



Institute for the Wireless Internet of Things at Northeastern University

| Colosseum Evolution
AI, NRDZ, Digital Twin, OTIC

Colosseum Team:

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Platforms for Advanced
Wireless Research



MITRE



MASSACHUSETTS
TECHNOLOGY
COLLABORATIVE



N COLOSSEUM
at Northeastern University

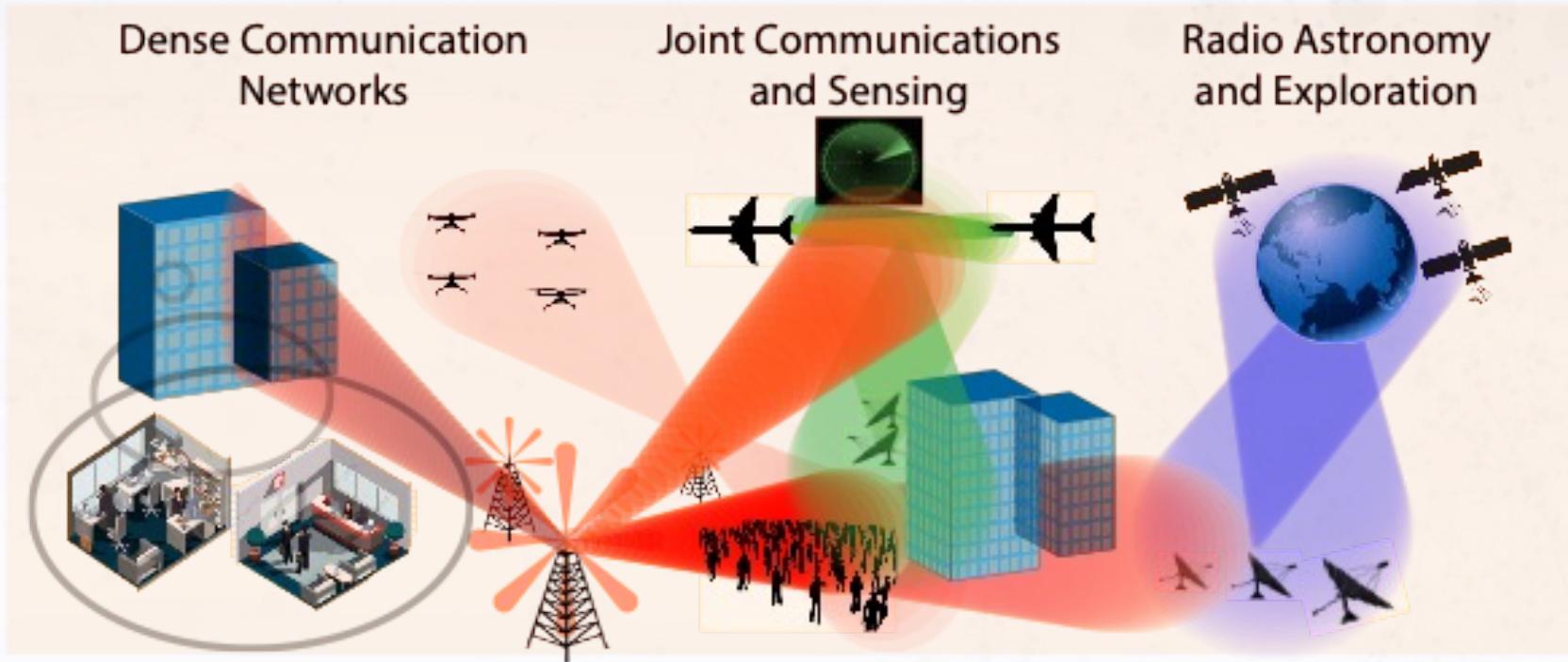
AI Cluster for Colosseum

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

Possible use cases:

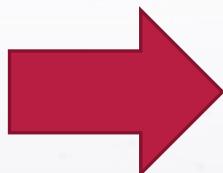
- Efficient training of large-scale wireless datasets collected on Colosseum
- Real-time, AI-driven 5G signal processing on for PHY layer & above
- Model-free adaptation to current network conditions and requirements

National Radio Dynamic Zones



Spectrum is a

- **limited** resource with
- many **different** uses and stakeholders



How can we improve the coexistence of different services?

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

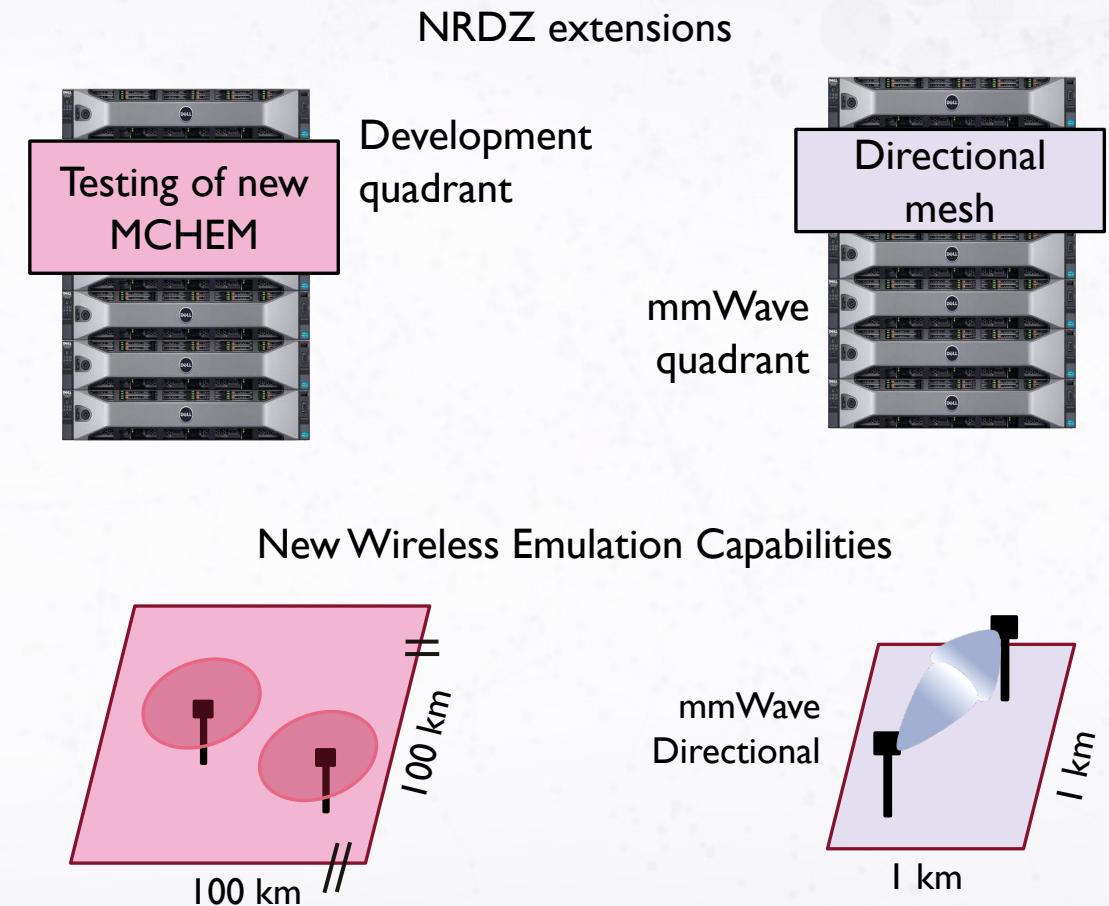
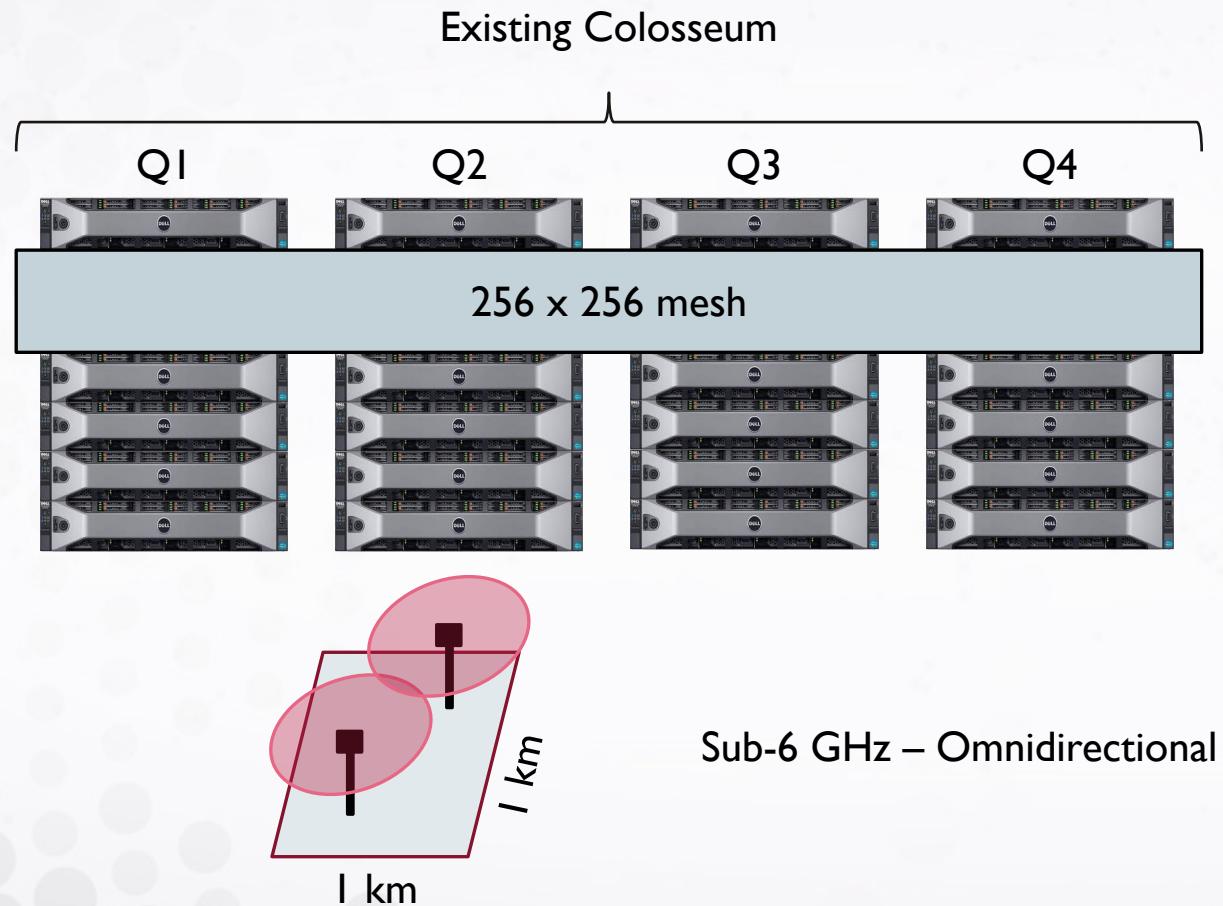
- Hardware-in-the-loop
- Software-based protocol stacks



Emulate NRDZs in Colosseum

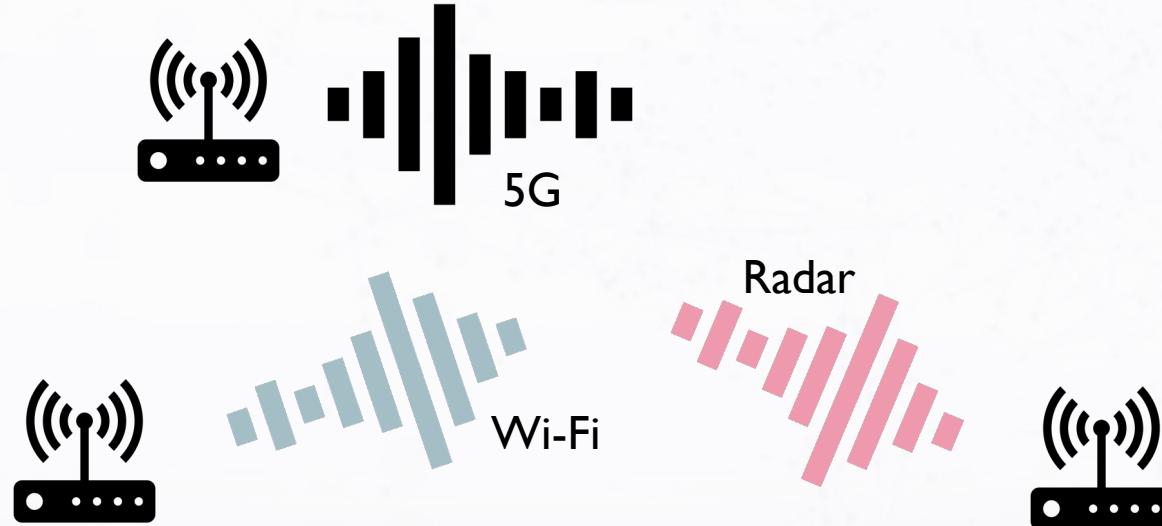
1. Open RF experimental environment available to the NSF community
2. Large scale
3. Integrated with other over-the-air testbeds (PAWR)

Current Colosseum and Planned Extensions



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

Spectrum Sharing

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

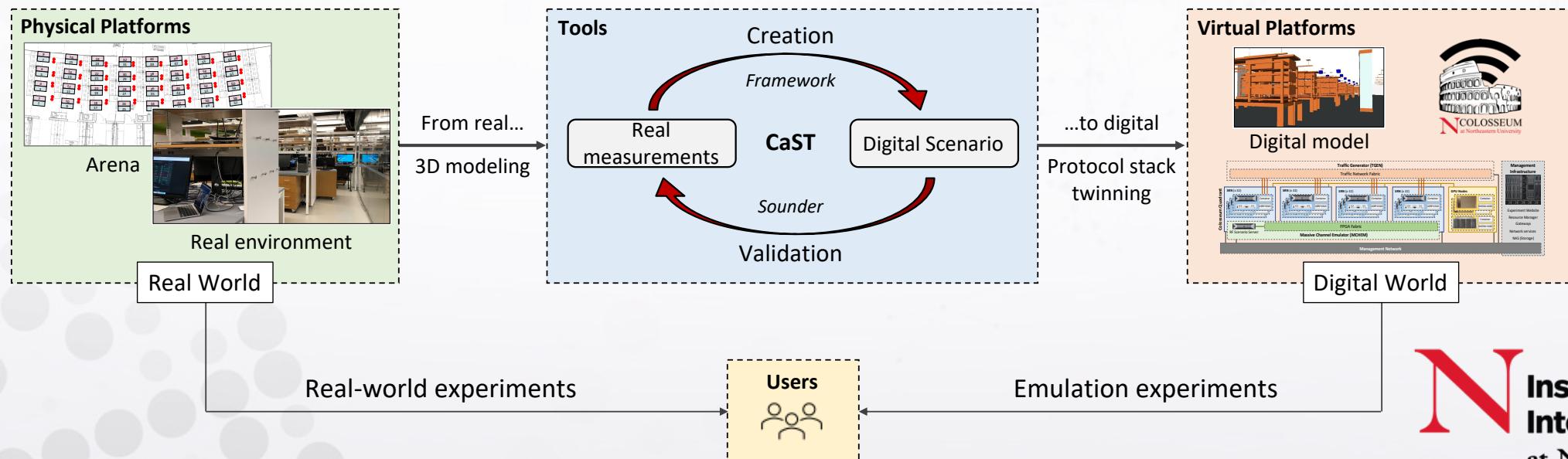
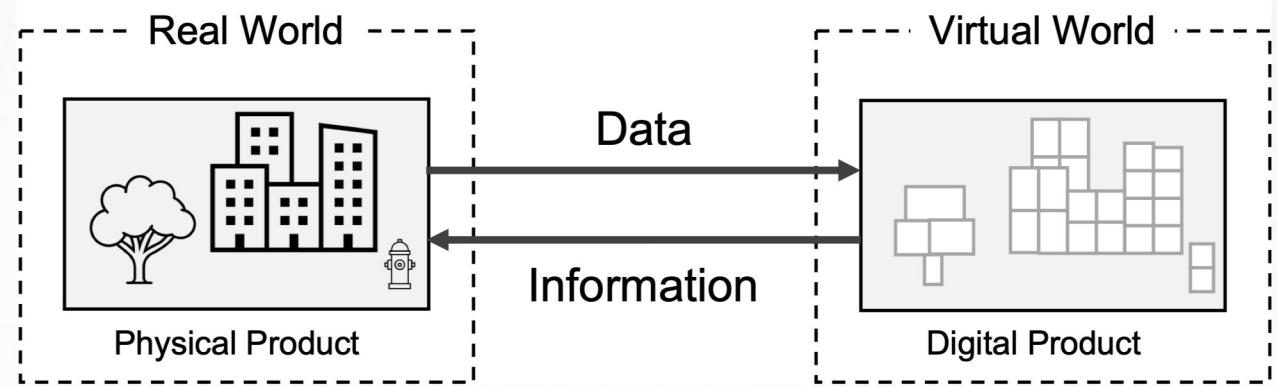


Wireless Digital Twins

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



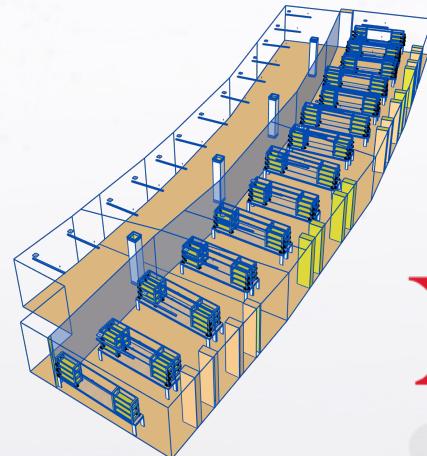
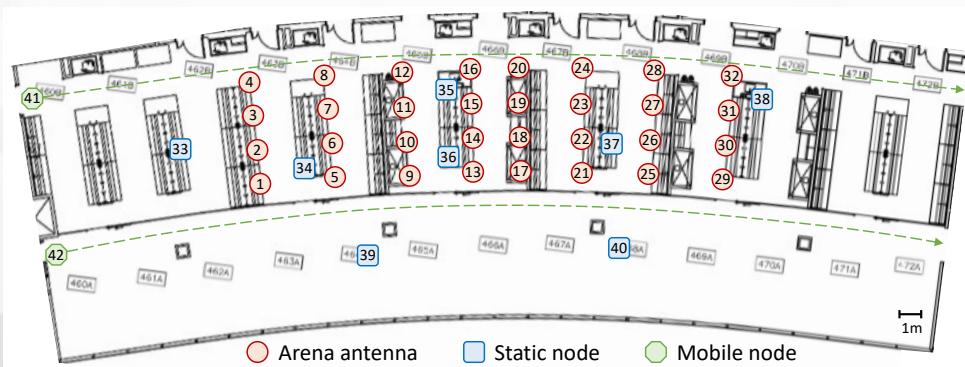
Twinning Arena and Colosseum



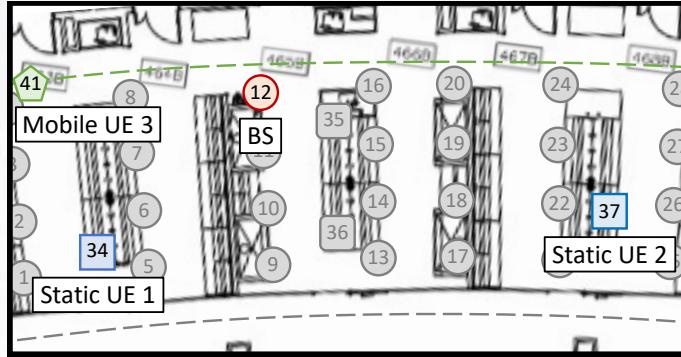
Arena: over-the-air testbed in indoor environment



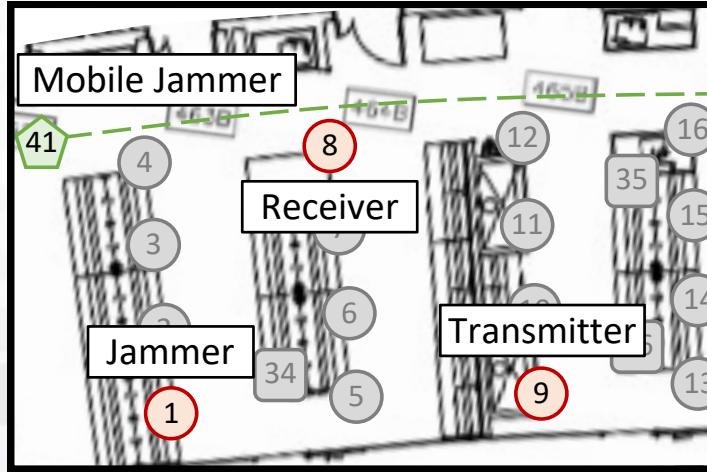
Ray-tracing in the same environment



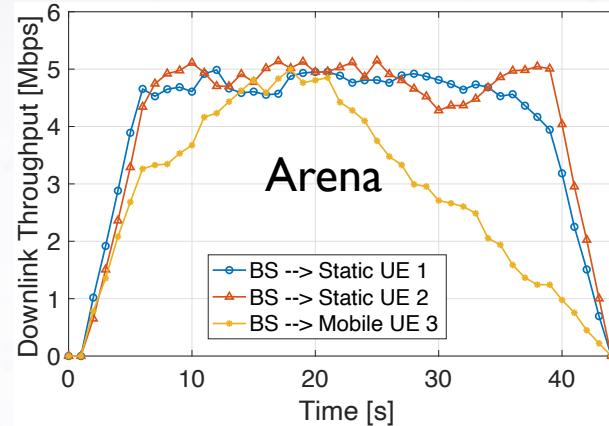
Twinning Arena and Colosseum Cellular and Jamming Experiments



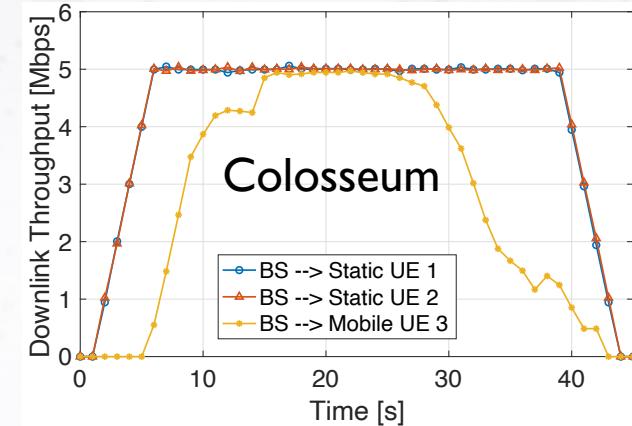
srsRAN cellular experiment nodes
with 5 Mbps Downlink UDP traffic



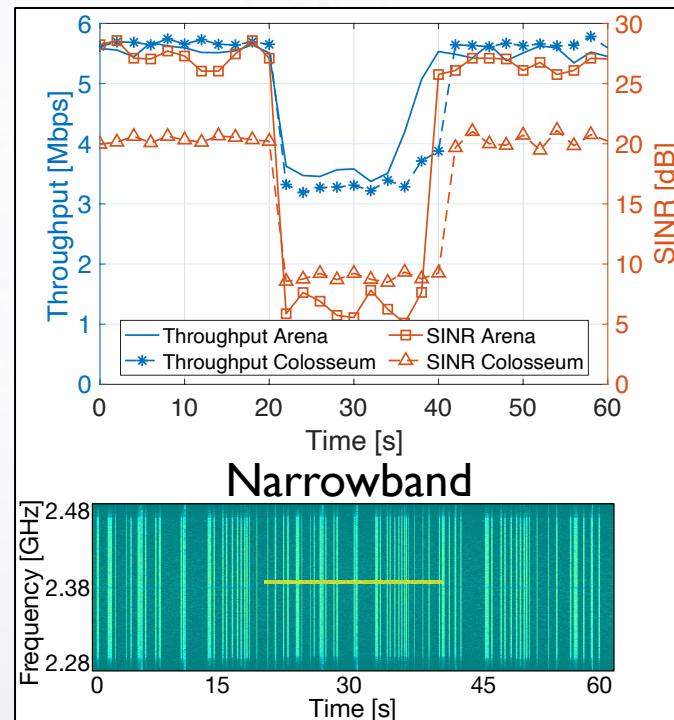
Wi-Fi jamming experiment nodes with a
narrowband and a wideband jammer



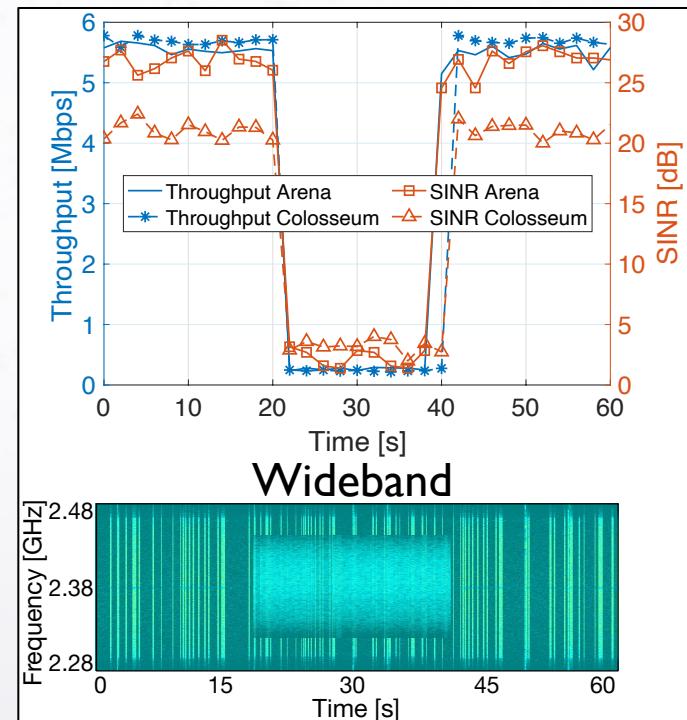
Arena



Colosseum



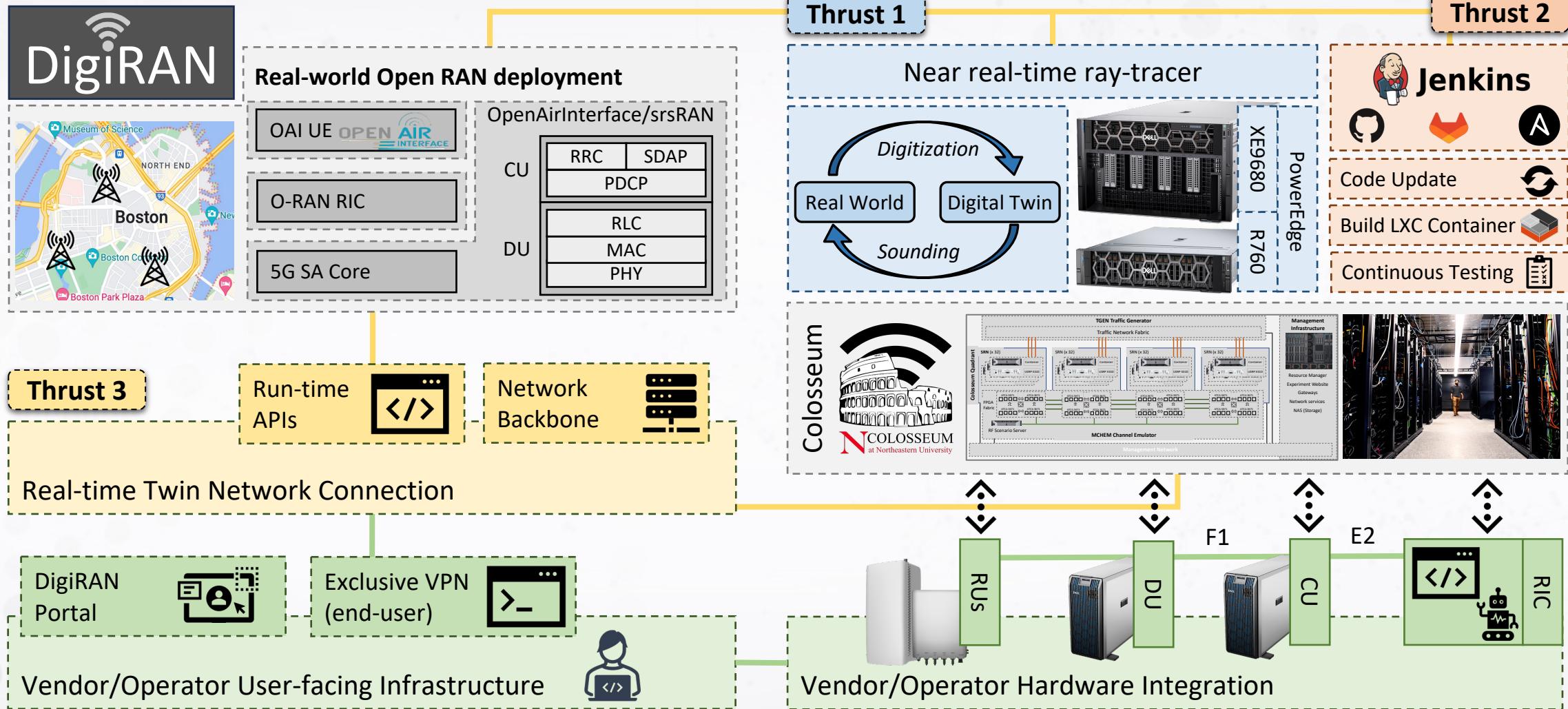
Narrowband



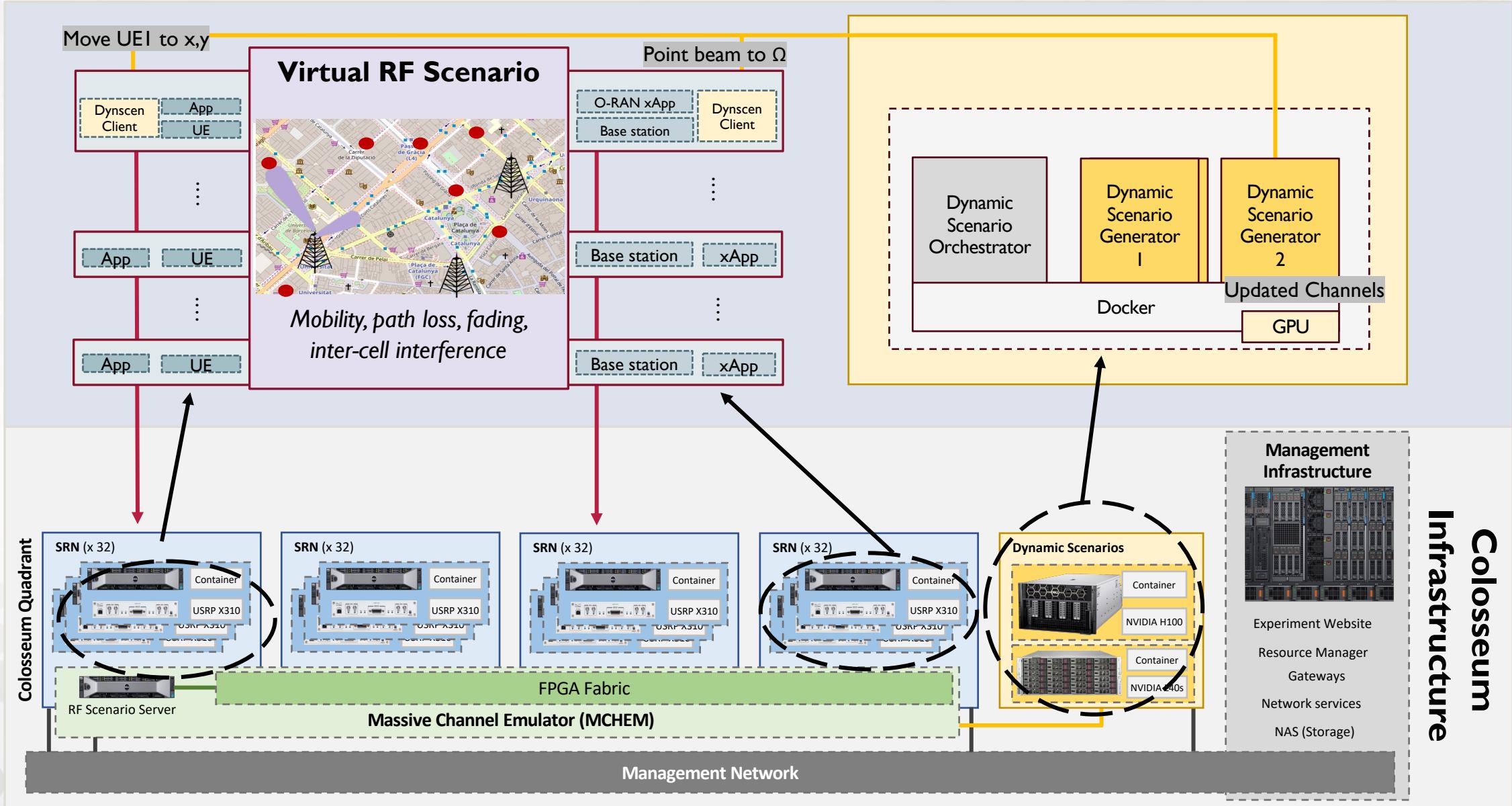
Wideband



DigiRAN: Digital Twin Framework for Open RAN Development, Testing & Integration



Updates on the real-time MCHEM (Thrust 1)



Updates on the real-time MCHEM (Thrust 1)

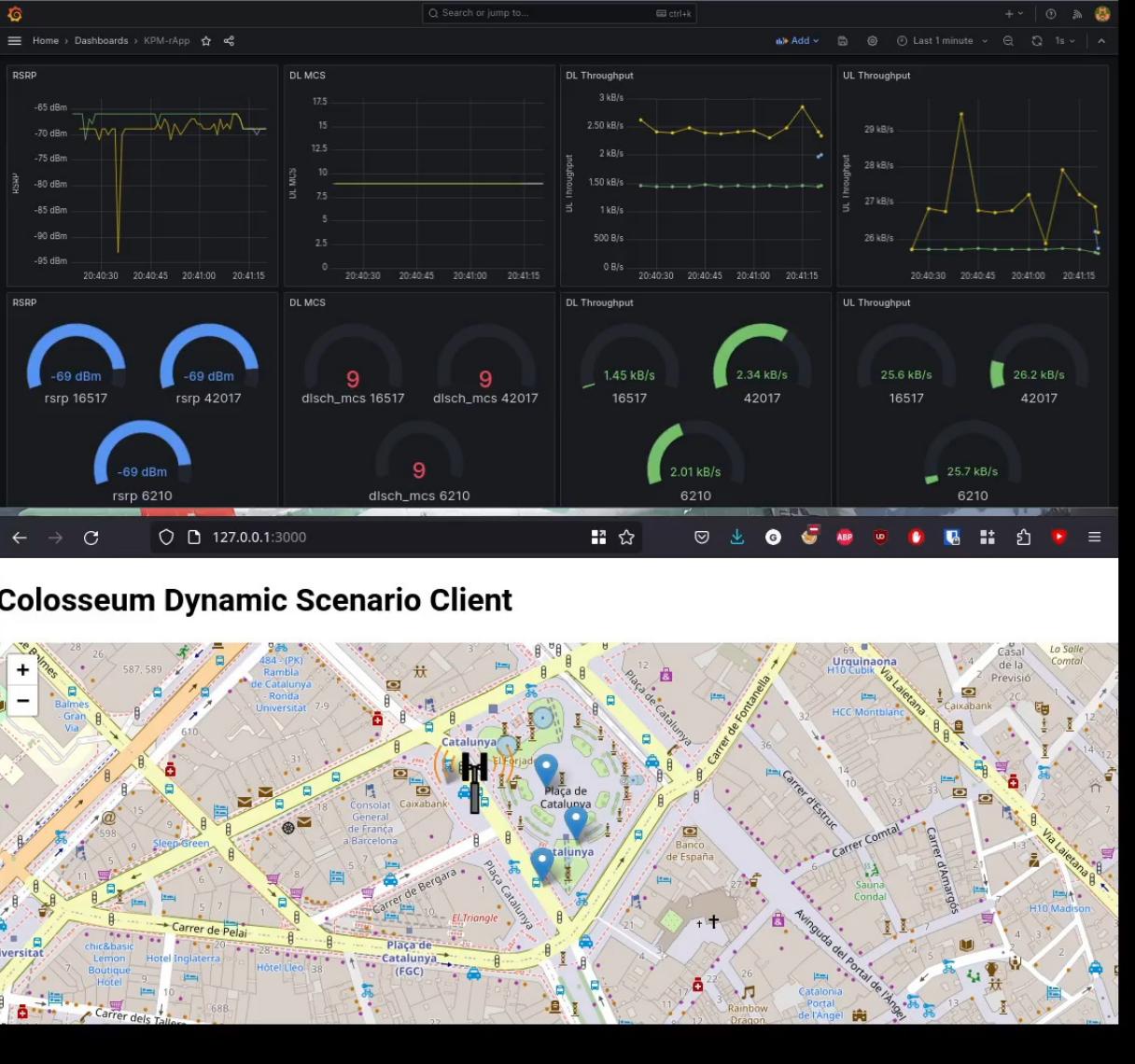


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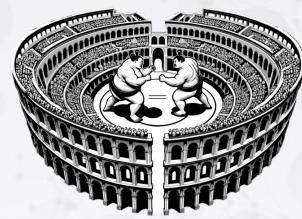
0.0.0, i2 = 0, SINR = 0 dB, CQI = 0
[PHY] DCI false positive. Dropping DCI
index 1. Mismatched bits: 98/216. Current DCI threshold: 49
[PHY] RSRP = -69 dBm, RI = 1, il1 = 0.0.0, i2 = 0, SINR = 0 dB, CQI = 0
[PHY] RSRP = -69 dBm, RI = 1, il1 = 0.0.0, i2 = 0, SINR = 0 dB, CQI = 0
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[PHY] RSRP = -69 dBm, RI = 1, il1 = 0.0.0, i2 = 0, SINR = 0 dB, CQI = 0
[PHY] =====
[PHY] Harq round stats for Downlink: 1253/1/0
[PHY] =====
[PHY] RSRP = -69 dBm, RI = 1, il1 = 0.0.0, i2 = 0, SINR = 0 dB, CQI = 0
[PHY] =====
3405, ulsch_total_bytes_received 1595577
UE a421: LCID 1: TX 918 RX 290 bytes
UE a421: LCID 2: TX 0 RX 0 bytes
UE a421: LCID 4: TX 60286 RX 63212 bytes
UE RNTI 1842 (3) PH 0 dB PCMAX 0 dBm, average RSRP -69 (16 meas)
UE 1842: UL-RI 1, TPMI 0
UE 1842: dlsch_rounds 103/1/1/0, dlsch_errors 0, pucch0_DTX 1, BLER 0.00006 MCS 9
UE 1842: dlsch_total_bytes 15526
UE 1842: ulsch_rounds 2225/10/6/2, ulsch_DTX 0, ulsch_errors 1, BLER 0.00310 MCS 28
UE 1842: ulsch_total_bytes_scheduled 190
792, ulsch_total_bytes_received 190444
UE 1842: LCID 1: TX 906 RX 290 bytes
UE 1842: LCID 2: TX 0 RX 0 bytes
UE 1842: LCID 4: TX 3228 RX 3445 bytes
[PHY] =====
[PHY] Harq round stats for Downlink: 105/1/1
[PHY] =====
[PHY] RSRP = -69 dBm, RI = 1, il1 = 0.0.0, i2 = 0, SINR = 0 dB, CQI = 0
[PHY] =====

```

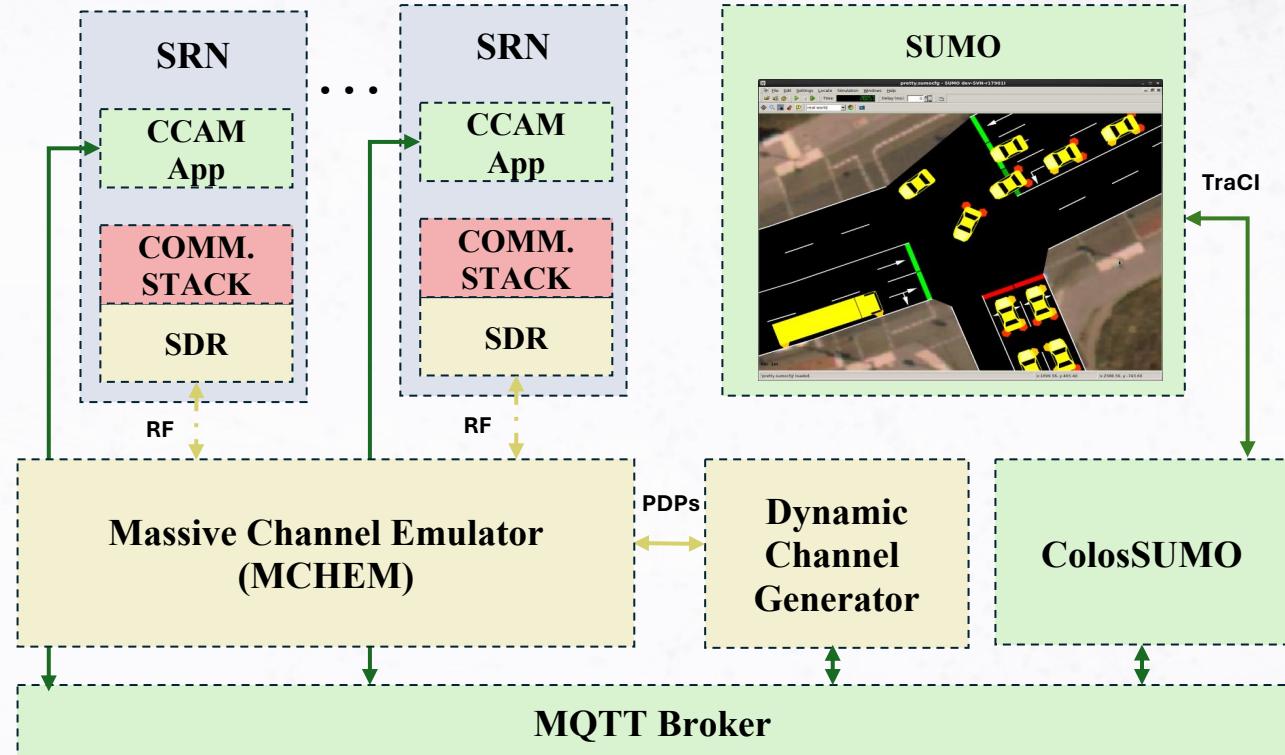
22.04 1% 916611% 2024-02-14 01:41:20



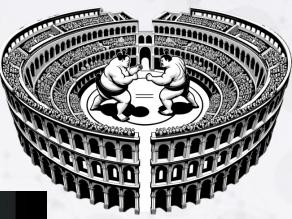
ColosSUMO – Architecture



- Three main components:
 - SUMO simulates the vehicles' movements
 - Colosseum emulate the wireless communication
 - CCAM Apps runs on SRNs, communicate using the SDRs and control virtual cars
- MQTT mediates communication between the components
- ColoSUMO glues everything together

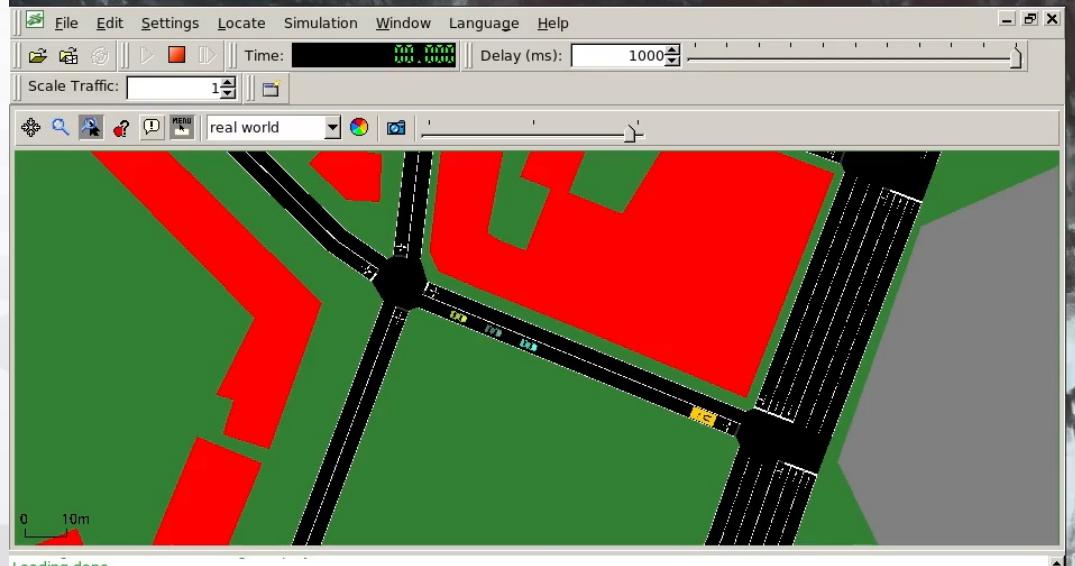


ColosSUMO – Demo



```
gabrielegemmi@dev-srn-001:~/git/colosseumo$ workon colosseumo
(colosseumo) gabrielegemmi@dev-srn-001:~/git/colosseumo$ python client.py
Traceback (most recent call last):
  File "client.py", line 7, in <module>
    client.connect(sys.argv[1], 1883)
IndexError: list index out of range
(colosseumo) gabrielegemmi@dev-srn-001:~/git/colosseumo$ python client.py dev-srn-001
(colosseumo) gabrielegemmi@dev-srn-001:~/git/colosseumo$ python client.py dev-srn-001^C
(colosseumo) gabrielegemmi@dev-srn-001:~/git/colosseumo$ python client.py dev-srn-001
(colosseumo) gabrielegemmi@dev-srn-001:~/git/colosseumo$ python client.py dev-srn-001
(colosseumo) gabrielegemmi@dev-srn-001:~/git/colosseumo$
```

```
u 20.04 0:- 1:-* 2:-#- 3:- 4:- 5:- 17! 11d18h 1.82 104x3.0GHz 187.4G7% 117G89% 2024-03-12 13:01:37
ours (healthy) 80/tcp, 8080/tcp, 8805/udp          oai-smf
a1a2e284fc7  oaisoftwarealliance/oai-amf:v2.0.1   "/openair-amf/bin/oa..."
ours (healthy) 80/tcp, 8080/tcp, 9090/tcp, 38412/sctp oai-amf
cb1c3f820a6a oaisoftwarealliance/oai-ausf:v2.0.1   "/openair-ausf/bin/o..."
ours (healthy) 80/tcp, 8080/tcp, 9090/tcp, 9600/tcp   oai-ausf
47ddba532c6d oaisoftwarealliance/oai-udm:v2.0.1   "/openair-udm/bin/oa..."
ours (healthy) 80/tcp, 8080/tcp, 9090/tcp, 9600/tcp   oai-udm
1a683776ea6b oaisoftwarealliance/oai-udr:v2.0.1   "/openair-udr/bin/oa..."
ours (healthy) 80/tcp, 8080/tcp, 9090/tcp, 9600/tcp   oai-udr
33f28d90df28 oaisoftwarealliance/trf-gen-cn5g:latest "/bin/bash -c ' ip r..."
ours (healthy) 80/tcp, 8080/tcp, 9090/tcp, 9600/tcp   oai-ext-dn
d1e54fdf9ac2 oaisoftwarealliance/oai-nrf:v2.0.1   "/openair-nrf/bin/oa..."
ours (healthy) 80/tcp, 8080/tcp, 9090/tcp, 9600/tcp   oai-nrf
52cedc179aeb mysql:8.0                            "docker-entrypoint.s..."
ours (healthy) 3306/tcp, 33060/tcp                 mysql
ubuntu@srn-131-dev:~/oai-cn5g-fed/docker-compose$
```



```
UE b91d: dlsch_rounds 3872/1/0/0, dlsch_errors 0, pucch0_DTX 1, BLER 0.00000 MCS (0) 9
UE b91d: ulsch_rounds 42843/20/0/0, ulsch_errors 0, ulsch_DTX 0, BLER 0.00000 MCS (0) 28
UE b91d: MAC: TX 1233439 RX 3533873 bytes
UE b91d: LCID 1: TX 961 RX 290 bytes
UE b91d: LCID 2: TX 0 RX 0 bytes
UE b91d: LCID 4: TX 1005634 RX 15176 bytes
UE RNTI e7d2 CU-UE-ID 3 in-sync PH 0 dB PCMAX 0 dBm, average RSRP -65 (16 meas)
UE e7d2: dlsch_rounds 3786/0/0/0, dlsch_errors 0, pucch0_DTX 0, BLER 0.00000 MCS (0) 9
UE e7d2: ulsch_rounds 40448/1161/175/80, ulsch_errors 28, ulsch_DTX 18, BLER 0.01268 MCS (0) 28
UE e7d2: MAC: TX 1005836 RX 3787184 bytes
UE e7d2: LCID 1: TX 961 RX 286 bytes
UE e7d2: LCID 2: TX 0 RX 0 bytes
UE e7d2: LCID 4: TX 662684 RX 648326 bytes
u 22.04 0:-* 1:- 2:- 66! 11d8h 1.05 46x1.2GHz 120.061% 40G22% 2024-03-12 13:01:38
acceleration": 0, "acceleration": 0, "speed": 20, "time": 0.01, "x": 6390.35, "y": 5897.85, "sender": "\\", "seqn": null}} from apiresponse/p.0 topic
DEBUG:root:API returned {"type": "api_return", "content": {"sumo_id": "p.0", "api_code": "ccvd", "transaction_id": 1021, "response": "{\"type\": \"vehicle_data\", \"content\": {\"sumo_id\": \"p.0\", \"controller_acceleration\": 0, \"acceleration\": 0, \"speed\": 20, \"time\": 0.01, \"x\": 6390.35, \"y\": 5897.85, \"sender\": \"\", \"seqn\": null}}"}}
DEBUG:root:Unlocking caller waiting for semaphore[1021]
WARNING:root:Logging current position {'x': 6390.35, 'y': 5897.85}
DEBUG:root:Sending broadcast packet via stack from p.0 to p.1: {"type": "vehicle_data", "content": {"sumo_id": "p.0", "controller_acceleration": 0, "acceleration": 0, "speed": 20, "time": 0.01, "x": 6390.35, "y": 5897.85, "sender": "p.0", "seqn": 1010, "ts": 1710248498.7961795, "recipient": "p.1"}}
DEBUG:root:Sending broadcast packet via stack from p.0 to p.2: {"type": "vehicle_data", "content": {"sumo_id": "p.0", "controller_acceleration": 0, "acceleration": 0, "speed": 20, "time": 0.01, "x": 6390.35, "y": 5897.85, "sender": "p.0", "seqn": 1010, "ts": 1710248498.7961795, "recipient": "p.2"}}
u 22.04 0:-#- 1:-* 2:- 66! 11d8h 1.03 46x1.2GHz 120.061% 9.4G80% 2024-03-12 13:01:38
DEBUG:root:Received {"type": "api_return", "content": {"sumo_id": "p.1", "api_code": "cclsa", "transaction_id": 2968, "response": "true"} from apiresponse/p.1 topic
DEBUG:root:API returned {"type": "api_return", "content": {"sumo_id": "p.1", "api_code": "cclsa", "transaction_id": 2968, "response": "true"}}
DEBUG:root:Unlocking caller waiting for semaphore[2968]
DEBUG:root:Sending API call apicall/p.1 with content {"type": "api_call", "content": {"sumo_id": "p.1", "api_code": "ccpsa", "transaction_id": 2969, "parameters": {"\"type\": \"vehicle_data\", \"content\": {\"sumo_id\": \"p.0\", \"controller_acceleration\": 0, \"acceleration\": 0, \"speed\": 20, \"time\": 0.01, \"x\": 6390.35, \"y\": 5897.85, \"sender\": \"p.0\", \"seqn\": 1010, \"ts\": 1710248498.7961795, \"recipient\": \"p.1\"}}}}
DEBUG:root:Blocking caller through semaphore[2969]
DEBUG:root:Sending API call apicall/p.1 with content {"type": "api_call", "content": {"sumo_id": "p.1", "api_code": "ccvd", "transaction_id": 2970, "parameters": {"\"type\": \"vehicle_data\", \"content\": {\"sumo_id\": \"p.1\", \"controller_acceleration\": 0, \"acceleration\": 0, \"speed\": 20, \"time\": 0.01, \"x\": 6390.35, \"y\": 5897.85, \"sender\": \"p.1\", \"seqn\": 1010, \"ts\": 1710248498.7961795, \"recipient\": \"p.2\"}}}}
DEBUG:root:Blocking caller through semaphore[2970]
u 22.04 0:- 1:-* 2:- 3:-# 4:- 5:- 66! 11d7h 0.88 46x1.2GHz 120.061% 8.8G89% 2024-03-12 13:01:37
DEBUG:root:Sending API call apicall/p.2 with content {"type": "api_call", "content": {"sumo_id": "p.2", "api_code": "ccsa", "transaction_id": 2870, "parameters": {"\"type\": \"vehicle_data\", \"content\": {\"sumo_id\": \"p.0\", \"controller_acceleration\": 0, \"acceleration\": 0, \"speed\": 20, \"time\": 0.01, \"x\": 6390.35, \"y\": 5897.85, \"sender\": \"p.0\", \"seqn\": 1010, \"ts\": 1710248498.7961795, \"recipient\": \"p.2\"}}}}
DEBUG:root:Blocking caller through semaphore[2870]
DEBUG:root:Sending API call apicall/p.2 with content {"type": "api_call", "content": {"sumo_id": "p.2", "api_code": "ccvd", "transaction_id": 2871, "parameters": {"\"type\": \"vehicle_data\", \"content\": {\"sumo_id\": \"p.2\", \"controller_acceleration\": 0, \"acceleration\": 0, \"speed\": 20, \"time\": 0.01, \"x\": 6390.35, \"y\": 5897.85, \"sender\": \"p.2\", \"seqn\": 1010, \"ts\": 1710248498.7961795, \"recipient\": \"p.1\"}}}}
DEBUG:root:Blocking caller through semaphore[2871]
DEBUG:root:Received {"type": "api_return", "content": {"sumo_id": "p.2", "api_code": "ccsa", "transaction_id": 2870, "response": "true"} from apiresponse/p.2 topic
DEBUG:root:API returned {"type": "api_return", "content": {"sumo_id": "p.2", "api_code": "ccsa", "transaction_id": 2870, "response": "true"}}
```

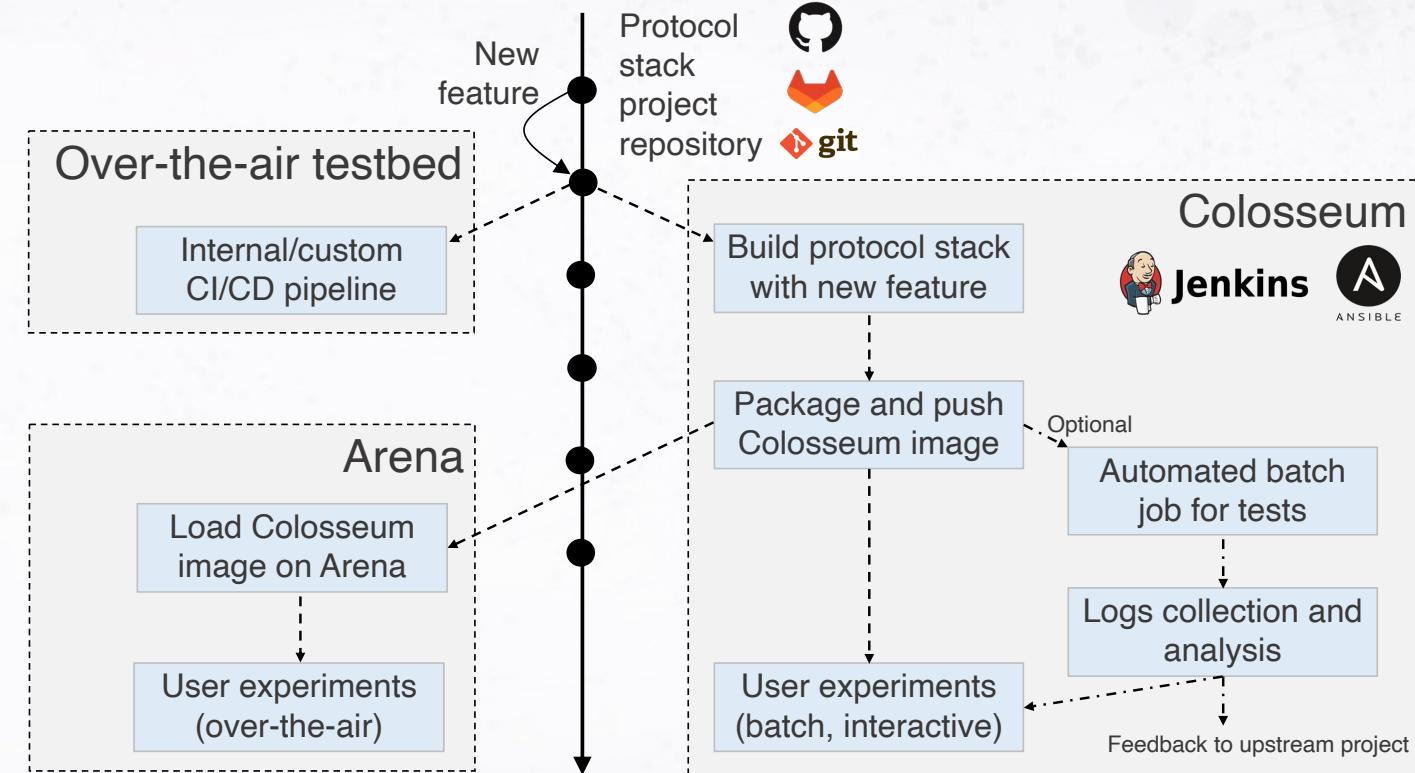
Protocol Stack Twinning - End-to-End CI on Colosseum

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

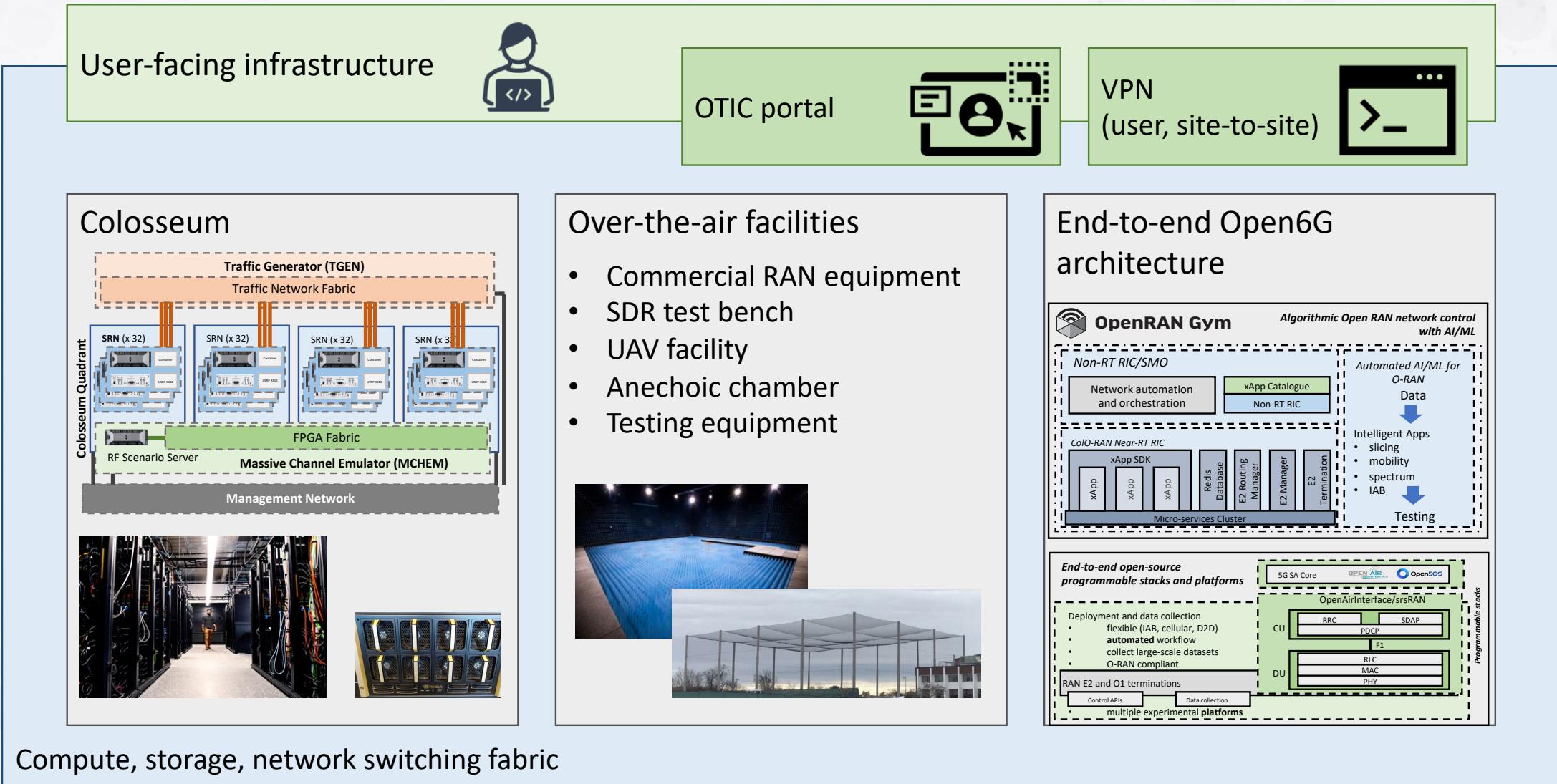


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N Institute for the Wireless Internet of Things at Northeastern

OTIC Architecture





Institute for the Wireless Internet of Things

at Northeastern University

Thank You! (Questions?)



Platforms for Advanced
Wireless Research



MITRE



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