PIs)

Tommaso Melodia

Principal Investigator

Tommaso serves as the project Principal Investigator, with responsibilities of overall project leadership, coordination, outlining new research directions, and evolution of the capabilities of Colosseum.

Stefano Basagni

Co-PI

Stefano serves as Director of Community Outreach and Engagement. His responsibilities include coordinating with the communities of Colosseum stakeholders, event organization and supervision, as well as engaging the Colosseum community for feedback and guidelines on continuous development, management and usage of the system.

Kaushik Chowdhury

Co-PI

Kaushik serves as Director of Research Planning. He is responsible of managing the capabilities of the system concerning external access for research. He is also involved in Colosseum enhancements for supporting advanced studies on machine learning in wireless.

Abhimanyu (Manu) Gosain

Co-PI

Manu Gosain serves as the project manager for the Colosseum team. He manages engagement with Academic, Industry, SME, and federal agency users to customize research topics and deployment on Colosseum. He also serves as the main interface with PAWR platforms for consistence and integration of the experimenter frameworks.

Team (continued)

Northeastern Team

- Leonardo Bonati
- Salvatore D'Oro
- Pedram Johari
- Francesco Restuccia
- Subhramoy Mohanti
- Miead Tehrani Moayyed
- Chineye Tassie
- Michele Polese
- Ahmed Aly

Cerbo Team

- Michael Seltser
- Ajeet Bagga
- Ventz Petkov
- Paresh Patel

Consultants

- Kurt Yoder
- Shweta Shrivastava

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